AN IMPACT ASSESSMENT MODEL FOR TECHNOLOGY DEVELOPMENT PROGRAMS

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ABSTRACT

AN IMPACT ASSESSMENT MODEL FOR
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Economic and social development of a country is directly related with the sustainable technology development capabilities and innovation capabilities of its own. Technology development activities are assumed to be the most challenging process of the R&D ecosystem. Mostly the public sector funds the technology development programs because of the required huge resources, difficulty in coordination of multiple partners and risky management stages. This dissertion aims to submit an impact assessment model for especially public funded technology development programs for sustainability, accountability and effective management purposes. Proposed model consists of three sub modules which are technology asessment module, economic output assessment module and economic outcome assessment module. An experimental case study has been conducted to prove the usefulness of the proposed model. Case study assessments are done with 35 qualified personnel who are researchers, project managers, academic staff and program experts from Turkey's the most prestigious institutes, universities, research centers and funding corporations. Analytical hierarchy process (AHP) and TOPSIS methods are used to analyze the qualitative technology maturity level with respect to 9 technological indicators. Expert assessments are done to measure the economic outputs return value by means of 8 economic output indicators. The results show that any technology development program must give priority for qualitative researcher employment, national design competence and activation of technological prototype outputs respectively. The achieved qualitative technology maturity level is calculated for sustainability purposes, the insufficient maturity areas and a network impact schema are displayed and an economic return rate is calculated for accountability purposes.

Keywords: Impact Assessment, Technology Development Program, Economic Impact Assessment, AHP, TOPSIS

ÖZ

TEKNOLOJİ GELİŞTİRME PROGRAMLARI İÇİN BİR ETKİ DEĞERLENDİRME MODELİ

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Bir ülkenin sürdürülebilir ekonomik ve sosyal gelişimi, kendine ait teknoloji geliştirme yetenekleri ve inovasyon yetenekleri ile doğrudan ilişkilidir. Teknoloji geliştirme faaliyetleri, tüm Ar-Ge sisteminin en zorlu süreci olarak kabul edilmektedir. Bu faaliyetlerin gerektirdiği geniş kaynaklar, birden fazla paydaşların koordinasyon zorlukları ve birçok riskli yönetsel gereksinimler sebebiyle teknoloji geliştirme programlarına çoğunlukla kamu sektörü fon sağlamakta ve yürütmektedir. Bu nedenle, gelişmiş ülkeler sürdürülebilirlik, hesap verebilirlik ve etkinlik amacıyla çeşitli etki değerlendirme faaliyetleri uygulamaktadırlar. Bu tez özellikle kamu tarafından finanse edilen teknoloji geliştirme programları için sürdürülebilirlik, hesap verilebilirlik ve etkili yönetim için bir etki değerlendirme modeli sunmaktadır. Önerilen model üç alt modülden oluşmaktadır. Bunlar sırasıyla teknoloji değerlendirme modülü, ekonomik çıktı değerlendirme modülü ve ekonomik sonuç değerlendirme modülüdür. Önerilen modelin kullanılabilirliğini kanıtlamak için deneysel bir vaka çalışması yapılmıştır. Uzman incelemeleri, Türkiye'nin en itibarlı enstitülerinden, üniversitelerinden, araştırma merkezlerinden ve fon kurumlarında çalışan 35 nitelikli araştırmacıları, proje yöneticileri, akademik personel ve program uzmanları tarafından yapılmıştır. Analitik hiyerarşi süreci (AHP) ve TOPSIS yöntemleri, 9 teknolojik göstergeye göre nitel teknoloji olgunluk düzeyini analiz etmek için kullanılmıştır. Programın ekonomik çıktılarının gerçekleşen ekonomik geri kazanım değerleri ve beklenen ekonomik geri kazanım değerleri hesaplanmıştır. Sonuçlar, bir teknoloji geliştirme programının nitelikli araştırmacı istihdamı, ulusal tasarım yeterliliği ve teknolojik prototiplerin kullanıma alınması göstergelerine öncelik vermesi gerektiğini göstermektedir. Ulaşılan nitel teknoloji olgunluk seviyesi sürdürülebilirliğinin nasıl sağlanabileceğinin anlaşılması amacıyla hesaplanmıştır. Ayrıca yetersiz kalınan göstergeler de görülebilmektedir. Bununla birlikte, hesap verilebilirlik kapsamında bir ağ etki şeması ve ekonomik geri kazanım oranları hesaplanmıştır.

Anahtar Sözcükler: Etki Değerlendirme, Teknoloji Geliştirme Programı, Ekonomik Etki Değerlendirmesi, AHP, TOPSIS

To

my mother Kıymet, my wife Gülçin and my daughter Ayşenaz,

I owe them for every peaceful moment of mine.

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LIST OF ABBREVIATIONS

ADD2	: Advancement Degree of Difficulty Assessment
AHP	: Analytical Hierarchy Process
ASI	: Addiction Severity Index
BSC	: Balanced ScoreCard
CDR	: Critical Design Review
COSEPUP	: Committee on Science, Engineering, and Public Policy
DEA	: Data Envelopment Analysis
DoD	: Department of Defence
GPRA	: Government Performance and Result Act
IOM	: Institute of Medicine
KDP	: Key Decision Point
LCC	: Life Cycle Cost
NAE	: National Academy of Engineering
NAS	: National Academy of Sciences
NASA	: National Aeronautics and Space Administration
NCSTE	: National Centre for Science and Technology Evaluation
OECD	: Organisation for Economic Co-operation and Development
PDR	: Preliminary Design Review
PMS	: Performance Measurement Systems
R&D	: Research and Development
SDR	: System Design Review
STI	: Science Technology Innovation
TARA	: Technology Area Reviews and Assessments
TOPSIS	: Technique for Order Preference by Similarity to Ideal Solution
TRA	: Technology Readiness Assessment
TRL	: Technology Readiness Level
TSB	: Technology Strategy Board
TSR	: Treatment Services Review
TÜBİTAK	: The Scientific And Technological Research Council Of Turkey

CHAPTER 1

INTRODUCTION

1.1. Statement of The Problem

Technology has been the pioneering power of economical, industrial and the social development of nations. Throughout the history, any nation which has excelled others in economic, military or social aspects somehow achieved that by means of technological superiority.

Scientific knowledge creation, technology development and industrialization activities are the most important drivers of a country's economic and social development. Developed countries as well as developing countries pursue scientific activities and support the technological developments in order to achieve a sustainable and a stable economy. There is a direct and/or indirect relationship between the scientific activities, technology development, engineering capacity, innovation capacity and economic welfare. As a matter of fact these consequtive processes end up with economic and industrial formation of the economy and society.

The passion for maintaining as developed country status comes from national strategic perspective, and it requires efficient and effective scientific/technology policies. Technology affects people’s life in all aspects through the lifetime so it must be managed in the national, international, organizational and technical levels. In this context, R&D and technology development funding mechanisms serve for the economic and social interests of countries. The most critical parts of the national strategic development plans consist of technology policies. These policies historically should be evaluated within two paradigms which are “mission” and "diffusion" oriented paradigms that are emerged in scientific strategies after the Second World War.

The relationship between the basic research, applied research, technology development and product development activities are considered to be in a linear process in the post Second World War era. Within the report named "Science – The Endless Frontier" (Bush Vannevar, 1945) it is mentioned that continuous additions to knowledge of the laws of nature are directly linked to the new products, new industries and more jobs. Additionally, the only source of new knowledge has been defined as the basic scientific research in the context of new and improved weapons. This report has been prepared just after the Second World War era by the effects of war. Bush Vannevar was the leader of the commitee which persuaded US presidency for the nuclear bomb development and the Manhattan Project. The Manhattan Project (1942-1945) was one of the pionering modern projects which had been managed systematically so it had became a critical power factor for terminating the war. That outstanding and multi phased project included all the research development activities such as basic scientific research (radioactivity studies), applied research (uranium and plutonium enrichment), technology development (nuclear energy generation) and product development (nuclear bomb generation by uranium and plutonium) processes simultaneously. The success and impact of Manhattan Project emphasized the importance of basic science and caused the new modelling of scientific studies.

Dramatic advance in atomic bombs, nuclear ships, intercontinental missiles showed the high potential of organized science and technology. New and high level expectations from the science and technology resulted huge post war military-industrial complex. The impact of technology became significant in social science and philosophy (Kuehn, T., & Porter, A. L. 2019).

During the following decades, funding of the scientific activities in a linear model is used to meet the specific defence needs and technological goals of the society. Governments focussed on predetermined research areas and the concept of “technology development” became more significant. Then mission oriented policies implemented to fullfil the significant social demands.

Research an development processes are classically divided into three main stages; scientific and applied research, technology development and the system/product development stage respectively. Technology development processes are the most challenging stage of the research, development and innovation systems. Because, this stage is the successor of the uncertainty of applied research, and also the predecessor of high demands of the system/product development activities. So this stage is a critical bridge that transforms the scientific researches to commercially available industrial products by means of multidisciplinary efforts and partners. As a matter of fact the planning, management, implementation, assessment of technoology development activities are very challenging. Many uncertainties, risks, technical and administrative difficulties can be experienced in this stage and many scientific and technological initiatives fail at this stage. Therefore, this process is mostly called ‘the pit of hell’ or ‘the valley of death’.

Each stage of technology development activities such as; awareness, planning, acquisition (transfer or development), application, planning and service termination must be managed proficiently.

1.2. Purpose of The Study

The author of this thesis conducted coordination, monitoring and audit of the technology development project activities for more than ten years. He clearly observed that some hidden, unmeasured and tacid factors interfere with the project success so one should assess these factors and their impacts for the technology programs. The quality of the researchers, the politics of the nation, procurement capability, the export licence and procurement restriction issues are hidden parameters of a technology development program. They must be visualized, prioritized, executed and monitored. The importance, capacity, maturity and sustainability of these parameters are not measured or weighted within an impact assessment context in the literature. The “Technology Readiness Level (TRL)” method is examined in detail which is popular for measurng the maturity of technology development programs. It is clear for the author of this thesis that TRL is an insufficient and incapable method for measuring technology maturity for an emerging technology in a developing country with limited resources. So, a qualitative and analytic method should be implemented as a complemetary method for assessment of the technological and economical results of technology development programs.

If a technology development program is completed successfully, it will have a positive impact on people, stakeholder institutions, related sectors and country welfare in the short term and long term. In the scope of this thesis, critical processess of technology development programs are modelled, technology development indicators, economic output indicators, economic outcome indicators are identified within 3 seperate modules. The model and the indicators are emerged from the difficulties and challenges faced during the program executions.

1.3. Theory and the Research Questions

According to the literature, the current R&D assessment or evaluation studies mostly deals with the basic and applied R&D activities and they mostly use quantitive methods which measures specific outputs.

The TRL method has a linear scale and focusses on the functionality of the outputs and the completion of certain tasks. TRL calculation is formed with a 1 to 9 scales and each level shows a certain maturity level. Each level completion is based on a set of questions. The answers and the completion criteria to these levels are certain activities, documents and physical evidences etc.

The TRL method has several incompetency as described in the literature but the main issue is it leaves many blind corners for the assessment of the program. Additionally, the TRL calculation method may be useful for a developed country which has unlimited resources, qualified management skills and qualified design and manufacturing capabilities. But any developing country which is executing a technology development program absolutely have restrictions and limitations about the above mentioned capabilities. So that these capabilities must be tracked and improved continuously for a sustainable success of technology development program.

Technology can be defined as competency in the knowledge, capability and equipment of a specific solution for a specific requirement of humankind. The human factor is the main component for the definition, implementation and activation of technology.

The main theory of this thesis is; technology development activities higly dependent for the qualified scientific knowledge, qualified researchers and management competency. So the the technology assessments also must be made in a qualitative manner as well as quantitative methods. This theory also indicates that, the technology development programs are very challenging processes and program's sustainable success can not be measured by only the functionality of the outputs of the program but it is also is highly dependent for;

- Resources that comes from long term policies,
- Active and updated technology management
- Project execution and national system development processes

Above mentioned perspectives must be evaluated with a qualitative methodology especially for developing countries.

This theory is chosen to submit the critical processes of technology development programs and to stimulate an awarenes about the hidden and covered factors of successful or ineffective programs.

The possible effects of this theory will create an awarenes about the different views and expectations of the partners, the weak and strong dimensions of programs, the responsibilities of the partners and a qualitative assessment of technological maturity level.

This study has three research questions. Two of them are related with sustainability purposes and the next one is related with accountability purposes;

a) Taking into account the responsibilities of all stakeholders (in a qualitative approach), what are the achieved technological maturity level?
b) Which factors are mostly influencing the technological outcomes?
c) What are the economical outputs/outcomes of the technology development programs?

1.4. Researchers's Motivation

The author of this thesis experienced the planning of projects, coordination and execution of managerial processes, reporting to executive board, leading the test and evaluation activities, closing the project work packages during his profession as a scientific programs an expert. The author encountered so much challenging fields during his employment in TÜBİTAK which is the main and pionering funding mechanism for academic, industrial ecosystem in Turkey. TÜBİTAK is a public funding corporation that is supporting and funding academic community, private sector, nationwide enterpreneurs, international collaborations and personel enterpreneurs nationwide. It is also supporting and funding high technology development programs for providing needs of public corporations and defence sector. The scientific, technological and industrial stakeholders of national innovation system get grants by mechansms of research and development programs.

It is considered that the challenging fields and specific obstacles are mostly same for the success of the program as well as the impact areas of the program at the end. By using an inductive problem analysing approach three main indicators and nine sub indicators are determined and used in a newly developed model.

The submission of this dissertion thesis is submitted to express the importance of technology development programs which have distinctive and hard processes to be completed.

While working as a scientific progrqms expert of the program, it has been encountered frequently that highly technological programs/projects has some structural and systematic problems. Most of the program/projects had technology dependent nature and have highly challenging processess in different aspects. The roles and the responsibility of the stakeholders are not clearly identified, the success factors are not prioritized, technological and economical returned values are not measured. It is a critical necessity that the policy making, management and accountability dimentions of should be assessed systematically at the end of the programs. Additionally, technology development program/projects needs high level of management disciplinary, system engineering management disciplinary, condensed risk management disciplinary and coordination of partners from different corporate cultures. It has been clear that above mentioned items must be identified, prioritizied, managed and systematically analyzed in an impact assessment context. Because the success of the program and the maturity of the acessed technology are considered directly dependent for the above mentioned fields. The main goal or the success factor of the the program should be to obtain the technology maturity. Technology maturity is consisted of not only project outputs but some national and sustainable qualities which are critical in the long term economic welfare.

1.5. Significance of The Study

The proposed qualitative technology maturity level calculation methodology will submit a deep understanding about the weak and strong sides, responsibilities and achievements of the program stakeholders as well as the quality of program/project outputs.

Technology maturity level will be assessed in a qualitative approach by expert reviews who actually work and take part in the technology development projects and activities. A new set of indicators are identified taking into account the responsibility of program stakeholders.

The Analytical Hierarchy Process (AHP) method is used for technology assessment purpose which will enable policy makers, program managers and system developers to evaluate their responsibilities as well as success areas.

The main impact factors of the program will be identified, for next stage program plannings.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

Science is the discovery and explanation of the nature. Technology is the knowledge of controlling and influencing the nature for humanitarian purposes. There is a direct relationship between the scientific activities and the economic welfare throughout technology phase. The studies of science and economy relationship are belong to the field of technological innovation (Bets, F. 2013).

Technology does not consist of artifacts but of the public knowledge that underlies the artifacts and the way they can be used in society (Kuehn, T., & Porter, A. L. 2019).

Technology is application of knowledge to develop tools, materials, techniques, and systems to help people meet and fulfill needs (Greisler, D. Stupak, R. J. 2006).

Technology can be defined as a body of knowledge devoted to creating tools, processing actions and extracting of materials (Ramey, Karehka. https://www.useoftechnology.com/what-is-technology/. Accessed 22 Dec. 2019).

The importance of technology for a firm is described as : "A firm, as a collection of activities, is a collection of technologies. Technology is embodied in every value activity in a firm, and technological change can affect competition through its impact on virtually any activity" (Porter, E. M. 1985).

Technological Development is the systematic use of scientific, technical, economic and commercial knowledge to meet specific business objectives or requirements (Al-Hâkim, L. 2016).

Technology should not be perceived as only the equipments or tools we use to make our life easier, but also the “body of knowledge” and “collection of activities” that are used to fulfill our needs. If a technology development program is completed successfully, it will have a positive impact on people, stakeholder institutions, related sectors and country welfare in the short term and long term. These effects are defined as follows:

Scientific Impacts: The accumulation and renewal of the knowledge base, including tacit knowledge.

Technological Impacts: Technical solutions, patents, new products and processes, new research equipment and infrastructure, technology management skills, design production and verification capabilities, development of methods and other technical capabilities.

Economic Impacts: The results and outcomes that affect the economic life of society. Increasing domestic and international trade, high level of competitiveness, productivity of manufacturing, efficiency of enterprises and networking activities are also evaluated among economic outcomes and values.

Social Impacts: The long term effects of the program effecting the social life of the communities are evaluated as social impacts. Long-term investments, rising employment, rising income level, changes in the social life and the culture of the society are evaluated as social effects. Also, including education, health and welfare, safety, new skilled workforce, employment, proliferation of research results and expertise of decision making, new modes of operation and structures are accepted as social impacts.

2.2. Importance of Public Fundings

The impact analysis and impact evaluation concepts became an essential part of the basic and applied research, technology development and innovation management activities especially after the cold war era. Also, the whole R&D funding mechanisms are expected to have an accountability and sustainability perspective. So, the strategic objectives of countries are to create a positive impact on the prosperity in the long term.

The impact analysis studies are indispensible part of the public and private sector funding mechanisms related with the research, development, innovation management activities. Due to the fact that above mentioned activities has a broad range and scope, there is a wide differentiation in the scope, method and contents as shown in Figure 1.

Behn (2003) has identified the main purposes of performance measurement in eight categories as shown in Table 1. The public managers main purpose is identified as the performance improvement and the rest seven purpose are seen as subsidiary purposes.

Table 1
Purposes of Performance Measuring Activities

The purpose	**The public manager's question that the performance measure can help answer**
Evaluate	How well is my public agency performing?
Control	How can I ensure that my subordinates are doing the right thing?
Budget	On what programs, people, or projects should my agency spend the public's money?
Motivate	How can I motivate line staff, middle managers, nonprofit and for-profit collaborators, stakeholders, and citizens to do the things necessary to improve performance?
Promote	How can I convince political superiors, legislators, stakeholders, journalists, and citizens that my agency is doing a good job?
Celebrate	What accomplishments are worthy of the important organizational ritual of celebrating success?
Learn	Why is what working or not working?
Improve	What exactly should who do differently to improve performance?

Behn (2003) discussess that, before beginning a public agency's performance measurement, a clear and cohorent mission, strategy, mission, objective formulation must be accomplished as well as the program structure. Without understanding the policy objectives and rational program structure the performance measurement would be meaningless. The program managers need to know policy objectives for performing an effective performance. The program managers would get alarmed with the performance measurement if there is not a cohorent strategy, mission and objective with a clear program structure. You can not measure anything without clear, agreed policy objectives and a program structure. In such a situation of unclear and unagreed objectives, any performance data can be used to show the failure of managers or agencies.

The most common reasons to carry out assessment and evaluation studies are determined as follows (Kusters, C. 2017):

- Accountability
- Strategic management
- Operational management
- Policymaking or influencing
- Knowledge generation
- Empowerment of stakeholders
- Development of learning organizations and the generation of kno wledge
- Enhancement of practical wisdom and good practice judgements

Impact analysis is mostly required by the public funding mechanisms for the accountability, sustainability, performance measurement, decision making etc. purposes. Government-funded, large-scale R&D projects are subject to performance measurement by most developed countries for several decades. The most forceful case is the US Government Performance and Result Act (GPRA) came into force in 1993 in the United States. Results oriented management based on the GPRA which came into force in 1999 (Kim, E. 2017).

After the enaction of GPRA, all federal agencies are required to evaluate and report the results of their publicly funded activities annually. Their activities are subject to mandatory performance analysis and quantification. The public funds spendings are asked to be accountable by means of efficiency and effectiveness. Also the direct results, indirect outputs and side effects are required to be measured for verification of project outputs.

COSEPUP is a joint committee whose members are from NAS, NAE, and IOM, organized a panel about the implementation and coordination issues of GPRA in 2000 and a Status Report published in 2001 (A Status Report, GPRA, 2001). This report recommends that publicly funded programs of basic and applied research should be evaluated regularly through expert review. The performance indicators of quality, relevance, and where appropriate, leadership are proposed for harmony within the research institutes. It is also strongly recommended that human resources should be explicitly an indicator of performance plans and reviews. It is important to sustain researchers inside the program and to measure the negative impacts of budget reduces for the researcher participation. Human resources are seen as the future science and engineering workforce. One key remaining issue is mentioned that it is unknown in which degree the oversight groups are using the results of the "results act" for programmatic decision-making.

COSEPUP report emphasizes that expert review is the most effective technique for evaluating research programs. The proposed evaluating criterias are quality, relevance and leadership are explained in dept as follows: Review of quality is the most common form of expert review. Relevance is the fullfilment of agency's mission with the research subjects. Leadership is the positioning of a nation's research programs in the international level. The qualitative performance criterias of quality, relevance, and leadership are strongly suggested for evaluating research programs which are more effective than quantitative performance indicators. Focus groups experiences testify that the three criterias (especially quality and relevance), are very usefull criterias for the government agencies themselves. Also the human resources as a performance indicator must be clearly or prominently submitted inside the plans or reports.

GPRA mostly benefit from two standardized assessment tools (ASI & TSR) which measures mainly treatment services and outcomes. Those standadized tools are proven in measuring outcomes but policy makers and practitioners opposes that approach because the context of programs are more important than outputs themselves (Darby, K., Kinnevy S.C., 2010).

The reason why the reasearch and development activities has a broad range of scope is that the researchers have lots of questions to be answered within the whole framework. The research and development theoretical framework is defined as a six dimensional ecosystem as depicted in Figure-1. It can be seen from the figure that if one dimension has a process related or organizational hierarchy it is linked by arrows. If the elements of one dimension has not a hierarchical structure they are linked with straight lines. In the process of modelling a research activity the researcher must select elements from one to six dimentions. The selection of one element in one dimention of the framework will absolutely effect and limit the selections in the other dimentions. So it is critical to make the first selection in a dimension of the framework. As a matter of fact, the model development stage from the theoretical framework is a interactive process. The theoretical framework of research and development activities are defined as follows:

Firstly, the research type is consisted of functional activities such as the scientific, technological, system development and commercialization activities which are mostly sequencial activities. Innovation management can be defined as managing all or some of those activities. In todays world innovation management concept involves R&D management, technology management, product development and commercialization processes. Each of these terms are special processes and must be managed interactively.

Secondly, the research scope is designed whether the scope is at the project, program, organization, sector or national level. All level of scope has specific methods and approaches which gives expected reasonable results.

Thirdly, the the research partners are corporations which takes part during the research and development activities. They are policy makers, sponsoring agencies, program developers, and project executers.

Fourthly, the researcher organizations are corporations which the research and development activities are executing, running or taking place. These are research centers, public or private institutions, universities and companies which have R&D units.

Fifthly, the research methods are mainly classified into two categories which are qualitative and quantitative methods. Quantitative methods mostly measure the tangible and countable results. The qualitative methods try to measure the intangible, uncountable results and try to make clear tacit knowledge. The hybrid method uses both qualitative and quantitative methods and mixes them to get the advantages of them and elimine the disadvantages of both methods. Triangulation is defined as a method that is combination of several research methods (combination of qualitative, combination of qualitative or combination of both) in the study of a specific research problem. In this method the goal is obtaining high level of reliability by application of different methods and getting the same or similar results.

Sixthly, the research impact measurement time is also another critical dimention of the framework. The timing of the impact measurement might be executed before the research activity as a prediction (ex-ante), during the research activity as monitoring or after the termination of research as assessment (post-ante). It is called evaluation that is executed about the long term effects of the research.

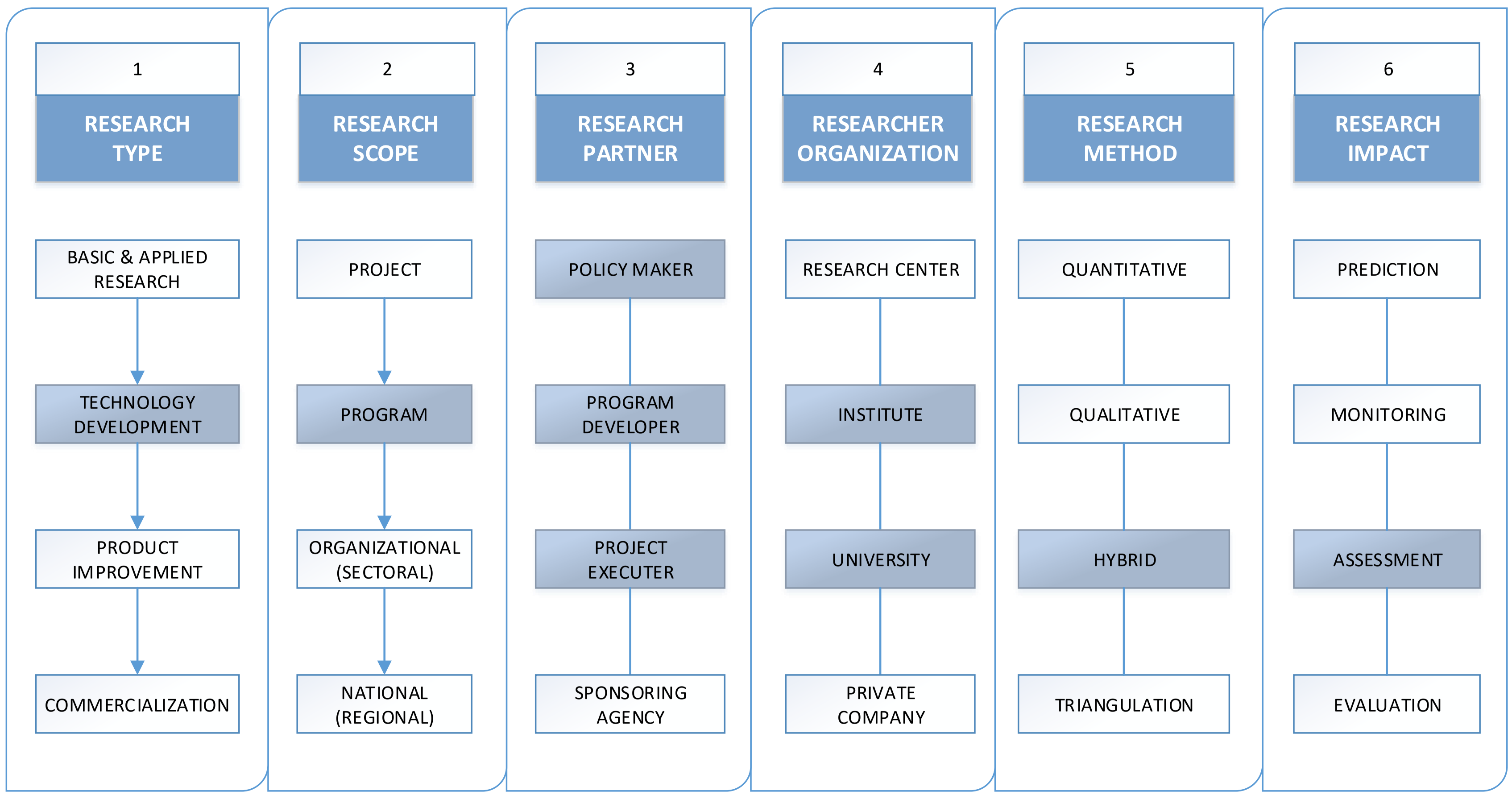

Figure 1. The Six Dimensions of R&D Activities

2.3. Technology Maturity Perspective

Technology maturity assessment is a critical part of technology management discipline. Technology management discipline consists of planning, implementing, assessing, utilization and termination of technology phases according to the strategic and operational requirements of companies, organizations or nations.

It must be considered that a spesific technology output is not necessarily specific to any pruduct or service sector. Any technology developed and reached the TRL6 level may track completely different system development and commercialization path. As a result of this fact, the success of one technology in a specific area depends not only the technology maturity level of itself but also depends on the sub-systems and sub technologies of the containing system. This concept is stated clearly on a broader competition perspective by Michael Porter that “Competition shifts from the functionality of a discrete product to the performance of the broader product system, to systems of systems, in which the firm is just one actor” (Porter, M., HBR, November 2014).

Technology has a broader and penetrating impact on the value chain so it includes all of formal R&D organization roles. Technology strategy of any corporation is an essential part of overall competitive strategy so effective technological change will impact the industry structures and competitive advantages. A technology can be assumed to be mature only with great caution technological skills are a function of many factors—management, company culture, organizational structure and systems, company reputation with scientific personnel, and others (Porter, M.E. 1985).

Starting from the basic technology level to the application of technology inside a system is highly beneficial due to the fact that the developer companies or the nations gain the “technology know-how” at the end of the whole process. The technology development process has very challenging and exhausting issues and always requires an outstanding performance for a technological and economical benefits. The management of the technical processess, assigning the roles, evaluation of the performance and taking critical decisions and understanding the key indicators during the development phases, makes the difference for a successful program.

Technology Readiness Levels (TRLs) assess the maturity of a specific technology in a standardizied way with a set of metrics. It provides to compare different types of technologies consistently in the context of specific application, implementation and environment (Frerking, M. A., & Beauchamp, P. M., 2016)

The most popular and leading method to evaluate the maturity level of the developed technologies are the "Technology Readiness Level (TRL)" measurement methodology. In this methodology the technology maturity is scaled into nine levels and each level represents the completion of certain tasks. The completion of ech level is dependent to the previous level either fully or partially completed. (Figure 2) Each TRL level completion is measured by answering certain survey questions.

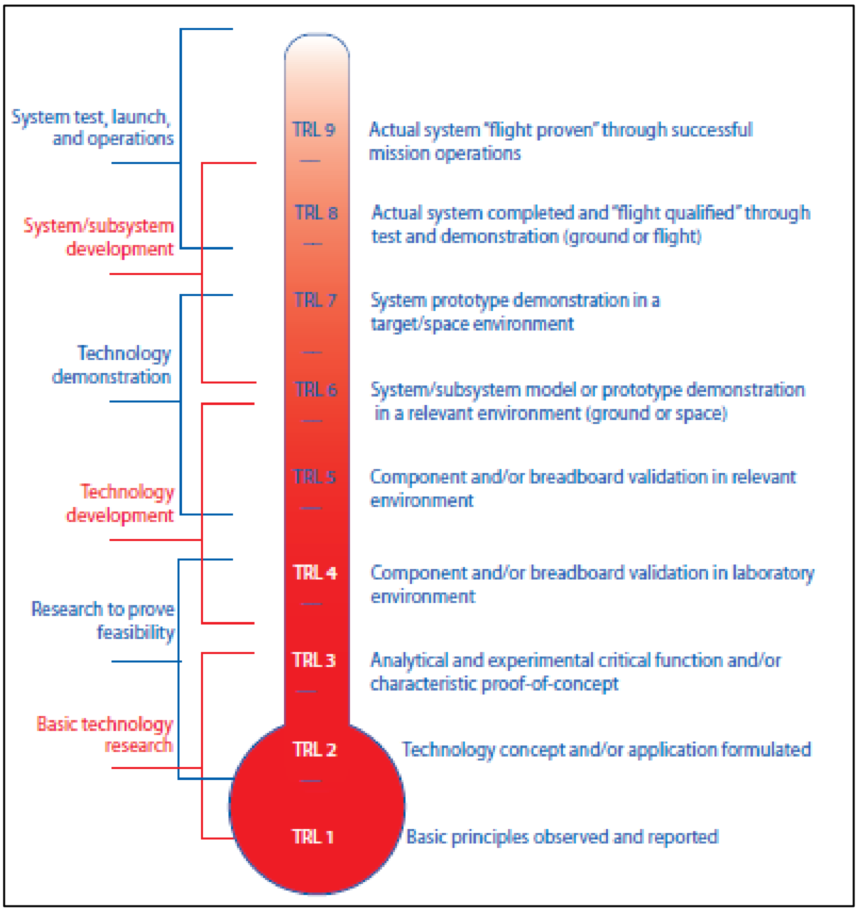

Figure 2. Technology Readiness Levels (Source: NASA, SEH, 2017)

The technology readiness level of TRL1, TRL2, TRL3 and TRL4 are mostly executed by universities, publicly funded institutions and research centers. If these efforts does not ent up with outputs such as patents or proof of concept prototypes, these researches would be considered failed. These phase must be considered as the knowledge generation and the first level of technology push approaches (Figure 3).

The technology readiness level of TRL4, TRL5 and TRL6 are executed by public, private and mixed funded institutions, research centers and they act as a bridge and as true drivers of innovation (Francesc Guell, 2017). At these stage the conceptual idea is turned into a working prototype.

The technology readiness level of TRL7, TRL8 and TRL9 are mostly executed by public and private companies and different industries. At this stage the laboratory prototype is turned into a commercial product (which is ready for serial production) with considerations of production costs and needed production equipments. The main goal of these partners are entering new products and services to the market, completeing the commercialization process. These phase might be named as the product development and the main concern of the industrial firms are about unit cost, produceability, market availability and competency issues.

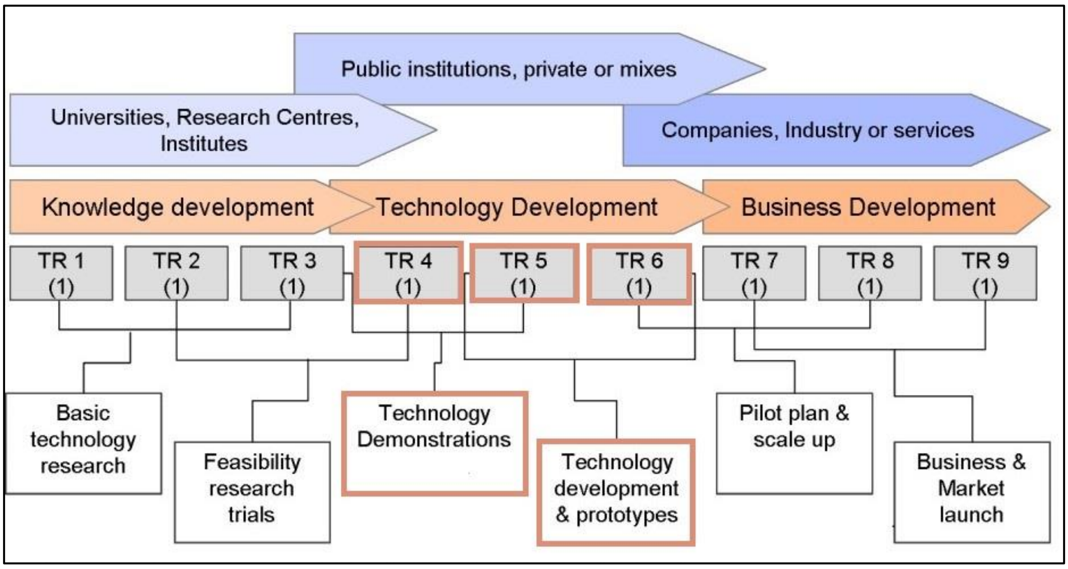

Figure 3. Technological Innovation Chain
(Source : https://www.fguell.com/en/design-thinking-vs-technological-innovation/)

The technology development phase of the R&D activities takes a critical role within the whole process. Because of the unpredictable and ambiguous nature of the technology development phase most of the development programs fails. This phase is where most of the academic and the technology development projects fail and die. NASA and UK's Technology Strategy Board uses TRL terms to demonstrate the innovation process and the 'valley of death' or the "innovation gap" which occurs between TRL4 and TRL7 (Figure 4).

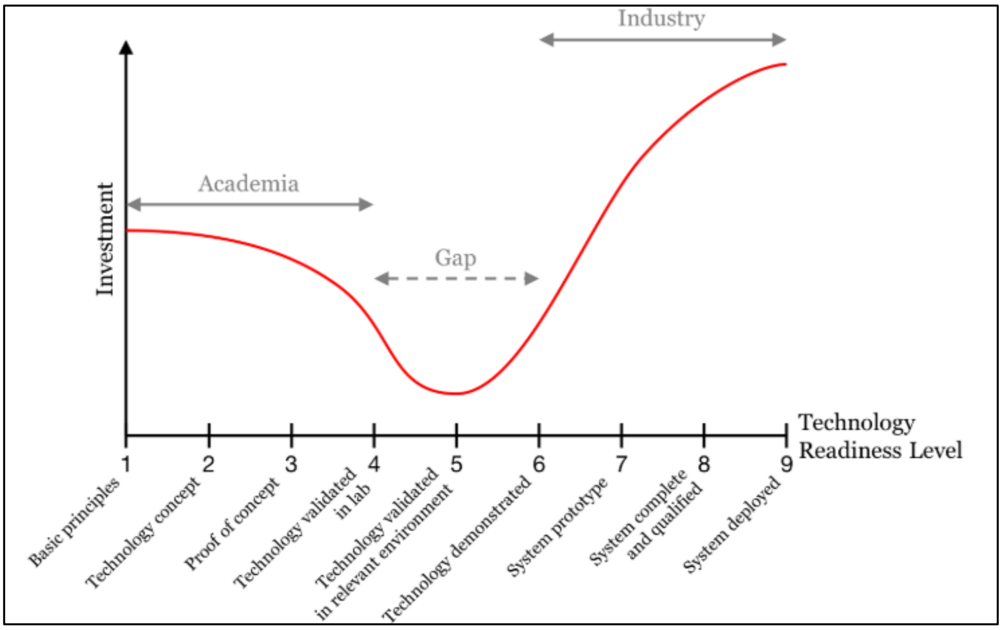

Figure 4. Technology Valley of Death
(Source: https://blogg.pwc.no/digital-transformasjon/bridging-the-technological-valley-of-death)

The causations and results of the failing technology development programs are not studied in detail, so there is a literature gap related with this area. Besides, the driving success factors has not been systematically identified. Despite the fact that reasons of failing programs are mostly tacid, intangible and qualitative factors, most of the impact analysis studies are bibliometric and has quantitative indicators. So qualitative researhes are strongly needed to focus into that phase. Possible reasons of getting stuck in the valley of death might be considered as:

1. Loose coordination and collaboration between the academia and the industry,
2. Academics are unaware of the engineering challenges,

3. Industry has not enough technology absorbing capacity,
4. Subject technology is not state of the art,
5. There is not enough supporting and collateral technologies.

