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A Product-Based Strategic Technology Management Methodology for Developing Countries

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As the degree of globalization increases, developing country's race with countries practicing knowledge society norms requires creative techniques. Countries with limited technological capabilities tend to confront with middle-income trap that makes them create strategies profiting from technological innovation. The well-known method is to perform a technology foresight study and establish the technologies that the country must develop to improve its wellbeing. This paper proposes a differed approach in which a high technology product is serving as the prime motivation behind the nations planning of technology progress. The outcome of the methodology is the selection, prioritization and planning of necessary technologies of the product using all technological capabilities of the nation. Results of the exercise are instrumental in establishing the technology base of the country and enhance its promise of improving technological capability to a higher level. The paper explains the developed methodology and discusses its outputs.

Keywords: Technology management; technological maturity; technology development; technology taxonomy; product development; conceptual design; technology readiness level.

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1. Introduction

In the present state of the globalized world, it became crucial for developing countries to reassess their economic status and develop new policies that would enhance their wellbeing. It is well established that science and technology are important factors in the economic transformation of developing countries and economies in transition [Juma *et al.* (2001)]. This paper is intended to describe a new approach for developing countries in their efforts to reinforce their economic transformation and become an innovative society.

An essential element of strategic action and policy-making is to recognize the possibility of alternative futures and to implement policies that make the best alternative possible. Reick and Dickson [1993] emphasized the importance of technology strategy and proposed a model that links six technologically-related tasks that would lead to a strategy. The policy-making is based on active participation of all the stakeholders and their systematic efforts in gathering information. It is, therefore, no coincidence that technology foresight (TF) activities became widespread in the last quarter of the 20th century [Porter (2010)]. Another factor behind the growing interest in TF is the need to set priorities in R&D. R&D efforts are to be directed towards fulfilling social needs as well as providing sources for innovations that contribute to sustainable growth, competitiveness and job creation. TF is a tool that can be used to match future needs of societies with the support of science and technology [Miles (2002)].

The success of technology foresight studies and strategic technology management efforts of nations partly depends on their national cultures. Halkosa and Tzeremesa [2013] indicated that higher power distance index, individualism and uncertainty avoidance values of Hofstede [1980] have adverse effects on countries' innovation efficiency. It is also well known that the organization of a society — especially the institutional, political and legal systems — are essential ingredients of success. In the absence of appropriate legal systems, clear and enforceable property rights, competitive markets and mechanisms for good governance, the benefits of a market economy cannot be fully realized [Teece (2009)]. Teece [1986] has also pointed out that profiting from innovation requires several conditions. A tight appropriability regime is necessary to allow the innovator to profit from an innovation. Competitive advantage depends on the stage of the dominant design, and complimentary assets are necessary for successful commercialization.

Exploration of appropriate methods for determining policies to transform into an innovative society needs a survey of contemporary innovation literature. According to Betz [2011], in transferring knowledge to utility, three types of innovation scales are practiced. Radical innovation is a basic technological innovation that establishes a new functionality. Incremental innovation is a change in an existing technology system that does not alter the functionality but incrementally improves performance or lowers cost. Next generation technology innovation is a change in an existing technology system that does not alter the functionality but dramatically improves performance, safety, or quality, and lowers the cost.

Betz [2011] also refers to two levels of innovation: macro-level innovation of national science and technology policies and micro-level innovation of products/

services in businesses. Macro-level national innovation systems consist of universities, industry research laboratories and government laboratories supporting radical innovation efforts. Micro-level innovation includes high-tech businesses that produce new products/services that use newly invented technologies. At macro-level innovations, governments have become the major sponsor of scientific research and a major sponsor of technological development in selected areas, such as military and aerospace technologies, which this paper addresses. Managing the entire national innovation system falls under the topic of science and technology policy of a national government. An internationally competitive national innovation system should have several aspects, such as industrial sectors should have strong research capabilities and university sector should be high-quality research-oriented. Moreover, industrial or service sector should be strong and internationally competitive. Also, nations' culture should value high-quality performance. Government policies should strongly fund appropriate R&D activities in universities on selected mission areas using peer-review to evaluate the quality of research. Moreover, science and technology policy must balance research for technology improvement in current industries and substantiate research to establish new internationally competitive industries in new technologies [Betz (2011)].