The TRL method which is widely used among space and defence companies has some shortcomings about its implementation, application and scope. Many researchers and developers identified these shortcomings that some of them are mentioned below:

Mankins (2002) states issues about the programmatic context such as “An approach is needed using a research discipline-neutral methodology that integrates a wide array of technical and programmatic information regarding the competing systems concepts as well as their component technologies. However, such a methodology must be capable of capturing in a consistent, cross-disciplinary way the best judgement of diverse specialists.”

As Mankins (2002) stated, “TRLs alone are not sufficient for successful technology management and risk assessment. Many other complementary methodologies have been introduced in order to better identify uncertainties during research and development, to take action upon these uncertainties and to develop long-term technology opportunities based on needs.”

Olechowski, Eppinger, and Joglekar (2015) identifies mainly 3 systematic issues. Firstly it is not clear how to make prioritization of technology development efforts. Secondly, the whole project progress is unclear in a technology development perspective. Thirdly the technology readiness of overall system could not provide an understanding of the system’s overall maturity fort he managers. Fourthly, existing academic TRL visualization forms have centered around the product architecture.

Tomaschek, K. (2016) states that “practitioners face challenges in combining TRLs with additional technology management approaches. A reason for these challenges might be that Technology Readiness Levels are pushed beyond their original scope of pure maturity assessment. Data analysis shows that TRLs are predominately used in engineering and research functions within organizations, which develop or acquire complex technological systems. The four most critical TRL challenges relate to themes of systems engineering. The survey results show the high importance for a useful way to assess the maturity of complex systems. The fact that the top four challenges have one common underlying dimension indicates that TRLs in their original form are not sufficient for assessing the maturity of technologies in complex system engineering."

Zhao, D. (2015) states that "TRLs establish the maturity of a new technology at a given time. To mitigate the risk management issues of TRL methodology NASA has already used the Advancement Degree of Difficulty Assessment Method (ADD) and they combined the TRL and the ADD method in both 'Mars Exploration Program' and 'Sunjammer Mission'."

Due to the fact that TRL measurement has serious risk management issues Advancement Degree of Difficulty Assessment Method (ADD) is a method developed to measure the risks and difficulties when deciding to have a higher level technology readiness.

NASA Technology Maturity Assessment (TMA) is managed within the framework of Product Breakdown Structure (PBS). NASA TMA is a two step process as 1) the determination of the technology maturity level of each component/sub-system/system in the TRL concept 2) determination of difficulty related with current TRL to the required TRL level through the Advancement Degree of Difficulty Assessment (AD2) method. The AD2 assessment is used to estimate cost and schedule plans and make risk assessments. At the end of the day, technology assessment plan (which components, sub-systems and systems needs to be advanced to upper technological level), cost plan, schedule plan and risk assessment plan should be prepared (NASA System Engineering Handbook, 2017).

There is a fundamental link between evaluation and foresight: evaluation results are used for foresight purposes and vice versa. Accordingly, development measures should target both areas. Evaluation and foresight support the continuous development of research and innovation policy and strategic decision making. As such, they are instruments of common learning, understanding and exploitation. Therefore, it would be valuable to pay special attention to the successful organisation of evaluation and foresight and the division of responsibilities for the activities involved (OECD, 2009).

2.4. Methodology Perspective

Expert review is mostly used to assess the quality of researchers, projects and programs. This method is also accepted to have more than traditional peer review by scholars in the field. United States DOD uses Technology Area Reviews and Assessments (TARA) process to evaluate science and technology programs through expert peer reviews (A Status Report, GPRA, 2001).

Expert review method is also used in NASA program management perspective to understand the core activities of the projects, identify purpose and objectives, assess the findings etc. The high level decision maker groups can not get intimate knowledge by their own efforts, because of the fact that they do not have experience and enough time about the processes conducted. Expert assessments are not conducted as formal action processess but they are recorded as a report. These reports are used to take actions about the concerns. No formal success and failure determination is made but corrective actions are requested for following judgements (NASA NPR 2010).

Fang-Ming Hsu, (2009a) measured the performance of the 189 Taiwan government sponsored projects funded between 1997 – 2005 under the Industrial Technology Development Program (ITDP) with Data Envelopment Analysis (DEA) methodology. Four input and seven output quantitative measures are determined and it has been shown that environmental influences have an effect on the efficienct score measurement. The rationale of this study is explained as the previous government funded program performance evaluations had been relied mainly on inputs rather than project outputs. Project outputs are defined as project scope, technical complexity and staffing which all of them should be accepted as project performance.

Hakyeon Lee (2009) has studied performance comparisons of six national R&D programs with heterogeneous objectives in Korea by using DEA mothodology. In his study he used two inputs and ten outputs as quantitative indicators such as funds, researchers, papers, patents etc. He provides applicable results for policy makers on national R&D programs, and shows that DEA is an applicable methodology for the purpose. The source allacation for R&D programs according to such performance rankings must be carefully considered because measures were highly dependent on the input and output variables. As some limitations are mentioned, the timing of data collection for some projects were not suitable, timing was even before the projects due dates.

Lazzarotti, V. (2011) has made an R&D performance evaluation for a private sector company by using Balanced ScoreCard (BSC) methodology. He uses perspectives such as; financial perspective, customer perspective, innovation and learning perspective, internal business perspective, alliances and networks perspective. He classifies indicators as covering input, output and process aspects and all the indicators are quantitative nature.

Several publicly funded large scale R&D project performances are assessed by using an impact analysis model with AHP methodology within a framework (Kim, E. 2017). That study used expert review data to make a quantified integrated index for ranking and comparison of projects that conducted in Korea. He mapped the evaluation framework according to BSC perspective. The outcomes are categorized as intangible, tangible and project specific outcomes as well as technological and economic outcomes. The case study for verification of proposed model is conducted and after using AHP methodology and quantitative data gathered from the project participants a government funded infrastructure development project ranked as first for economic and industrial performance. The technological level of the proposed model is assumed to be high bu its usabilility was a problem.

There are many methodological challenges in public funding assessments. The main challenges might be considered as shifts in the principles for governing research, the rise of multi-purpose assessment, the spread of performance-based funding and external accountability for research, the use of metrics and indicators in research assessment, the emphasis on research impact as a component of research value (Oancea, A. 2019).

2.5. Modelling Perspective

There are many criterias for impact assessment modellings. The scope of the assessment is the first dimension to be considered. So the models might be designed according to the project, program, organizational, sectoral or national frameworks.

In China, Science and Technology Ministry published the government regulation on evaluation management document in 2001. China initiated the national medium- and long-term Science and Technology Development Plan, at the beginnig of 2006. NCSTE of China uses internal and external expert reviews for program evaluation. It has developed a relatively mature evaluation framework with in three dimensions that covers programme goals and objectives, programme management and implementation, and programme effectiveness and impacts. Each dimension is examined with the use of some key questions (OECD, 2009).

Academy of Finland implemented an impact assessment of scientific research in 2006. They approach the impact problem by dividing "impact" into two parts: scientific and social impacts. This is justified for the evaluation of basic research. The inevitable time span from the original research results to the far-reaching social impacts may be several decades. That makes it difficult to identify and measure far-reaching impacts. As a matter of fact, impacts are the result of complex cause-and-effect chains over long periods of time (OECD, 2009).

Intellectual structure of evaluation is another modelling perspective. Evaluation is a field where academics and non-academic practitioners both are working scholarly and practically. There is a rich history of collaboration between practitioners and academics. Articles published solely by academics are cited most frequently but if an article has an extraordinarily large number of citations, it was authored by a practitioner. All programs of any kind are evaluated in the sense that value judgments are made about them by stakeholders and interested parties. The field of evaluation consists mostly of work dealing with social work and community, public health, and organizational management and performance (Ayob, A. 2016).

2.6. Indicators Perspective

Multiple dimensions of R&D performance analysis has been discussed and the performance indicators are categorized. The performance indicators must be selected carefully with respect to the measurement needs. These need can be determined by the perspectives of performance analysis, the purpose of R&D performance analysis, the type of R&D, the level of the analysis, and the phase of the innovation process (Ojanen, V., Vuola, O. 2003) (Ojanen, V., Vuola, O. 2006).

Performance measurement system design starts with identifying the measurement objectives which belongs to the funding program. After identification of the objectives, the next step is identifiying the performance dimentions to be monitored. The third step is using operative techniques to measure the performance according to a control object (Manzini, R., Lazzarotti, V., Chiesa, V. 2008).

Fang-Ming Hsu (2009b), has explored the additionality of government subsidies in the research and development (R&D) behaviour of recipient firms. Input additionality, behavioural additionality and output additionality are examined within the Taiwan government sponsored 127 R&D programmes over 9 years. He found that behavioral additionality of public programmes has an effect on the learning processes of the participants. He also explores how additionality factors are differing in various sectors.

AEA, (2015) gives examples of totally 44 research and technology indicators and outcomes that are categorized in 10 different category. The scope of those indicators expands from the basic scientific research, technology development programs to the product development activities. They consist of the input indicators as well as the output indicators presenting the economic, social and sectoral impacts of the programs.

It is shown that the the selection of R&D performance indicators must be selected according to the subject business unit or the collaboration network, R&D level and scope of the program or project when assessing R&D activities.

After a detailed surveillence on the performance measurement or the impact assessment literature of government funded R&D activities, it is realized that research type is mostly the basic & applied research, research scope is mostly on the project, program or organizations level, research methodology is mostly bibliometric and quantitative.

US managers use quantitative output metrics while German managers prefer input metrics for measuring intrinsic worth of R&D (Werner, B. M., & Souder, W. E., 2016).

The best approach would be to integrate multiple objective (quantitative) and subjective (qualitative) methods and indicators accordind to a literature search (Werner, B. M., & Souder, W. E., 1997).

CHAPTER 3

TECHNOLOGY DEVELOPMENT FRAMEWORK

3.1. Technology Policy

Due to the fact that public funding mechanisms began to conduct strategic, complex, multidisciplinary and huge budget programs during the 1960s and the 1970s science and technology policies grew up in a “mission oriented” direction. Manhattan Project (developing a nuclear bomb) and Apollo Project (landing on the moon) are well known examples of that policy. Mission oriented technology policies are for achieving specific goals, completing tasks and applying methodologies which are not just about spending funds for challenges but spending by using specific methods.

This period lead to the establishment of innovation agencies, innovation oriented industry policies and program grands towards the society expectations. OECD was instrumental in establisment of such a science policy which justified the need for science as a) Research should be done for national, politically-determined goals, b) Research should be planned and organised to that end, c) Research should be more interdisciplinary, in order to solve real-world problems; (OECD, 2014);

Alternatively, the “diffision oriented” technology policies are emerged for leveling up the proficiency in the whole technology field taking into consideration the public objective, with supplementary policies (ex. tax reliefs for green investment). (Mazzucato, M. 2018). It is considered that, in the post war era the several diffusion oriented countries like Germany and Japan performed better economically than mission oriented countries like France and UK. Besides, US has tried to make a structural transition from mission oriented toward a diffusion oriented paradigm in its industrial technology policy (Chiang, 1991).

The past few decades of research policy has some rising principles, such as formal accountability, marketization, and competition, in the governing of research at international, national and organisational levels. As result of those principles, performance-driven assessment technologies has a growing reliance for informing public investment in research. Additionally performance driven assessment technologies are used to drive research activity towards aims such as global competitiveness and measurable contribution to the ‘knowledge economy’ (Department for Business, Innovation and Skills. 2016).

On the other hand debates are ongoing in the strategic level for the significance of publicly funded R&D programs. The mission oriented publicly funded R&D programs faces new challenges and Manhattan and Apollo programs are not the right models for todays programs. Economists overlooked the significance of the programs which has specific objectives. Program developers should take into account the characteristics of such programs and the deployment of the technology. Publicly funded R&D programs are necessary where potential applications are not clear so private sector enterpreneurs are reluctant for investment. Those programs mostly require basic research (Foray, D. 2012).

In todays 21st century, one or both of above mentioned policy approaches are needed to apply with respect to the specific conditions of each country. Both of the above mentioned policy paradigms requires a common capability area called “technology development” for diversified requirements. It is accepted by science, research and innovation community that technology development capability plays an important role for countries that aims to achieve technological and economical superiority by implementation of any policy approaches.

Science, technology and innovation (STI) policies become sophisticated when the policy instruments are diversified. Different types of STI policy implementations caused failures because of risky and incompatible applications. The dispersion of public funds to international, national, sectoral actors caused the multi-actor, multi-level and multi-disciplinary governance forms. As a result, assessment of the diversified public fundings and their side effects become more difficult (OECD, 2016).

So, in the first stage the national technology policy must be compatible with the nations strategic program and long term needs. Secondly, technology programs have to be structured according to the policy goals vice versa. This is a critical point for an effective program management and performance evaluation for the managers. Othervise, the results will be uneffective, useless and the sources will be wasted.

Due to the fact that todays technological superiority competition has a complex and multidisciplinary nature, the emerging high technologies such as quantum computing (QC), artifical intelligence (AI), nanotechnology, robotics, space techlologies etc. requires different types of capabilities for successful applications. So, both mission oriented and diffusion oriented policies must be implemented at the national and organizational levels. It is very hard to match countries with strict policy approaches, but diversified policies in sectoral and organizational level might be considered. Mission oriented policies resulted first comer disruptive technologies such as nuclear energy, internet, global positioning systems, high power lasers etc. Diffusion oriented policies resulted technologies such as infrared imaging, higt tech monitoring, cellular communication, solar panels etc.

The economic development, trading increase and the social prosperity of nations are highly related with their capability of developing technologically and commercially admirable products and services. Such capabilities mostly requires long term, collaborative and multi-disciplinary actions. Above mentioned policies resulted two different paradigmas for achieving production and development capabilities; the “technology push” and the “market pull” paradigmas. Technology push paradigma generally creates the destructive technology for long term goals and the market pull paradigma mostly adopts and modifies the technology for near and mid term goals as economic and industrial beneficiaries. Above mentioned strategic paradigmas must be considered as the inevitable reflections of policies on the product development field.

The technology push paradigma has driven by mainly the results of scientific and basic research activities. This kind of scientific activities may or may not have a justification by any pre-defined need declaration but curiosity of humankind for the unknown is sufficient. Also, this kind of activities does not necessarily end up with successfull technological and industrial developments. However the successfully completed scientific and technological development activities have high impact potential on the whole economy as well as the societies. Any technological development which wipes away the antecedent alternatives from the market may be called destructive developments. The technology push paradigma is considered as a higly important case for competitiveness advantage, sustainable development, high tech product development, high profit rates and consequently becoming a developed nation. That is the main reason why developed countries are constantly funding scientific and technology development activities by public and private mechanisms.

The second one, market pull paradigma has driven by the demands of the market shareholders (the customers). The term of "innovation" emerges from this approach because innovation process highly demands and focuses on the economic outputs, profits and potential of the market.

Developed countries and long term financially capable corporations give high priority for technology push paradigma and continuously funds emerging technologies such as quantum computer, quantum entanglement, artifical intelligence and machine learning applications. (USA, China, IBM, Google, Boston Dynamics etc.). Besides, some developed and developing countries and innovative corporations give priority for the market pull paradigma such as the electric vehicles, cell phone applications, IoT and Industry 4.0 applications. (South Korea, Germany, Tesla, Samsung, Bosch etc.).

The technology development concept has emerged as the crossing junction of both scientific activities and the product development activities. The technology push and the market pull paradigmas are both combined and bridged with the technology development activities which requires coordination of universities and industry along with research centers and public institutes. So the planning, utilization, management of technology became more important as well as the assessment and evaluation of technology development activities.

3.2. Technology Development

'R&D process' is a generic term and sometimes it is used to mean only a fraction of a whole concept. But R&D term consists and represents a series of consequtive, interactive and interdependent activities. These activities can be analyzed in the following stages: a) Basic research and applied research b) Technology development applications c) System development and mass production d) innovation.

Due to the management and intellectual needs, it has often been necessary to separate "basic" research from "applied" research. Basic research is often described as an exploration of nature without any intellectual constraints or guidance. The only required output of basic reseach is new knowledge and the outcomes of basic reseach are unpredictable in advance. Applied research is described as a scientific activity whose inputs are new knowledge and outputs are also new knowledge, but knowledge which must be useful and applicable to a specific solution of a explicit problem.

The application of basic research might need several decates for implementation. For example, general relativity theory is published in 1915 by Albert Einstein, and the the propositions of this theory are verified several years later. In 1970's satellite navigation system implementation studies began in US DoD. While developing the GPS technology for time transfer and position determination purposes, general relativity propositions are used for time and position corrections while GPS satellites and the earth rotates in different speeds. Only 77 years later proposition of general relativity, in 1993, its application of GPS satellites became operational worldwide.

Studies on the nature of semiconductors are another example of basic research. Karl Braun discovered and documented the first semiconductor diode effect in 1874. A basic research on the semiconductor surface in 1947 at Bell Labs (for amplification purpose) led to the discovery of transistor effect which is an another output of basic research. After the discovery of transistor effect, in 1954, the usage of transistors for hand sized radio devices are realized as an example for applied research by Texas Instruments Company. Additionally, the development of various transistor types for various electronic devices are considered as technology and product development activities.

The term “applied research” is used after the post second war era reports instead of the term “technology development”. After developing technological complex systems, systematic research on the various applications of applied research, so many product developments from technological improvements caused to emergence of special R&D process called “technology development”.

Since then, technology development processes takes an important part in the whole R&D and innovation management systems. Management and implementation of the technology development process is highly risky and challenging because it requires multi-disciplinary, multi-stakehoder, scientific and industrial perspectives.

“To optimise the economic and social benefits from public research and the return on public R&D investments, effective linkages are needed between academia and industry. Knowledge flows between public research institutions and industry are channelled through spin-offs, joint research projects, training, consultancy and contract work, the commercialisation of public research output, staff mobility between workplaces and informal cooperation by researchers.”(OECD, 2016 STI Outlook). It is clear that the effective linkage between academia and the industry can only be established by an effective, accountable and sustainable technology development programs.

When it comes to innovation concept this processes extends with service, marketing and commercialization activities. R&D processes are preferred to but not necessarily designed to reach marketing and commercialization stage for different reasons. Besides, the innovation management system is consisted of the whole R&D processes and including the commercialization stage, financial stage, sensing customer expectations and the all interactions with the field. The concept of product life cycle management mandates to take into consideration the customer expectations, design issues and engineering problems at the first stages of product development. This concept minimizes the product manufacturing costs, maintaining costs, service costs and maximizes the customer expectations.

3.3. Impact Assessment of Programs

Impact assessment begins where technology forecasting ends. The casual elements responsible for the impacts of technology are the development and the diffusion of that technology (Porter, A. L., Roper, A. T.,…,1991).

Impact is defined in OECD-DAC Glossary (2002), as 'positive and negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended'. This definition also suggests the possibility of different kinds of links between all kinds of development intervention. The effects may be on the direct or indirect users of the project outputs, on the project or programs itself or even on the decision and policy makers on the wider context.

There are two main reasons for policy makers to concern the publicly funded research evaluation. Firstly, they want to know public research investment fields and the economic and social returns for society. Secondly, countries increased public investment not only in higher education and business sector but also in government institutes despite budget constraints. Impact assessment might be considered as part of an evaluation process. Policy makers needs to assess the impact of strategic research grants. R&D impact is measured in two different categories as economic and social. But the scope of these measurements, sufficient methods and available indicators are controversial issues. The effect of creating change in terms of science and technology can be examined in various ways (OECD, 2009).

Impact assessment activities mainly links the causes and effects and explains how and why the actual results achieved. It must be emphasized that the resulting reports of research program evaluations must be effective on the government agency decision makers. The strategic management and policymaking studies should benefit from evaluation results. On the other side program managers strongly need to get feedbacks or effects of executed performance measurements. They need to feel confident being on the route of policy goals. Also, program managers might use program evaluation results for controlling, motivating and improving responsibilities. The six stages in the research impact assessment plan is defined as (Novo Nordisk, 2017):

- What is Research Impact (understand the context)
- Identify the Assessment Purpose
- Measure: Define Indicators of Success
- Develop the Design, Methods and Data Collection
- Communicate and Use Findings
- Manage Assessments

In an organizational perspective, technology management is applied to shape and realize strategic and operational goals by means of organization's technological capabilities. The core six technology management activities are defined as; acquirement (development, transfer or cooperation), utilization, identification, learning, protection and selection of technology. The two critical management activities which are technology forecasting and technology assessment are assumed to be supporting activities. It is accepted that the forecaasting is a part of selection process and assessment is a part of utilization, learning and protection of technology. Technology management concept and related management related tools are explained for an organization or company’s point of view (Çetindamar, D. 2013).

According to Figure 5 technology development process is an alternative option for technology acquirement core process. Technology assessment is useful for utilization, protection and learning processess. Organizations may acquire technology in three different strategic perspective. At the national level, governments should consider technology developing by using national resources especially for the critical sectors such as healthcare, agriculture, defence, energy etc.

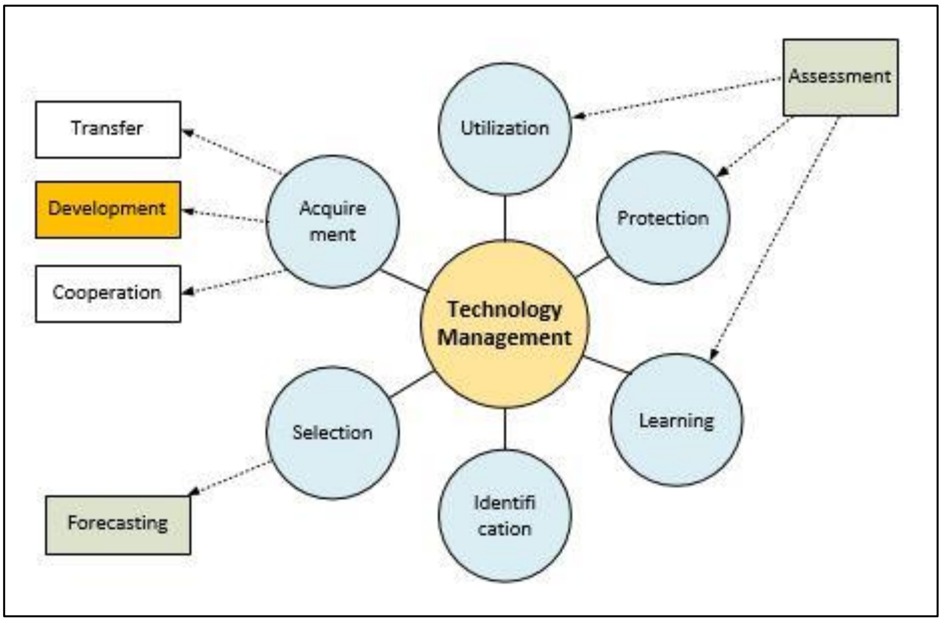

Figure 5. Technology Management Processes
(Source: Çetindamar, D. 2013)

Kocaoğlu, D. (2010) defines the innovation process by 5 consecutive steps in the first row of Figure 6. by It can be easily seen that technology development process outputs are directly linked and connected with the innovation concept.

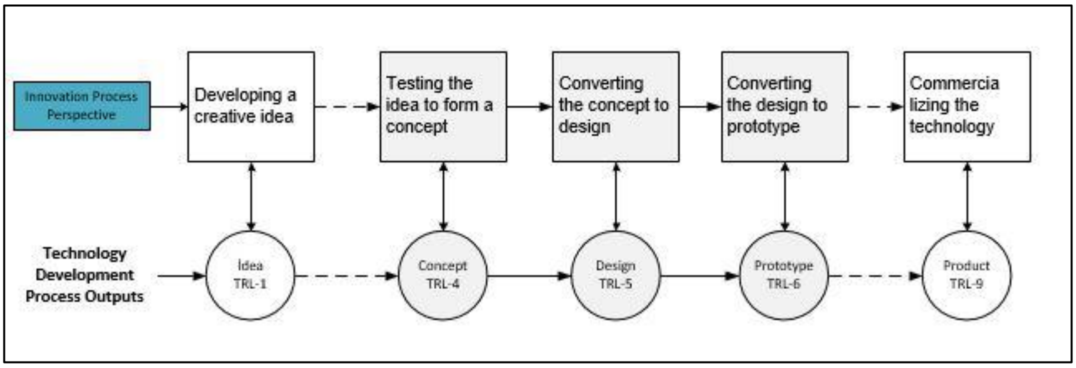

Figure 6. Innovation Process and Technology Development Relationship

According to the NASA Program and Project Management perspective (NASA Program and Project Management Handbook, 2010. NPR 7120.5) system development process is split into five phases and three sections named formulation, implementation and operation. (Figure 7). Project formulation begins in Pre-Phase A. This phase involves concept studies (designs), operational analysis, feasebility, technology needs analysis and alternative technology analysis. After this phase the program requirements are specified with the collaboration with stakeholders.

At the end of Phase A, the concept study is completed and the budget, schedule and life cycle cost are estimated. At the end of Phase B, performance requirements of whole system and all the sub systems are determined by breakind down the system requirements into sub system requirements. At the end of Phaase C, the final design or the critical design is completed and system is ready for assembly phase. At the end of the Phase D, system is integrated and tested. The determination to pass one phase is with review meetings taking into account Key Decision Points (KDP). (NASA NPR 7120.5).

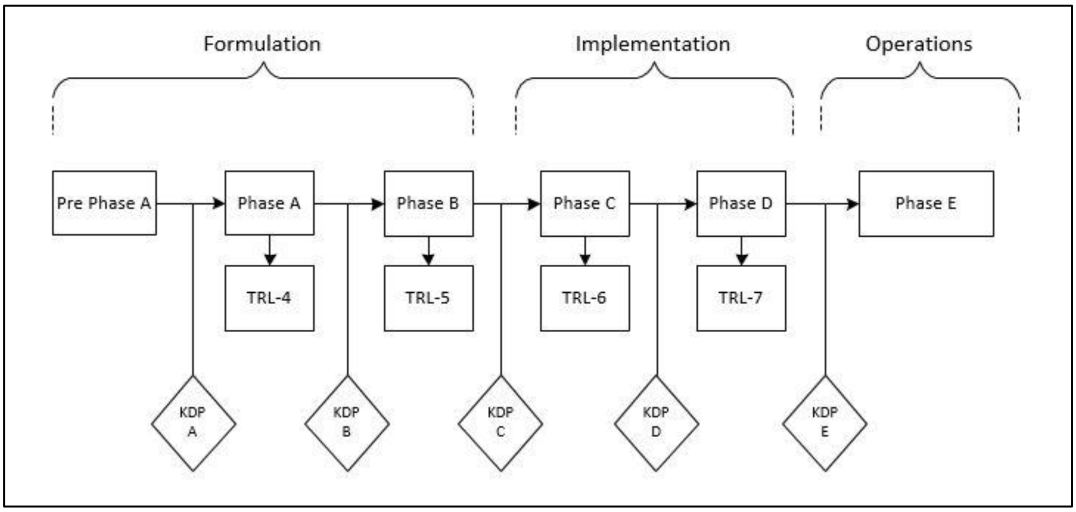

Figure 7. NASA Program Cycle

US Department of Defence has a very similar model for mapping of technology readiness levels to US Department of Defense System Acquisition Process as shown in Figure 8. (Olechowski, A. 2015).

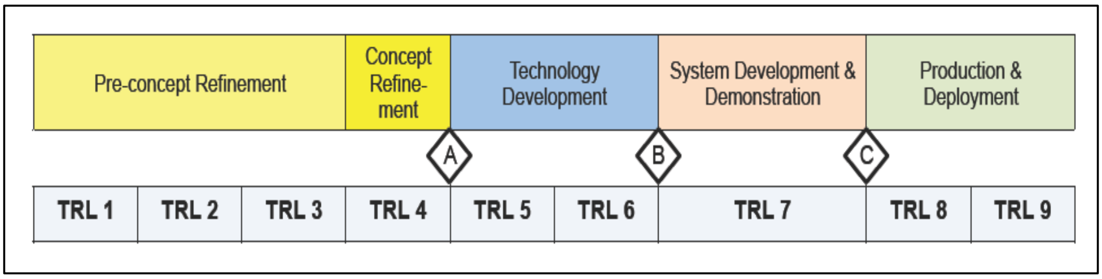

Figure 8. US DoD Mapping of Technology Readiness Levels
(Source: Olechowski, A. 2015)

TRL method is considered a part of the technology readiness assessment (TRA) model. TRA model consists of three sequential steps which are identifying critical technology elements, assessing TRL levels and developing a technology maturity plan (TMP). These reviews are shown as milestones in Figure 9. (Sanchez, R. (2011). TRA Guide, US DoE).

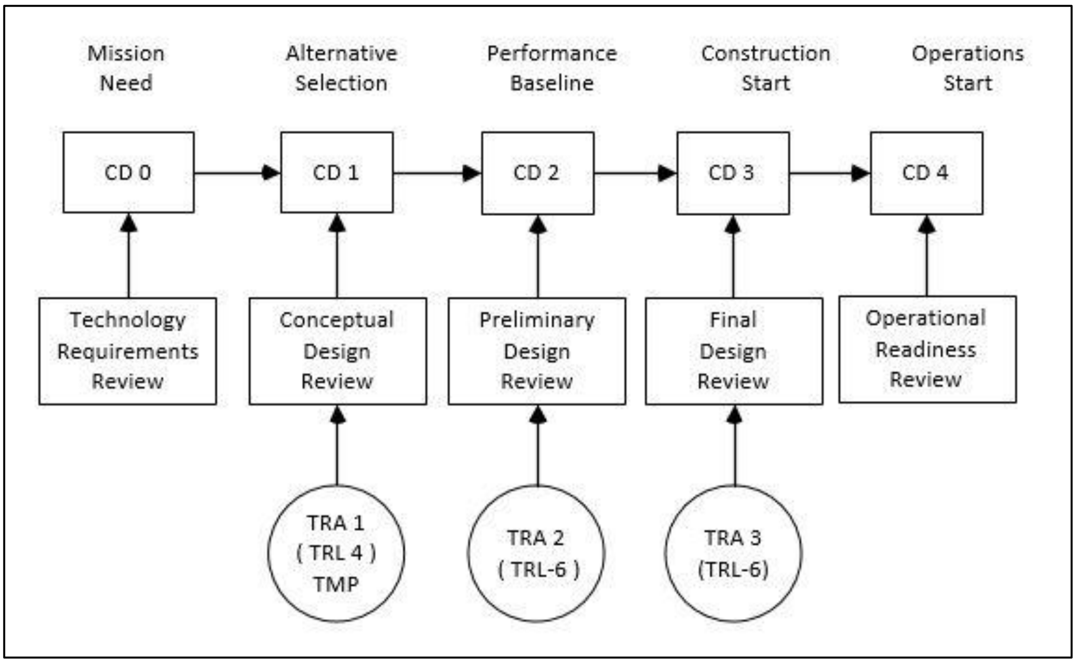

Figure 9. US DoE Technology Assessments for Critical Decisions

Although technology development programs are the continuation of applied research, they are also the pioneering activities of system/product development activities. So they are critical activities and management, implementation, assessment of technoology development is very challenging. Many uncertainties, risks, technical and administrative difficulties can be experienced in this stage and many scientific and technological initiative fail at this stage. Therefore, this process is mostly called "the pit of hell".

The first challenge at this stage is that the information obtained from basic and applied scientific research should be assimilated and very well understood. Secondly, it should be demonstrated that scientific research is turned into technologies that are applied on feasible and successful prototypes. Thirdly, the developed technology must be suitable for mass production, making it part of a product that will provide commercial or strategic benefits of the society. Fourth, one of the most important challenges of technology development activities is the necessity of working in cooperation with many units and stakeholders in the country. Moreover, this cooperation and coordination should be maintained in the medium and long term. Fifth, technology development needs and involves intensive experience, expertise and qualified engineering activities. These activities include design, procurement, production, integration, testing and so on.

Technology development activities has a common understanding with the NASA Program Cycle perspective, US DoD perspective, US DoE perspective, system engineering perspective and its outputs (laboratory, engineering and system prototypes) perspective (Figure-10).

Technology management activities should also consider "Technology Life Cycle" processess which must be managed for a continuous and sustainable economic growth.

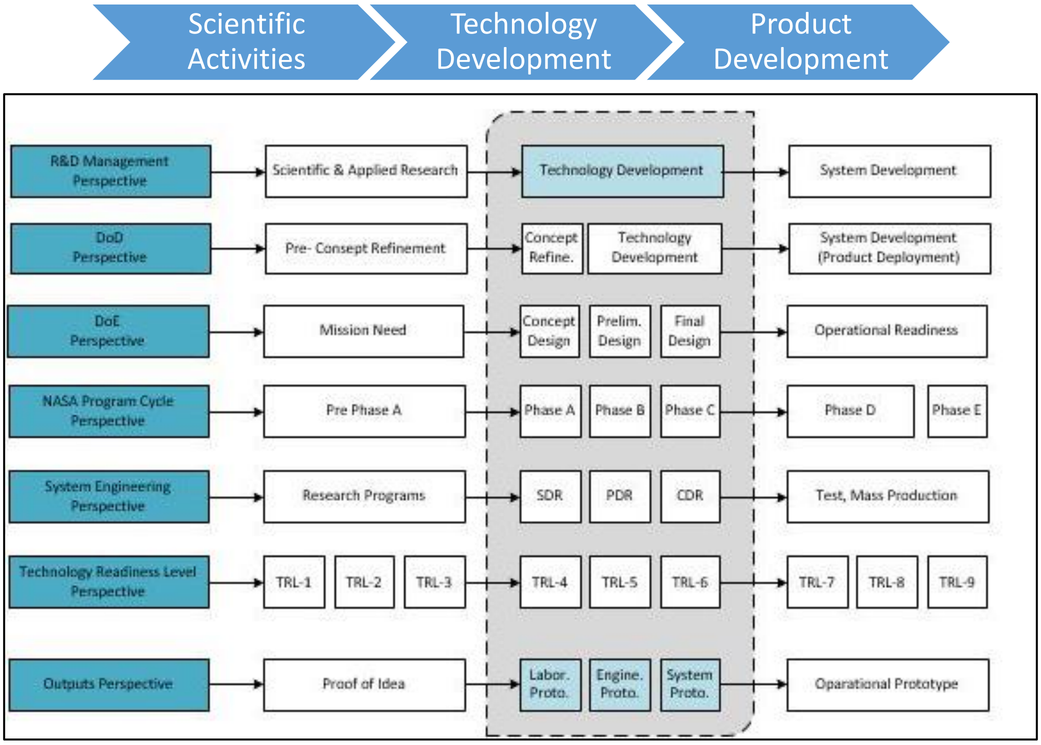

Figure 10. The R&D Activity Stages by Different Perspectives

The choice of design and method for demonstrating program outcomes depends on the questions asked and the context of the program being assessed. (AEA, 2015). So, the proposed impact assessment model for a technology development program is generated according to the Figure 11.

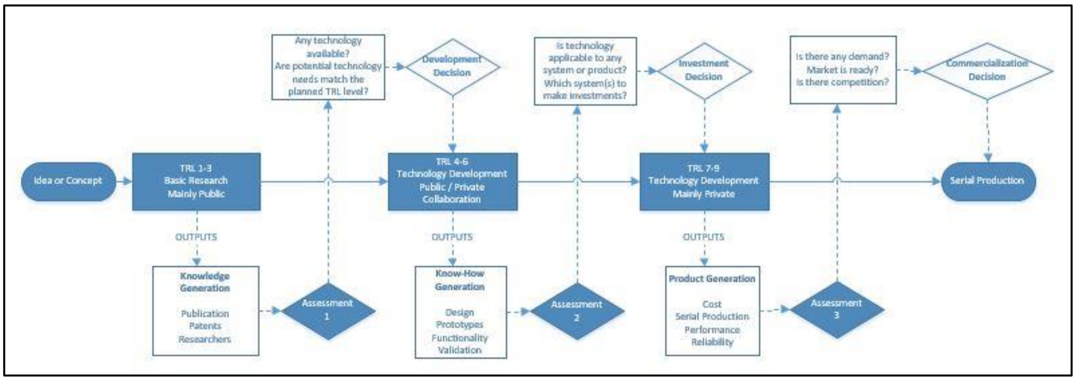

Figure 11. Technology Development, Outputs and Decision Points

Impact evaluation are considered mostly as changes which are not direct results of the program. So the scope of this model is limited to only impact asssessment and outcome assessment of technology development programs. At the end of outcome evaluation, actual changes are measured and documented in a systematic way by the proposed model.