Innovation literature frequently refers to the generation and the adoption (imitation) of innovations as important categories [Damanpour and Wischnevsky (2006)]. The generation of innovation refers to situations where a firm is the first mover and generates a product, process or technology that was previously unknown. On the other hand, if a firm adopts (imitates) innovation, it assimilates knowledge and technologies that have been developed elsewhere and that are new to the organization [Pérez Luño *et al.* (2014); Teece (1986)]. Although the pace of change in technologies dictates the dynamism of the industrial environment, companies perceive their environments as dynamic when they compete in sectors with short product life cycles. That is, when competition fosters frequent launching of new technologies and products in small intervals.

Stable environments persist in the case of defence and aerospace sectors, which this research is based on. This is because of the long life cycles of defense and aerospace products and the influence of public sector in their development. Earlier research suggests that in stable environments, innovation adoption (imitation) has a higher probability of profitable performance than innovation generation. Such environments are characterized by longer product life cycles where customers demand similar products with minor modifications [Pérez Luño *et al.* (2014)]. Adoption of incremental innovations would also be a more efficient solution in stable environments.

Innovative activities are expected to produce sustainable performance. Dynamic capabilities enable enterprises to create, deploy and protect the intangible assets that support superior long-run business performance [Teece (2009)]. The class of assets that is especially difficult to trade involves knowledge assets. Intangible assets are not easy to replicate. Replication involves transferring or redeploying competencies from one economic setting to another. Cetindamar *et al.* [2009] made an attempt to understand the technology management using dynamic capabilities approach. Since productive knowledge is typically tacit, replication cannot be achieved by simply transmitting information. Archibugi and Pietrobelli [2003] discuss the techniques that are used in transferring knowledge. They conclude that the transfer depends on the technology and the policies in the developing and transferring countries. Kharbanda [2001] stresses the importance of indigenous technology capabilities in strategic technology management and its probable positive effect on leap-frogging.

Adoption of organizational procedures is even more difficult than product adoption. Teece [2009] suggests that economic prosperity depends on good governance, well-organized and managed business enterprises and the ownership and control of difficult-to-imitate intangible assets, including intellectual property. When the basic foundations of good governance are in place, countries will prosper, and the level of their prosperity depends on countries' ability to create, utilize and protect tangible assets that are organized by inclusive institutions. A sustainable, innovative society can only be established if the innovation culture is supported by inclusive political institutions pertaining technological, political and legal systems.

In developing countries, the possibility of having radical innovations is small, because of their short scientific and technological background and history. For radical innovation, high-quality research-oriented universities and high-quality research institutes are essential. Incremental innovations backed up by imitation — exploitation and exploration — are more suitable for innovative work. Incremental innovations would improve knowledge and could lead to the next generation technology innovations.

Since the 1980s strategic technology management has been a major issue in Turkey. Karagozoglu [1987] explored the strategies pursued by 61 Turkish firms to cope with technological dependence. A technology foresight study of Turkey was performed during the first few years of the 2000s [Saritas *et al.* (2006)]. The methodology used in this study was an adaptation of available methods to nation's culture. The exercise was seeking technologies that would enhance the wellbeing of Turkey between 2003 and 2023. Although this study was successfully completed, and road maps were being developed for nine technological areas, implementations had been restricted only to the funding policies of projects. Defence, aeronautics and space industries — which this paper is concerned — were among the nine technologies.

It may be argued that this major Turkish attempt for becoming a knowledge society by implementing science, technology and innovation policies did not match with Kondratiev's long wave cycles [Schumpeter (1949); Narkus (2012)], and therefore it was destined to failure. Although these cycles are noticeable in developed countries, due to globalization they influence developing countries as well. The fifth cycle began to take shape after the widespread use of IT and communications technologies. The timing of Turkish effort coincides with the improvement phase of the fifth cycle. Therefore, it had the chance to succeed. However, organizations of society, mainly institutional, political and legal systems, were not in place for it to become operational. It may be debated that, GDP increase in the 2000s was due to a successful synchronization with the improvement phase of the fifth cycle. It must also be noted that Turkey's national culture shows high scores in Hofstede's power distance and uncertainty avoidance indices, which does not support innovation efficiency. Technology foresight studies aim to identify a set of technology areas that would enhance the countries socioeconomic standing. An approach that addresses a comprehensive set of fundamental goals needs a strong political will and strong institutional support to become successful.