3.4. Technology Maturity Concept

It is interesting that technology maturty concept is emerged and developed by the program executer personnel but not the policy makers. The usefullness of the concept is accepted by the policy makers so the measurement of maturty became legal obligation. We may list the necessity for technology maturity measurement as follows:

1. Field experiences
2. Policy determination
3. Program management
4. Risk management

A GAO report (1999) focussed on the impact of technology maturity on product outcomes and also it is clearly declared that the essential determinants of firms' success is development of a mature technology before it is included in products. US DOD practices show that main problems of developed wepon systems still comes from insufficient and immature technologies used in systems. Before using a technology inside a product or system, every stakeholder (users, developers, sponsors etc.) of the product must be certain about the maturity and the desired functionality of the subject technology.

Another GAO report (2020) states that technology readiness assessments are done for program managers, technology developers and system engineers for specific purposes.

Policy determination requires to fullfil the aims of strategies as well as feedbacks from the field. The current status of the technology field provides strong and weak points. So policy makers can impose effective policies.

Program management tells us where you are, where do you want to go and what you need to do for achieving the purpose. So technology readiness scale certainly helps us to determine critical decision points. Also by determining the technology readiness level, the risks of using that technology and the risks of developing that technology may be determined.

The need for technology readiness level measurement issue emerged after major system projects began to be realized during the Second World War. During the Second World War some major system development projects were running and the executives were under pressure especially for time, scope, coordination and integration constraints as well as the needed development of state-of-the-art technologies and final production. The Manhattan Project that was aiming to build a nuclear bomb made a big impact for building some modern concepts such as systems, system of systems, project management, systems engineering and technology development. Until the Second World War the scientific research was mostly executing by European countries and US was not dominant in basic scientific research areas. After the 2nd World War it is very well understood that which nations wants to lead economic, social and especially military dominance should also own modern and domestic technological capabilities. It was clear that most of the technological capabilities were coming from scientific research areas. Develped countries made systematic and structural changes in their scientific, technological and system development processes. Additionally, during the 1950's and 1960's large-scaled, large-budget, long term and complicated system development projects were initiated related with the military and space missions. These projects were consisted of so many sub systems and multi technological components that are required to perform together. As a result, the projects became so complicated as well as the technology development and management activities.

During the execution of large scaled, large budget projects, there was a risk that the projects would fail if there was lack of competency or lack of maturity in any of the sub-technologies that constitute the final systems. The decision point for approving a new technology inside a hi-tech system is critical, because of the engineering parameters such as functionality, maintainability, robustness, etc.

To address these risks before the launching the large scale system development projects, it was necessary to know the level of sophistication and competence of the sub-technologies that were expected to be used within the system. At this viewpoint, a systematic technology maturity level calculation method was required and developed.

Any technological item which is intended to be used in a hi-tech product, must be qualified by a systematic method, starting from the scientific research activities and ending with the operational use or its mass production to the market. One of these qualification methods is called the “Technology Readiness Level (TRL)” method.

Within the structure of this method, technology maturity levels are divided into 9 stages (Figure-2). It begins with the first hierarchical level (TRL-1) which indicates that “basic scientific principles are observed and reported” and ends with 9th hierarchical level (TRL-9) which indicates that “technological system is proven through successful mission operations”.

TRL-1, TRL-2, TRL-3 levels of the above figure are considered as basic scientific research stages, TRL-4, TRL-5, TRL-6 levels of the above figure are considered as technology development stages and TRL-7, TRL-8, TRL-9 levels of the above figure are considered as prototype validation and system development stages. In the measurement of technology maturity levels with the above mentioned method, each TRL stage is defined with predetermined questions. If the questions of each level is answered positively that stage is assumed to be completed.

NASA introduced the technology readiness level (TRL) scale as a tool for technology maturity assessment of complex systems development in the 1970s. TRL assessment tool is used to take technology management decisions within NASA's Mars Curiosity Rover mission which is a multi-million dollar program. Also, United States Department of Defense began to use of TRLs in all of its new procurement programs starting from 2001.It is the most widely used tool for such maturity assessment cases and all technology development processess (Olechowski, A. 2015).

The basic properties of TRL Calculation Method is;

1. Technology readiness levels are divided into 9 stages and each of them are defined beginning from the bottom level up to operational usage.
2. Levels of 1-2-3 are representing the basic scientific research activities
   Levels of 4-5-6 are representing the technology development activities
   Levels of 7-8-9 are representing the system development and operational activities
3. Each level is evaluated by answering several questions by Yes or No
4. Questions of each level are pre defined and fixed.
5. Evaluation method is mostly output oriented.
6. This method has a point of view of NASA. The evaluation point of view for DoD may differentiate. It is mostly NASA centric not DoD.

Some popular public and private sector companies tries to adopt this method in their product development processess suc as NASA, Raytheon, BP, Bombardier, John Deere, Alstom, Google etc. TRL scale is used for technology development assessment tool for several organizational and systematic reasons that is why organizations have widely adopted. First, it provides a common and standardized understanding of technology maturity and risk. The defined levels can be used as a standard language while discussing maturity across the organization and between disciplines. It is also useful for exchanging information between different groups such as development group and a project group. Secondly, it provides a systematic approach and technology oriented system development processes, with the TRLs acting as decision points, guides of research area scopes, steps (Olechowski, A. 2015).

Aditionally below mentioned items are considered advantages of TRL calculation method;

1. This method has an output oriented and quantitative calculation.
2. The existence of outputs and pre defined specific documents and results of some specific activities are questioned.

3. The evaluation is completed by implementing a survey with a group of expert who are expected to answer Yes sor No.
4. It is considered relatively easy to implement because an analysis is not needed.

The disadvantages of TRL Calculation Method are reported in the literature mostly related with practical cases. Despite the fact that NASA is the most accomplished practitioner, it is not fully satisfied with their implementations and they are studying to improve their processes. After a semi structured interviews with high level TRL users, it is reported that users face 15 challenging difficulties which might be grouped into three categories: system complexity, planning and review, and assessment validity. (Olechowski, A. 2015). Below mentioned four challenging difficulties migt be mitigated with proposed assessment model of this thesis:

- Prioritization of technology development indigators
- Lack of improvement plans
- Subjectivity of the assessment
- Imprecision of the scale

TRL tool is mostly meeting NASA's needs more than DoD’s needs, because NASA built systems are produced in smaller quantity compared to DoD’s large scale production. It does not take into account manufacturing, integration, transition, difficulty of advancing maturity issues. TRL states the status of technology readiness on a scale only in a particular point in time. TRL combines many dimensions of technology readiness into one metric therefore it does not give a complete picture of risks in integrating a technology into a system. Due to variation in acquisition programs, resources, requirements, funding, schedule, and other program specific attributes, no one maturity assessment method fits all. Also there is a lack of a guideline explaining how to implement the TRL assessment (Azizian, N., Sarkani, S., & Mazzuchi, T., 2009)

During NASA's Ares Project technology development activities, the TRL calculator program was used to measure the suitability of the developed technology, but there were no results to be assured. Due to the fact that that TRL processes are stated to be incompatible with NASA program logic, William Nolte (one of the developers of TRL method) was employed and the question types were rearranged according to Ares Project. It is stated that Technology end users' questions are basically related to the existence of equipment, the capability and capacity of equipment and materials. As a result, it is needed to build 9 level risk and complexity table (Hueter, 2010).

According to a Software Engineering Institute study presentation (Garcia, S., Graettinger, C., & Forrester, E. 2006) , TRL terms are not technology-independent (ex. breadboard), it is just one of the numerous management criterias, the users of Software Engineering Institute think that TRL scale provides them at most 30% of their decision criteria. This study points out that TRL uses only one scale and addresses only two dimentions of technology adoption the completeness and the environment. Completeness is increasing of technology, components integrated to prototypes and then integrated to final form. Environment in which technology functions, is starting from laboratory setup to relevant environment and finally to the operational environment. This study also proposes new dimentions for practice-based technologies instead of TRL levels definitions.

Aditionally below mentioned items are considered disadvantages of TRL calculation method;

1. The challenges facing developing countries in technology development activities cannot be compared with those of developed countries. TRL method is designed for a developed country (especially for USA) which has almost no restriction or resource issues. Those issues are mainly lack of human resources, lack of qualified researcher, lack of infrastructure, procurement restrictions, scientific research incapability, management difficulties, system development inexperience and so on. So TRL method do not intend to measure this kind of restrictions and deficiencies which are real problems for a technology developing country.
2. This method of technology level acquisition does not provide information related with activities such as; human resources quality, infrastructure facilities,

management activities, procurement activities with export licence restrictions, national design and manufacturing capabilities, characteristics of the prototype and so on.

3. It is not possible to measure the impact or benefit of stakeholder organizations (technology policy-making institutions, customer authority, program management, project management) during and after the technology acquisition activities.
4. The output oriented and one dimensional measurement method is popularly used. However, technology development activity is a multi-stakeholder, multi-disciplinary, multi-dimensional concept involving different kind of activities. The impacts and competence of these dimensions should also be measured.
5. TRL method does not give a qualitative information. It can not give any hint about possible management issues. The effectness of this method is considered to supply only 30% of data required by the decision making authority.
6. We cannot easily find out answers for below mentioned questions; What are the issues that need to be managed and what are the missing processes? Where are the weak processes and outputs during the technology management processes? We can only evaluate the functionality of the prototypes, but this result is not satisfactory for most of the cases.
7. No forsight for the possible future development activities.
8. Gives no information related with the possible risks.
9. Gives no information related with the required efforts for advancing the current technology maturity level.
10. The relationship and cooperation between the technology developer and the technology user must be considered and evaluated because the main purpose is using the technology inside a product or system.

- **Detailed Descriptions Of Outputs:** The terms ‘prototypes’ and ‘outputs’ are used to define the same output mostly. The outputs are clearly defined below to be able to mean the same maturity of technology outputs and their functionality.

- **Laboratory Prototype (TRL-4 Output):** It dont need to have a visual similarity with the intended final product. It is intended to provide feedback related with the system requirement items. The developer will be sure about which design is feasible and which are not. The designer will be able to consider how the prototype can be improved in which attribute such as used materials, mechanical properties, functional properties, or form of it. It doest need to have a good form or even work well. Its main idea is to demostrate the functionality or to communicate with the partners about the idea or to convince the management of the program. Sometimes "breadboard" or "proof of concept prototype" term is used insted of laboratory prototype.
- **Engineering Prototype (TRL-5 Output**): It has to reflect the form of the intended final prototype and has to give the feeling of final prototype. It is intended to provide feedback related with the preliminary design. It dont need to have detailed finish, it may be handmade but it has to give idea for serial production. The material used dont need to have enough quality and it can be inexpensive. It is not intended for operational use and it is for general look. It has to give information to the partners about final price, materials, serial manufacturing details, safety and logistics factors. Sometimes "form study prototype" term is used instead of "engineering prototype"
- **System Prototype (TRL-6 Output):** It is intended function of the output. It is intended to provide feedback related with the critical design. It has a final scale similar to final prototype so will be able to test for design flaws before the operational tests and mass production process. It should show all practical purposes of the final version and it shows every aspect of the final product in details such as manufacturing, appearance, integration, packing and instructions. It shows that prototype is ready for production after minor improvements. Sometimes "pre production prototype" or "functional prototype" term is used insted of "engineering prototype".

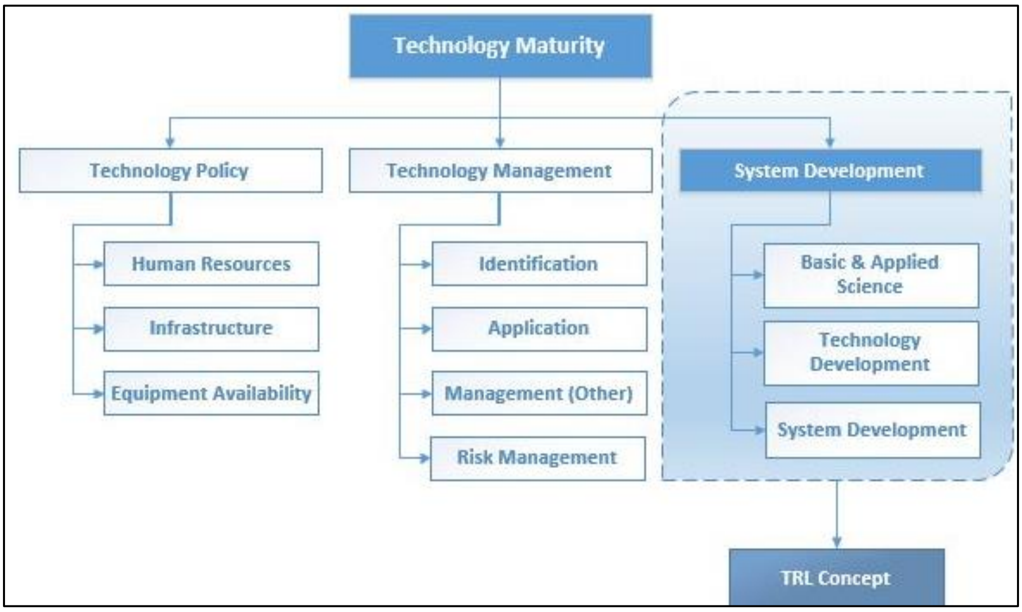

Figure 12. Technology Maturity Concept

It is a well known fact that, in order to get a useful technological device demanded by the market, some complementary technological conditions must be established. Today, we can see the first prototypes of the newly developed quantum computer technology today depends on the fact that some subsidiary technologies such as cryogenic materials technology, entangled photon generation technology, algorithm development software technology etc. In this context, it is useful to consider not only the applicability of a single technology but also environmental factors and their interactions. The technology development assessment system should not be focussed on the project outputs, but also consider the complementary technologies and acquired capabilities to build higher level product and systems.

The need for a qualitative method is for complementary purposes. The combination of both TRL method and the proposed method will submit a better understanding of state of technology rather than application of solely one of them.

Table 2
Prototype Outputs of Technology Development Activities

Technology Readiness Level	Outputs to be tested	Attributes to be tested	Test Medium (NASA)	Test Method
TRL-4	• **Laboratory Prototypes** • Components (breadboard) • Integrated but components with low fidelity	• Proof of Concept approved • Critical functions of components tested. • Performance characteristics of components tested. • System characteristics are defined.	The components are demonstrated in a laboratory environment.	Verification / Proof of Concept
TRL-5	• **Engineering Prototypes** • Components (brassboard) • Components are integrated and with high fidelity • Engineering model is completed.	• Form Study approved • Critical functions of system tested. • Performance characteristics of system tested. • Internal entegration of components (fit) are completed. • Product Work Breakdown Structure WBS defined.	The components are demonstrated in a relevant environment.	Verification
TRL-6	• **System Prototypes** • All Functions are tested • Systems or sub systems integration is completed	• System integration completed. • All system functions tested. • Engineering applicability of the system is demonstrated.	The prototype unit (or one similar enough) is demonstrated in a relevant environment.	Demonstrasyon
TRL-7	• Pre-Production Prototypes are completed • Systems are tested.	• All interfaces are tested on hard and anormal conditions. • System environmental integration (with external components) is completed. • System complete environmental integration is tested.	The prototype unit (or one similar enough) is successfully operated in space or the target environment or launched.	Demonstrasyon/ System Tests

CHAPTER 4

RESEARCH METHODOLOGY

4.1. Methodological Classification

Generally methodologies are classified in two main groups as qualitative and quantitative methodology. Both of them has specific advantages and disadvantages with respect to their conclusions. To be able to mitigate the disadvantages of one method and get more reliable results, there is a third methodology which is called mixed (or hybrid) methodology that uses both qualitative and quantitative approaches together. Additionally some researchers do not prefer to mix the methods rather choose to apply different methods seperately for the same research problem. So they are questioning to get similar or reasonable answers for the same problem by using different methods. This approach is callled triangulation.

When it comes to evaluation of research and development activities, a variety of methodologies can be used to measure and analyze the developed technologies. These methodologies can be classified into 2 main types as follows:

Qualitative methods are judgements or knowledge generation from the countable data set which are made of numbers. Semi-quantitative methods are usually transformed qualitative judgments to countable data by measurement techniques. Qualitative methods are heuristic approaches. Heuristic methods can be used to find a satisfactory solution for a problem and they can be useful for avareness of the tacid and covered knowledge that ease of making a decision. Qualitative approaches mostly provide satisfactory results and credibility for most of the stakeholders.

Quantitative Evaluation Methods:

- Cost-Benefit Analysis
- Bibliometric Analysis
- Patent Analysis
- Economic Analysis
- Questionnaire Survey

Qualitative Evaluation Methods:

- Expert Review
- Peer Review
- Workshops
- Interviews
- Decision Tree Analysis

Hybrid Methods:

- Analytical Hierarchy Process
- Balanced ScoreCard Method
- Data Envelopment Analysis

Triangulation is confirming results obtained by one method with other results of another one or two methods which have different approaches. For example, when a qualitative method judge the results of a project as good, this may be cross-checked and verified with a quantitative method.

Complementarity methods may be used to get better understanding about the results of main method. For example, theory based approaches may be used to justify unexpected results of main method.

Control group methodologies, both experimental and quasi-experimental, have two main drawbacks. Firstly, generalization of one study to a wider context is not possible. One can not feel sure that similar results will occur if the intervention is repeated in different conditions. Secondly, the results for different target groups varies and that fact cannot be explained unless evaluation is executed as part of the overall evercise (Ellis, J. 2015).

4.2. R&D Evaluation Based Classification

The mostly used R&D Evaluation methods are shown in Figure-13 (Developed from: Poh, K.L. 2001). These methods are divided into three main branches which are weighting & ranking mathods, benefit-contribution methods and bibliometric methods. Brie descriptions of each method is given below:

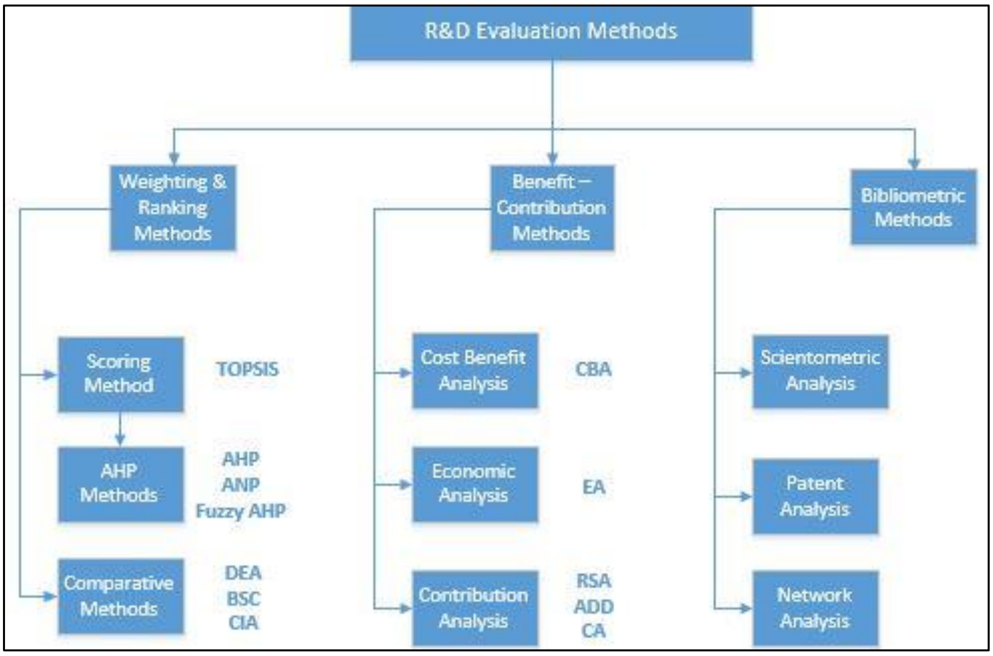

Figure 13. R&D Evaluation Methods

- **Analytical Hierarchy Process (AHP) :** Used as a decision support system tool and supports multi criteria decisions. This method weights the criterions and then assigns values to each alternative so that alternatives get points for ranking or evaluating purposes.
- **Analytical Network Process (ANP)** : An expended version of AHP method used in case the criterions and alternatives are dependent and interactive with each other. It differs from AHP that ANP also calculates dependency factors for each

criteria or alternative. The analysis procedure is relatively difficult and complex according to AHP.

- **Fuzzy Analytical Hierarchy Process (Fuzzy AHP) :** An expended version of AHP method used in case the strict judgements about the criterions and alternatives are not available or unwanted. The analysis procedure is relatively difficult and complex according to AHP.
- **Data Envelopment Analysis (DEA) :** A performance measurement method, used by government or non-government organizations for evaluating the relative efficiency of decision-making units (DMU's) in organisations. This method identifies the best performing units by using inputs, outputs or both to ease decision making and comparing the units. DEA is generally used to get the production function of a firm with a given set of inputs, so as to calculate the maximum output that can be achievable by each production unit.
- **Contribution Analysis (CA):** This method uses clearly detemined cause and effect questions to explore whether or not the programme has made a difference. It investigates the factors that caused the difference or attribution on the observed results. It is especially useful where the program has been designed on a theory of change that is clearly declared at the beginning. (Mayne, J. 2013)

Attribution analysis makes a cause and effect determination but contribution analysis focuses on identifying likely influences. Contribution analysis, connects the dots between what was done and what resulted, examines interacting variables and factors, and considers alternative explanations and hypotheses, so that in the end, we can reach an independent, reasonable, and evidence-based judgment based on the cumulative evidence (Patton, M. Q. 2008)

- **Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) :** This method is used to rank or evaluate the alternatives by taking into consideration both the closeness to the possible ideal solution and the distance to the possible negative ideal (worst) solution. This method uses the basic approach of ELECTRE method.
- **Economic Analysis (EA):** Economic analysis mainly focusses on the profit of the program or company and it is shows the economic perspective. In this method

optimum use of resourses and inputs are critical. This method is useful for production process of an industry.

- **Cross Impact Analysis (CIA) :** A quantitative cross impact analysis method is applied to estimate the reciprocal impact across technologies. The impact estimation may be done by literature surveys, expert interviews as well as patent data. The common areas and references of one organizations outputs compared with the other organizations (or sectors) above mentioned outputs in order to get reciprocal impacts. This method gives information about the stong and weak aspects of the organization as well as opportunities and threats within the compared ecosystem.
- **Advancement Degree of Difficulty (ADD) :** ADD method is used to measure the work and difficulty level when current TRL level is desired to leverage to the target TRL level. Due to the fact that TRL measurement method has shortages about the development capabilities to upper level ADD method is mostly used with TRL measurement studies.
- **Cost Benefit Analysis (CBA) :** A method to compare the costs and expected benefits of projects or alternatives. This method is not interested the internal processess but only the input and output values. The cost and benefit values must be on equal term to be able to make comparison.
- **Balanced ScoreCard (BSC) :** A strategic management method used by government or non-government organizations that analysis an organization or an activity with 4 different dimensions of the purpose; Financial, customer, internal processes, learning and growth. This method tries to develop objectives, performance indicators, targets and initiatives related to those perspectives to meet strategic targets. BSC is a tool that tries to implement some process related actions coming from the strategy of the organization.

The BSC is gerenally agreed as a useful approach for a strategic management system and it has also been adapted for performance management and innovation management and R&D management. The goal of BSC method is to obtain a good strategic position and it tries to focus on future results of organization.

- **Decision Tree Analysis (DTA):** It is a strategic decision making method, shows the roadmaps with alternatives, their costs, possible outcomes, risks. Finally this method calculates the expected value of each alternative for decision makers.
- **Root Source Analysis/ValuStream™ :** It is a systems engineering methodology developed by NASA. It systematically reviews critical issues, high risk points and knowledge needs that matures technology. This method tracks the activities if the materials and processess, design, analysis, manufacturing, fielding and requirement verification issues are identified, included and validated. A brief monitoring chart of Root Source Analysis is shown in Figure 14 (Hueter, 2010).

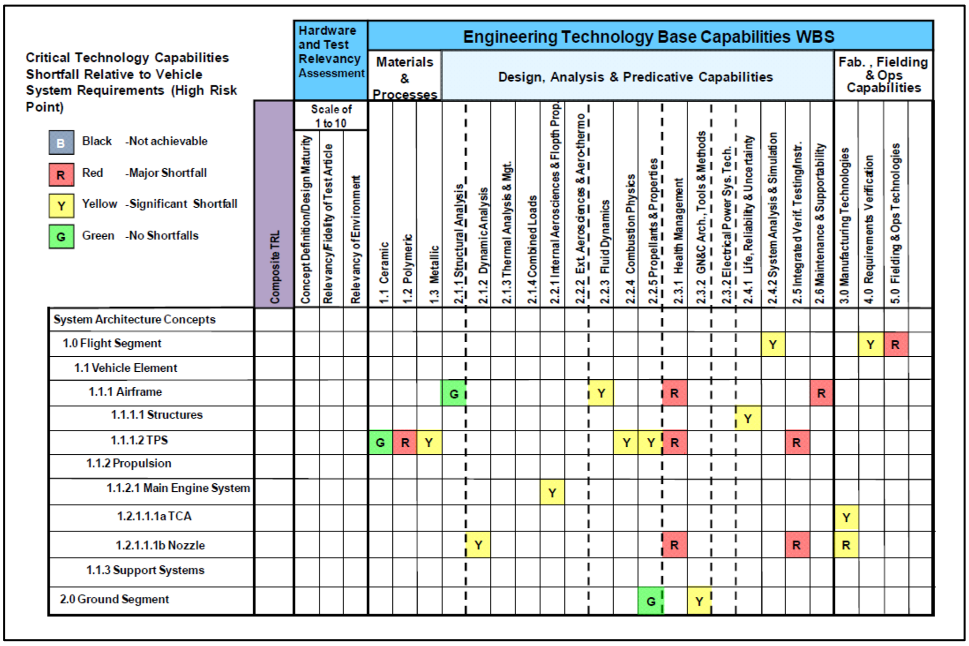

Figure 14. Assessment with Value Stream Method

- **Bibliometric Methods:** Bibliometric methods can be listed as scientometric analysis, network analysis and patent analysis etc. This methods are mainly used for basic and scientific research activities and all has quantitative nature.

4.3. Analytical Hierarchy Process (AHP)

AHP is one of the most widely used multi-criteria decision making methods. T. L. Saaty developed it by using reciprocal pairwise comparison matrices (Saaty, T. L., 1977).

It is a powerful and easy-to-understand methodology that allows groups and individuals to combine qualitative and quantitative factors in decision-making (Saaty, T.L. 1990; Saaty, T. L. 1996).

AHP when used as a R&D evaluation method, it is the close second best method. And has the highest local weights in two criteria “multiple objective” and “nature of data” (Poh, K.L. 2001).

AHP method is used in engineering, manufacturing, education, personel, public management, industry, social fields, management (Vaidya, O. 2006).

AHP is used in the selection of competing alternatives and resource allocation. However, it is mostly used in weighting criteria and selection and grading of alternatives (Russo, R. 2015).

In a technology selection process, a ranking is made between several technology levels by directly comparing, weighting the criteria and subcriteria with each other and weighting these criteria with technology alternatives (Hueter, 2010).

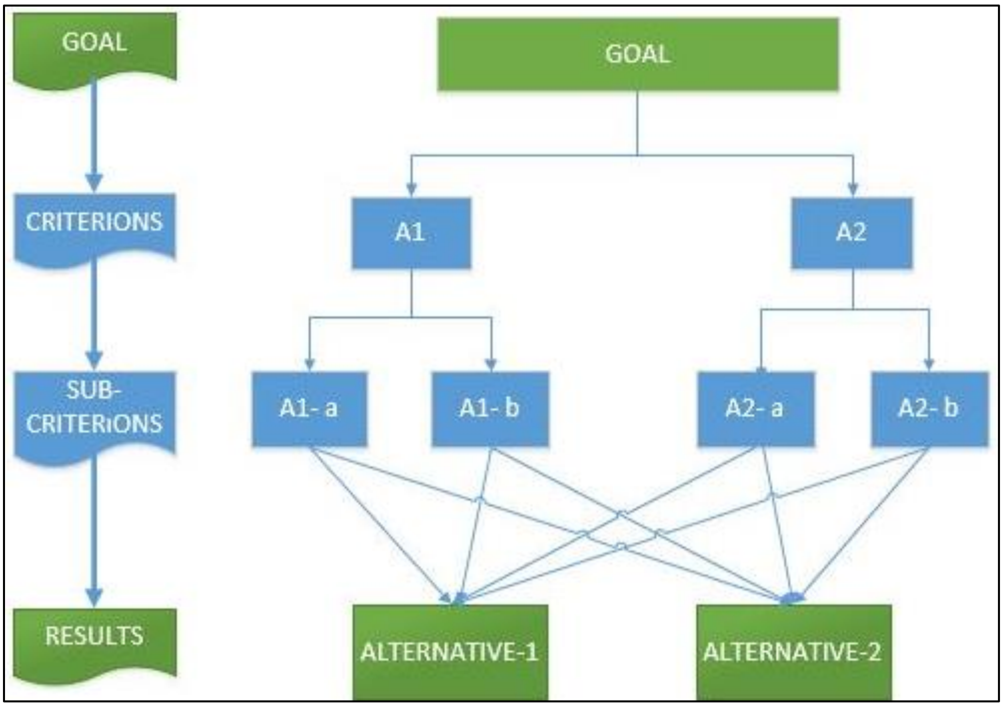

Figure 15. AHP Hierarchy Structure

"AHP has been applied in a wide variety of practical settings to model complex decision problems. One of its major strengths is its ability to compare and rank decision alternatives based on both qualitative and quantitative factors. As a result, the AHP has been applied to an extremely wide range of problems from business, energy, health, transportation to politics solving problems in prior-itization, resource allocation, prediction, planning, risk analysis, conflict analysis, etc. (Saaty and Vargas,1982, 1994). As mentioned in the previous section, the AHP has also been applied to R&D project evaluation" (Poh, K.L. 2001).

4.4. Expert Review

Expert review is a widely applied technique that is used by various professions, in the field science and engineering to answer complex questions through consultation with expert advisers. All science and engineering programs in government agencies, universities, and private laboratories use at least some expert review to assess the quality of programs, projects, and researchers. Expert review is more than traditional peer review by scholars in the field. Expert review is done by the users of the research in any organization who can evaluate the relevance of the research to agency goals (AEA, 2015).

Expert review is considered as a comprehensive version of peer review. Peer review is defined as "a rigorous, formal, and documented evaluation process using objective criteria and qualified and independent reviewers to make a judgment of the technical/ scientific/business merit, the actual or anticipated results, and the productivity and management effectiveness of an Office's portfolio of projects" (Stern, E., DFID, 2012).

Expert review might be used support decision makers by evaluating outputs and the impacts of public investment in R&D. It is also one of the most commonly used method to evaluate public fundings. Additionally, impact assessment requires new metrics and approaches because, involvement of stakeholders are needed as well as new communication channels (between decision makers, agents and stakeholders (OECD, 2009).

Expert review method is suitable when below mentioned research areas are the focus point of the research program (Ruegg, R., & Jordan, G., 2007);

- Determining the contribution of the shareholders to the program
- Determining the types of outcomes
- Determining the scientific qualitiy of program's research
- Determining the technical risk level of the program
- Determining if the technology will work for intended purpose
- Determining if the resources are used efficiently for desired outputs and oucomes
- Determining if the program is productive and well managed
- Determining the mechanisms and the processes made contribution to the program goals

Most of the mentioned research areas are also the focus point of this thesis. Expert assessment methodology is considered the most suitable data acquisition method for this study. The program's data about technology maturity, relevance to the national policy, management and development aspects will be visible by means of expert judgement. It is clearly understood that expert review and assessment is used as a suplementary tool besides the TRL measurement tool and system engineering management tool which are focussed on specific processes and actions.

Expert opinion is the method by which a group of experts come together to evaluate the advantages of a technology and determine the level of technology. It has an unstructured nature and some of the experts may highly influence the results. This is one of the weak point of this method. Additionally, it is hard to bring together tens of experts and have a concensus on the subject on limited time schedule.

Interviews with experts in their fields (technology development activities) may have structured or unstructured nature. It does not provide deeper data about a specific and complex problem. Researcher get generalized and superficial information. Survey with experts may have a structured nature, bu it is unavailable to get deeper data about such a data complex problem.

CHAPTER 5

MODEL DEVELOPMENT

5.1. Model Design

The model and the indicators selection is stricly depends on the research questions, program attributes, research questions as shown in Figure 16. (Source: AEA 2015)

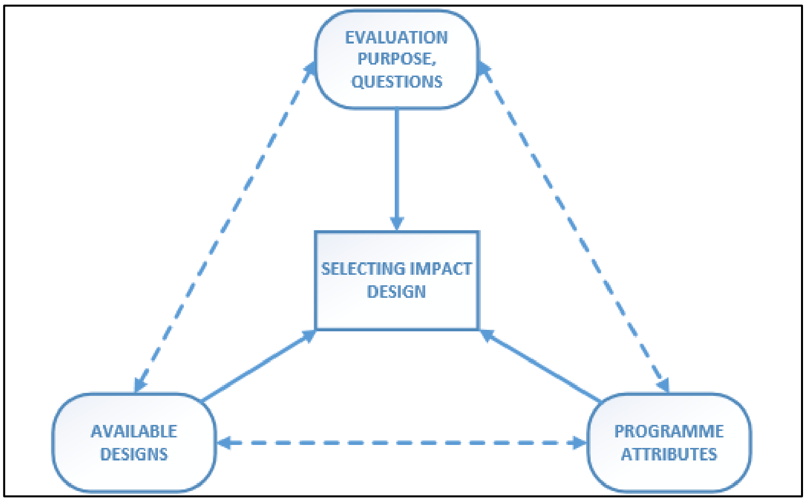

Figure 16. Impact Evaluation Design

The reason for sumitting a method for technology development program is identified above. And the applied procedures are explained below:

Level -1: The four main dimentions of the research design are:

1. Research reasoning and questions are identified
2. The scope and the attributes of the program are identified
3. Models in the literature are searched
4. Available impact assessment methods are identified

Level -2: Designing the impact assessment model

5. Program partners and their relationships are identified
6. R&D Level is identified and boundaries are explained
7. Criterions and sub criterions (indicators) are identified
8. The outputs and targeted results are identified
9. Data acquisition method is identified
10. Analyzing and synthesis methods are identified

- Research Questions

Identifying the research questions are critical and important because questions give the indicators context.

a) Taking into account the responsibilities of all stakeholders (in a qualitative approach), what are the achieved technological maturity level?
b) Which factors are mostly influencing the technological outcomes?
c) What are the economical outputs/outcomes of the technology development programs?

- Program Attributes

The scope (control object) of the model is a “technology development program” that is established specifically for defence industry or a guided technology area. The scope is not defined in the macro scale as a sectoral, regional or a national perspective.

- Available Impact Assessment Designs

After searching impact assessment methods and its applications related with impact assessment studies 10 methods have been investigated. All methods have advantages and disadvantages according to the application types and scope. The nature of this study is mostly qualitative and needed some scoring and ranking procedures. So analytical hierarchy method AHP with TOPSIS is most suitable and compatible for the study. Detailes about impact assesment methods are explained research methodology chapter shown in Figure-13.

- Selection of Assessment Design

The objective of the proposed model is analyzing the indicators of the program, improving the performance, explaining and weighting the hidden parameters, making clear the risk points and measuring the impact of the program.

- Program Partners

According to the professional job experience and also according to the literature the main partners affecting the program and impacts from the program are 1) Technology policy developer units 2) Program developer corporations 3) Project executer units 4) Sponsoring agents. In some cases the sponsoring agents are the same with program developer corporations so this partners are considered the same as program developer corporations. So the proposed model is consisted of firs three partners.

- R&D Level

In the literature the mostly studied R&D activities are basic and applied science studies. The assessment of technology development programs are studied for comparison reasons but the qualitative assessment of these programs has not been studied in detail. The technology development activities are consisting the TRL-4, TRL-5, TRL-6 levels of the R&D levels. So the assessment of maturity are made according to the output prototypes of those TRL levels.

- Criterions and Subcriterions (indicators)

Indicators are mostly submitted by the program experts and confirmed by program academic supervisers The technology develoment module indicators have qualitative nature but the economic outputs impact module has quantitative nature.

Selected indicators are revised by 8 academic personel 3 program coordinator experts, that are actively monitoring the program, and responsible for reporting the results of the program to the sponsoring institutions.

Technology maturity related indicators must be considered directly related with the program impact as well as the economic output indicators (direct results). But the economic outcome indicators (long term results) must be considered partly related with the program. The each three horizontal dimention of the model shows the impact of each three partners. So, the relationship between the technological indicators, economical output indicators, and the economical outcome indicators are linked horizontally for each partners impact assessment.

The models main assumption is, qualitative results are more important than quantitive outputs for the success of a program especially for technology maturity assessment. Quantitative results are (economic, financial, social) tangible and partly results of qualitative results of scientific and technological developments.

When selecting the indicators, below criterions are considered:

- The indicators are selected in a partners responsibility perspective, to be able to assess the role and importance of the partners as well as the impact on them.
- The indicators are selected to represent the whole significant development activities.
- The indicators breakdowned in a detailed manner that can represent the weak domains.
- The indicator selection is not biased, they represent the mutli dimensions of the system. The supervisers checked all pre-determined indicators to avoid selection bias.
- The orthogonality of the indicators are sensitively adjusted because they shouldn't be any conflicting meanings among themselves. That is the main reaason the fuzzy AHP methodology is not needed.
- The indicators does not contain complexity and ambiguity because the expert should be sure about the literal meaning and the percieved meaning are the same.

- The indicators are believed to represent what the program is established to achieve as well as what we should measure. The data we get with suitable metrics will help us to be able to answer the research questions.
- The consistency analysis of the AHP methodology will help to compare the ideal data and the actual data we acquired. So the consistency analysis between two data sets will give clues about the missing and unusable data points.

- Outputs and Target Results

For simplicity and the easy of understanding, each technology level is summorized with their specific output. The output of TRL-4 is the laboratory prototype, The output of TRL-5 is the engineering prototype, the output of TRL-6 is the system prototype. The functionality, application and test medium, special properties of these prototypes are explained in detail in Table 2:

- Data Acquisition Methods

Sample and data collection is made by the expert judgements and interviews by collecting qualitative and quantitative judgement of the experts that actively took part in the decelopment program. The methodology mostly has qualitative nature so expert judgement and interview methods are prefered for getting data. The interviews and judgement meetings have been done 2 years after the program completion. Detailes about data acquisition methods are explained in Section 3.2.

- Analysis and Synthesis Methods

Analysis are made with AHP methodology. The the structure and the weighting of the indicators are made with 35 expert judgements. Also the ANP and Fuzzy AHP methods are investigated but decided not to use them because of their complexity and unapplicability for this model model.

Requirement analysis, structuring the model, data analysis (AHP) and synthesis (TOPSIS) stage algorithms are shown in Figure-17.

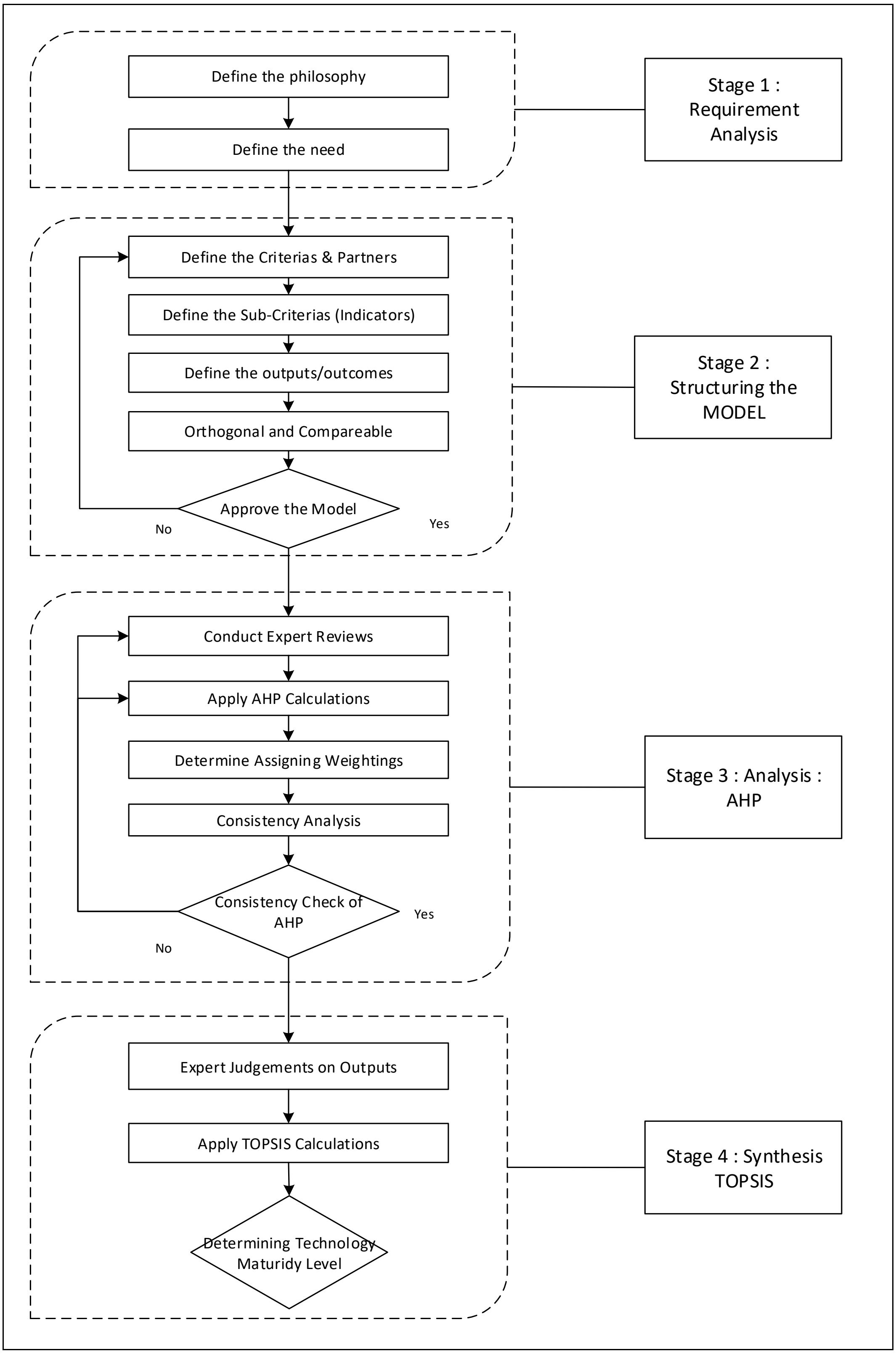

Figure 17. Modeling, Analysis and Synthesis Stages

5.2. Proposed Model Structure

The theory is applied by forming a technological impact asessment model which has three modules. (Figure-18) .The first module contains nine technological development indicators which will be weighted by using analytical hierarchy process (AHP) and then the impacts of these indicators on the prototypes will ve syntezed with TOPSIS method. Technology development process is the core activity of R&D processes because it has a duty to transform the scientific research of academia to a commercial product of the industry. Also technology development process should be named as the critical bridge between scientific research results and the commercial market investments according to the innovation perspective. (Figure 19). The second module is economical outputs impacts module contains eight indicators and will be assessed by surveys with project managers (Figure-20). The third module is the economical outcomes impact module and contains six indicators and will not be assessed by any application or case study (Figure-21).

The proposed model combines TRL assessment and program performance within the scope of the technology development program. The results are evaluated by qualitative 9 indicators with AHP method. Technology development activities have quantitative content in terms of the functionality of the outputs as well as qualitative contents in terms of the competence of the relevant stakeholders.

The technological impact assessment model is consisted of three main modules as shown in Figure-18. The restrictions, indicators, characteristics of these modules are described below:

- Technological Impact Module (Figure 19)

1. The technological impact factors must be analyzed within 5 years which begins from program completion time.
2. Totally 9 indicators are identified inside 3 categories which are technology politics, program management and system development.

3. The mentioned 3 categories directly related to the responsible and partner corporations or establishments that are technology policy developer corporations, technology development program manager corporations and project executer corporations respectively.
4. The mentioned 3 categories may be reorganized according to the Balanced ScoreCard perspective which has 4 dimentions as finance/resources, customer relations, learning and development, internal processes.
5. The technological impact module impact analysis is proposed to be done with expert judgements and analyzing by using analytical hierarchy process (AHP).

- Economical Output Impact Module (Figure 20)

1. The economical output impact factors must be analyzed within 5 years which begins from program completion time.
2. Totally 8 indicators are identified inside 3 categories which are intellectual property rights, public fundings and networking, program outputs.
3. The economical output impact module analysis is proposed to be done interviews with program and project managers

- Economical Outcome Impact Module (Figure 21)

1. The economical outcome impact factors must be analyzed within 10 years which begins from program completion time.
2. Totally 6 indicators are identified inside 3 categories which are employment increase, incestment increase, trading increase.
3. The economic outcomes are expected to impact on national prosperity by means of economic, trading, employment, sectoral development areas.
4. The economical outcome impact factors may be analyzed by tracking to the past.

5.3. Model Indicators

- Technological Impact Module Indicators

1. Technology Policy Related Indicators

a) Sustainable and Qualified Researcher Capability
- Qualified researchers with doctorate degree working on high tech projects.
- Qualified researchers working on high tech projects.
- Collaboration capability with higly skilled consultants.

b) Physical Infrastructure Capability
- Availability of laboratory and test infrastructures
- Useability of laboratory and test infrastructures
- Compatibility of laboratory and test infrastructures

c) Equipment and Machinery Capability
- Procurement of non-critical equipments
- Procurement of equipments on time which are subject to export licence
- Availability of procurement alternatives for critical components

2. Program Management Related Indicators

a) Technology Identification (requirements meet state-of-the-art)
- The identification of requirements meet the technology trending
- Avarenes of technology and its possible applications

b) Management and Coordination
- Management of program contents
- Management of time and cost
- Program coordination activities

c) Technology Activation
- Tracing of project requirements updates
- Tracing of dual use opportunities of project outputs
- Activation of outputs in a system or product and planning

3. System Development Related Indicators

a) National Design Capability

- Design process and knowledge generation by project personnel
- Design know-how is documented and understood
- Design is innovative and applicable

b) Production and Integration Capability

- Availability of national manufacturing infrastructures and firms
- Feasability and compatibility of system manufacturing
- Completion of manufacturing documantation

c) Testing and Verification Capability

- System interfaces are defined and integrated
- Prototype requirements are tested and demonstrated
- Completion of test scenarios and documentation
- VnV (verification and validation) test technologies are acquired. (test technologies for all possible test scenarios, running all possible test scenarios in operational environments or in simulated environments)

- Economical Outputs Impact Module Indicators

1. Intellectual Property Rights Related Indicators

a) New Patents

- Economic value of obtained patents

b) Patent Sales and Revenues

- Patent sales revenues
- Royalty revenues
- Royalty revenues
- Licensing revenues

2. Economic Value of New Public Fundings and New Collaborations

a) Procurement Orders

- Received orders (serial or individual) related with direct project outputs.
- Received orders (serial or individual) related with indirect project outputs.

b) Economic value of publicly funded new projects

- Publicly funded new (sub) projects related with current program

c) Economic value of new external projects & consultancy

- New (sub) projects with 3rd party corparations related with current program
- Consultancy services submitted to persons or corporations

3. Economic Value of Program Outputs

a) Economic value of direct project outputs

- The (approximated) price of project direct outputs delivered to the customer

b) Economic value of indirect project outputs

- The (approximated) price of project indirect (collateral) outputs produced

c) Economic value of internally funded projects

- Internally funded new (sub) projects related with current program

- Economical Outcomes Impact Module Indicators

1. Employment Increase

a) Employment increase within the sectoral companies

b) Employment increase from participated international projects

2. Investment Increase

a) Capital of newly established companies

b) New sectoral investments

3. Trading Increase

a) Incomes from domestic sales

b) Incomes from international sales, participations

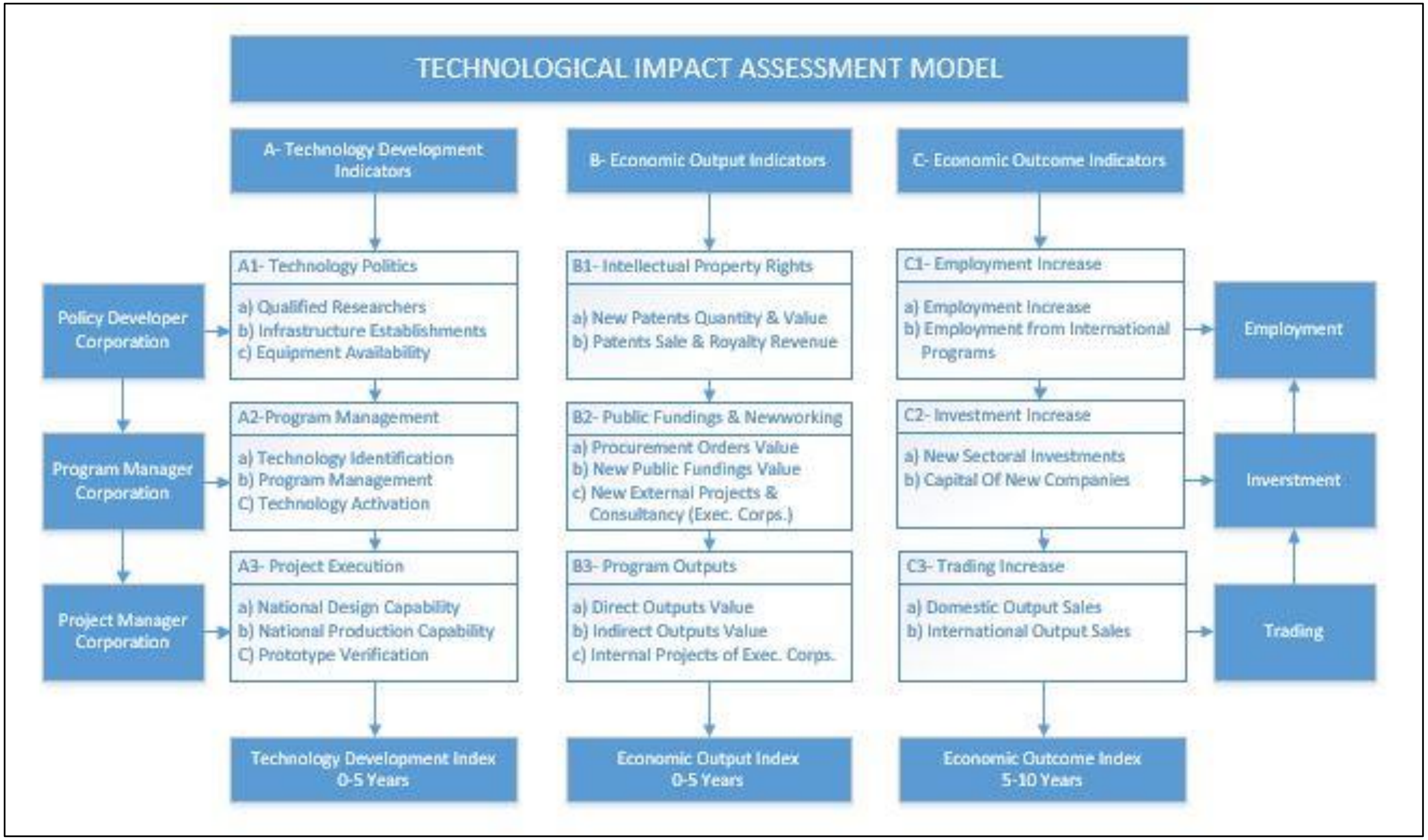

Figure 18. Impact Assessment Model

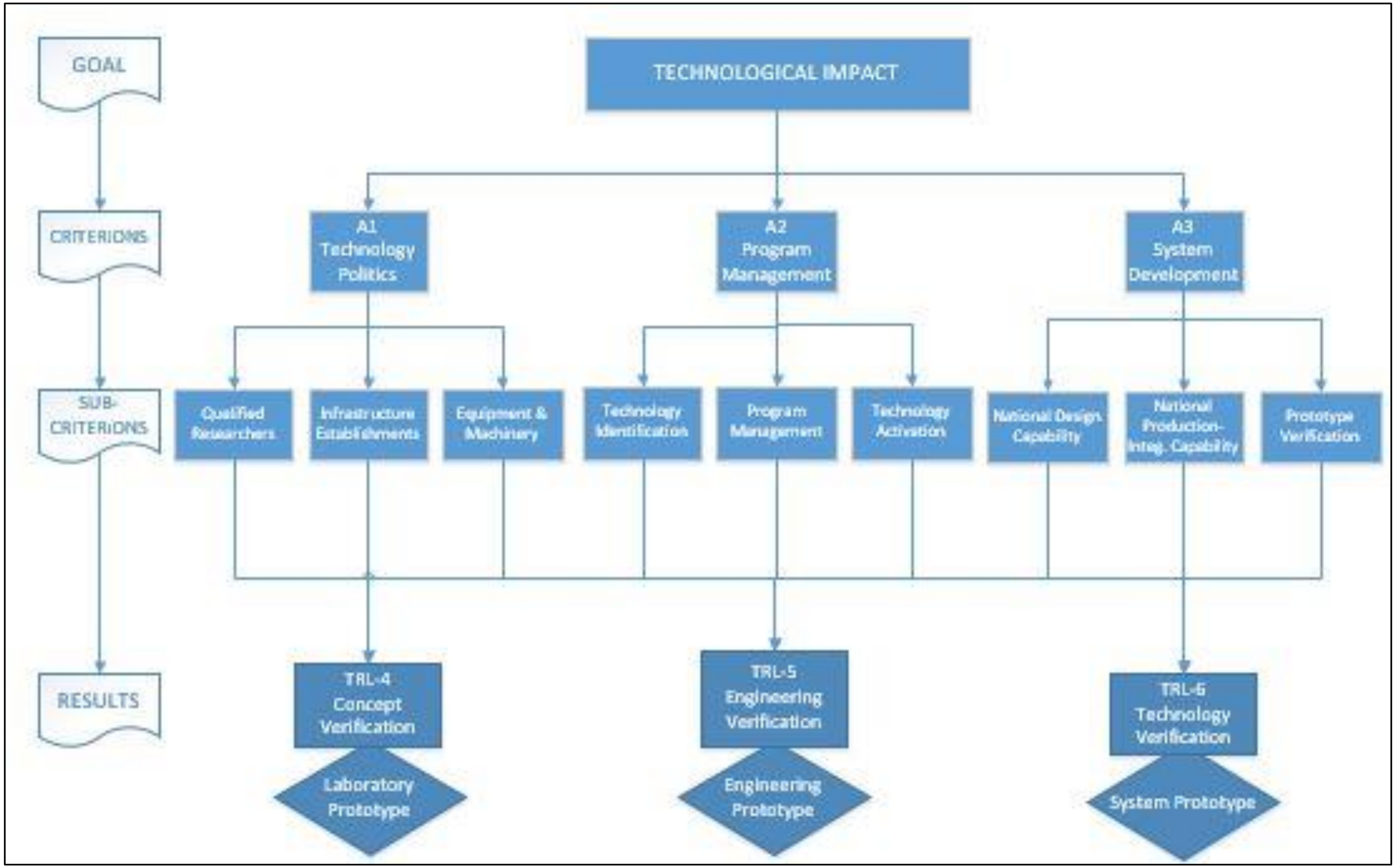

Figure 19. Technological Impact Module

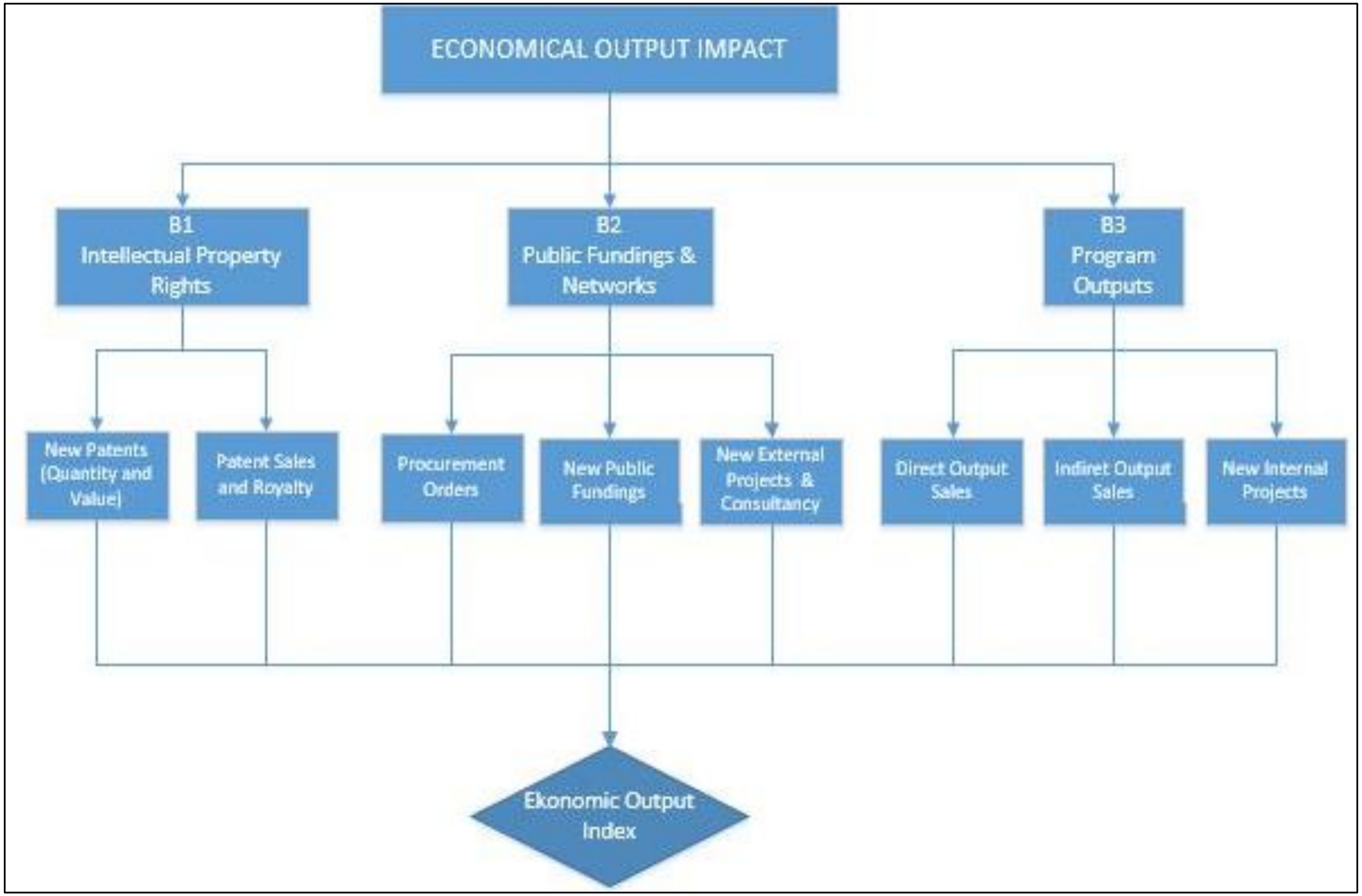

Figure 20. Economical Outputs Impact Module

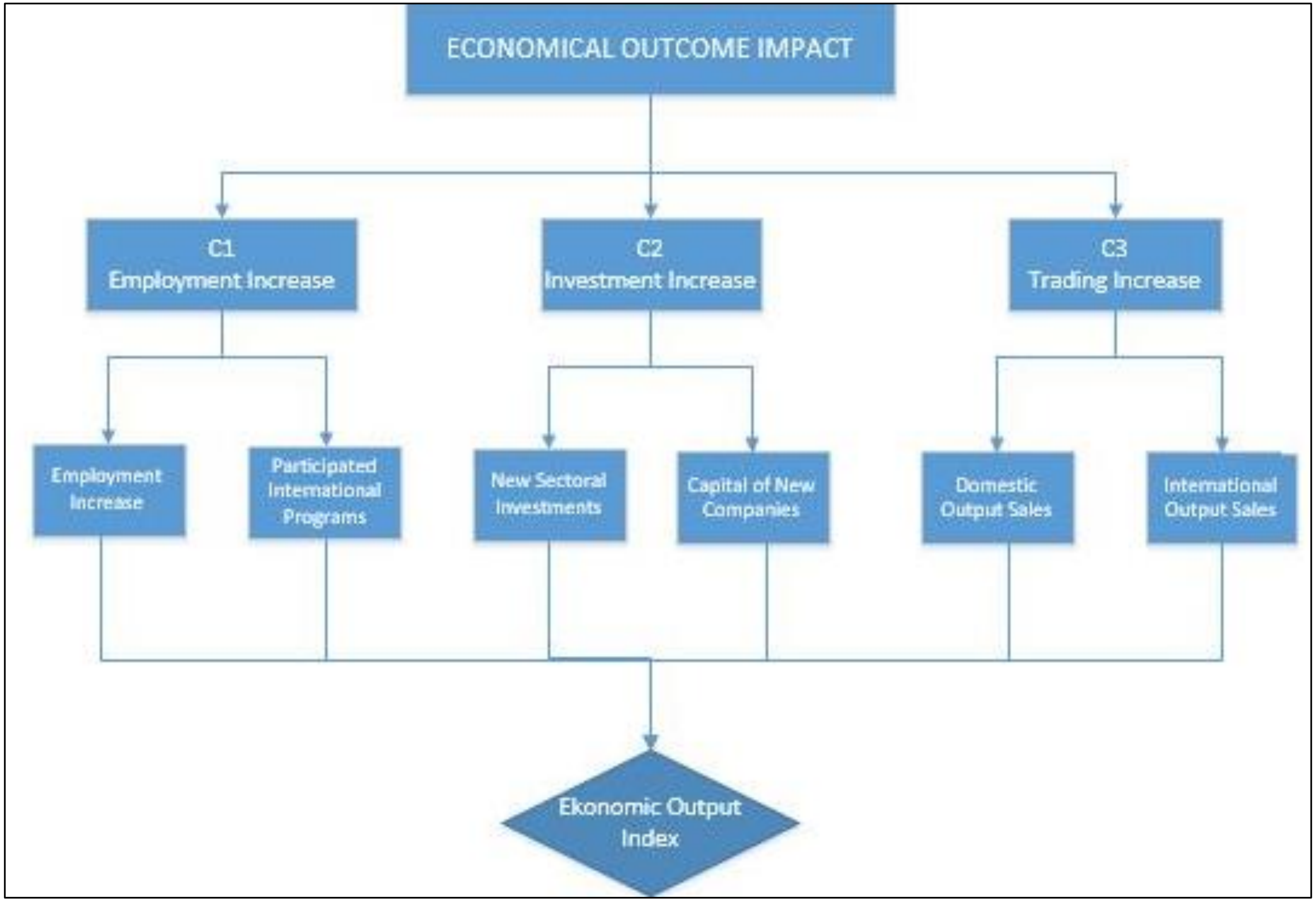

Figure 21. Economical Outcomes Impact Module

- The rationale for suggesting a new technology maturity level measurement system (referans)

1. The US Department of Defense (DoD) rules to measure the technology maturity level for its projects, but does not recommend a specific method how to measure it.
2. There is a large ambiguity for the implementation of a technology readiness level evaluation and application.
3. Current TRL system gets answers about what has been obtained. However it does not get answers about who, how, how much contributed about the result. These questions are very important for the sustainability, maintainability and applicability of the technologic outputs.
4. In the current TRL system the prerequisite for reaching the upper level depends on the completion of certain outputs and activities at the lower levels. However a lower level of output does not mean that it is of the desired quality. Each level must have independent qualitative competence criterias (eg. equipment competence at laboratory level, qualified researcher competence, infrastructure competence) for making a judgement about the technology level.

- Qualitative Technology Maturity Level Analysis

This study is proposed as a qualitative alternative and complementary to the current TRL measurement method. This is a qualitative measurement of technology maturity level especially focussed on the technology development region of a R&D and innovation process. The identified total of 9 criterias that have a direct impact on the technology development process are shown Figure-19 (Technology Competence Indicators and Sub-Indicators). These criterias are categorized according to the 3 main stakeholders which are responsible for the whole process in different levels. The targeted levels of the proposed method are also the same as those of the prototype outputs of TRL4, TRL5, TRL6 levels.

In this context, the stakeholders / institutions / organizations located in the host country, that will take part in the activities within the scope of a Technology

Development Program, their foreseen responsibilities and required activities, evaluation indicators, sub-indicators are identified in the proposed model.

The proposed technology maturity level qualitative analysis model's advantages are listed as folllows:

1. The challenges facing developing countries in technology development activities absolutely cannot be compared to those of developed countries. The developing countries will be able to analyze its restrictions and incapabilities about procurement, human resources, infrastructure, supply chains, financial, management, inexperience on system development and scientific issues. The proposed model is more appropriate for them to qualify its capabilities. The model especially tries to measure the shortcomings and the constraints in the above specified areas.
2. It gives qualitative information on human resources, infrastructure facilities, management activities, procurement activities subject to export licence, management issues, qualifications of prototypes etc.
3. Risk assessment can be made by identifying the weak dimensions of technology development activity.
4. Obtained information by this model can be used to predict the future developments and projects. Additionally, a technology forecasting study can also be conducted by using the indicators of the method proposed.
5. This model submits qualitative information about current technology maturity level as well as it submits information about what needs to be done to reach a higher maturity level.
6. Despite the fact that the link and cooperation between technology developer and technology user is not directly measured, the roles of customer authority are defined as indicators in the model. So it can be seen indirectly.
7. Technology development activity is a multi-stakeholder, multi-disciplinary, multi-dimensional concept involving different activities. The effects and adequacy of these dimensions can be measured.

8. The impact of stakeholder organizations (need authority, program management, project management, technology policy-makers) in technology development activities can be measured.
9. An important scientific systematic and qualitative method will be provided to the multi criteria decision maker groups about technology policy development and technology development activities.
10. Regarding the developed technology, questions like, Where should we go? What are the issues that needs to be managed? are missing. These questions will be able to answered.
11. Although the qualitative technology maturity level measurement method is currently designed to be implemented at the end of a program, it can also be used as a program preparation model as a ex-ante model. Interview / survey questions of the model can be used to provide information in the context of scope planning, budget planning, human resource planning, infrastructure investment, critical equipment procurement planning and risk assessment which are absolutely necessary to be analyzed at the very first stages of every technology development program.

The proposed technology maturity level qualitative analysis model's possible disadvantages are listed as folllows:

1. Qualitative data is intended to be obtained, so the opinions of a significant number of experts experts are needed to participate.
2. As in any qualitative research, prejudice, bias, etc. in opinions of experts must be controlled. The reliability analysis of the data obtained should be done accordingly.
3. Since the aim is to use the developed technology on a system, the correlation between the technology developer and the technology user opinions should also be measured.
4. The hardware and software technology programs has different processes and qualities. This deficiency can only be achieved by changing the development criterias and developments.

5.4. The AHP Method

In this study, Analytical Hierarchy Process (AHP) will be used as the analysis method for the proposed technology maturity assessment module. As a data collection method, expert judgement will be used. The reasons, originals of the AHP methodology and the rationale of the usage of a linear 1 to 9 scale proposed in 1977 (Saaty, T. L. 1977) and is still a favourable option for this methodology (Franek, J. 2014). The corresponding verbal statements of AHP metrics (from 1 to 9) are stated in Table 3 (Saaty, T. L. 1990).

Table 3
The Fundamental Scale of AHP

Intensity of importance on an absolute scale	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice.
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i (1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9)	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

Franek, J. (2014) has compared 8 different scale (power, root square, geometric, inverse linear, asymptotical, balanced, rogarithmic and linear) and made a conclusion that Saat 9 point scale is a useful option. “The Saaty original 9 point linear scale is set as benchmark for comparison of other judgment scales. Decision-maker can face selection the most suitable scale for his problem. According to presented results the Linear (Saaty scale) is still a favorable option” (Franek, J. 2014).

The Analytic Hierarchy Process (AHP) is how to derive relative scales using judgment or data from a standard scale, and how to perform the subsequent arithmetic operation on such scales avoiding useless number crunching. The most effective way to concentrate judgement is to take a pair of elements and compare them on a single property without concern for other properties or other elements (Saaty, T. L. 1990).

The choice of alternatives in the AHP method can be evaluated in two different ways (Saaty, T. L. 1990):

a) Relative Measurement: This method is the method by which the most appropriate alternative is selected.
b) Absolute Measurement: This is the method by which each of the alternatives is compared to the most ideal condition.

The results of both methods should not be expected to highlight the same option. There are two different perspectives. One of them tries to be descriptive (what can be) and the other one tries to be normative (what should be).

When expert opinions are taken and multiple experts' evaluations are used, the geometric mean method is used, not the arithmetic mean data. The geometric mean of multiple data is taken in this study because the reciprocal of the geometric mean of all data is equal to the geometric mean of the reciprocals of each data.

(Vaidya, O. 2004) has studied the AHP analysis methodology as a multiple criteria decision-making tool, referred 150 applicaiton papers and 27 of them analyzed in detail. It is mentioned that the AHP method can be used in social, educational, managerial, engineering, political, personal, educational, governmental areas.

To decompose a hierarchy into clusters, one must first decide on which elements to group together in each cluster. This is done according to the proximity or similarity of the elements with respect to the function they perform or property they share and regarding which we need to know the priority of these elements. One must then conduct comparisons on the clusters and on the subclusters and then recompose the clusters to obtain a true reflection of the overall priorities. If this process works, the result after the decomposition should be the same as the result if there were no decomposition"(Saaty, T. L. 1977).

It has been proved that the geometric mean, not the frequently used arithmetic mean, is the only way to do that. If the individuals have different priorities of importance, their judgements (final outcomes) are raised to the power of their priorities and then the geometric mean is formed (Saaty, T. L. 2007).

The basic steps of AHP methodology is defined as follows (Adapted from Vaidya, O. 2006):

1. The assessment goal is determined.
2. The program stakeholders and their missions are determined.
3. The main criterias are classified with respect to stakeholders.
4. The hierarchy is structured in different levels, as of goals, criteria, sub-criteria and alternatives. One goal, three criterias, nine sub-criterias and 3 output alternatives are defined.
5. Four comparison matrixes are prepared. One is for main cluster (level-2), the other three are for sub-clusters (level-3)
6. Each element in the corresponding level and cluster are compared with each other.
7. For each cluster [n(n-1)/2] comparisons are made (here n=3). The corresponding elements are assigned to the reciprocals of the comparisons, the diagonal elements are assigned to 1.
8. The comparison matrixes unified by geometric mean of data.
9. The comparison matrixes are normalized and weighted.
10. The consistency analysis is done. Maximum eigen value matrix is calculated, consistency index CI, consistency ratio CR. , and normalized values for each criteria/ alternative.
11. Maximum Eigen value, CI, and CR values checked for consistency. The consistency criteria is for CR shouls be less than 0.1 and this criteria is satisfied

for all four clusters. If the consistency criteria could not be achieved and it was below the criteria value, the AHP procedure would be repeated.

12. The main cluster weights are multiplied by each related sub-cluster weights (local weights) and global weights of each indicators are achieved.
13. The scoring of the TRL outputs are measured by TOPSIS method. Since this is not a ranking analysis, absolute measurement technique scale is used. Maturity level of each TRL output is assessed by assigning values in a 1-9 linear scale. TOPSIS method will evaluate the each three TRL output level by considering how close to the ideal level and how far to the worst level.

Table 4

Calculation of Multiple Experts' Assessments

	Criterion-1	Criterion-2
Criterion-1	1	2
Criterion-2	1/2	1

Assessment of 1st expert

+

	Criterion-1	Criterion-2
Criterion-1	1	4
Criterion-2	1/4	1

Assessment of 2nd expert

	Criterion-1	Criterion-2
Criterion-1	$\sqrt{(1\cdot1)}$	$\sqrt{(2\cdot4)}$
Criterion-2	$\sqrt{(1/2\cdot1/4)}$	$\sqrt{(1\cdot1)}$

Geometric mean of expert data

	Criterion-1	Criterion-2
Criterion-1	1,00	2,83
Criterion-2	0,35	1,00

Aggregated of data

	Criterion-1	Criterion-2
Criterion-1	0,74	0,74
Criterion-2	0,26	0,26

Normalized matrix

	Weighted Value
Criterion-1	0,74
Criterion-2	0,26

Weighting factors

- AHP Methodology and Consistency Calculation

AHP meethodology may be used for absolute measurement and normative measurements as described below (Saaty, T. L. 1987).

a) Absolute measurement (scoring) is used to rank alternatives for an ideal solution. Each criterions has pairwise comparisons and each alternatives has weighted scores from each criterions. Summing of the scores of each criterions lets us to rank alternatives. This makes a normative scale score for the alternatives. Qualitative measures (such as excellence, good, medium, poor etc.) may be used for ranking when the judgement must be qualitative. These qualitative measures are weighted with normalized quantitatative scales. This measurement scale might be used in cases where the alternatives must be evaluated qualitatively.

In this study a linear measurement scale (1-9 likert) is used to evaluate the performance level of each alternatives. Those performance levels are multiplied by the weighted values of the criteria. So the weighted performance level of the alternatives are obtained. This option is easily applicable and understandable for this study.

b) Relative measurement is mostly used when a selection will be done. The selected alternative is dependent to the number of alternatives. This method might be used to choose a car or to buy a house.

AHP procedures are executed as according to the following stages:

- Building the standard decision matrix (A)

The AHP method begins with shaping the standard decision matrix. It is A is defined as;

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \qquad a_{ii} = 1 \ , \ a_{ij} = \frac{1}{a_{ji}}, \ a_{ij} \neq 1 \qquad (5.1)$$

Pairwise comparisons are done by 35 experts individually. Comparisons are done by four matrices, one for main criteria matrix and three of them are for sub-criteria matrices according to the model developed in Figure-18. The results are aggregated by getting the geometrical means of 35 experts' evaluation matrixes' elements. Simple explanation of the geometric mean of multiple assessments are shown in Table-4. Then we got 4 aggregated standart decision matrices as shown in the first matrices from Table -9 to Table-15.