This paper originates from the investigations performed in the Turkish Aerospace Industries (TAI) Inc., and therefore technologies that support defence and aerospace industries are of concern. The characteristic of defence and aerospace industries is distinctive. Even in the industrialized countries with extensive experiences, aerospace platform development demands 20–25 years. Long development duration is due to the complexity of platforms, strict rules of safety and extreme needs of the customer. Almost always, products are developed upon the request of the customer. Components of aerospace equipment may have to operate under extreme conditions, demanding leading-edge technologies and innovative solutions.

It is widely accepted that technological capabilities are essential foundations for innovative activity. Rush *et al.* [2007, 2014] describes a technology capability audit tool that was designed to assist policymakers to understand the level of innovation readiness of firms. Technological capability assessment studies were carried out by TAI, Inc. in 2007 and 2009. The objectives of these studies were to assess the competence levels of the firm in the selected technologies. An adapted form of UK6 technology taxonomy [EDA (2014)] was used in order to work with coherent definitions of technologies. A simple four-step competence level metric was designed to judge the level of competence in the selected technologies. As a result of this work, competence levels were assessed based on the technology taxonomy and this information was instrumental in the company's road map construction efforts [Ertem *et al.* (2009)].

National- and firm-level attempts on technology foresight and technology assessment efforts inspired the authors of this paper to think about creative ways of selecting and managing technologies that will improve the technological competence of the country. The methodology explained here seeks technologies for a high-tech platform to be built. The high-tech platform used in this study is a fighter aircraft. The target platform calls for a stable environment which is needed for incremental innovation and adoption of innovation. Aiming a high-tech platform may be regarded as too ambitious for countries with less technological competence. However, a high-tech platform as a target, can inspire a large number of public and private institutions. Institutions gathering around the goal can also strengthen the collaborative culture. Being a collectivistic society and with a medium pragmatism score [Hofstede (1980)], Turkish culture suits well in cooperating towards a common goal.

TAI is Turkey's technology center in the design, development, modernization, manufacturing, integration and life cycle support of integrated aerospace systems, from fixed and rotary wing air platforms to UAVs and satellites. R&D projects are conducted on national and international platforms. The primary objective of the TAI fighter aircraft project, which was the source of this paper, was to assess the prospect of building a fighter aircraft by performing a conceptual design exercise. However, a rational decision requires an assessment of technological capabilities of the firm and the country. A fighter aircraft is made up of a large number of components.

Design and building these components need an extensive range of technological expertise. In the study, Turkish Air Force (TurAF) future operational requirements were determined. Requirement analysis and conceptual design of the aircraft and systems were performed. National capacity and capabilities were analyzed and international cooperation models were established. At the end of the study, the schedule and the budget of the development program were estimated and submitted to Undersecretaries for Defence (SSM) and TurAF for further decision-making.

The extent of work explained above covers a wide range of investigations, and therefore, a comprehensive systematic approach was needed. There are three noteworthy characteristics of the present approach. The first characteristic is that substantial time is needed for aircraft development and therefore the process will be conducted in a stable environment. Stable environment enables both technology development and product development. The second characteristic is that since a particular end product (fighter aircraft, in this case) is targeted, it is indeed relatively simple to identify necessary technologies that support the end product. The third characteristic is that since leading edge technologies are involved probable innovative outcomes would be worldwide competitive.

Technologies to be advanced in the country, not only will serve the production of the high-tech platform, but also has the ability to increase the technological capabilities of the nation. It may even be argued that reaching the end product is a secondary concern; the primary concern is the development of necessary technologies that would create other product spin-offs enhancing the industrial and technological base of the nation.

The objectives of the study can be summarized as:

(i) To determine technologies that are necessary for the production of the platform.
(ii) To determine technologies that would make the platform competitive.
(iii) To motivate stakeholders towards a common goal.
(iv) To identify critical technologies and critical systems/subsystems.
(v) To propose management procedures for selected technologies of the platform.
(vi) To prepare technology development plans for the critical technologies.

The remainder of this paper is organized as follows: Sec. 2 describes the differences between the technology base of industrialized and developing countries with reference to the methodology that is outlined in the paper. Section 3 lays out the constituents of a high-tech platform and explains conceptual design process. Sections 4–6 describe how technology priorities, critical technologies and systems are determined. Section 7 outlines the methodology showing relations between the activities. Section 8 entitled "Results" outlines several results obtained as the methodology was implemented. Discussion, conclusions and recommendations are given in Sec. 9.

2. The Technology Base

In countries with less technological capability, customarily technology transfer is regarded as the transfer of production know-how. In most of the cases, manufacturing technologies are transferred. Transferred technology is always the codified part.