- Computing the Normalized Decision Matrix (A')

We want the solution of (Eq.2)

$$A.w = n.w \quad \text{or} \quad (A - nI).w = 0 \tag{5.2}$$

This is a system of homogeneous linear equations. It has a nontrivial solution if and only if the determinant of $(A - nI)$ vanishes, that is, n is an eigenvalue of A. Thus all its eigenvalues except one are zero. Thus n is an eigenvalue of A, and one has a nontrivial solution. (Saaty, T. L. 2012). If n is the eigenvalue of A matrix, then w is the corresponding eigenvector. So, A is the pair wise comparison matrix, n is the independent rows of the matrix, w is the eigenvector of the matrix. If the pairwise comparisons are completely consistent, the matrix A has rank = 1 and also:

$$\lambda_{\max} = n \tag{5.3}$$

$$A.w = \lambda_{\max}.w \tag{5.4}$$

It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. A necessary condition for consistency is that A has to be reciprocal. The consistency is defined by the relation between the entries of A as: (Amiri, M. 2010) (Wang, J. J., & Yang, D. L. 2007)

$$a_{ij} = a_{jk} - a_{jk} \tag{5.5}$$

Equation.2 can be measured by normalizing the each column of A matrix then A' is defined as Normalized Decision Matrix. Each column of standard decision matrix is normalized through dividing each element of the decision matrix by the sum of each column (Eq. 3).

$$A'_{ij} = \begin{bmatrix} a'_{11} & a'_{12} & \dots & a'_{1n} \\ a'_{21} & a'_{22} & \dots & a'_{2n} \\ \dots & \dots & \dots & \dots \\ a'_{n1} & a'_{n2} & \dots & a'_{nn} \end{bmatrix} \qquad a'_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} (i = 1,2,3...n) \qquad (5.6)$$

In this study each element of comparison matrix is normalized within their column as a 3 x 3 matrix:

- Computing the Eigenvector Matrix (w)

So, we can solve the eigenvector of A matrix. The eigenvektor matrix is obtained by taking average of each row of A' matrix. Then eigenvektor matrix (w), in other words, the relative weights are obtained as;

$$w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix} , \qquad \sum_{i=1}^{n} w_i = 1 \qquad (5.7)$$

- Compute the weighted normalized decision matrixes (A'')

Weighted normalized decision matrix is obtained by product of standard decision matrix with eigenvektor matrix.

$$A'' = A \ x \ w = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \dots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1 a_{11} & w_1 a_{12} & \dots & w_1 a_{1n} \\ w_2 a_{21} & w_2 a_{22} & \dots & w_2 a_{2n} \\ \dots & \dots & \dots & \dots \\ w_n a_{n1} & w_n a_{n2} & \dots & w_n a_{nn} \end{bmatrix} \qquad (5.8)$$

- Compute $\boldsymbol{\lambda_{max}}$:

AHP methodology assumes that the principal eigenvector solution is essential for deriving the scale of priorities. In any matrix small perturbations in coefficients imply small perturbations in eigenvales. A reciprocal matrix A with positive entries is consistent if and only if λ_{max} = n with inconsistency λ_{max} > n and assuming w as the eigenvector corresponds to the eigenvalue of λ_{max} (the highest eigenvalue of the matrix) and it is calculated as : (Saaty, T. L. 1977)

$$\lambda_{\max} = \sum_{j=1}^{n} \left(\frac{(A.w)_j}{n.w_j} \right) \tag{5.9}$$

There must be an acceptance criteria for decision makers to be sure that w does reflect the expert's actual opinion. Then we obtain an approximation to A by a consistent matrix.

The interesting result that inconsistency throughout the matrix can be captured by a single number $(\lambda_{\max} - n)$ which measures the deviation of the judgments from the consistent approximation and it is an index of departure from consistency. (Franek, J. 2014) (Akgün, İ. 2019)

- Compute and Check Consistency Index (CI)

In a general decision-making environment, experts can not estimate exact values of comparison matrix but it is acceptable that they make small deviations from ideal judgement. Therefore, the consistency index (CI) is compared with the same index obtained as an average over a large number of reciprocal matrixes of the same order whose entries are random. If the ratio (called the consistency ratio CR) of CI to that from random matrixes is significantly small (carefully specified to be about 10% or less), we accept the estimate of w. Otherwise, we attempt to improve consistency." (Saaty, 1990). Then the consistency index (CI) is defined as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} \tag{5.10}$$

If the matrix is perfectly consistent then CI=0. When dealing with rising number of pair-wise comparisons the possibility of consistency error is also increasing. Thus

Saaty (1980) suggested another measure the CR (consistency ratio) that can be calculated like so

$$CR = \frac{CI}{RI} \tag{5. 11}$$

where RI (Random Index) is represented by average CI values gathered from a random simulation of Saaty pair-wise comparison matrixes CIs. The suggested value of the CR should be no higher than 0.1 (Saaty, T. L. 1980). The proposed the RI values measured by (Saaty, T.L. 2012) and (Franek, J. 2014) are given in Table-5.

Table 5
Avarage Random Consistency Index (R.I.)

n	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Reference**
RI	0,0	0,52	0,89	1,11	1,25	1,35	1,40	(Saaty, T.L. 2012)
	0,0	0,525	0,882	1,11	1,25	1,341	1,404	(Franek, J. 2014)

RI values derived for various n numbers and the results of 500.000 simulations data are acquired. In this study n=3 for all comparison matrixes so RI = 0,525 is used.

- Compute Final Weights

To determine the final weights for the sub-criterions in the third level, local weights are multiplied by the related main criteria in the hierarchy. For example, the local weight of sub-criteria "A1.a Qualified Researchers" is 0,64 and the weight of related hierarchical criteria "A1 Technology Policy" is 0,42. So the global weight of qualified researchers is the multiplication of these values as 0,64 x 0,42 = 0,27.

The results indicate that A1 (technology policy) is the most important criteria. The sub criteria A1.a (qualified researchers) is the most critical sub-criteria as a local indicator as well as a global indicator (Table-6).

Table 6

Main Criteria and Indicator Weights

Main Criteria	A1			A2			A3		
Criteria Weight (cw)	0,42			0,28			0,30		
Sub-Criteria	**A1.a**	**A1.b**	**A1.c**	**A2.a**	**A2.b**	**A2.c**	**A3.a**	**A3.b**	**A3.c**
Local Weight (lw)	0,64	0,19	0,17	0,23	0,37	0,40	0,48	0,24	0,28
Global Weight (cw x lw)	0,27	0,08	0,07	0,07	0,10	0,11	0,15	0,07	0,08

At the end of the AHP process, the local and global weigths are calculated. All of the four consistency ratios of the pairwise comparison matrixes are no higher than 0.1 and they meet the consistency criteria. So the related weights are shown to be consistent as shown in Table-7

Table 7

Results Obtained with AHP

Matrix Cluster	w_i	λ_{max}	CI	RI (n=3)	CR
Main Criteria	0,42 0,28 0,30	3,0061	0,0031	0,525	0,0058
Technology Policy	0,64 0,19 0,17	3,0002	0,0001	0,525	0,0002
Program Management	0,23 0,37 0,40	3,0000	0,0000	0,525	0,0000
System Development	0,48 0,24 0,28	3,0207	0,0103	0,525	0,0196

The weighting factors are calculated and the consistency criteria is established so the AHP stage is completed and TOPSIS stage started.

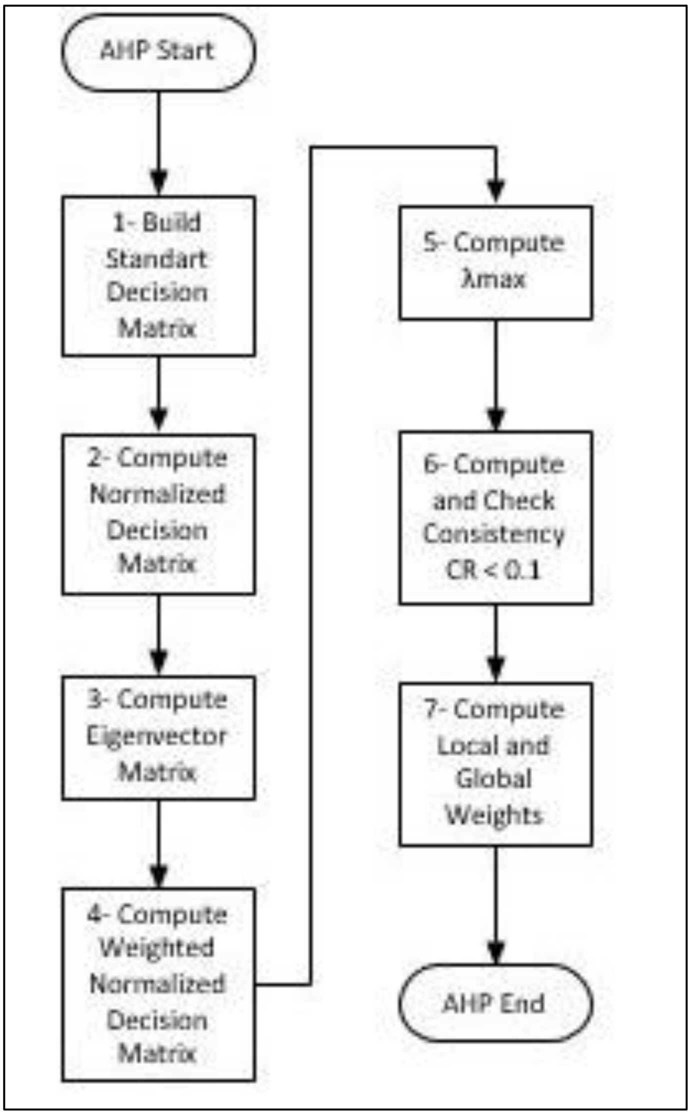

Figure 22. AHP Application Work Flow

5.5. The TOPSIS Method

AHP application without TOPSIS is done for ranking alternatives relatively. By doing so, eavh alternative has relative weighting scores for each indicator. Multiplication of indicator weights with alternative weights gives us relative ranking of alternatives. But adding TOPSIS methodology let us to rank alternatives in a normative way and compare with respect to an ideal solution. So, applicaiton of TOPSIS method is useful for technology maturity measurement.

TOPSIS methodology assumes that each of the assessment criterias has a uniform incresing or a decreasing tendency. This method is used to make an assessment on the maturity level of the alternatives according to the closest to the ideal solution and the farest to the worst solution as the best candidate. TOPSIS method may be used with different measurement scales depending on the purpose.

In this study a linear measurement scale (likert 1-9) is used to evaluate the performance level of each alternatives. Those performance levels are multiplied by the weighted values of the each criteria. So the weighted performance level of the alternatives are obtained. This option is used in this study because it is easily applicable and understandable. TOPSIS procedures are executed as according to the following stages:

- Build the Weighted Expert Judgements

The weighted scores of indicators are calculated in the AHP stage. At this stage, an assessment is made about the maturity of the alternatives by using a 1-9 measurement scale. Geometric mean of evaluator's scoring are displayed by r_{ij} with a linear (1 to 9) metric scale. Each evaluator are expected to make assessment for each alternatives in a 1-9 level scale, consequently, r_j^* is the positive-ideal solution which is equal to 9 and r_j^- is the negative-ideal solution which is equal to 1. So, the weighted values are r_j^* *and* r_j^- respectively.

$i =$ index for alternatives
$j =$ index for indicators

- Compute the positive-ideal (S^*) and negative-ideal (S^-) solutions

The v_i scores are weighted expert judgement scores of alternatives which equal to

$r_{ij} =$	Experts judgements
$v_{ij} = r_{ij} \, x \, w_j$	Weighted expert judgements
$r_j^* = 9$	Positive ideal score
$r_j^- = 1$	Negative ideal score

$v_j^* = r_j^* x\ w_j$ Weighted positive-ideal scores of sub-criterions

$v_j^- = r_j^- x\ w_j$ Weighted negative-ideal scores of sub-criterions

Both of the positive-ideal and negative-ideal scores are calculated for each indicators.

- Compute the Seperation Values

There are two seperation values. Seperation from the ideal solution is called ideal solution (S_i^*) and the seperation from the worst solution is called negative ideal solution(S_i^-).The number of S_i^* and S_i^- values are calculated for each of the alternatives. ($i = 1,2,3$)

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2} \quad \text{Distance to the ideal solution} \quad (5.12)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad \text{Distance to the worst solution} \quad (5.13)$$

- Compute the Normative Maturity Level Solution

The maturity point of alternatives are calculated by computing the distance to the ideal position (CC_i^*) by means of distance to the ideal and worst solutions. The distance to the ideal position is calculated as follows:

$$CC_i^* = \frac{S_i^-}{S_i^- + S_i^*} \quad (5.14)$$

CC_i^* values might get values as $0 \le CC_i^* \le 1$ and in case of $CC_i^* = 1$, it means that the subject alternative has the absolute maturity.

The case study values are:

$S_1^* = 0{,}743,\ S_2^* = 0{,}655,\ S_3^* = 0{,}668$ are calculated as positive ideal values.

$S_1^- = 2{,}467,\ S_2^- = 2{,}426,\ S_3^- = 2{,}379$ are calculated as negative ideal values.

So, the normative maturity levels are calculated as;

$$TRL4 = CC_1^* = \frac{S_1^-}{S_1^- + S_1^*} = \frac{2{,}467}{2{,}467 + 0{,}743} = 0{,}77$$

$$TRL5 = CC_2^* = \frac{S_2^-}{S_2^- + S_2^*} = \frac{2{,}426}{2{,}426 + 0{,}655} = 0{,}79$$

$$TRL6 = CC_3^* = \frac{S_3^-}{S_3^- + S_3^*} = \frac{2{,}379}{2{,}379 + 0{,}668} = 0{,}78$$

Above mentioned calculations are normalized with the weighting factors which came from AHP pairwise comparisons. So, we took into account the importance degree of the indicators.

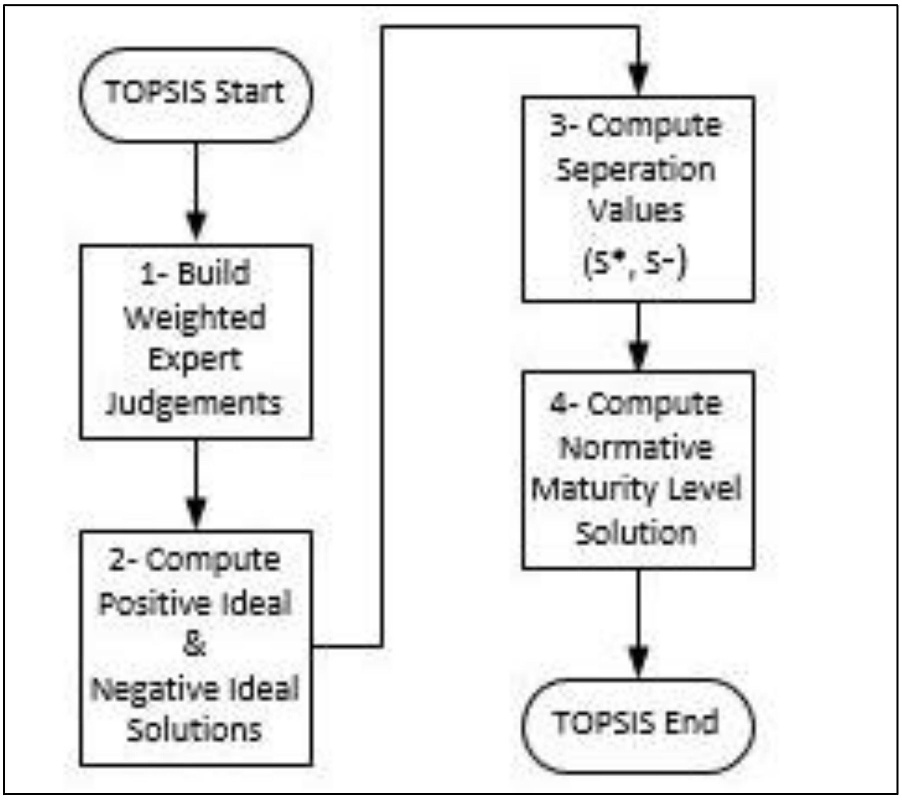

Figure 23. TOPSIS Application Work Flow

If we seperate the combined data as researchers data and supervisors data, we can detect the researchers bias for the maturity level in Table 8 and Figure 24.

Table 8

Maturity Assessment wrt Partners

	All	**Researchers**	**Supervisers**
TRL-4	**77**	**80**	**68**
TRL-5	**79**	**80**	**73**
TRL-6	**78**	**79**	**73**

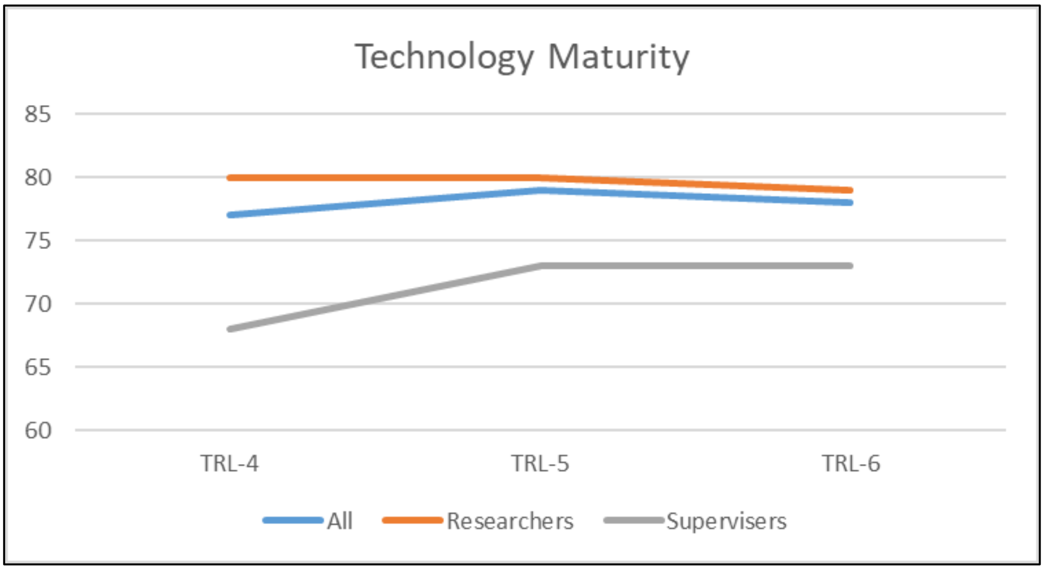

Figure 24. Maturity Assessment wrt Partners

CHAPTER 6

EXPERIMENTAL CASE STUDY

6.1. Case Study Design

The submitted technology development assessment model is verified by an experimental case study. The subject program is a high technology development program which is consisted of 5 sub projects executed by 5 different partners. The program name, scope and the partners will not be declared in this thesis because of confidentiality issues. The programs first phase conducted for 5 years and ended in 2018. Despite the fact that technological and economical impact model is suggested to conduct within 5 years starting from program due date, 2 years of period resulted enough data for this study. Only the first 2 projects (named here Project-1 and Project-2) are included to this case study because their outputs were subject to aimed core technology. The three projects left behind were out of the core technology concept, they had complementary scope, they as projects not taken into account of the case study. The case study program is conducted for the defence industry and the outputs are demanded by the government agencies. The outputs became operational in a relevant environment.

Semi structured interviews are executed with the project managers, researchers, program academic supervisers and program management experts. The results are coherent with the AHP results. So, triangulation method is successfully applied.

15 researchers and 5 project managers from one research center and five institutions which are publicly funded, 5 experienced academic supervisers for technology programs from public universities, 5 program coordinator experts from program management office, 5 experts from sponsoring organization, totally 35 experts

participated to this case study. Their expertice and qualification are highy compatible for this study.

The participant experts are employees from 5 TÜBİTAK Institutes, 1 University Research Center, 2 TÜBİTAK Program Management Groups and 4 Public Universities. Their qualifications and experience are considered to be highly compatible for the study as follows:

Sampling Process:

a) The research universe is defined as the all researchers, project managers, program coordinator experts, superviser academicians who took part in any technology development program.
b) Sampling size is determined so as to represent the universe sufficiently. Mostly sampling size is considered sufficient when it is between 30-500 samples. Also 30-40 samples are acceptible for experimental case studies. Qualitative studies require less number of participants because of the time and cost considerations.
c) The purposive sampling technique is selected to get the fundamental properties of the technology development programs. All selected experts are highly experienced about the program and processes.
d) In this study the expert assessment sampling framwork is classified into 5 main groups. 1) Project managers 2) Researcher 3) Program's academic supervisers 4) Program coordinator experts 5) Sponsoring agency experts. Totally 35 experts (5 project managers, 5 program academic supervisors, 5 program coordinator experts, 15 project researchers, 5 sponsoring agency experts) are joined to the assessment and they are selected according to following criterias:

Project Managers:

- Took part actively in the technology development program as a project manager for minimum 5 years.
- Academic titles are associate professor, Phd, senior researcher
- Active as a project manager

- Accepted to take part in the assessment
- Objective about the technology execution activities, no conflict of interest
- Each one still working as project manager in a technology development program.
- 2 of them has associate professor degree, 2 of them has PhD degree, 1 of them has senior researcher degree.

Academic Supervisers:

- Took part actively in the technology development program as a project superviser minimum for 5 years.
- Academic titles are professor or associate professor
- Active in program supervision
- Accepted to take part in the assessment
- Objective about the technology execution activities, no conflict of interest
- Each one still working as project superviser in a technology development program.
- Each one has researcher experience
- 4 of them has professor degree, 1 of them has associate professor degree.

Researchers:

- Took part actively in the technology development program as a researcher minimum for 5 years.
- Professional titles are work package leader, researcher, senior researcher, (severals with Phd degree)
- Active as a program researcher
- Accepted to take part in the assessment
- Objective about the technology execution activities, no conflict of interest
- Each one still working as project researcher in a technology development program.
- 6 of them has PhD degree, 4 of them has senior researcher degree, 5 of them has researcher degree.

Program Coordinator Experts:

- Took part actively in the technology development program as a program coordinator expert minimum for 5 years.
- Professional titles are senior program expert, program expert (severals with Phd degree)
- Active in program coordination
- Accepted to take part in the assessment
- Objective about the technology execution activities, no conflict of interest
- Each one still working as project coordinator expert in a technology development program.
- 2 of them has PhD degree, 2 of them has senior expert degree, 1 of them has expert degree.

Sponsoring Agency Experts:

- Took part actively in the technology development program as an expert minimum for 5 years.
- Professional titles are senior program expert
- Active in program coordination
- Accepted to take part in the assessment
- Objective about the technology execution activities, no conflict of interest
- Each one still working as project coordinator in a technology development program.
- 1 of them is a branch director and all of them are employee of Turkish Ministry.

6.2. Semi Structured Interviews

Semi structured interviews are executed with the project managers, program academic supervisers and program management experts. The main topics of these interviews are summarized below:

- Opinions of Program Supervisers

- Superviser-1 (MK)

He is a highly qualified academic researcher and he had been graduated from one of the top universities of Turkey. He is currently employed by another university and his network was relatively limited. He was also conducting projects before the program was started and he was selected as a academic superviser at the beginning of the program. The consultancy for the program made a significant effect on his career. His projessional network is expanded with the program executer organizations and personnel (public institutions, company, universitiy and also other academic stuff) .

He submitted and rewarded another public funded project that the scope was related with the main program. He also submitted an unofficial consultancy for an executer institution that they could produce a output out of the program scope.

Due to the fact that he had limited networks and he was from the provinces, the impact of the consultancy activity for his professional career and networkings were so high. It is considered that the reason of high degree impact on his profession is because of his effective harworking, networking capacity and professional quality.

The most deterrrent factor for the success was the lack of collaboration between executer partners. The different point of views, strong personel manipulation, suspensive behaviours on the technical issues, prejudice on the partners were the frustrating factors for an effective and intended success.

- Superviser-2 (ME)

Every technologic development begins with researchers. Infrastructure and other equipments mean less importance if corporations have not qualified researchers that are expected to use them.

Infrastructures means physical assets as well as library infrastructures which pay the way for researcher demands, new ideas and finally the technology development activities. Equipment capability has less importance due to the replaceability options.

Ambiguous and unlear targets causes increasing alternatives and inefficient energy usage.

Activation of project outcomes will cause positivity in physical and moral status of project staff. So the technological expectations will be higher from the folllowing projects.

Validation and verification activities are critical for getting free from the dependence of foreign resources.

- Superviser-3 (EY)

Qualified researcher indicator is the backbone for the lower level TRL research activities. Researches may begin from a pure sheet of paper but the intellectual capacity is essential.

Technology identifiction issue is considered as the most important part. Universities, firms and customer corporations take actions without any knowledge of current technology maturity level as well as targeted maturity levels. This is considered as one of the main cultural issues in the technologicaly non-developed countries.

Program management competency is achieved by MBA programs and PMP trainings inside the country. Turkey has achieved competency in program/project management field.

Activation of technological and engineering products requires a culture of "Product Transition Plan" implementation. Denial of error/failure concepts causes overlooking of those phase.

- Superviser-4 (AD)

Experience and knowledge capacity is critical parameters for qualified personnel. Also diffusion of knowledge and personnel training must be sustained.

Machinary and equipments are considered more important than infrastructure facilities for continuous project activities. Identifiying the technology requirements should have elastic targets with respect to project plans.

Activation of outputs will inevitably raise the quality of project activities.

- Opinions of Sponsoring Agency

- Expert-1 (YO)

While identifying the technology requirements, main target should be to achieve technology know-how. However, identifying the need of customers; functionality, performance measurablity and accountability fields are also important. Functionality may be provided but in some cases performance requirements might not be provided due to the major forces or domestic incapabilities.

The case of meeting the project requirements and getting into use of technology should be considered as an ideal situation.

Qualification of researchers should be considered of national development criteria. Briefly, production, integration and testing triplet is considered as a silver medal, then design activities should be considered as a gold medal. We cannot accept any project output as a fully national product whether we dont have the design capability or intellectual property. Specially, cryptology, cyber security, electronic warfare, reconnaise and surveillance systems might be accepted in this category.

The incapabilities of verifiation and validation activities are felt strongly nationwide. Academic project outputs rarely pass into the technology development stages, besides industrial projects solely focus on the product itself. So, it is very important to fill the gap between these two stages. Designing mission oriented technology development programs which lays on TRL 5-6 levels has a critical importance.

- Opinions of Project Managers

- Manager-1 (AY)

He is higly qualified senior researcher in the institute and also has an assocoate professor academic title. He has private sector experience in US before participation to this project. He emphasizes that if the institute could get a funding mechanism (approximately 1-2 million dollars) they could establish one of the most qualified and solution provider spin-off company. According to his projections, this spin-off would compete with the leading companies worldwide about the studied technology. His main argumant is that they has qualified researchers, platform dependant desigh capability, modular design capability and all needed equipments.

He mentiones that all the partners related with the subject technology (whether took part in the program or not) saw that this technology is applicable to any product or system so they all try to enter that subject technology area. This must be considered the main impact of the subject technology development program.

- Manager-2 (BO)

The impact of the program is mainly on the infrastructure investment and qualified researcher. These indicators will provide sustainable economic additionality.

Students from masters and doctorate program participated in the program, and got their graduate degrees. While the program was running some experienced and qualified researchers changed their jobs after taking job propositions from leading defence companies such as ASELSAN, Roketsan. This must be the sign of a additionality to qualified researcher population inside the country. Also one patent application is made and scientific publications are published that is related with the program activities.

The research team of the organization is highly motivated to take part in new projects, make more productions, and to develop their experience and proficiency in this specific reseach area. This must be also considered as an indicator for long term technological and economical impact for the organization.

The infrastructure and the qualified researchers has priority over the equipment availability. Because without infrastructure and qualified researcher, the equipments will have less importance.

The program management has the first priority and the identification of target technology level has second priority over the technology activation. Because the technology activation is dependent to the program management processess.

The national design capability, national production capability and the verification of the prototypes has the priority in the mentioned sequence.

- Manager-3 (KE)

Targeting the tecnology state-of-art level is critical for achieving the worldwide innovative products.

Program management is important for meeting the requirements on time, on budget, without waivers and with stakeholders satisfaction. Despite its importance is overlooked and not considered as a primary element, possible management deficiencies may reduce all partners performance. Technology activation is a clear proof success of the a development program.

National design, production, integration and validation activities should be considered as a whole concept. Incapability in any of those items might cause unrepeatable prototype development and import dependency respectively.

- Opinions of Program Coordinators

- Expert-1 (İK)

Technology policy, one of the main criterions, regulates the human, infrastructure and equipment resources in order to make successful projects and determines the starting points (initial conditions) of R & D projects in the country. Technology policies affect all programs and projects running inside the country. Technology Management focuses specific technology related activities. System Development encompasses the necessary competencies for the success of a single project that has been correctly constructed within the ecosystem.

Technology Management is a main criterion that includes the steps to correctly manage a process starting from user requests of a project ending up with the serving the prototypes to the user capability.

System Development is a main criterion that indicates TRL-4, TRL-5 and TRL-6 level qualified prototypes are designed, manufactured and verified within the systems engineering discipline.

If technology policies are implemented correctly in a country, the program plannings and project executions will be mature and competent. Otherwise, in case of the country's technology policies are not implemented correctly (or there is no technology policy), the technology development programs can not be efficient and effective, and the design, production and test skills can be absorbed successfully. Consequently the national public resources (intellectual, financial, economical etc.) are wasted.

According to the above described assessments, the prioritization between three main criterias has been made starting from the most comprehensive and effective one over the others. In the long term perspective of a national technology development programs, it is considered that the importance and priority of "Technology Policies" over the other two main criterias must be higher. The “System Development” activities has slightly higher priority over the “Technology Management” activities.

All three sub-criterias listed under Technology Policies are indispensable for conducting R&D studies. While prioritizing among the sub-criterias under main criteria, two critical issues are considered for prioritization: 1) what is the compensation time and cost of these sub-criterias while they are absent 2) effect of the absence of one sub-criteria to the others.

- Qualified researcher

One project manager stated that “if I would have qualified researcher i could compensate the absence of equipments somehow, and i could find a solution for infrastructure absence inside the country.” This statement was pretty assertive but emphasises the requirement on the quality and quantity of the researcher.

The existence of qualified research is the indispensible element of R&D ecosystem. The attainment of researchers generally requires qualified education and long tern experience especially for high tech technology (or state of the art technology) programs and projects. It is a fact that such qualified researchers are absent or exist scarcely in developing countries.

Although an infrastructure installation is essential for the training and retention of qualified researchers, it is considered that the availability of qualified researches is the primary condition for the establishment of good infrastructure inside the country. So, the sub-criterion of qualified researcher is considered to have one level higher priority over infrastructure installation.

- Infrastructure installation

Technology policies form the research ecosystem that consisted of organizational structures (research institutes and centers, university laboratories, research facilities etc.), the administrative conditions (managerial, judicial, financial etc.) and intellectual capacity which are also needed to begin and continually sustain R&D activities. Researh ecosystem infrastructures are established by strategic plannings, usage of pecuniary resources for a long period and continuous improvement. These conditions are pre-requisites to attract qualified researcher personnel from all over the world.

- Machinary – equipment availability

This sub-criterion has been understood as the technology specific laboratory equipment, test and measurement devices needed for conducting activities. In some cases, it may be necessary to obtain ad-hoc equipment or defence related critical/strategic equipments from abroad and even they may be subject to export restrictions. For example, export licensing in Germany is the responsibility of the Federal Office of Economics and Export Control (BAFA) and export licencing in USA is under ITAR (International Traffic in Arms) regulations. In most developed countries procurement of critical technological equipments are subject to permissions of political and administrative authorities therefore the needed cost, time and efforts increases.

However, if a team of qualified researchers is available, it is often possible to provide alternative solutions for tool-equipment deficiencies (to develop alternative designs/methods, or to search for alternative equipments and use existing devices more efficiently and collaborative inside the country).

- Technology identification (state of the art)

At the planning phase of the projects, identifying the subject technology's maturity level and the key performance indicators (KPI's) of projects are indispensable processes. The quality of these activities are highly related with the efficient usage of time, budget and human resources of the projects.

Determining the technology maturity levels, the technical and performance requirements (in other words, the –the initial conditions-) of the project is essential for time, budget and human resources efficiency. However, in order to mitigate the advanced technology deficit, organizations must follow the systematical development approaches, conduct sequential projects.

The handicaps of assigning inadequate performance requirements may be compensated by effective project management, supplementary budget and coordination with the customer.

- Project management

Project management discipline consists of various disciplines (according to Project Management Institute (PMI) there are 10 sub management areas called knowledge areas). This indicator mainly considers the scope, budget and procurement management, rapid decision making process, coordination activities.

High technology development programs produce physical outputs as prototypes of TRL-4, TRL-5, TRL-6 levels. Project management is necessary for the success rate of final outputs and successful product oriented activities.

In case of absence or the mismanagement of one sub criterion, its effects to other sub criterions and compensability are assessed while prioritization process.

Inaccurate and/or poor management of budget and work packages, insufficient training, lack of decision making on time, unable to find alternatives for restricted procurements, lack of coordination between stakeholders may have devastating consequences that cannot be compensated even by additional time or budget. A proficient project management may resolve the mistaken requirements and ambiguities during the implementation process.

Technology activation, the sub-criterion of putting the TRL-6 level outputs into service by the user (in a similar way transferring the TRL-4 and TRL-5 level outputs to the next level) was considered as the second priority after the project management sub-criterion.

In order to produce a fielded system prototype, below mentioned rational processes must be managed. 1) Determining where, how, under what conditions and by whom the outputs will be used, 2) Preparing all operational concept and verification / validation test documents and updating them simultaneously with the R&D studies, 3)

Conducting the inspection and acceptance test procedures by using verification and validation technologies,

Projects where the potential user's (customer) intention to use the outputs are uncertain, even though all the project activities have been successfully completed, the outputs are doomed to remain on the shelf and unable to get into the serial production phase.

The three sub-criteria under the "System Development" criterion were considered to have close priority for outputs of TRL 4, 5 and 6 levels. It is critical to prioritize which sub-criterion is needed more for sustainable system development capability.

National design competence was considered to be the sine qua non for all three TRL outputs. The competence in product / system design is the primary element in project success relative to other sub-criterias.

In the projects which aims to get engineering and system prototype outputs, domestic production / integration competence has second priority after the product / system design competence.

The test and verification of the prototypes has vital importance especially in strategic and critical technologies. The developer may want to conceal key performance parameters because of either intellectual property rights, confidentiality or trading rights. So, verification and validation technologies are considered "must have" assests. However, verificaiton competency has the third priority among other sub-criterias.

- Opinions of Project Researchers

- Researcher-1 (KB)

Qualified researchers are the outputs of consistent and good implemented technology policies. The higher cost comes from raising qualified researchers but it is the driving power of technology.

Infrastructure is one of the basic needs of researchers. Technological activities can not be runned without infrastructures, but the equipment need can be subsitituted with other solutions.

How often new projects are runned and more designes are realized more production capability is achieved.

- Researcher-2 (BB)

If the quality of researcher is sufficient then he gets more effective results from the equipments and infrastructure. The criteria for the quality should be work experience rather than personel education. Most corporations prefer to employ new researchers rather than holding the experienced personnel so the efficiency decreases and the execution becomes harder.

Investing for salely equipments without qualified researchers will result wasting resources and time.

Policy makers (decision makers, senior managers) should have proficiency about the projects as well as researchers and they should assign the targets at the beginning. Otherwise there will be higher risks for executing the projects. Failure in assigning project requirements will result unrealistic and uncertain management results.

Second critical point is the productive management execution after the assignment of clear project scope and targets.

The activation and taking into inventors of project outputs, and completing the delivery documentation must be mandatory. So many project outputs, know-how and prototypes becomes useless despite the condensed labor and money. No complementing and consequtive project will result loosing the qualified researchers. Specific policies may mitigate the losses.

National design capability is far more important than the production capability. National design capability can not be achieved without qualified scientists and researchers. Production of foreigner designs will result being a fasonry or a carrier.

- Researcher-3 (EYY)

Design capability is tthe first step of national product development capacity because develoment is only possible with planning and designing. Achieved values will take us forward with respect to national needs and capacity.

The verification and validation of prototypes are very important activities before the serial production and activation. Robust design, production and validation of products results serial production and marketing chance.

- Researcher-4 (DÖ)

Identifying the technology performance criterias can be categorized into two types. Uncertain and ambiguous customer requirements and design solution related requirements.

Uncertain customer requirements causes time and cost loss. Design solution related requirements block the effective and better designs. So validation of customer requirements are essential before the project beginning.

National design capability is very important but it must be supported by continuous training activities. Design activities differ from production and testing by using unversal design tools, mathematical modellings etc. So corporations must hold design capability up-to-date and ready by supporting training activities.

It is unquestionable that verification and validation activities are the best way to confirm design requirements. The failures of validation causes to return back to design revisions.

6.3. The AHP Calculations and Results

Table 9
AHP Results of Main Cluster

Standart Decision Matrix

	A1	A2	A3
A1	1,0	1,6	1,3
A2	0,6	1,0	1,0
A3	0,8	1,0	1,0
SUM	2,39	3,62	3,29

Normalized Decision Matrix

	A1	A2	A3
A1	0,42	0,45	0,39
A2	0,26	0,28	0,30
A3	0,32	0,28	0,30
	1,00	1,00	1,00

Eigenvector

W
0,42
0,28
0,30
1,00

Table 10
AHP Consistency Results of Main Cluster

Weighted Normalized DM

A'' = A x w	(A x w) / (n * wi)
1,26	1,0026
0,84	1,0017
0,91	1,0018

n=	3	
RI=	0,525	
λmax =	3,0061	
CI =	0,0031	
CR=	0,0058	< 0.1

Table 11
AHP Results of A1 Sub-Cluster

Standart Decision Matrix

	1a	1b	1c
1a	1,0	3,5	3,7
1b	0,3	1,0	1,1
1c	0,3	0,9	1,0
SUM	1,56	5,34	5,85

Normalized Decision Matrix

	1a	1b	1c
1a	0,64	0,65	0,64
1b	0,19	0,19	0,19
1c	0,17	0,17	0,17
	1,00	1,00	1,00

Eigenvector

W
0,64
0,19
0,17
1,00

Table 12
AHP Consistency Results of A1 Sub-Cluster

Weighted Normalized DM

A'' = A x w	(A x w) / (n * wi)
1,92	1,0001
0,57	1,0000
0,51	1,0000

n=	3
RI=	0,525
λmax =	3,0002
CI =	0,0001
CR=	0,0002

Table 13
AHP Results of A2 Sub-Cluster

Standart Decision Matrix

	2a	2b	2c
2a	1,0	0,6	0,6
2b	1,6	1,0	0,9
2c	1,7	1,1	1,0
SUM	4,28	2,72	2,51

Normalized Decision Matrix

	2a	2b	2c
2a	0,23	0,24	0,23
2b	0,37	0,37	0,37
2c	0,40	0,40	0,40
	1,00	1,00	1,00

Eigenvector

W
0,23
0,37
0,40
1,00

Table 14
AHP Consistency Results of A2 Sub-Cluster

Weighted Normalized DM

A" = A x w	(A x w) / (n * wi)
0,70	1,0000
1,10	1,0000
1,20	1,0000

n=	3
RI=	0,525
λmax =	3,0000
CI =	0,0000
CR=	0,0000

Table 15
AHP Results of A3 Sub-Cluster

Standart Decision Matrix

	3a	3b	3c
3a	1,0	2,4	1,5
3b	0,4	1,0	1,0
3c	0,7	1,0	1,0
SUM	2,09	4,37	3,50

Normalized Decision Matrix

	3a	3b	3c
3a	0,48	0,54	0,43
3b	0,20	0,23	0,28
3c	0,32	0,23	0,29
SUM	1,00	1,00	1,00

Eigenvector

W
0,48
0,24
0,28
1,00

Table 16
AHP Consistency Results of A3 Sub-Cluster

Weighted Normalized DM

A" = A x w	(A x w) / (n * wi)
1,47	1,0101
0,72	1,0050
0,84	1,0055

n=	3
RI=	0,525
λmax =	3,0207
CI =	0,0103
CR=	0,0197

Table 17
The Weighted Values of AHP Hierarchy Indicators

Main Clusters' Weight			Indicators' Local Weight			Global Weight	
A1	Policy	0,42	1a	Qualified Researchers	0,64	0,27	27%
			1b	Infrastructure Establishments	0,19	0,08	8%
			1c	Equipment Availability	0,17	0,07	7%
A2	Management	0,28	2a	Technology Identification	0,23	0,07	7%
			2b	Project Management	0,37	0,10	10%
			2c	Technology Activation	0,40	0,11	11%
A3	Execution	0,30	3a	National Design Capability	0,48	0,15	15%
			3b	Domestic Production Capability	0,24	0,07	7%
			3c	Prototype Verification	0,28	0,08	8%
Total		1,0				1,0	100%

Table 18
The AHP Results wrt Each Expert Group

	All	Project Researchers	Supervisers	Prog experts	Customer Staff	Project Managers
Main Criteria Priority	Tech Policy	Tech Policy	Tech Policy	Tech Policy	Tech Policy	System Develop
	42%	44%	54%	43%	52%	54%
1a) Qualified Researchers	27%	27,80%	34,69%	28,45%	30,49%	10,50%
1b) Infrastructure Establishments	8%	9,09%	7,72%	10,46%	7,14%	3,21%
1c) Equipment Availability	7%	7,14%	11,63%	4,27%	14,18%	2,62%
2a) Technology Activation	7%	8,09%	10,62%	3,20%	3,42%	5,25%
2b) Project Management	10%	8,18%	9,75%	10,78%	9,29%	14,10%
2c) Technology Activation	11%	10,68%	7,94%	10,54%	12,14%	10,76%
3a) National Design Capability	15%	15,87%	8,34%	10,89%	10,45%	31,05%
3b) Domestic Production Capability	7%	6,58%	4,79%	11,22%	2,43%	13,09%
3c) Technology Prototype Verification	8%	6,56%	4,52%	10,20%	10,47%	9,41%

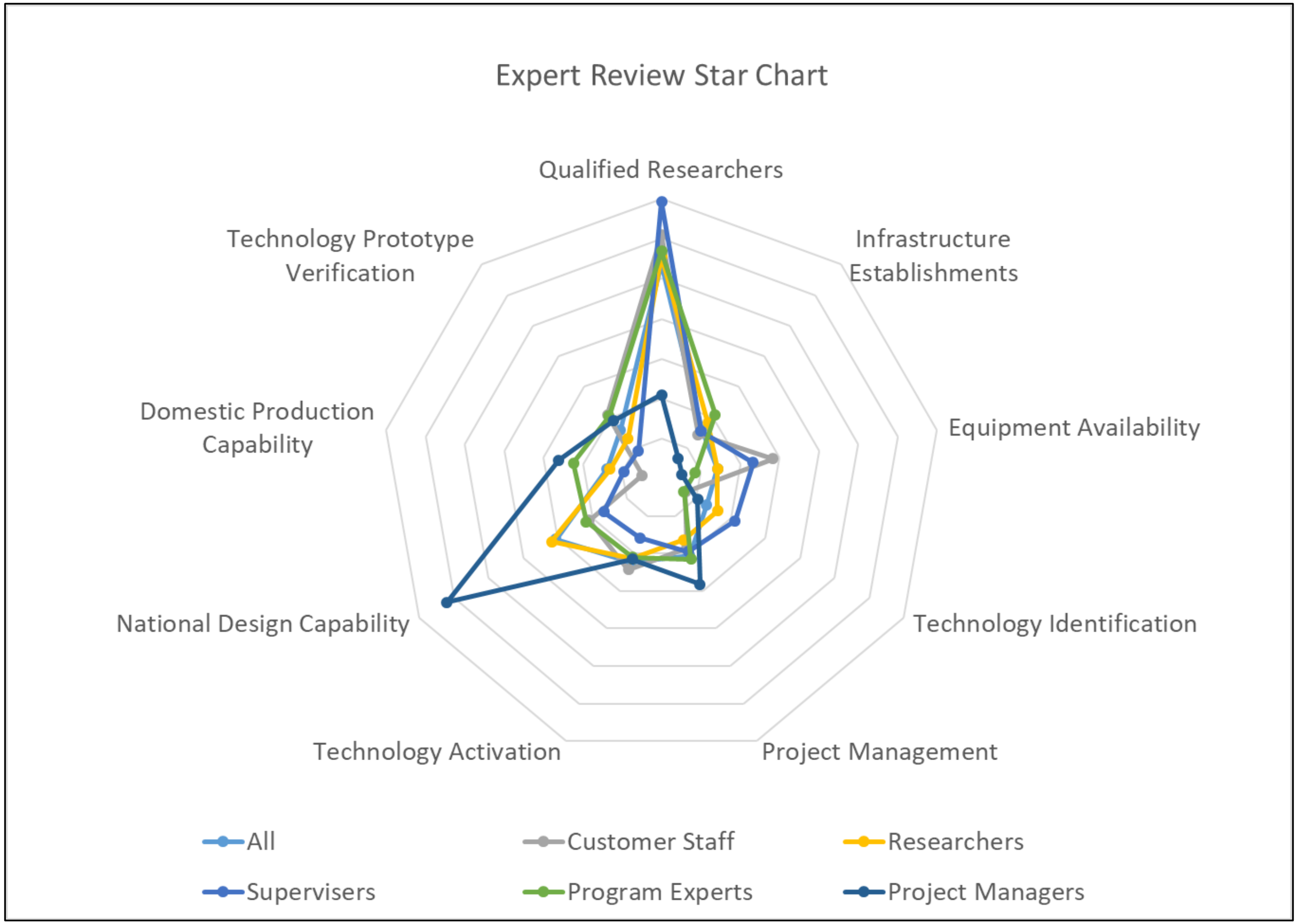

Figure 25. Expert Review Star Chart

6.4. The TOPSIS Calculations and Results

Table 19
The Weighting Factors

		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c
Weighting Factors	w_j	0,27	0,08	0,07	0,07	0,10	0,11	0,15	0,07	0,08

Table 20
Experts Judgements of Sub-Criterions

		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c
TRL-4 Maturity (Expert Reviews)	r_{1j}	8,50	7,79	7,05	6,62	6,58	5,11	7,02	5,28	5,72
TRL-5 Maturity (Expert Reviews)	r_{2j}	7,80	7,05	6,63	6,94	6,83	6,34	7,52	6,34	6,81
TRL-6 Maturity (Expert Reviews)	r_{3j}	7,28	6,88	6,57	7,09	7,05	7,66	7,22	7,09	7,81

Table 21
Weighted Expert Judgements of Sub-Criterions

$v_{ij} = w_i \ x \ \ r_{ij}$		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c
TRL-4 Maturity (Weigted)	v_{1j}	2,29	0,62	0,50	0,43	0,68	0,57	1,02	0,38	0,48
TRL-5 Maturity (Weigted)	v_{2j}	2,10	0,56	0,47	0,45	0,70	0,71	1,10	0,46	0,57
TRL-6 Maturity (Weigted)	v_{3j}	1,96	0,54	0,47	0,46	0,72	0,85	1,05	0,51	0,66

Table 22
Positive Ideal and Negative Ideal Scores of Sub-Criterions

		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c
Positive Ideal	r_j^*	9,00	9,00	9,00	9,00	9,00	9,00	9,00	9,00	9,00
Negative Ideal	r_j^-	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00

Table 23
Weighted Positive Ideal (and negative ideal) Scores of Sub-Criterions

$v_j^* = r_j^* \ x \ w_j$		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c
Positive Ideal (Weighted)	v_j^*	2,42	0,71	0,64	0,59	0,92	1,00	1,31	0,65	0,75
Negative Ideal (Weighte)	v_j^-	0,27	0,08	0,07	0,07	0,10	0,11	0,15	0,07	0,08

Table 24
Distance To Positive Ideal Solutions

S_i^*		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c	Sum
TRL-4 Distance To Positive Ideal	S_1^*	0,018	0,009	0,019	0,024	0,062	0,189	0,083	0,072	0,076	0,743
TRL-5 Distance To Positive Ideal	S_2^*	0,103	0,024	0,028	0,018	0,050	0,088	0,047	0,037	0,034	0,655
TRL-6 Distance To Positive Ideal	S_3^*	0,214	0,028	0,030	0,016	0,040	0,022	0,067	0,019	0,010	0,668

Table 25

Distance To Negative Ideal Solutions

S_i^-		A1.a	A1.b	A1.c	A2.a	A2.b	A2.c	A3.a	A3.b	A3.c	Sum
TRL-4 Distance To Negative Ideal	S_1^-	4,068	0,288	0,185	0,135	0,328	0,210	0,770	0,094	0,157	2,497
TRL-5 Distance To Negative Ideal	S_2^-	3,347	0,228	0,161	0,150	0,358	0,355	0,903	0,147	0,237	2,426
TRL-6 Distance To Negative Ideal	S_3^-	2,850	0,216	0,157	0,158	0,386	0,551	0,824	0,191	0,326	2,379

Table 26

Calculated Technology Maturity Levels

TRL-4 Maturity	CC_1^*	0,77
TRL-5 Maturity	CC_2^*	0,79
TRL-6 Maturity	CC_3^*	0,78

6.5. The Economic Analysis Results

Table 27

The Economic Outputs' Impact Assessment – Project 1

ECONOMIC IMPACT OF PROJECT -1									
PARTNERS	**B1- Intellectual Property Rights**		**B2 -Public Fundings & Networks**			**B3- Program Outputs**			**TOTAL EXPENDITURES**
	a)New Patents	**b)Patent Sales and Royalty**	**a)Procurement Orders**	**b)New Public Fundings**	**c)New External Projects & Consult**	**a)Direct Outputs (Sales)**	**b)Indirect Outputs (Sales)**	**c)New Internal Projects**	
Project-1 Executer : Public Institute	4 Patent application, 16 National 7 Intrl Publication	1 licencing activity going on	1 system procurement : **1 mil €** 4 Sub-System Procurement : **4 x 500k €**	1 Spin-Off Project : **5 mil TL** 1 Indirect (infrastructure) project : **5 mil TL**	3 Project Proposals at starting phase : **1 mil €**	Prototype-1 : **20 mil €** Component-1 (Focus) : **500k €** Component-2 (Tele) : **1.250k €** Component-3 (5KL) : **500k €**	Equipment (supplied to public corp. & serial production available) : **200k €** Software-1: free Software-2: **100k €**	N/A	Infrastructure, equipment, personel, travel,procurement, consultancy are included
Descriptions	*Value Estimation Unavailable*	*Value Estimation Unavailable*	*Estimated Values (Compared to international market & subject to export restrictions)*	*Realized Values*	*Estimated Values*	*Realized Values (Compared to international market & subject to export restrictions)*	*Estimated Values*	*Estimated Values*	**14.184.397 EUR**
TOTAL	Expected Value		Estimated Return Value (B2a+B2c +B3b)			Realized Return Value (B3a+B2b)			Euro/TL Currency (Avg) 3,5250
	0 EUR		4.300.000 EUR			25.086.879 EUR			
RETURN RATE	0%		30%			177%			

Table 28

The Economic Outputs' Impact Assessment – Project 2

ECONOMIC IMPACT OF PROJECT -2									
PARTNERS	**B1- Intellectual Property Rights**		**B2 -Public Fundings & Networks**			**B3- Program Outputs**			**TOTAL EXPENDITURES**
	a)New Patents	**b)Patent Sales and Royalty**	**a)Procurement Orders**	**b)New Public Fundings**	**c)New External Projects & Consult**	**a)Direct Outputs (Sales)**	**b)Indirect Outputs (Sales)**	**c)New Internal Projects**	
Project-2 Executer : Public Institute	1 Patent application, -- National -- Intrl Publication	(500 $ per product projected)	N/A	N/A	40.000 TL Consultancy	Prototype-1 : **500k $** Component-1 (AF) : **2.000k $** Component-2 (PK) : **150k $** Component-3 (KIS) : **50k $**	Component (KIS) : **50k $**	N/A	Infrastructure, equipment, personel, travel,procurement, consultancy are included
Descriptions	*Value Estimation Unavailable*	*Value Estimation Unavailable*	*Value Estimation Unavailable*	*Value Estimation Unavailable*	*Realized Values*	*Prototype-1 realized others Estimated Values per year*	*Estimated Values*	*Value Estimation Unavailable*	**4.527.297 USD**
TOTAL	Expected Value (B1b)		Estimated Return Value (B3a others +B3b)			Realized Return Value (B2c+B3a1)			USD/TL Currency (Avg) 3,0040
	500 EUR		2.250.000 USD			513.316 USD			
RETURN RATE	0%		50%			11%			

Table 29

The Economic Outputs' Impact Assessment – Supervisors

ECONOMIC IMPACT OF PROJECT SUPERVISORS									
PARTNERS	**B1- Intellectual Property Rights**		**B2 -Public Fundings & Networks**			**B3- Program Outputs**			**TOTAL EXPENDITURES**
	a)New Patents	**b)Patent Sales and Royalty**	**a)Procurement Orders**	**b)New Public Fundings**	**c)New External Projects & Consult**	**a)Direct Outputs (Sales)**	**b)Indirect Outputs (Sales)**	**c)New Internal Projects**	
Project Consultants	N/A	N/A	N/A	1 Academic Project : 360k TL	Consultancy for 3rd Project Partner resulted new product : 17k €	N/A	N/A	N/A	Meetings, site visits, report evaluations are included
Descriptions	*N/A*	*N/A*	*N/A*	*Realized Values*	*Realized Values*	*N/A*	*N/A*	*N/A*	**N/A**
TOTAL	Expected Value		Estimated Return Value (B2c +B3b)			Realized Return Value (B3a+B2b)			Euro/TL Currency (Avg) 3,5250
	0 EUR		0 EUR			119.128 EUR			
RETURN RATE									

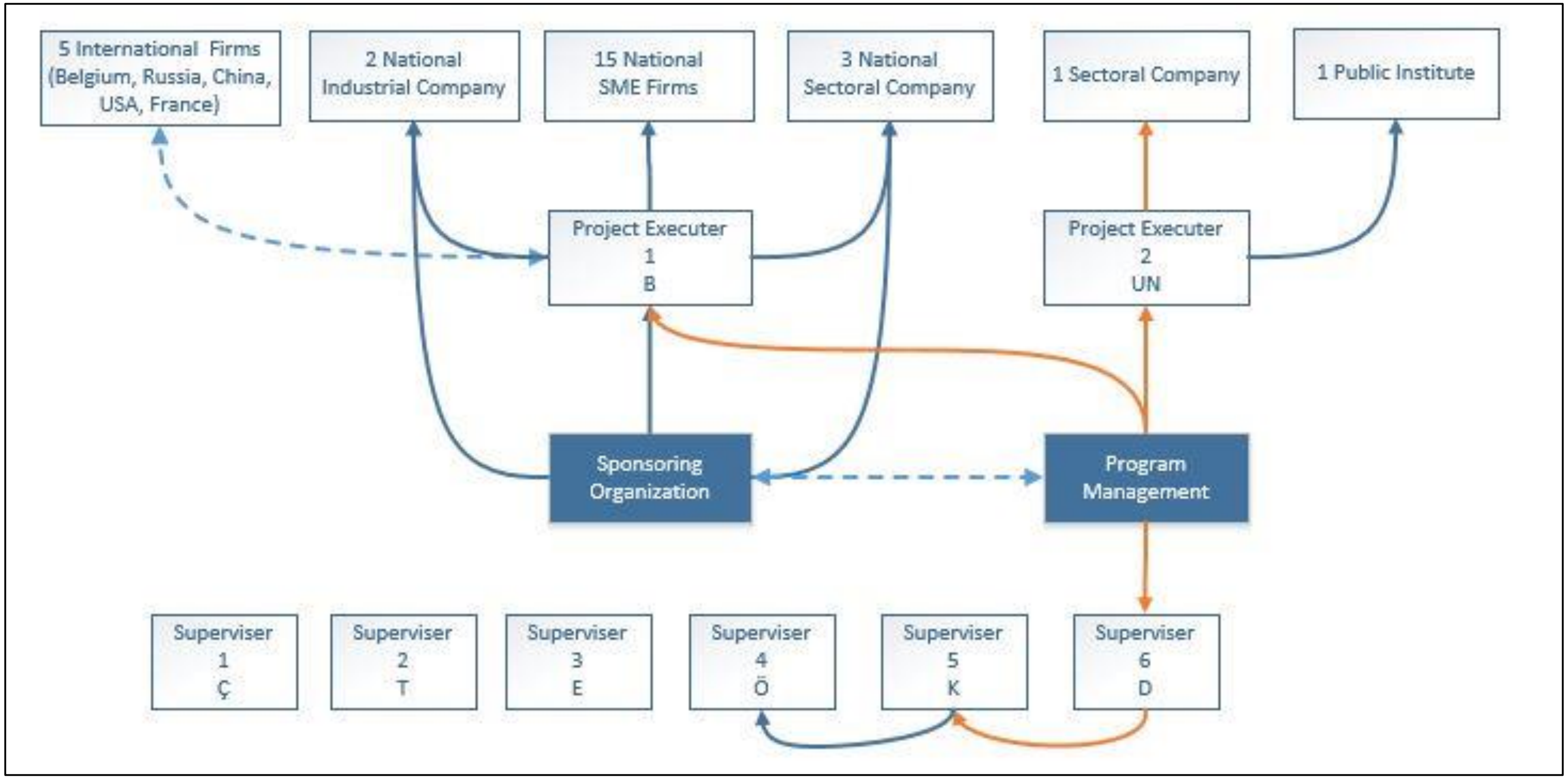

Figure 26. The Networking (new interactions) Impacts

CHAPTER 7

CONCLUSION

7.1. Summary of Dissertation

Technology development programs are considered as the most significant stage of the whole R&D process. This idea is supported by the technology development literature review. Impact assessment of publicly funded R&D activities has great popularity in the government agencies, research centers and private firms worldwide. Many public and private corporations are specifically focussed on impact assessment, evaluation and performance measurement in developed countries. For e few decades, governments consider that it is necessary to measure the impact and performance of government-funded large-scale R&D projects. One of those efforts might be mentioned as the US Government Performance and Result Act (GPRA) of 1993 in the United States. This act forces government agencies to measure the performance and impact of all publicly funded R&D programs. Due to the fact, Technology Readines Level (TRL) measurement method is developed by NASA and it is implemented by various government and high-tech firms. Although the methodology and the scope of measurement systems significantly differ, there are several other assesment tools but accountability, relevance and effectivity of current methods are still an issue.

The research questions of this thesis arised from programmatic issues experienced on the field. While trying to implement TRL method for Turkish government funded technology development programs, it has been observed that academics and project managers faced difficulties about the method and its results. Most of the difficulties arised from the method itself, secondly the absence of training materials and the lack of assessment policy were other reasons. The literature review revealed that TRL methodology has many other difficulties and implementation issues worldwide. So starting from the personal experiences, a new and qualitative technology maturity assessment method is submitted. This method is consisted of three main categories (modules) which are technology maturity assessment, economic output assessment and economic outcome assessment. Totally nine indicators for technology maturity assessment, eight indicators for economic output assessment and six indicators for economic outcome assessment are submitted. Networking assessment was not intended at the beginning of the study but the expert review results gave a chance to depict the networking effects for the case study.

A case study is executed to prove the applicability of the proposed model. Technology assessment module and the economic output assessment module are realized by a currently finished Turkish government-funded project. The case study project was under government agency management and sponsoring with the execution of five research centers and firms. Due to the core technology development scope and activities only two of them took part in the case study. Analytical Hierarch Process method is selected for data analyzing and expert reviews are done from the actual field. Highly qualified and senior experts who are from universities, research centers, institutions, agencies are participated to the case study reviews by semi-structured interviews (Totally 35 experts profiles are submitted in Appendix A). The results are significantly important for accountability, sustainability, management and economic feedback needs of decision makers. Summary of case study results are as follows:

Technology maturity assessment level is completed by %79 for TRL6 prototypes.

Project-1 Economic output assessment: 177% realized return rate, 30% estimeted return rate.

Project-2 Economic output assessment: 11% realized return rate, 50% estimeted return rate.

7.2. Technology Policy Discussions

1. In the political domain, more investments should be made for raising the qualified researcher resources. Case study AHP results indicate that the most significant indicator is the qualified researchers by %27 priority. Besides, qualified researcher indicator is assessed by the experts that it has 6,9% immaturity in the case study so took the first rank. So, more policy improvements should be done for raising qualified researchers in the field.

Improving overall human resources and skills are described in (OECD 2016) report as;

a) Improving the education system (in general or focusing on tertiary education)
b) Improving the attractiveness of scientific and research careers
c) Building a broad innovation culture

We can add some additional factors as;

d) Field experience is critical for know-how generation and should be supported.
e) Qualified researchers are the driving power of technology
f) Technology development activities must be considered as a matter of intellectual and learning issue rather than a support for industry. Besides industrial projects should focus on new technologies rather than the product itself.

2. Technology development activity requires intellectual capital and qualified human affiliation. Despite the fact that industrial technological applications reduce labour force, development of technological applications depends on strongly the skilled labour force. So, one the principal political objectives should focus on raising skilled and qualified researcher population. These kind of political targets will create labour, more and more technology developments and positive industrial impacts.

3. COSEPUP report empasizes that human resources as a performance indicator is not clearly or prominently submitted inside the plans or reports. The fundamental importance of the human resources for the nation is clear but importance of this resource for the scientific and engineering research is overlooked. The explicity of this resource inside the evaluations are important in two ways. First, more researchers will participate in the projects with their advisors and secondly the funding reductions in researches directly effects the preperation of next generation young scientists, researchers and engineers for the next stage of programs. (A Status Report, GPRA, 2001). AHP weighting study and the results of this thesis strongly supports that recommendation by assigning %27 factor for qualified researcher. That indicator must be considered as main competency criteria of the assessmet model.
4. As seen in Figure 25, only project managers assess the "national design capability" in the first priority. They are responsible for the budget, time, cost and delivery of the project. In the systems engineering perspective, design capability strongly effects above mentioned project activities and the managers are fully aware of that situation. So, the policies should consider national design issues and project implementations should have fully national design capabilities. For overall 35 experts "national design capability" has the second priority by %15 and it is strongly dependent for sustainable technological projects.
5. "Technology Activation" has third priority by %11. Technology policies must force decision makers so as to activate the outputs of programs, broaden the usage of outputs, take the outputs into inventory quickly.
6. "Technology Policy" got the main priority among the main criterias. If the policy goals are ambiguent and unknown, the performance measurement would be meaningless and no project manager would like to perform any performance measurement. Because any results of any performance analysis would indicate failures without any clear national objectives or requirements. During the case study application of this model, some of the project managers and researchers questioned if it was a real performance measurement for themselves. After describing the philosophy, no one hesitated to join the study. So the managers need a clear mind and coherence with the policy goals. This must be considered as the lack of current policy understanding in the field.

7. When the government implements mission oriented technology programs, the program would get a strong opportunity for the application of the technology because the most potential user would be the government (Foray, D. 2012). Hereby, there should be strong demand for the outputs and activation. The proposed model assigns %11 weight for the "technology activation" indicator in the 3rd rank. This must be considered as a confirmation that case study project is an application of a mission oriented policy and the experts are strongly aware of that situation. But the supporting organization should take that responsibility and realize the implementation goals. As one of the project managers mentioned, spin-off mechanism should be available when necessary.
8. While basic competences are generally considered important for absorbing new technologies, high-level competences are essential for the creation of new knowledge and technologies (OECD 2016). The results are coherent with the OECD report that qualified researchers, design capability, program management indicators are high-level competencies for creation of new knowledge and techniques.

7.3. Answers to the Research Questions

This study has three research questions. Two of them are related with sustainability purposes and the next two ones are related with accountability purposes;

Question-1: Taking into account the responsibilities of all stakeholders (in a qualitative approach), what are the achieved technological maturity level?

- Answer-1

According to the case study, technology maturity level of TRL 4-5-6 prototypes (outputs) are close to each other, they are as follows:

Table 30
Calculated Maturity Levels

TRL Level	Output	Muturity Level
TRL-4	Laboratory Prototype (proof of concept)	%77
TRL-5	Engineering Prototype (form study)	%79
TRL-6	System Prototype (functional)	%78

Question-2: Which factors are mostly influencing the technological outcomes?

- Answer 2a

The weighting values clearly show that the priority is mainly on the intellectual property, human resources, intangible values (Indicator 1a, 2a, 3a has total of % 49 weight factor). This results indicate that technology is mainly subject to the education and intellectual capacity of researchers so the impacts should be on these areas.

Table 31
Prioritization of Technology Development Program Indicators

Rank	**Indicators**	**Weighting Factors**
1	Qualified Researchers	27%
2	National Design Capability	15%
3	Technology Activation	11%
4	Program Management	10%
5	Infrastructure Establishments	8%
6	Technology Prototype Verification	8%
7	Equipment Availability	7%
8	Technology Identification	7%
9	Domestic Production Capability	7%
	Total	**100%**

- Answer 2b

All consistency criterias are achieved. CR values are far more less than 0.1 as AHP methodology requires.

Table 32
Consistency Ratio Values

	CR Value	Consistency Criteria
Main Criteria Matrix	0,0058	< 0,1
Sub-Criteria-1 Matrix	0,0002	< 0,1
Sub-Criteria-2 Matrix	0,0000	< 0,1
Sub-Criteria-2 Matrix	0,0197	< 0,1

- Answer 2c

The TRL-6 level has 78% maturity so it could have 12% maturity for ideal points. Which indicators were mostly effected the lack of maturity level for excellence? When we conduct a sensitivity analysis to measure the unsuccesfull indicators for TRL-6 level, we get the weighted insufficiency numbers for each indicator seperately.

The most insufficient indicators are; qualifiied researchers, national design capability, project management, with 6,9%, 2,1%, 1,2% consequently. As a result, qualified researcher indicator could increase the maturity by 6,9% if it could be perfect. The results are as follows:

Table 33
Unsuccessful Indicators Ranking for TRL-6

Rank	**Indicators**	**Weighted incompetency for 12%**	**Percentage incompetency for 100%**
1	Qualified Researchers	6,9%	49%
2	National Design Capability	2,1%	15%
3	Project Management	1,2%	9%

- Answer 2d

According to the impact analysis results, the impacts on partners can be analyzed on (the horizontal scale of the model) three dimensions. The strong, weak and risky area can be detected. The most insufficient stakeholder was (with respect to related indicators) technology policy development office with 50%.

Table 34
Inefficient Partners Ranking for TRL-6

	Partners	**Percentage inefficiency**
1	Sponsoring Agency (Technology Policy)	60%
2	Program Developer Agency (Program Management)	18%
3	Project Execution Institute (System Development)	22%
	Total	**100%**

Question-3: What are the economical outputs/outcomes of the technology development programs?

- Answer 3a

The economic impact assessment has done with the project managers and the academic supervisers that took part in the program execution and monitoring activities according to the indicators submitted in Figure-20. The results are summarized in Table 30 and Table 31. Within this table the realized and estimated economic values are summed. The estimated vales are not realized and they are ongoing processess, and the interviews are done within the two years of program completion. So the economic values are subject to increase. The values must be considered as a potential area for economic impact. It is clear that economic impact assessment must be done periodically after the program completion for an inclusive evaluation.

The economic values are not representing the formal values, they are obtained from one to one project manager interviews. All the Turkish currency values are exchanged to US currency or euro for comparable results.

In this case study the economic output return rates of Project -1 and Project-2 are calculated as percentage of totally spended project cost. Project-1 economic output assessment is calculated as 177% realized return rate, 30% estimeted return rate as shown in Table-30. Project-2 economic output assessment is calculated as 11% realized return rate, 50% estimeted return rate as shown in Table-31.

Table 35
Economic Outputs of Projects

	Realized Return Rate (Current Orders, Sales)	Expected Return Rate (Potential Orders, Sales)
Project 1	177 %	30 %
Project 2	11 %	50 %

The new projects and the consultancies of the project academic supervisers may also be added to economic outputs and that items are calculated separately and shown in Table-32.

The succes of Project-1 outputs are strictly related with functioning prototypes. So, the sponsoring agency continued to fund new projects and deliveries.

- Answer 3b: Networking Impact Assessment Results

The network map of the program has depicted in Figure-26 as an output of the expert judgements with the partners, researchers, project managers and colsultants. The brown colored connections represent the new projects which are realized and yielded short term financial outputs. The blue colored connections represent the new collaborations, consultancies or further project preperations which are related with the program outcomes and expected to have medium term financial outcomes. The connections and networks of the project executer company with 5 international companies is a sign of technology (sub-component) transfer capacity.

It can easily be seen that the sponsoring organization has begun to establish new networks and project plannings with sectoral and industrial companies related with the subject technology. This must be considered as a strong evidence of industrialization of the technology development program.

7.4. Implementation Suggestion

- To Policy Developers

Totally %49 weighted importance of technology development programs are related with intellectual capacity (quality of researchers, national design capability and technology identification). So,

a. Quality of researchers is the most important but the weakest point of system.
b. Have to stop brain migration and hold national intellectual capacity.

c. 60% of the inefficiency/immaturity of program caused by technology policy related issues.

- To Program Developers

a. Academic project outputs (TRL3 or TRL4) are hardly used in technology development stages (TRL4 TRL6), there is not a forcing, facilitating or motivating mechanism for that purpose. Most of the academic project outputs are not upgraded for technological level because of academic and funding considerations. But technological and economical considerations should have high priority for the accountability of public fundings. So, it is very important to fill the gap between these two stages. Designing mission oriented technology development programs which focus on TRL 5-6 levels has a critical importance. TUBITAK is coordinating various academic and industrial programs. It is a critical point that academic project outputs should pass to the technology development stage and then industrial product development stage. But the traceability of academic programs are not possible. A new technology development program should be implemented for developing academic 1001 Program outputs (TRL3 or TRL4) to the technology demonstrating outputs (TRL6 or TRL7). So, succesfull 1001 projects may be directly upgraded to the technology development level.
b. Failed project may be analyzed in detail and get the cause and effect relations.
c. Technology outputs activation may have high priority within the system.

- To Project Executers

- Investment for intellectual capacity should be considered as a natural consequence of related necessary technology policies.
- Employ qualified researcher for sustainable technology development capacity.

7.5. Limitations

The AHP hierarchy alternatives level (4th level) consist of TRL outputs (laboratory prototype, engineering prototype and the system prototype). We can easly see from the TOPSIS evaluation results that the calculated maturity levels of these outputs are so close. The possible reasons of this result may be as the projects are conducted in a way that activities focused on the final prototype and the mid stage prototypes or outputs are not studied seperately. So the team could not resolve the differences.

So, the next version of the model may be structured to re-evaluate the alternatives level. This level may consist of only one output or it may consist of the critical components of the final output.

7.6. Further Research

- A New Sub-Model for Qualified Researchers

Due to the fact that qualifiied researchers are the most important and impacting indicator of the programs, a new sub-model especially for researchers should be developed. So the details of this criteria would be able to analysed.

- Assessment of Single Output

This study proved that AHP methodology can bu used to assess a single program's technological maturity level. It can also be used to rank and score multiple technological development programs/projects with single or multiple outputs.

- Assessment of Basic and Applied Research

This methodology is also available for the basic and applied research projects. The results may bu used to rank and score a group of basic and applied research projects as well as the quality of the conducted project activities.

- Scoring Project Proposals

The results may bu used to rank and score a group of project proposals for basic research projects as well as technology development projects.

- New Indicator set

The indicator set of this study may be revised for different assessment goals.

- Network Impact Assessment

A new set of indicators with AHP method would be more satisfactory for the assessment of networking of the projects. This study didnt intend to detail that field.

1- Technology Readiness Level calculations may differ according to the developed countries. A new study with respect to the country applications might be useful.
2- Technology Readiness Level calculations may differ according to the technology categories. A new study with respect to the technology categories might be useful.

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APPENDICES

A. PARTICIPANT PROFILES

Table 1. Expert Profiles

	Expert Profiles						
Partner	**Organization**	**Total Number**	**Prof. Dr.**	**Ass. Prof. Dr.**	**Research er (PhD)**	**Senior Research er**	**Research er**
Public Corp.	Institute (BİLGEM)	**8**		1	4	2	1
	Institute (BTE)	**4**			2	1	1
	Institute (UME)	**2**			1		1
	Institute (ILTAREN)	**1**				1	
	Institute (SAGE)	**2**				2	
	Research Center (UNAM)	**3**		1	1		1
Funding Agency	Public Funding Group	**5**			2	2	1
Sponsoring Agency	DoD and Under-Secretery	**5**				2	3
Academia	Public University (Ankara)	**2**	2				
	Public University (YTE)	**1**		1			
	Public University (18 Mart)	**1**	1				
	Public University (Marmara)	**1**	1				
TOTAL		**35**	4	3	10	10	8

B. TECHNOLOGIC IMPACT QUESTIONNAIRE

ANALİTİK HİYERARŞİ SÜRECİ (Analytical Hierarchy Process) – AHP

Yukarıda tanımlanan ve alt bileşenleri verilen **3 Ana Kriterin** ve alt kriterlerin birbirlerine göre önemi konunun uzmanı olan sizler tarafından kıyaslamalı olarak değerlendirilecektir.

- Kriterler arasında kıyaslamalı olarak kişisel tecrübelerinizi ve teknoloji geliştirme faaliyetindeki uzmanlığınızı dikkate alarak değerlendirmelerinizi belirmeniz istenmektedir.
- Geliştirilen teknoloji seviyesine ulaşılmasında ve elde edilen kazanımlarda hangi kriterin daha etkin, daha kritik ve daha önemli olduğunu değerlendirmeniz istenmektedir.
- 2 kriter değerlendirilirken sadece kıyaslama yapılan kriterlerin birbirlerine göre önem derecesi kıyaslanmalıdır. Diğer kriterler göz önüne alınmamalıdır. (Örneğin : A ile B kıyaslanırken C ve D dikkate alınmamalıdır.)

- Karşılıklı 2'li kıyaslamalar arasında uyumluluk (consistency) olmasına dikkat edilmelidir. (A kriteri B kriterinden önemli ise, B kriteri de C kriterinden önemli ise; A kriteri C den önemli olmalıdır)
- Her bir kriterin program başarısına olan etkisi bütün boyutları ile düşünülerek ve programın çıktıları açısından önemi değerlendirilerek puanlama yapılmalıdır.

- 2 kriter kıyaslanırken göreceli olarak önemli olduğunu düşündüğünüz kriterin önem derecesini 1 ila 9 arasında puan vererek kıyaslayınız. Puanlamaların anlamı şu şekildedir:

Tablo 1. AHP ölçeğinin dereceleri ve açıklamaları Saaty (1980)

Önem Ölçeği	Tanım	Açıklama
1	Eşit derece önemde	Öğeler **eşit önemde**/ aralarında kayıtsız kalınıyor
3	Orta derece önemli	İlk öğe (A) diğer öğeye (B) göre **biraz daha önemli**/ tercih ediliyor
5	Kuvvetli derece önemli	İlk öğe (A) diğer öğeye (B) göre **fazla önemli**/ tercih ediliyor
7	Çok kuvvetli derece önemli	İlk öğe (A) diğer öğeye (B) göre **çok fazla önemli**/ tercih ediliyor
9	Kesin önemli	İlk öğe (A) diğer öğeye (B) göre **aşırı derece önemli**/ tercih ediliyor
2,4,6,8	Ara değerler	**Tercihler arasında uzlaşma gerektiğinde** kullanılmak üzere **ara değerler** olarak kullanılabilir.