However, much of the knowledge about how to perform elementary processes and how to combine them efficiently is tacit. Therefore, transfer of technology should be supported by indigenous technology development. Innovative consequences can be achieved by rediscovering the necessary technologies in the country. This outcome can be produced if the country makes plans to internalize the transferred technologies. Only, in this case, knowledge can be sustained and used for other products.

New product development efforts depend on the technological competence of the country or the company. Several pursued systems might have already been developed and used in countries with high technological competence levels in fundamental/enabling and system-related technologies. Therefore, enough knowledge might have been accumulated which would enable the country to produce new systems. In most of the cases, an emerging technology is transitioned into a system that would increase the end products capability. Procurement occurs only if purchasing is an economic compromise.

Countries with less technological competence having ambition to develop high-tech products confront with limited knowledge and experience on many systems and subsystems. Therefore, in most cases, although the design of the platform might be achieved locally, most of the systems and/or subsystems are purchased and integrated. Challenge is to determine the systems and subsystems that will be produced locally. The methodology described in this paper addresses this selection. As the nation embarks on the production of selected subsystems and systems, the importance of capabilities and the state of technological ability becomes obvious. The development of a product is realized in two phases. The first phase would be the technology development phase. Technology development phase serves to increase competence levels in all the necessary technologies and capabilities, which are essential to produce the product. Technology development phase is in principal an R&D assignment, thus contains high risks. When this phase is completed, the product development phase starts, in which the systems, for which the technologies are developed and demonstrated, will be integrated into the final product.

An important long-term aspect of technology absorption and technology generation is that it reduces the life cycle cost of the product. Although nationally developed systems utilize substantial amount of funds during the technology development phase, the return on investment of knowledge growth is extremely high when life cycle cost of the platform is considered. In order to reduce costs in the long term, it is indeed necessary for the nation to develop knowledge base of the contemporary technologies.

3. Technology and Product

The platform to be produced embraces systems, subsystems, components and technologies. As shown in Fig. 1, foundation contains the fundamental knowledge needed for the platform. Conventional fundamental/enabling technologies constitute most of the base. However, if long-term aspects of the development are considered, the use of emerging technologies is essential. Long-term aspect of the methodology, which is described here, supports the selection of emerging

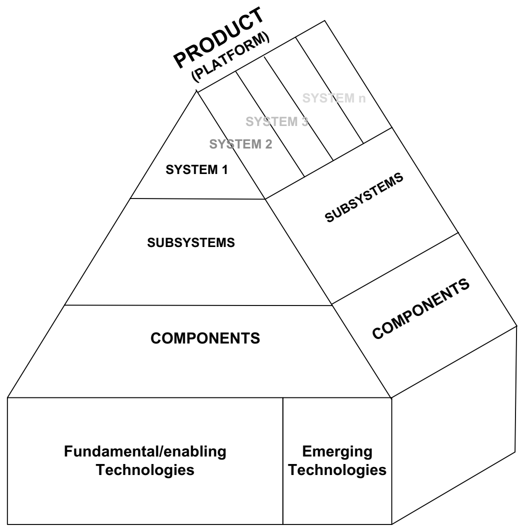

Fig. 1. Technology, system and product pyramid.

technologies that may be instrumental to the enhancement of nation's long-term wellbeing. Knowledge of technologies is essential in producing necessary components of the platform. Components form subsystems and subsystems form systems. Assembly of systems is the platform. Elements of the end product can be represented as a pyramid of Fig. 1.

All high-tech platforms consist of a large number of systems, subsystems and components. Design and manufacturing of these items are supported with a large number of technologies. In order to describe the platform, one should prepare a product breakdown which includes systems, subsystems and components. For our target platform, fighter aircraft, 48 systems and 248 subsystems were identified. The next step is to specify technical specifications of the breakdowns' constituents using requirements of the customer. This step is referred as the conceptual design. Reaching an acceptable resolution and, therefore, meaningful specifications, demands an iterative process similar to the solution of elliptic partial differential equations using Liebmann's method. For conceptual design, resolution of platform breakdown at subsystems level is adequate. The boundary conditions of the domain are the requirements of the customer. At the start of iteration, a first guess of systems and subsystems is made by assigning their technical specifications. The next step is to check whether these specifications satisfy platform requirements. If not, system/subsystem specifications and customer requirements are revisited and the iteration loop continues. The principle actors of this effort are system experts who have previous experience with related systems and subsystems.