İkinci öğe (B) birinci öğeden (A) daha önemli/ tercih edilir ise ölçek değerinin tersi kullanılır.

1/2 1/3 1/4 1/6 1/5 1/6 1/7 1/8 1/9

Örnek Çalışma :

Aşağıdaki örnek değerlendirme matrisinde her kriterin kendisi ile kıyaslanması doğal olarak "1" değerini almıştır.

Uzman değerlendirici matris köşegeninin sadece altındaki değerleri belirtmesi yeterli olacaktır. Matrisin kıyaslamalı karşı değeri çarpmaya göre ters sayı olacaktır. Mesela ;

Programın "Sistem Geliştirme (C)" kriteri "politikalar (A) " kriterinden ***fazla önemlidir ve daha tercih edilir*** ise [CA] hücresine 5 değeri verilir. [AC] hücresi otomatik olarak 1/5 değerini alacaktır.

		Teknoloji Politikaları	Program Yönetimi	Sistem Geliştirme
		A	B	C
Teknoloji Politikaları	A	1	1/3	1/5
Program Yönetimi	B	3	1	1/2
Sistem Geliştirme	C	5	2	1

Matrisin tüm değerleri yukarıdaki şekilde doldurulmalıdır. (Köşegenin sadece altında kalan bölümün doldurulması da yeterli olacaktır.)

	Main Criteria (Ana Kriterler)	**Related Partner (İlişkili Kuruluş)**	**Case Study Example (Vaka Analizindeki Kuruluş)**
A	Teknoloji Politikaları	Technology Policy Bureu (Teknoloji Politika Belirleyici Bür)	Science and Tech Policy Bureu (Bilim Teknoloji Politikaları)
B	Program Yönetimi	Program Manager Corporation (Program Yönetici Kurum)	Funding Agency (TÜBİTAK or SSB or Ministry)
C	Sistem Geliştirme	Project Executer Corporation (Proje Yürütücü Kurum)	Executive (Yürütücü Kuruluş)

Yukarıda yapılan değerlendirmeleriniz doğrultusunda; kişisel tecrübe ve uzmanlığınızın sonucunda programın başarısı için, program öncesi ve sonrasında dikkat edilmesi gereken önemli hususları belirtmenizi rica ederim. Her kriter için ayrı ayrı görüş belirtebilirsiniz.

TEKNOLOJİK ETKİ DEĞERLENDİRME FORMU

1. **AŞAMA (Ana Kriterlerin Önceliklendirilmesi)**

		Teknoloji Politikaları	Program Yönetimi	Sistem Geliştirme
		A	B	C
Teknoloji Politikaları	A	1		
Program Yönetimi	B		1	
Sistem Geliştirme	C			1

A- Teknoloji Politikalarının Etkileri (Altyapı, İnsangücü, Ekipman)

- Gerekli nitelikli araştırmacı yetiştirilmesi ve gerekli kaynağın kullanımının göstergesidir.

(doktoralı araştırmacı, akademik faaliyetler dâhil)

- Gerekli altyapı kurulumunun tamamlanması ve gerekli kaynağın kullanımının göstergesidir.
- Gerekli makine teçhizat ekipmanın alımı ve gerekli kaynağın kullanımının göstergesidir.

B- Program Yönetiminin Etkileri (Teknolojiyi tanımlama, yönetme ve kullanıma alma)

- İsterlerin son teknoloji seviyesinde yeterli olgunlukta tanımlandığının göstergesidir.
- Bütçe Yönetiminin teknoloji faaliyetlerini destekleme seviyesinin göstergesidir.

(zamanında ve yeterli miktarda bütçenin sağlanması, bütçenin etkin kullanılabilirliğinin göstergesidir)

- Teknik Program Yönetiminin teknoloji faaliyetlerini destekleme faaliyetlerinin göstergesidir.

(proje yönetimi, karar alma süreçlerinin etkinliği, süreç yönetimi, yurtdışından tedarik faaliyetlerinin sürdürülebilirliği, yurtdışı izne bağlı ithalat kısıtlı tedarikler) .

- Geliştirilen teknolojinin kullanıma alınmış olmasının göstergesidir. (bir ürün veya alt bileşen içerisinde yer alması veya bir üst seviyede geliştirilmeye başlanması dâhil).

C- Yürütücü Faaliyetleri Etkileri (Proje Süreçleri)

- Milli tasarım yeteneğinin hangi yeterlilik seviyesinde elde edildiğinin göstergesidir.
- Yerli üretim ve ürün entegrasyon yeteneğinin hangi yeterlilik seviyesinde elde edildiğinin göstergesidir.
- Ürün test ve doğrulama yeteneğinin hangi yeterlilik seviyesinde elde edildiğinin göstergesidir.

A-1 Teknoloji Politikaları

Bu örnek vaka çalışmasındaki faaliyetler göz önüne alındığında;
Teknoloji Politikalarının sonuçlarının etkili olduğu A,B,C kriterleri belirlenmiştir.

- Program sonunda elde edilen çıktılara ve sonuçlara olan etkiler göz önüne alındığında, aşağıdaki belirtilen A,B,C kriterlerininin her birinin önemli etkileri olduğu bilinmektedir.
- Aşağıdaki belirtilen A,B,C kriterlerinin sonuçlara etkileri açısından, birbirine göre (bire bir) önem derecesini karşılaştırınız. Karşılaştırmaları 1-9 arasında puan vererek puanlayınız.

		Nitelikli Araştırmacı	Altyapı Kurulumu	Alet Ekipman Yeterliliği
		A	B	C
Nitelikli Araştırmacı	A	1		
Altyapı Kurulumu	B		1	
Alet Ekipman Yeterliliği	C			1

Program başlatılması öncesi ve sonrasında dikkat edilmesi gerektiğini düşündüğünüz görüşleri ve hususları belirtebilirsiniz. Her kriter için ayrı ayrı görüş belirtebilirsiniz.

A- Nitelikli araştırmacının önemi?

B- Altyapı kurulumunun önemi?

C- Alet ekipman yeterliliğinin önemi?

A-2 Program Yönetimi

Bu örnek vaka çalışmasındaki faaliyetler göz önüne alındığında;
Müşteri Kurum ilişkilerinin sonuçlarının etkili olduğu A,B kriterleri belirlenmiştir.

- Program sonunda elde edilen çıktılara ve sonuçlara olan etkiler göz önüne alındığında, aşağıdaki belirtilen A,B kriterlerininin her birinin önemli etkileri olduğu bilinmektedir.
- Aşağıdaki belirtilen A,B kriterlerinin sonuçlara etkileri açısından, birbirine göre (bire bir) önem derecesini karşılaştırınız. Karşılaştırmaları 1-9 arasında puan vererek puanlayınız.

		Teknoloji Seviyesinin Tanımlanm ası	Proje Yönetimi	Teknolojini n Hizmete Alınması
		A	B	C
Teknoloji Seviyesinin Tanımlanması	A	1		
Proje Yönetimi	B		1	
Teknolojinin Hizmete Alınması	C			1

Program başlatılması öncesi ve sonrasında dikkat edilmesi gerektiğini düşündüğünüz görüşleri ve hususları belirtebilirsiniz. Her kriter için ayrı ayrı görüş belirtebilirsiniz.

A- Teknoloji hedef tanımının önemi: (Proje başlangıcında teknik ve performans hedeflerinin gerçekçi koyulması)

B- Program Yönetiminin önemi : (Bütçe ve kapsam yönetimi, Karar alma süreçlerinin hızlı olması, yurtdışı kısıtlı tedarik faaliyetlerinin yönetilmesi, koordinasyon vb.)

C- Hizmete alımın önemi (Proje çıktılarının kullanıma alınması) :

A-3 Proje Yönetimi (Sistem Geliştirme)

Bu örnek vaka çalışmasındaki faaliyetler göz önüne alındığında;
Proje Yönetimi Faaliyetlerinin sonuçlarının etkili olduğu A,B,C kriterleri belirlenmiştir.

- Program sonunda elde edilen çıktılara ve sonuçlara olan etkiler göz önüne alındığında, aşağıdaki belirtilen A,B,C kriterlerininin her birinin önemli etkileri olduğu bilinmektedir.

- Aşağıdaki belirtilen A,B,C kriterlerinin sonuçlara etkileri açısından, birbirine göre (bire bir) önem derecesini karşılaştırınız. Karşılaştırmaları 1-9 arasında puan vererek puanlayınız.

		Milli Tasarım Yeterliliği	Milli Üretim/ Entegrasyon Yeterliliği	Teknoloji Prototipinin Doğrulanması (Test) Yeterliliği
		A	B	C
Milli Tasarım Yeterliliği	A	1		
Milli Üretim/ Entegrasyon Yeterliliği	B		1	
Teknoloji Prototipinin Doğrulanması (Test) Yeterliliği	C			1

Program başlatılması öncesi ve sonrasında dikkat edilmesi gerektiğini düşündüğünüz görüşleri ve hususları belirtebilirsiniz. Her kriter için ayrı ayrı görüş belirtebilirsiniz.

A- Milli tasarım yeterliliğinin önemi:

B- Milli üretim/ entegrasyon yeterliliği:

C- Teknoloji prototipi doğrulaması:

C. ECONOMIC IMPACT QUESTIONNAIRE

EKONOMİK ETKİ DEĞERLENDİRME FORMU

PROGRAM SONUCUNDA, PROGRAM KAPSAMINA KATKILARINIZIN SONUCU İLE İLGİLİ OLARAK,

B-1 Fikri Ürün Hakları :

B-1 a) Kaç adet patent başvurusunda bulundunuz? Bu patent başvurularının ticari/maddi değerlemesini tahmini olarak yapabilir misiniz?

B-1 b) Patent satışı gerçekleştirdiniz mi? Royalty geliri elde ettiniz mi?

B-2 Alınan Yeni Kamu Destekleri ve Ağlar

B-2 a) Üretim siparişi aldınız mı? Toplam maddi tutarı ne kadardır?

B-2 b) Yeni Kamu Ar-Ge desteği aldınız mı? Toplam maddi tutarı ne kadardır?

B-2 c) Kurumsal olarak diğer kuruluşlar ile yeni projeler başlattınız mı? Kurumsal (veya kişisel) olarak danışmanlık hizmeti verdiniz mi Toplam maddi tutarı (değeri) ne kadardır?

B-3 Program Çıktıları

B-3 a) Program kapsamında tanımlı olan (direkt) ürettiğiniz çıktıların maddi tutarı ne kadardır?

B-3 b) Program kapsamında ticari olarak tanımlı olmayan fakat program faaliyetleriniz sonucu elde ettiğiniz ürettiğiniz (indirekt) ticari çıktılar var ise, maddi tutarı (değeri) ne kadardır?

B-3 c) Kurum içerisinde yeni iç projeler başlattınız mı? Toplam maddi tutarı (değeri) ne kadardır?

EKONOMİK ETKİ - ANKET ÇALIŞMASI

PROGRAM SONUÇLARININ GENEL VE NİTEL EKONOMİK DEĞERLENDİRİLMESİ:

Teknoloji Geliştirme Programını yöneten kuruluşun yapmış olduğu finansal/ekonomik destek miktarı, program süresince gerçekleşen maliyetlerinizi hangi seviyede karşıladı?

Program bitiş tarihinden sonraki 5 yıllık süreyi göz önüne alınız.

1- - Kuruluşa uzun vadeli (5+ yıl) ekonomik zarar verdi/verecektir.
2- -
3- - Kuruluş program sonunda ekonomik olarak zarar gördü
4- -
5- - Gelirler ve maliyetler başa baş seviyesinde
6- -
7- - Kuruluş program sonunda maliyetlerin çok üstünde ekonomik gelir elde etti.
8- -
9- - Kuruluşa uzun vadeli (5+ yıl) sürdürülebilir ekonomik katkı sağlandı/sağlanacak.

Gerekçelerinizi, değerlendirmelerinizi ve önerilerinizi belirtmenizi rica ederim.

D: TOPSIS ASSESSMENT QUESTIONNAIRE

TRL-4 Aşama Çıktısı = Konsept doğrulama aşaması, çıktısı laboratuar prototipidir.

TRL-5 Aşama Çıktısı = Mühendislik doğrulama aşaması, çıktısı mühendislik prototipidir.

TRL-6 Aşama Çıktısı = Teknoloji doğrulama aşaması, çıktısı sistem prototipidir.

Çıktıların Detaylı Açıklaması (TRL-4, TRL-5, TRL-6)

Üç farklı aşamadaki çıktıların (TRL-4, TRL-5, TRL-6 seviyelerinin çıktıları), teknolojik olgunluk seviyelerinin belirlenmesi amacıyla fonksiyon ve nitelikleri aşağıda belirtilmiştir. Prototip ve model ifadeleri aynı çıktıyı ifade eder.

1- Konsept Doğrulama Prototipi (TRL-4 Çıktısı, System Design Review)

- Ürünün son hali ile görsel benzerlik amaçlanmaz.
- Geliştirici, tasarımın hangisinin yapılabilir olduğunu anlamaya, konsept tasarımı doğrulamaya çalışır.
- Tasarımcı, malzeme mekanik özellikler, fonksiyonel özellikler ve formu gözden geçirebilecektir.
- İyi bir formu olması veya iyi çalışması bile gerekmeyebilir.
- Ana fikir; fonksiyonelliği gösterebilmek, paydaşlarla fikir paylaşmak veya yönetimi ikna edebilmektir.

2- Mühendislik Prototipi (TRL-5 Çıktısı, Preliminary Design Review)

- Son ürün ile ilgili fikir vermeli ve son ürün şeklini yansıtmalı
- Ön tasarımla ilgili geribildirim sağlamalı
- Detaylı tamamlama gerekmez, el işçiliği de içerebilir ama seri üretim hakkında fikir verebilmeli. Kalite ve fiyat son hali içermeyebilir.
- Nihai görünüm veya operasyonel kullanım amaçlanmaz.
- Fiyat Malzeme, seri üretim detayları, güvenlik ve lojistik faktörleri ile ilgili bilgi verir.

3- Fonksiyonel Prototip (TRL-6 Çıktısı, Critical Design Review)

- Çıktının amaçlanan fonksiyonunu gösterir.
- Kritik tasarımla ilgili geri bildirim sağlaması beklenir.
- Final protototipine benzer ölçekte olur.
- Operasyonel test ve seri üretim öncesinde tasarım kusurları test edilebilir.
- Final versiyonun pratik amaçlarını her açıdan detaylı gösterir (Üretim, görünüm, entegrasyon, paketleme, talimatlar vb.)
- Küçük geliştirmeler sonrasında prototipin üretime hazır olduğu gösterilir.
- Bazen “üretim öncesi prototip” ifadesi fonksiyonel prototip yerine de kullanılır.

Her bir program çıktısı için (TRL-4, TRL-5, TRL6 için)

Aşağıdaki değerlendirmelerinizi 1-9 arasında puan vererek puanlayınız.

1. **Nitelikli Araştırmacı Varlığının** Teknoloji Olgunluk Seviyesine Etkisi
   Nitelikli Araştırmacılar TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **nitelikli araştırmacı** seviyesi nedir?

	Vasat			İyi			Mükemmel		
	1	2	3	4	5	6	7	8	9
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

2. **Altyapı Kurulumu Faaliyetlerinin** Teknoloji Olgunluk Seviyesine Etkisi
   Mevcut altyapı TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **mevcut altyapı** seviyesi nedir?

	Vasat			İyi			Mükemmel		
	1	2	3	4	5	6	7	8	9
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

3. **Ekipman Teçhizat Kullanım Yeterliliğinin** Teknoloji Olgunluk Seviyesine Etkisi
   Mevcut ekipman ve teçhizatın TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **mevcut ekipman teçhizat** seviyesi nedir?

	Vasat			İyi			Mükemmel		
	1	2	3	4	5	6	7	8	9
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

4. **Teknolojinin En İleri Seviyesinin Tanımlanmasının** Teknoloji Olgunluk Seviyesine Etkisi
Teknolojinin En İleri Seviyesinin Tanımlanması TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **Teknolojinin En İleri Seviyesinin Tanımlanması** hangi seviyede etkili olmuştur?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

5. **Program Yönetiminin (Teknik ve mali yönetim, tedarik faaliyeti)** Teknoloji Olgunluk Seviyesine Etkisi
Program Yönetiminin (teknik mali yönetim ve tedarik) TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **Program Yönetiminin (teknik mali yönetim ve tedarik)** hangi seviyede etkili olmuştur?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

6. **Geliştirilen Teknolojinin Kullanıma Alınmasının** Teknoloji Olgunluk Seviyesine Etkisi
Teknolojinin kullanıma alınması TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili kullanıma alma hangi seviyede gerçekleşmiştir?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

7. **Milli Tasarım Yeterliliğinin Kazanılması Faaliyetlerinin** Teknoloji Olgunluk Seviyesine Etkisi
Milli Tasarım Yeterliliğinin Kazanılması TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **Milli Tasarım Yeterliliğinin Kazanılması h**angi seviyede gerçekleşmiştir?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

8. **Yerli Üretim ve Entegrasyon Faaliyetlerinin** Teknoloji Olgunluk Seviyesine Etkisi
Yerli Üretim ve Entegrasyon Faaliyetleri TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **Yerli Üretim ve Entegrasyon Faaliyetleri** hangi seviyede gerçekleşmiştir?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

9. **Prototip Doğrulama ve Test Faaliyetlerinin Teknoloji Olgunluk Seviyesine Etkisi**
Prototip Doğrulama ve Test Faaliyetleri TRL-4 TRL-5 ve TRL-6 aşama çıktılarının başarılı olmasında ne kadar etkili olmuştur? TRL-4 TRL-5 ve TRL-6 aşamaları ile ilgili **Prototip Doğrulama ve Test Faaliyetleri** hangi seviyede gerçekleşmiştir?

	Vasat			**İyi**			**Mükemmel**		
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
TRL-4 Laboratuar									
TRL-5 Mühendislik									
TRL-6 Sistem									

E. EXPERT ASSESSMENTS FOR AHP

Only “Main Criteria” assessments are depicted for an example.

The rest of 3 sub-criteria assessments are not listed.

Table 1 : Expert Assessments for Main Criteria

1	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/3	1/5
B	3	1	1/3
C	5	3	1

2	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/5	1/7
B	5	1	1/3
C	7	3	1

3	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	8	7
B	1/8	1	5
C	1/7	1/5	1

4	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1	7
B	1	1	5
C	1/7	1/5	1

5	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/5	1/3
B	5	1	1/2
C	3	2	1

6	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	6
B	1/5	1	5
C	1/6	1/5	1

7

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	3
B	1/5	1	1/5
C	1/3	5	1

8

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1	5
B	1	1	5
C	1/5	1/5	1

9

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/5	1/3
B	5	1	2
C	3	1/2	1

10

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	3
B	1/5	1	1/7
C	1/3	7	1

11

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	7	5
B	1/7	1	1/3
C	1/5	3	1

12

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	1/3
B	1/5	1	1/5
C	3	5	1

13

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	2	1/5
B	1/2	1	1/3
C	5	3	1

14

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/3	1/5
B	3	1	1/2
C	5	2	1

15

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/3	1/5
B	3	1	1/2
C	5	2	1

16

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1

17

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	2	1/3
B	1/2	1	1/3
C	3	3	1

18

	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/2	1/2
B	2	1	1
C	2	1	1

19			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/4	1/3
B	4	1	1/2
C	3	2	1

20			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	7	6
B	1/7	1	5
C	1/6	1/5	1

21			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1

22			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	2	6
B	1/2	1	4
C	1/6	1/4	1

23			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	6	5
B	1/6	1	3
C	1/5	1/3	1

24			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	3
B	1/5	1	3
C	1/3	1/3	1

25			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/2	1/5
B	2	1	1/3
C	5	3	1

26			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	3	5
B	1/3	1	3
C	1/5	1/3	1

27			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	3	5
B	1/3	1	1
C	1/5	1	1

28			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	3	3
B	1/3	1	1
C	1/3	1	1

29			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	2	1/2
B	1/2	1	1/3
C	2	3	1

30			
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/4	1/7
B	4	1	1/5
C	7	5	1

	31		
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	3
B	1/5	1	1/3
C	1/3	3	1

	32		
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	1/5	1/7
B	5	1	1/3
C	7	3	1

	33		
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	7
B	1/5	1	7
C	1/7	1/7	1

	34		
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	5	1
B	1/5	1	1
C	1	1	1

	35		
	Technology Politics	Program Mngmt	System Developm.
	A	B	C
A	1	7	5
B	1/7	1	7
C	1/5	1/7	1

Standart Decision Matrix for Main Criteria

	Technology Politics	Program Mngmt	System Developm.
	A1	A2	A3
A1	1,0	1,6	1,3
A2	0,6	1,0	1,0
A3	0,8	1,0	1,0

F. EXPERT ASSESSMENTS FOR TOPSIS

Table 1 : Expert Assessments for A1.a Indicator

Qualified Researchers	A1.a	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	8	7	9	9	9	9	8	9	9	9	9	7	9	8	9	8,50
Engineering Prototype	TRL-5	8	8	8	9	7	8	6	9	9	8	8	7	9	6	8	7,80
System Prototype	TRL-6	7	9	7	9	8	5	6	9	9	8	8	6	9	4	8	7,28

Table 2 : Expert Assessments for A1.b Indicator

Infrastructure Establishments	A1.b	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	7	9	7	8	6	8	8	9	7	9	9	7	9	6	9	7,79
Engineering Prototype	TRL-5	6	7	8	6	5	8	6	9	7	8	8	7	8	6	8	7,05
System Prototype	TRL-6	5	8	9	5	4	9	6	9	7	8	7	6	8	8	7	6,88

Table 3 : Expert Assessments for A1.c Indicator

Equipment Availability	A1.c	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	7	9	7	9	5	8	9	7	9	8	9	5	6	3	9	7,05
Engineering Prototype	TRL-5	5	9	8	8	4	9	6	7	9	7	8	5	6	4	8	6,63
System Prototype	TRL-6	5	8	9	6	4	9	6	7	9	6	7	5	6	7	7	6,57

Table 4 : Expert Assessments for A2.a Indicator

Technology Identification (State of the Art)	A2.a	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	7	8	7	7	3	9	7	9	9	7	7	6	8	3	7	6,62
Engineering Prototype	TRL-5	6	7	8	7	4	8	7	9	9	7	8	6	9	4	8	6,94
System Prototype	TRL-6	5	6	9	7	5	9	7	9	9	7	9	6	7	5	9	7,09

Table 5 : Expert Assessments for A2.b Indicator

Project Management	A2.b	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	8	8	8	8	6	6	6	9	5	8	7	4	5	6	7	6,58
Engineering Prototype	TRL-5	8	7	9	8	5	6	7	9	5	8	8	4	6	7	8	6,83
System Prototype	TRL-6	7	6	9	8	5	8	7	9	5	8	9	4	6	9	9	7,05

Table 6 : Expert Assessments for A2.c Indicator

Technology Activation	A2.c	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	9	3	7	8	8	2	5	6	5	9	4	4	5	4	4	5,11
Engineering Prototype	TRL-5	9	4	8	8	8	5	5	6	5	9	6	6	5	8	6	6,34
System Prototype	TRL-6	8	9	9	8	9	9	8	6	5	9	8	7	5	9	8	7,66

Table 7 : Expert Assessments for A3.a Indicator

National Design Capability	A3.a	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	9	8	8	9	9	9	6	9	9	9	4	7	4	6	4	7,02
Engineering Prototype	TRL-5	7	7	8	8	8	9	7	9	9	9	7	7	5	7	7	7,52
System Prototype	TRL-6	7	4	9	7	8	7	8	9	9	9	7	6	5	9	7	7,22

Table 8 : Expert Assessments for A3.b Indicator

Domestic Production Capability	A3.b	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	
Laboratory Prototype	TRL-4	6	6	7	5	7	6	4	7	5	9	4	4	4	4	4	5,28
Engineering Prototype	TRL-5	6	8	7	5	7	7	7	7	5	9	7	4	5	6	7	6,34
System Prototype	TRL-6	6	9	9	5	8	9	8	7	5	9	9	4	5	8	9	7,09

Table 9 : Expert Assessments for A3.c Indicator

Technology Prototype Verification	A3.c	Case Study Project Researchers												Supervisers			Geo-Mean Values
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**1**	**2**	**3**	Mean
Laboratory Prototype	TRL-4	6	6	7	8	7	5	4	9	5	9	4	7	6	3	4	5,72
Engineering Prototype	TRL-5	6	8	8	8	8	7	6	9	5	9	6	7	6	5	6	6,81
System Prototype	TRL-6	6	9	9	8	8	9	8	9	5	9	9	7	6	8	9	7,81

G. CURRICULUM VITAE

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CURRENT POSITION

- TÜBİTAK MAG (Engineering Research Grant Commitee)
  Scientific Programs Expert, 2019 –

PREVIOUS POSITIONS

- TÜBİTAK SAVTAG (Defence and Security Technologies Research Grant Commitee)
  Scientific Programs Expert, 2013 - 2019
  - *Planning, Coordination and Management of Various Projects*
  - *Coordinator of Hi- Tech Technology Development Defence Projects (Publicly Funded)*
  - *System Engineering Activities*
  - *Project Test and Verification Activities*

- MKE CORPORATION (R&D Department)
  R&D Engineer, 2000 – 2013
  - *Domestic Defence Industry Projects*

EDUCATION

Middle East Technical University, Science and Technology Policy Studies
(PhD Candidate 2014 - 2020)

Anadolu University, Business Administration (2nd University)
BSc 2009 – 2013

Ankara University, Graduate School of Natural and Applied Science, Physics Engineering
MSc 2005 - 2009

Istanbul Technical University, Faculty of Arts and Science, Physics Engineering
BSc 1992 - 1996

PERSONAL INTERESTS

Philosophy, Cinema, Music

H. TURKISH SUMMARY / TÜRKÇE ÖZET

Giriş

Teknoloji ülkelerin ekonomik, endüstriyel ve sosyal gelişimlerinin öncü kuvvetidir. Tarih boyunca ekonomik, askeri ve sosyal açılardan diğer ülkelere üstünlük kuran ülkelerin, bunu teknolojik üstünlük kurarak başardıkları söylenebilir.

Bilimsel araştırmalar, teknoloji geliştirme faaliyetleri, mühendislik kapasitesi, innovasyon kapasitesi ve ekonomik refah seviyeleri arasında doğrudan veya dolaylı bir ilişki bulunmaktadır. Bu ardışık faaliyetlerin sonucu toplum ve ekonominin yeniden yapılanmasıdır.

Gelişmiş ülkenin statüsünü devam ettirme arzusu, bu ülkenin stratejik perspektifinden kaynaklanır ve bu durum etkin ve etkili bilimsel/teknolojik politika geliştirilmesini gerektirir. Teknoloji insanların hayatlarını her açıdan ve ömür boyu etkiler bu yüzden milli, uluslararası, orgaizasyonel ve teknik seviyelerde yönetilmesi gerekmektedir. Bu bağlamda, Ar-Ge ve teknoloji geliştirme destek mekanizmaları ülkelerin ekonomik ve sosyal kazanımlarına hizmet eder. Bir ülkenin stratejik gelişme planlarının en kritik bölümünü teknoloji politikaları oluşturur. Bu politikalar ikinci dünya savaşı sonrası ortaya çıkan değerler dizisi açısından "görev odaklı" ve "yayılım odaklı" olmak üzere değerlendirilebilir.

İkinci dünya savaşı sonrasında, Manhattan Projesinde yöneticilik yapmış bir bilimi adamı olan Bush Vannevar tarafından ABD Başkanına bir savaş sonrası değerlendirme raporu sunulmuştur (Science – The Endless Frontier, 1945). Sürekli desteklenen bilimsel faaliyetlerin yeni ürün, yeni endüstri ve daha çok iş sonucunu doğuracağı belirtilerek temel bilim, uygulamalı bilim, teknoloji geliştirme ve ürün geliştirme faaliyetleri doğrudan ilişkili olarak gösterilmiştir. Manhattan Projesi, temel bilim, teknoloji geliştirme ve ürün geliştirme (atom bombası) aşamalarını birlikte içeren büyük bir proje olması sebebiyle savaş sonrası dönemin bilim teknoloji politikalarının oluşmasında önemli etki meydana getirmiştir. Ayrıca sistematik teknoloji geliştirme kavramı, sistem mühendisliği kavramı ve modern anlamda proje yönetimi kavramlarının oluşmasında etkisi olmuştur.

Araştırma geliştirme faaliyetlerini klasik olarak sırasıyla üç aşamada değerlendirebiliriz; temel bilimsel araştırma, teknoloji geliştirme ve ürün geliştirme. Bu aşamalar içerisinde teknoloji geliştirme süreçleri en zorlu süreç olarak görülebilir çünkü temel araştırmaların belirsizliklerini ve risklerini alarak, ürün ve sistemlerin zorlu kısıtlamalarına uyarlamak şeklinde köprü görevi bulunmaktadır. Bu sebeple planlama, yönetim, uygulama, değerlendirme gibi zorlu alt süreçleri barındırmaktadır. Ayrıca riskler, teknik zorluklar, yönetim ve koordinasyon, disiplinler arası faaliyetler gibi zorlayıcı süreçlere sahiptir. Bu sebeple bu faaliyetler literatürde "cehennem çukuru" veya "ölüm vadisi" gibi sıfatlarla adlandırılmaktadır.

Bu tezin konusu on yılı aşkın bir zamanda teknoloji geliştirme faaliyetlerinin içerisinde bulunmuş olmak sebebiyle, teknoloji geliştirme faaliyetlerinin önemi, başarıyı etkileyen gizli faktörleri ve zorlukları karşısında sistematik bir performans ve etki ölçüm sisteminin modellenmesi ihtiyacından kaynaklanmıştır. Projelerin başarısına bazı ölçülmemiş ve gizli kalmış faktörlerin etkilediği gözlemlenmiştir. Araştırmacıların niteliği, ülke teknoloji politikası, tedarik kapasitesi, ihracat iznine bağlı alımların zorlukları teknoloji geliştirme faaliyetlerinin ölçülmeyen bilinmeyen zorluklarından sadece birkaçıdır. Bu gibi göstergelerin görünür kılınması, önem derecelerinin belirlenmesi ve izlenebilir olması sonraki projeler için çok önemlidir. Literatürde bu gibi göstergeler ölçülmemiş, ağırlıklandırılmamış ve sürdürülebilirlik, olgunluk, kapasite anlamında değerlendirilmemiştir.

Literatürde yer alan "Teknoloji Hazırlık Seviyesi" (TRL) metodu dünyada birçok devlet ve özel sektör kuruluşu tarafından uygulanmasına rağmen gerek Türkiye'deki uygulamalar ve gerekse dünyadaki uygulamalarda birçok uygulama zorluğu, belirsizlik, risk, kapsam darlığı gibi sebeplerle karar vericilere ve politika geliştiricilere yeteri kadar faydalı olamadığı görülmektedir. Tez içerisinde bu kapsamda detaylı literatür bilgisi verilmiştir. Bu sebeple, niteliksel görüşlerin yer aldığı analitik içerik barındıran, ölçülebilir ve kapsayıcı bir teknolojik ve ekonomik değerlendirme metodunun gerekliliği görülmüştür. Bu ihtiyacın teknoloji geliştirme programları için uygulanabilir olduğu gösterilmiştir.

Bir teknoloji geliştrime programı başarı ile tamamlandığı durumda sonuçları, insanlar, paydaş kurumlar, ilgili sektörler ve ülke refahı üzerinde kısa ve uzun vadede olumlu etkiler meydana getirecektir. Bu tez kapsamında, teknoloji geliştirme programlarının kritik süreçleri modellenmiştir. Üç farklı modül üzerinden teknoloji geliştirme göstergeleri, ekonomik çıktı göstergeleri ve ekonomik sonuç göstergeleri tanımlanmıştır. Bu göstergeler program yönetim ve koordinasyon faaliyetleri süreçlerinde meydana gelen zorluklar ve tecrübelerden faydalanılarak oluşturulmuştur.

Teori ve Araştırma Soruları

Literatür Ar-Ge faaliyetleri kapsamında çoğunlukla temel araştırma faaliyetlerinin sonuçlarını ve etkilerini bibliyometrik, niceliksel yöntemlerle incelemektedir. Teknoloji geliştirme faaliyetleri Ar-Ge faaliyetlerinin özel bir alanıdır ve kendine özel zorluklar içermektedir. Literatüre bakıldığı zaman NASA benzeri kuruluşların teknoloji geliştirme faaliyetlerini değerlendirirken TRL metodunu kullanmakla beraber özellikle uzman görüşü alarak niteliksel değerlendirmeler yapmak ihtiyacında olduğu görülmektedir. Bu husus Türkiye koşullarında gerçekleştirilen teknoloji geliştirme faaliyetlerinde de ön plana çıkmaktadır ve süreç ve çıktıların standart soru cümleleri veya niceliksel değerler ile kullanılan TRL metoduna ek olarak çok yönlü ve nitel uzman değerlendirmelerine ihtiyaç duyduğu değerlendirilmektedir. TRL metodunun eksiklikleri ve yetersiz kaldığı konular literatür eşliğinde tezde belirtilmiştir ve önerilen model bu eksikliği doldurabilecek içeriktedir.

Bu çalışmadaki temel teori, teknoloji geliştirme programlarının kaliteli bilimsel bilgiye, kalifiye araştırmacıya ve yönetim yeterliliğine yüksek oranda bağlı olduğudur. Bu sebeple bu değerlerin ölçümünün niteliksel olarak yapılması gerekmektedir.

Ayrıca teknoloji geliştirme programları sadece proje çıktılarının fonksiyonlarını gösterme özellikleri ile değil ayrıca aşağıdaki kritelerle de değerlendirilmesi gerektiğidir:

- Politikalar sonucu kazanılan kaynaklar
- Güncel ve etkin bir teknoloji yönetimi
- Proje yönetimi ve milli bir sistem geliştirme süreç yönetimi

Yukarıda belirtilen perspektif özellikle Türkiye gibi gelişmekte olan bir ülke için kritik önem sahiptir. Gelişmiş ülkelerin kapasiteleri, kaynakları, kaynaklara erişim imkânları, ilişkilerinin gücü, tedarik imkânları, yönetim ve organizasyon becerileri doğal olarak üst seviyededir ve sonuçlara etkisi süreç değerlendirmesinde göz önüne alınmamaktadır. Fakat Türkiye gibi ülkelerde bu alanlardaki yetersizlikler sonuçlar üzerinde etkili olmakta, sürdürülebilirlik ve hesap verebililik açısından değerlendirilmemektedir. Ayrıca bu faaliyetler çok paydaşlı faaliyetlerdir ve her bir paydaşın sorumlulukları ve sonuçlar üzerindeki etkisi ölçülmelidir.

Bu çalışma yukarıda belirtilen alanlarda farkındalık oluşturarak teknoloji geliştirme faaliyetleri ve teknoloji olgunluk ölçümü kapsamında güçlü ve zayıf tarafların tanımlanmasına katkıda bulunacaktır.

Bu araştırma aşağıda belirtilen üç adet araştırma sorusuna cevap aramaktadır. İlk ikisi sürdürülebilirlik kapsamındadırr sonraki ise hesap verebilirlik kapsamındadır:

a) Paydaşların sorumlulukları niteliksel bir yaklaşımla göz önüne alındığında, kazanılan teknoloji olgunluğu hangi seviyededir?
b) Teknoloji çıktı ve sonuçları en çok etkileyen faktörler nelerdir?
c) Teknoloji geliştirme programlarının ekonomik çıktı/sonuçları nelerdir?

Araştırmacının Motivasyonu

Bu tez ile teknoloji geliştirme gruplarında elde edilen tecrübeye dayanarak bu programların etki ve performanslarının ölçülmesi sonucunda elde edilen kazanımların sürdürülebilir ve hesap verilebilir olması için bir sistematik ölçülebilir yaklaşım ortaya konulmuştur.

Bununla birlikte teknoloji geliştirme programlarının ayırtedici özellikleri ve önemleri belirtilerek önemi ortaya konulmuştur. Mevcut süreçlerde yapısal ve sistematik problemler olduğu değerlendirilmektedir. Bu faaliyetlerin temel amacının teknolojik olgunluk olduğu göz önüne alınmalıdır ve bu kavramın ölçümünü oluşturan göstergelerin bütünsel açıdan ve tüm paydaşları içerecek şekilde modellenmesi gerektiği değerlendirilmektedir. Teknoloji olgunluğu, sadece proje çıktılarının fonksiyon göstermesi olarak algılanmamalı ve milli ve sürdürülebilir niteliklerin kazanılması olarak değerlendirilmelidir ve uzun vadede ekonomik refaha katkı vermesi beklenmelidir.

Çalışmanın Önemi

Bu çalışmada önerile teknoloji olgunluğu ölçüm modeli, zayıf ve güçlü yönlerin anlaşılması, program paydaşlarının sorumluluk ve başarılarının gösterilmesi, program/proje çıktılarının kalitesinin anlaşılmasını sağlayacaktır.

Teknoloji olgunluğu değerlendirmesi, konusunda tecrübeli ve uzman personelin görüşleri ile uzman değerlendirmesi yöntemi ile yapılmaktadır. Yeni bir gösterge seti tanımlanmıştır.

Analitik Hiyerarşi Süreci (AHP) yöntemi kullanılarak değerlendirme gerçekleştirilmiştir ve politika yapıcılar, program yöneticileri, sistem geliştiricilerinin sorumlulukları ve başarılı oldukları alanların belirlenmesi ölçülmesi sağlanmıştır. Teknoloji olgunluk seviyesi dünyada geniş şekilde kullanılan TRL metodundan farklı bir yöntem ve teknik ile değerlendirilmiş ve sayısallaştırılmıştır. Bu yöntem gelişmekte olan Türkiye gibi ülkelerde tamamlayıcı bir metot olarak kullanılabileceği bir vaka analizi çalışması ile gösterilmiştir.

Literatür

Teknoloji geliştirme faaliyetlerinin çok yönlülüğü sebebiyle çalışmanın literatür kısmı birkaç yönden ele alınmıştır. Bilim, doğanın açıklanması ve keşfedilmesidir. Teknoloji ise bu bilginin kontrol edilerek doğanın keşfi ve doğa bilgisinin kontrol edilmesidir. Bilimsel faaliyetler ile ekonomik gelişmeler arasında doğrudan bir ilişki bulunmaktadır (Bets, Frederick, 2013).

Teknoloji geliştirmenin çok farklı boyutlarda insan hayatına etkileri bulunmaktadır. Bu etkiler; bilimsel, teknolojik, ekonomik ve sosyal etkiler olarak sıralanabilir.

Çalışma kapsamında kamu destekli programlar incelendiği için kamu desteklerinin kapsam içerisindeki önemi ve literatür bilgisine yer verilmiştir. Behn (2003) tarafından kamu desteklerinin politikalarının önemi vurgulamıştır. Organizasyonel performans ölçümünde teknoloji politikalarının açık belirgin ve anlaşılır olmasının önemi vurgulanmıştır. Aksi taktirde performans ölçümünün zorlaşacağı ve faydasız olacağı belirtilmiştir. Ayrıca kamu desteklerinin amacı olarak, değerlendirme, kontrol, bütçeleme, motivasyon, yükseltme, kutlama, öğrenme ve gelişme olarak sekiz kategoride belirtilmiştir. Bununla birlikte (Kusters, C. 2017) tarafından performans ölçümü amacı olarak hesap verilebilirlik, stratejik yönetim, operasyonel yönetim, politika belirleme, bilgi artırımı, paydaşların güçlendirilmesi, öğrenen organizasyon ve iyi yargı kararı verme gibi hususlar belirtilmiştir.

Kamunun geliştirme faaliyetlerinin etkisinin ölçümü GPRA yasası ile ABD'de zorunlu hale gelmiş ve uygulanmıştır. Bu kanun ve uygulaması farklı teknoloji geliştirme uygulamaları tarafından eleştirilebilmektedir. COSEPUB raporu bu yönü ile NAS, NAE, IOM gibi kuruluşların uzmanlarının oluşturduğu bir doküman olarak önemlidir. Ayrıca kamu destekli Ar-Ge faaliyetleri altı ana başlıkta gösterilmiş ve sistemin kapsamı ve karmaşıklığı gösterilmiştir.

Teknoloji olgunluğu ölçümü için literatür incelendiği zaman çoğunlukla “Teknoloji Hazırlık Seviyesi” kavramı karşımıza çıkmaktadır. Bu kavram ve metodoloji NASA tarafından ortaya atılmış ve uygulanmıştır. Günümüzde bu metodu kamu ve özel sektörden birçok kurum kuruluş faaliyetlerinin olgunluk seviyesini ölçmek amacıyla kullanmaktadır. Bununla birlikte bu metoda yönelik hem uygulama hem kapsam hem de yöntem olarak eleştiriler mevcuttur. Bu eleştiriler bu bölümdeki literatür bilgileri ışığında belirtilmiştir. Teknoloji hazırlık seviyeleri tanıtılmış ve teknoloji geliştirme faaliyetleri için kullanılan “ölüm vadisi” kavramı ışığında teknoloji olgunluğunun ölçümünün zorluğuna değinilmiştir. Çoğunlukla, TRL1-3 aralığı akademik sistemin ve üniversitelerin faaliyet gösterdiği, TRL 4-6 aralığı araştırma merkezleri ve enstitülerin faaliyet gösterdiği, TRL 7-9 aralığı sanayi kuruluşları ve özel sektörün ilgi alanına giren faaliyetleri içerdiği gösterilmiştir.

TRL ölçeğinin ortasında yer alan teknoloji geliştirme faaliyetlerinin başarısızla sonuçlanmasının sebepleri olarak aşağıdaki sebepler gösterilmiştir;

- Akademi ve endüstri arasında yetersiz işbirliği ve koordinasyon olması
- Endüstrinin yeterli derecede teknoloji içselleştirme kapasitesinin olmaması,
- Söz konusu teknolojinin son teknoloji niteliklerinin olmaması
- Gerekli destekleyici yan teknolojilerin henüz gelişmemiş olması

TRL metodu uzay, savunma şirketlerinde kullanılıyor olmasına rağmen literatürde yetersizlikleri belirtilmiştir. Bu konu ile ilgili olarak (Mankins 2002), (Olechowski, Eppinger, and Joglekar 2015), (Tomaschek, K. 2016), (Zhao, D. 2015) ve (NASA System Engineering Handbook, 2017) literatürden örnekler olarak belirtilmiştir.

Bu çalışmada metodoloji olarak, konusunda uzman araştırmacı ve denetmenlerden alınan veriler, modele uygun olarak analitik hiyerarşi yöntemi ile analiz edilmiş ve kriterler ağırlıklandırılmıştır. Teknoloji geliştirme faaliyetlerinin parametreleri öncelik sırasına konulmuş ve paydaşlar perspektifinden de değerlendirilebilir hale getirilmiştir. Bu kapsamda uzman değerlendirmeleri Ar-Ge faaliyetleri için sıklıkla kullanılan bir yöntemdir. Fakat AHP analiz metodu bu yönde bir çalışmada ilk defa kullanılmıştır. Literatürde benzer bir AHP çalışmasına rastlanmamıştır. Bununla birlikte TOPSIS metodu vaka analizi çalışmasında normatif bir değerlerlendirme yöntemi olarak kullanılmıştır. Literatür çalışmasının bu kısmında uzman değerlendirmesi ve AHP metodolojisinin kullanımına yönelik örnekler verilmiştir.

Gelişmiş ülkelerde Ar-Ge değerlendirme faaliyetleri son on yıllarda sıklıkla yapılmaktadır. Kullanılan farklı modellemeler ve göstergeler literatür ışığında incelenmiştir. Bu açıdan oluşturulan model ilgili olduğu kapsamı ve içerdiği göstergeler bakımından literatürde yenidir ve özgünlük katmaktadır.

Teorik Çerçeve

Teorik çerçeve içerisinde öncelikle teknoloji politikalarının önemi ve gelişimi belirtilmiştir. Bu kapsamda (OECD 2014, 2016) ve (Department for Business, Innovation and Skills. 2016) kurumsal raporları başta olmak üzere literatür bilgileri ışığında politika belirlemenin önemi açıklanmıştır. Politika oluşumunda iki temel yaklaşımdan "görev odaklı" ve "dağılım odaklı" olma üzere bahsedilmiştir. Uygulamalarına yönelik örnekler verilmiştir.

Bunula birlikte teknoloji geliştirme konseptinin ortaya çıkışı, bu faaliyetlerin bütün Ar-Ge faaliyetleri içerisindeki yeri ve önemi belirtilmiştir. Bu sebeple teknoloji yönetimi kavramı ve bileşenlerine değinilmiştir. Teknoloji yönetiminin önemli bir bileşeni olan teknoloji etki analizi kavramının son on yıllarda kazandığı önem ve buna bağlı olarak hemen her ülkenin bu kapsamda geliştirdiği faaliyetler belirtilmiştir. Teknoloji kavramının önemi kadar, teknoloji geliştirme faaliyetlerinin izlenmesi, çıktı ve sonuçlarının analiz edilerek değerlendirilmesinin önemi ortaya konulmuştur.

Araştırma etki analizi planının altı önemli aşaması şu şekilde belirtilmiştir (Novo Nordisk,2017):

- Araştırmanın etkisi nedir (bağlamın anlaşılması)
- Değerlendirme amacının tanımlanması
- Başarı göstergelerinin tanımlanması, ölçülmesi

- Tasarım, metot ve veri toplama yönteminin geliştirilmesi
- İletişim ve sonuçların kullanılması
- Değerlendirmenin yönetilmesi

Teknoloji geliştirme kavramı birçok Ar-Ge faaliyeti içerisinde çeşitli şekilllerde yönetilmektedir. Her kurum kendi kültürü ve işleyişi bağlamında farklı isimlendirmeler yapsa da temelde süreçler birbirine benzer görünmektedir. Aşağıdaki tabloda farklı kurumsal ve süreç ile ilgili olarak teknoloji geliştirme alanının ortaklığı görülebilmektedir.

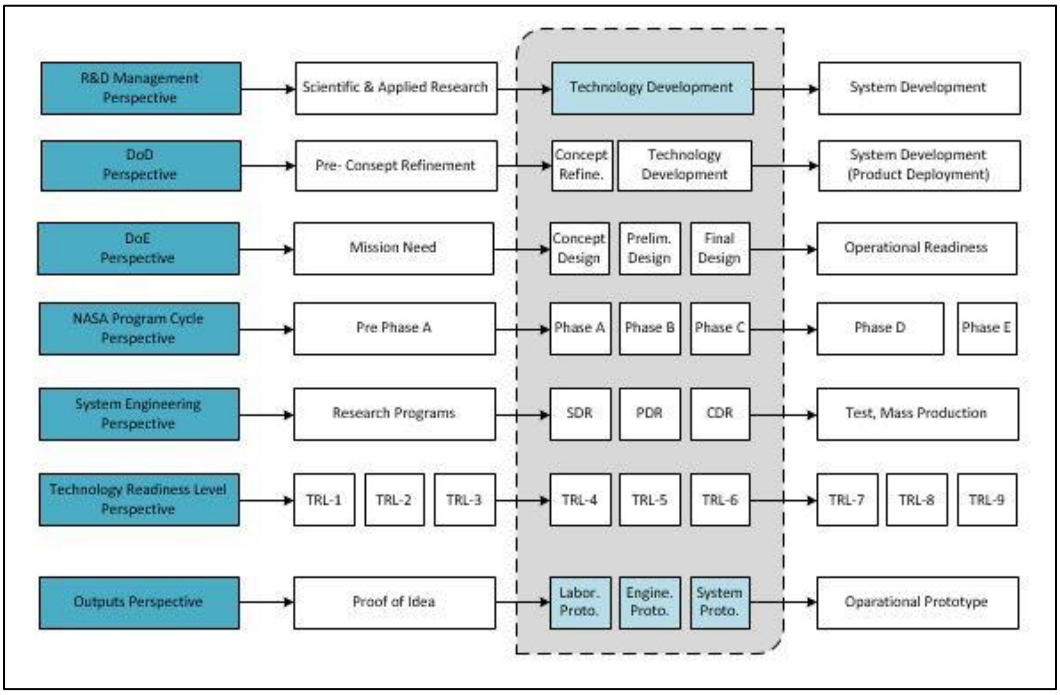

Figure 1. Farklı Perspekktiflerde Ar-Ge Faaliyetleri Aşamaları

Teknoloji Olgunluğu Konsepti

Teknoloji olgunluk kavramı politika geliştiriciler tarafından değil de program uygulayıcıları tarafından geliştirilmiştir. Fakat bu bağlam politika geliştiriciler tarafından kabul edilerek olgunluk ölçümü yasal zorunluluk olarak belirlenmiştir. Teknoloji olgunluk ölçümü için gereksinimlerin gerekçesi aşağıdaki şekilde özetleyebiliriz:

- Alan deneyimi
- Politika belirleme
- Program yönetimi
- Risk Yönetimi

TRL ölçüm yönteminin temel özellikleri aşağıdaki gibi sıralanabilir:

- TRL seviyeleri 9 aşamaya bölünmüştür;

1-2-3 seviyeleri temel bilimsel araştırmaları temsil eder
4-5-6 seviyeleri teknoloji geliştirme aşamalarını temsil eder
7-8-9 seviyeleri sistem geliştirme ve operasyonel aşamaları temsil eder.

- Her aşama, Evet/Hayır sorularının cevaplarına göre tamamlanmış görünür.
- Her aşama için sorular önceden belirlenmiştir ve sabittir.
- Değerlendirme çoğunlukla çıktı odaklıdır.
- Bu yöntem NASA bakış açısına göre hazırlanmıştır, DoD veya DoE değil.

Bu çalışmada TRL 4-5-6 seviyeleri teknoloji geliştirme alanı olduğu için bu seviyelerin çıktıları özel olarak detaylı tanımlanmıştır ve bu çıktıların olgunluğu hesaplanacaktır.

Laboratuar Prototipi (TRL-4 Çıktısı): Bu prototipin ana fikri fonksiyonların gösterilmesi, partnerlerle iletişim, program yönetimini ilerleme konusunda inandırmaktır.

Mühendislik Prototipi (TRL-5 Çıktısı): Bu prototipin ana fikri partnerlere son ürün hakkında son maliyet, malzemeler, seri üretim detayları, güvenlik ve lojistik hakkında bilgi vermektir.

Sistem Prototipi (TRL-6 Çıktısı): Bu prototipin ana fikri final ürünün bir benzerini üretmek ve böylece tasarım kusurlarının operaasyonel testler öncesi düzeltilmesidir. Üretim, görünüm, entegrasyon, paketleme gibi final ürünün tüm özelliklerini gösterir. Küçük düzenlemelerle üretim için hazır olduğu sözlenebilir.

Aşağıda belirtilen dört adet belirsizlik ve zayıflık önerilen metod ile giderilmektedir.

- Teknoloji geliştirme göstergelerinin önceliklendirilmemesi
- Teknoloji geliştirme planlarının bulunmaması
- Değerlendirmenin öznelliği
- Ölçeklerin keskin olmaması

Bu çalışmadaki yeni bir metodun önerilmesi tamamlayıcı niteliktedir. Sadece nicel bir metod kullanılması yerine, bu metodun TRL metodu ile birleştirildiğinde kazanılan teknoloji seviyesinin anlaşılması daha kolay olacaktır.

Metodoloji

Genel anlamda Ar-Ge faaliyetlerinin performansları ve sonuçlarının incelendiği metodlar iki kategoride incelenebilir. Yöntem olarak nicel, nitel ve karma yöntemler kullanılmaktadır. Ar-Ge çalışmalarının içeriğine yönelik olarak literatürde kullanılan yöntemler incelenerek alternatifler değerlendirilmiştir. Nicel ve nitel yöntemlerin zayıflıkları göz önüne alınarak her iki yöntemin birbirini destekleyeceği şekilde kullanılması değerlendirilmiştir ve karma araştırma yöntemi uygulanmıştır. Bu çalışma araştırma deseni bakımından zenginleştirilmiştir ve karma (triangulation) bir desene sahiptir. Geliştirilen model nitel araştırma desenlerinin uygulaması olarak örnek olay uygulaması yapılmıştır. Nitel ve nicel verilerin analiz edilmesi, kullanım uygulama kolaylığı ve anlaşılabilirlik yönünden AHP yönteminin en uygun olduğu değerlendirilmiş ve uygulanmıştır. Kapsamına ve veri türüne göre araştırma geliştirme faaliyetlerinin değerlendirilmesinde aşağıdaki metodlar literatürde kullanılmaktadır:

- Analitik Hiyerarşi Süreci (AHP)
- Analytical Ağ Süreci (ANP)
- Bulanık Analitik Hiyerarşi Süreci (Fuzzy AHP)
- Veri Zarflama Analizi (DEA)
- Katkı Analizi (CA)
- İdeal Çözüme Benzerlik Açısından Sıralama Tekniği (TOPSIS)

- Ekonomik Analiz (EA)
- Çapraz Etki Analizi (CIA)
- Zorlık Derecesinin Yükseltilmesi (ADD)
- Fayda Maliyet Analizi (CBA)
- Dengeli Dağılım Kartı Analizi (BSC)
- Karar Ağacı Analizi (DTA)
- Kök Sebep Analizi/ValuStream™
- Bibliyometrik Analiz Metodları

AHP metodu T.L.Saaty tarafından önerilmiş ve geliştirilmiş çoklu karar verme yöntemleri arasında yer alan güçlü bir değerlendirme metodudur. Bu yöntem karar verme süreçlerine etki eden her bir parametrenin uzmanlar tarafından belirli bir ölçek üzerinden karşılıklı kıyaslanması ile gerçekleştirilir. Veriler elde edildikten sonra standart karar matrisi oluşturulur, tutarlılık analizi gerçekleştirilir ve her kriterin alternatifler üzerindeki etkisi hesaplanarak en iyi alternatif seçimi için kullanılır.

Bu çalışmada AHP yöntemi elde eidlen modeldeki göstergelerin önceliklendirilmesi için kullanılmıştır. Hedef teknoloji seviyeleri olan TRL 4-5-6 seviyelerinin (alternatiflerin) olgunluk seviyelerinin ölçümü için TOPSIS yöntemi kullanılmıştır. Böylece alternatifler normatif ve birbirinden bağımsız bir şekilde değerlendirilebilmiştir ve en ideal duruma yakınlıkları ölçülebilmiştir.

AHP metodu çoklu karar verme tekniklerinden en çok kullanılanlardan biridir. T.L. Saaty tarafından geliştirilmiştir. Bu yöntem kriterlerin ve alt kriterlerin önceliklendirilmesi ile farklı alternatiflerin seçimi konusunda kullanılabilmektedir. (Hueter, 2010). AHP Ar-Ge proje değerlendirmelerinde uygulanmaktadır ve Ar-Ge faaliyetlerinin değerlendirilmesinde kullanılan en iyi ikinci metod olarak değerlendirilmiştir (Poh, K.L. 2001).

AHP mühendislik, üretim, eğitim, personel seçimi, kamu yönetimi, endüstri, sosyal alanlar, yönetim alanlarında kullanılmaktadır. (Vaidya, O., 2006). AHP yöntemi yarışan alternatiflerin seçimi için kullanılmakla birlikte, çoğunlukla ağırlıklandırma ve derecelendirme amacıyla kullanılmaktadır (Russo, R. 2015).

Model Geliştirme

Geliştirilen teknoloji geliştirme modeli, teknolojiyi geliştiren temel paydaşlar ve faaliyetleri bakımından bu faaliyetleri tanımlayıcı bir faaliyet olarak gösterilebilir. Önerilen model üç alt modülden oluşmaktadır. Bunlar sırasıyla teknoloji değerlendirme modülü, ekonomik çıktı değerlendirme modülü ve ekonomik sonuç değerlendirme modülüdür. Teknoloji değerlendirme modülü detaylı bir kasam çalışması sonucu 9 gösterge ile modellenmiştir ve AHP değerlendirmesine uygun olarak düzenlenmiştir. Ekonomik çıktı değerlendirilmesi (geri kazanım) 8 ekonomik çıktı göstergesi ile ölçülmüştür. Programın ekonomik çıktılarının "gerçekleşen" ekonomik geri kazanım değerleri ve "beklenen" ekonomik geri kazanım değerleri hesaplanmıştır.

Vaka Analizi

Önerilen modelin kullanılabilirliğini kanıtlamak için deneysel bir vaka çalışması yapılmıştır. Uzman incelemeleri, Türkiye'nin en itibarlı enstitülerinden, üniversitelerinden, araştırma merkezlerinden ve fon kurumlarında çalışan 35 nitelikli araştırmacı, proje yöneticileri, akademik personel ve program uzmanları tarafından yapılmıştır. Tüm uzmanlar farklı teknoloji geliştirme programlarında 5 yıldan 25+ yıla kadar iş tecrübesine sahiptir. Programların ekonomik çıktı etkisini ölçmek için de proje yöneticileri ile uzman değerlendirmeleri yapılmıştır. Üçüncü modül olan ekonomik sonuçlar modülü, incelenen vakada gereken zaman gecikmesi yeterince uzun olmadığından vaka çalışmasına dâhil edilmemiştir. Birinci modül için analitik hiyerarşi süreci (AHP) ve TOPSIS yöntemleri, 9 teknolojik göstergeye göre nitel teknoloji olgunluk düzeyini analiz etmek için kullanılmıştır. Kullanılan verilerin tutarlılığından emin olmak için tutarlılık analizi de yapılmıştır ve tutarlılık kriterinin çok üstünde başarılmıştır.

Söz konusu vaka analizi sonuçlarının iki tür hata içermesi söz konusudur (Gürbüz, S. 2016);

- Ekolojik yanılgı hatası: Bir araştırmada örgütsel düzeyde bilgi toplayıp, elde edilen verilerden bireysel seviyede çıkarımlar ve genellemeler yapılmasıdır.
- İndirgemecilik hatası: Küçük ve dar bir gruptan elde edilen verilerin daha büyük ve geniş bir grubu açıklamak için kullanılması.

Bu çalışmada kamu desteği alan, kamu ajansı tarafından yönetilen ve teknoloji geliştirme faaliyetinde bulunulan bir vaka incelenmiş ve ilgili ekosistemdeki paydaşlarla mülakatlar yapılmıştır.

Ekolojik yanılgı hatası olmaması için ilgili geliştirme faaliyetinde yer alan 3 kamu kuruluşu, 5 kamu enstitüsü, 1 özel ünversite araştırma merkezinde çalışan uzmanlar ve 4 kamu üniversitesinde çalışan akademik personel vaka analizinde katılımcı olarak seçilmişlerdir (Appendix-A). Bu grup tüm paydaşları kapsamaktadır.

İndirgemecilik hatası olmaması veya en aza indirilmesi için veriler analiz edildiğinde, sonuçların ve önceliklerin birbiri ile uyumlu olduğu görülmektedir. Mesela bütün alt grupların birinci önceliği nitelikli araştırmacı yetiştirilmesi kriteri olmuştur. Sadece proje yöneticisi alt grubunda bu kriter dördüncü önceliklidir.

Bununla birlikte uygulanan AHP metodu verilerin tutarlılığı için tutarlılık analizi (consistency analysis) yepılmasını gerektirmektedir. Elde edilen verilerin hepsi bu kriteri çok büyük güven aralığında sağlamıştır.

Bu vaka analizinde örnekleme seçimi olarak ‘amaçlı örnekleme’ yöntemi seçilmiştir. Bu vaka çalışmasına katkıda bulunabileceği düşünülen, aktif olarak çalıştığı bilinen ve ulaşılabilecek personel ile uzman değerlendirmeleri gerçekleştirilmiştir.

Sonuçlar

- **Teknoloji Politikaları Tartışmaları**

1. Politik alanda, yatırımlar kalifiye araştırmacı yetiştirmek üzere geliştirilmelidir. AHP analizi sonuçlarına göre nitelikli araştırmacı göstergesi önem sırasında %27 ile birinci seviyede çıkmıştır. Fakat örnek vaka analizinde gerçekleşen projede bu kriter, ideal çözüme yönelik %3.48 oranında yetersizliğe sahip çıkmıştır. En öncelikli göstergede en büyük yetersizlik oranı görülmektedir. Bu sonuçlar OECD 2016 raporunda belirtilen nitelikli araştırmacılara önem verilmesi gerektiği tespiti ile uyumlu çıkmıştır. OECD raporuna ek olarak;

- Araştırmacının alan tecrübesi bilgi üretiminde kritik bir değerdir ve desteklenmelidir.
- Nitelikli araştırmacılar teknolojinin yönlendirici gücüdür.
- Teknoloji geliştirme faaliyetleri entelektüel ve öğrenme faaliyeti olarak değerlendirilmelidir. Endüstriye destek ise ikincil derecede önceliklendirilmelidir. Bunun yanında endüstri projeleri üründen ziyade teknoloji alanlarına odaklanmalıdır.

2. Teknoloji geliştirme faaliyetleri entelektüel sermaye ve nitelikli insan katılımı gerektirir. Odaklanılması beklenen politik alan olarak, nitelikli kaliteli ve yetenekli araştırmacı yoğunluğunu artırılmalıdır.
3. COSEPUB raporu nitelikli araştırmacıların proje değerlendirilmesinde önemli bir gösterge olarak ele alınması gerektiğini belirtmiştir. Bu tespit nitel bir vaka analizi sonucunda %27 oranında öncelikle doğrulanmıştır ve önemi belirtilmiştir. Bu kriter teknolojinin yeterlilik ve olgunluk değerlendirmesinde en önemli kriterdir.
4. Şekil 25 de görüldüğü üzere proje yöneticileri %25 oranında milli tasarım yeteneğini ilk öncelik olarak görmüşlerdir. Bu önceliklendirme sadece proje yöneticilerinin önceliğindedir. Bu durum proje yöneticilerinin bütçe, zaman, maliyet alanında sorumlu olmalarından dolayı sistem mühendisliği perspektifinden bakıldığında, milli tasarım faaliyetlerinin öncelikli

değerlendirilmesi anlaşılır görünmektedir. Ayrıca toplam 35 uzman değerlendirmesinde ise milli tasarım yeterliliği göstergesi %15 değer ile ikinci önem derecesinde görünmektedir.

5. Teknoloji aktive edilmesi (hizmete alınması) %11 değeri ile üçüncü önceliklendirilen gösterge olmuştur. Bu husus çıktıların hizmete alınmasının önemini göstermiştir.
6. Teknoloji geliştirme faaliyetlerinin etki analizi bağlamında ve temel göstergeler açısından bakıldığında “Teknoloji Politikaları” nın en önemli gösterge olarak belirlenmiştir. Bu husus özellikle politika belirleyicilerin önemini ortaya koymuştur. Belirsiz ve karmaşık politik hedefler bulunması veya bu hedeflerin hiç bulunmaması durumunda, her türlü teknoloji çalışmasının başarısızlıkla sonuçlanacağı sonucu çıkartılmıştır. Paydaşlar açısından önem sırası program yönetimi ve sistem geliştirme olarak devam etmiştir.
7. Hedef odaklı teknoloji politikalarının en önemli özelliklerinden biri çıktıların müşterisinin hazır bulunmasıdır. Dolayısıyla müşteri kurum olarak projeleri destekleyen kurumların sonuçları aktive ederek envantere alması önemli bir sorumluluktur. Bu çalışmadaki vaka çalışmasında teknoloji aktivastonunun üçüncü sırada ve %11 olarak çıkmış olması bu çalışmanın hedef odaklı olmasının doğrulaması olarak görülmektedir. Uygulamaya alma sürecinin kolaylaştırılması açısından spin-off şirket kurulumunun kolaylaştırılması bir yöntem olarak önerilmiştir.
8. Yeni bilgi ve teknoloji üretiminde temel yeterlilikler yeni teknolojilerin özümsenmesinde önemli olarak görülmekle birlikte, bu hususta yüksek seviyede yeterliliklere ihtiyaç duyulmaktadır. (OECD 2016). Bu çalışmadaki AHP öncelik sıralamasına bakıldığında, nitelikli araştırmacıların bulunması, tasarım yeterliliği, program yönetimi gibi göstergeler yüksek seviyede yeterlilik olması bakımından yeni bilgi ve teknolojilerin özümsenmesinde önemli olduğu görülmüştür.

- **Araştırma Sorularına Cevaplar**

Bu çalışmadaki üç adet araştırma sorularına cevaplar elde edilmiştir. İlk ikisi sürdürülebilirlik ve diğeri hesap verilebilirlik amacındaki sorulardır:

Soru-1:

Paydaşların sorumlulukları niteliksel bir yaklaşımla göz önüne alınarak, kazanılan teknoloji olgunluğu hangi seviyededir?

Cevap-1:

TRL 4-5-6 prototiplerinin (çıktılarının) teknoloji olgunluk seviyeleri aşağıdaki gibi hesaplanmıştır:

Tabo 1 : Hesaplanan Teknoloji Olgunluk Değerleri

TRL Seviyesi	**Çıktı Adı**	**Hesaplanan Olgunluk Değeri**
TRL-4	Laboratuar Prototipi (proof of concept)	%77
TRL-5	Mühendislik Prototipi (form study)	%79
TRL-6	Sistem Prototipi (functional)	%78

Soru-2: Teknoloji çıktı ve sonuçları en çok etkileyen faktörler nelerdir?

Cevap 2a:

Göstergelerin ağırlıklandırma değerleri açıkça göstermektedir ki aye, insan kaynakları ve tasarım kabiliyeti gibi entelektüel sermaye gerektiren değerler (1a, 2a, 3a göstergeleri) toplamın %46 önem derecesine sahip görünmektedir. Bu durum teknoloji geliştirme faaliyetinin etkisinin eğitim ve entelektüel sermaya kapasitesinin artırılması ile doğrudan bağlantılı olduğu değerlendirilmiştir.

Tablo 2 : Önceliklendirilmiş Göstergeler

Rank	**Indicators**	**Weighting Factors**
1	Nitelikli Araştırmacı	27%
2	Milli Tasarım Yeterliliği	15%
3	Teknoloji Aktivasyonu	11%
4	Program Yönetimi	10%
5	Altyapı Kurulumu	8%
6	Prototip Doğrulama	8%
7	Ekipman Yeterliliği	7%
8	Teknoloji Tanımlama	7%
9	Yerli Üretim Yeterliliği	7%
	Toplam	**100%**

Cevap 2b:

AHP standart karar matrislerinin hepsi tutarlılık oranlarını sağlamıştır. CR değerlerinin hepsi metodun tanımında belirlenmiş olan 0.1 değerinin altında hesaplanmıştır.

Tablo 3 : Tutarlılık Oranı Değerleri

	CR Değeri	Tutarlılık Kriteri
Ana Kriter Matrisi	0,0058	< 0,1
Alt Kriter-1 Matrisi	0,0002	< 0,1
Alt Kriter-2 Matrisi	0,0000	< 0,1
Alt Kriter-3 Matrisi	0,0197	< 0,1

Cevap 2c:

En ideal duruma ulaşmak açısından yetersiz olunan kriterler vaka analizi sonuçlarına göre hesaplandığında, nitelikli araştırmacı, mili tasarım ve proje yönetimi göstergeleri çıkmıştır.

En ideal olgunluk seviyesine ulaşmada hangi göstergelerin yetersiz kaldığı TRL-6' referans alınarak Tablo 50'de aşağıdaki gibi hesaplanmıştır. TRL-6 da yetersiz kalınan oran %12 'dir. Buradan, nitelikli araştırmacı göstergesinin TRL-6 olgunluk seviyesine katabileceği %6,9 kadar etki olduğu anlaşılmaktadır.

Tablo 4 : Başarısız Göstergeler

Sıra	**Göstergeler**	**Ağırlıklandırılmış yetersizlikler 12% 'ye göre**	**Yetersizliklerin kendi içinde oranı**
1	Nitelikli Araştırmacı	6,9%	49%
2	Milli Tasarım Yeterliliği	2,1%	15%
3	Proje Yönetimi	1,2%	9%

Cevap 2d:

Etki analizi göstergelerine göre, paydaş sorumlulukları da ortaya çıkarılabilmektedir. Güçlü, zayıf ve riskli alanlar belirlenebilmektedir. Yetersiz bulunan göstergeler ilgili paydaş sorumluluklarına göre paylaştırıldığında aşağıdaki

Tablo 51 ‘deki bigi paydaş perspektifinden zayıf alanlar hesaplanabilir. Bu etki analizinde en yetersiz paydaş %50 oranla teknoloji politikasını oluşturan paydaş görünmektedir.

Tablo 5: Paydaş Performans Değerlendirmesi

	Paydaşlar	**Yüzde**
1	Destekleyici (Sponsor)Kuruluş (Technology Policy)	60%
2	Program Geliştirici Kuruluş (Program Management)	18%
3	Project Yönetici Kuruluş (System Development)	22%
	Toplam	**100%**

Soru-3: Teknoloji geliştirme programlarının ekonomik çıktı/sonuçları nelerdir?

Cevap 3a:

Ekonomik etki analizinde proje yöneticileri ile yapılan görüşmeler ile elde edilen ekonomik kazanımlar Tablo 30 ve Tablo 31 de özetlenmiştir. Ayrıca yakın zamanda beklenen ekonomik kazanımlar da ölçülmüştür. Kur hesaplamaları Avrupa Merkez Bankası (ECB) sitesi üzerinden yapılmıştır.

Ekonomik veriler proje süresi boyunca oluşan ortalama kurlara göre dolar ve Euro değerlerine çevrilmiştir. Elde edilen ekonomik kazanımlar aşağıdaki gibi özetlenmiştir.

Tablo 6: Ekonomik Kazanım Değerleri

	Proje Maliyetine Oranla Gerçekleşen Kazanımlar (Mevcut Siparişler, Satışlar)	Proje Maliyetine Oranla Beklenen Kazanımlar (Potansiyel Siparişler, Satışlar)
Proje- 1	177 %	30 %
Proje- 2	11 %	50 %

Ayrıca proje izleyicilerinin danışmanlık ve yeni projeler üretmesi açısından da projelerin ekonomik kazanımları değerlendirilmiştir.

Sonuç olarak, Proje-1 çıktılarının fonksiyonel olması ve bir ürüne dönüşme potansiyeli görülmesi sebebiyle hem proje yatırımı hem de ekonomik yatırımlar aldığını göstermektedir. Proje-2 ise çıktılarının fonksiyonelliğinin ileri zamanlara yönelik umut vadettiği görülmektedir.

Cevap 3b: Ağ Oluşumu Etki Ölçümü

Proje süresince ilgili kurum ve kuruluşlar birçok işbirliği ve ortak iş geliştirmeleri gerçekleştirmişlerdir. Bu husus hem bilgi ve tecrübe kazanımı hem de ortak işbirliği ve alt teknoloji transferi gerçekleştirebilmek adına önemli bir kazanım olarak değerlendirilmiştir. Özellikle Proje-1 kapsamında ulusal ve uluslararası firmalar ile mali içerikli ve teknik içerikli işbirliklerinin ölçülmesi ve görselleştirilmesi önemli görülmüştür. Araştırma öncesinde öngörülmemesine rağmen yöneticiler ile görüşmeler sonucunda bu yönde kayda değer sonuçlar görüşmüş ve Şekil-26 ile görselleştirilmiştir. Proje yürütücüsü kuruluşun başarılı çalışmaları sonucu desteleyici Bakanlık kuruluşunun da ilgili olan teknoloji temelli yeni projeler ve işbirliği girişimleri ve destekleri vermeye başladığı görülmektedir. Söz konusu ağ şemasının daha sonraki çalışmalarda detaylı göstergeler ile daha ölçülebilir hale getirilebilmesi mümkündür.

Destekleyici Bakanlık kuruluşunun yeni ağlar oluşturması, projeler planlaması, endüstri firmaları ile işbirliklerine gitmesi teknoloji geliştirme faaliyetlerinin açık bir başarı göstergesi olarak görülmelidir.

Uygulama Önerileri

Desteklenmekte olan akademik projelerin çıktıları genel olarak (TRL-3 veya TRL-4) seviyesinde sonuçlanmaktadır. Bu çıktıların teknoloji geliştirme seviyelerine (TRL-5 veya TRL-6) alınmış olması önceliklidir fakat bu yönde teşvik edici, motive edici veya zorlayıcı bir program bulunmamaktadır. Bu durum akademik veya destek mekanizmalarının uygun kurgulanmamasından kaynaklanabilmektedir. Bu sebeple, akademik ve bilimsel çalışmaların süreklilik gösterecek şekilde ve teknolojik olgunluk seviyeleri hesaplanıp planlanarak TRL 5-6 seviyelerine yükseltilmesi kritik öneme sahiptir. Böylece projelerin uygulama ve ekonomik fayda imkânı bulması kolaylaşacaktır.

TÜBİTAK birçok akademik ve sanayi projelerini destekleyici programları başarı ile yürütmektedir. Burada kritik olan husus, her bir program çıktısının teknoloji olgunluk seviyeleri ölçeğinde birbirini tamalamasıdır fakat bu programların doğrudan birbirleri ile ilişkilendirilmsi ve çıktıların diğer programlar tarafından kullanılabilir olması gerekmekedir. Akademik proje çıktıları, teknoloji geliştirme aşamasında kullanılabilmeli, teknoloji geliştirme aşamasının çıktıları ise ürün ve sistem geliştirme projelerinde kullanılabilmelidir. Böylece izlenebilir, hesap verilebilir ve sürekli fonlama sağlayan başarı hikâyelerine sahip projeler oluşabilecektir.

Bu kapsamda yeni bir teknoloji geliştirme programı uygulamaya alınarak 1001 Program çıktılarının (TRL-3 veya TRL-4) teknoloji geliştirme projeleri çıktılarına (TRL-6 veya TRL-7) dönüştürülmesi mümkün olabileceği değerlendirilmektedir.

Vaka Analizi kapsamında görüşleri alınan akademisyen, yönetici, araştırmacılardan AHP metodu kapsamında görüşleri alınmıştır. Bu değerlendirmelere ek olarak geliştirilen modelin göstergeleri ile ilgili olarak yarı yaplandırılmış mülakatlar yapılmıştır. Konusundaki uzmanların ilgili göstergeler ile ilgili görüşleri ayrıca tez içerisinde özetlenmiştir. Bu görüşler teknoloji geliştirme ekosistemindeki uzmanların hem kendi meslektaşlarına hem de politika geliştiricilerine faydalı olabilecek görüşler içerdiği değerlendirilmektedir.

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