One of the main tasks of the conceptual design processes is to produce necessary data for technology management. Therefore, the overall process consists of two parallel practices. One of them is the conceptual design process and the other is the management of the necessary technologies. During the iterations, customer requirements might change as the knowledge base becomes mature. Figure 2 shows a

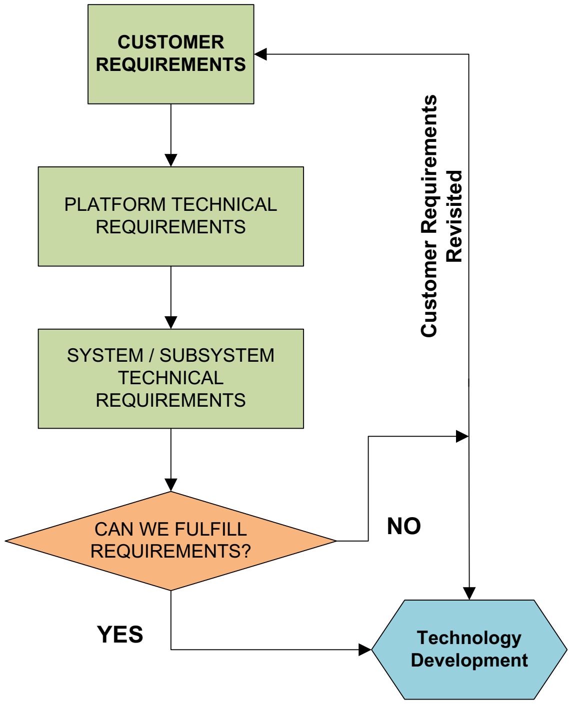

Fig. 2. Processes for determining system and subsystem specifications.

flow diagram depicting the iterative nature of conceptual design work, which produces information for technology management.

In this study, UK6 technology taxonomy [EDA (2014)] was adapted for aerospace applications. The value of technology taxonomy was appreciated as it exposes coherent technology definitions for experts. The taxonomy has two levels: fundamental/enabling technologies and system-related technologies. For the fighter aircraft target platform, 70 fundamental/enabling and 78 systems-related technologies were identified and redefined. The next step was the selection of technologies that support each subsystem by technical experts. The result of this selection is to produce a matrix that associates systems/subsystems with supporting technologies. The resulting technology versus product matrix is used as a tool to relate the two components. The matrix explained above serves as a tool for technology versus product bookkeeping which may assist further innovative projects.

4. Technology Priorities

Especially in the development of high-tech platforms, capabilities of the end product are vital in order to become competitive in the market. Although fundamental enabling technologies are essential, competitiveness usually calls for emerging technologies. Therefore, during the process it is necessary to address emerging technologies. Enabling and emerging technologies are the main study areas of universities and research institutes. In setting up the present methodology, one of the

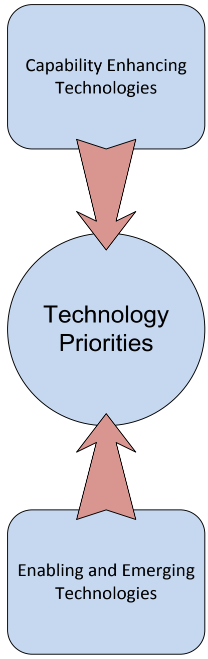

Fig. 3. Determining priority technologies.

intentions was to familiarize institutions that perform research on enabling and emerging technologies towards a common goal (fighter aircraft in this case).

The preliminary effort of finding priority technologies of the platform required two topics to be studied.

(i) Technologies that may increase the capabilities of the platform and make it more competitive.
(ii) Country's existing enabling and emerging technology potential.

Information regarding these two topics was compiled using expert opinions. Figure 3 shows top–down and bottom–up information sources that are to be matched for initial list of technology priorities. The first topic was studied with technical experts who were familiar with the systems and subsystems of the target platform. Experiences of experts on similar systems increase the value of this study. Therefore, a careful selection of experts is necessary.

At this stage, it is helpful to identify a number of "capability requirements" of the platform that are essential to make it competitive. It was established that this top–down study was being performed best by using search conference decision-making techniques. Small groups in search conference format were formed to address identified capability requirements of the platform. In the process, technology taxonomy — adapted for aerospace applications — was utilized to identify technologies that could enhance capability requirements and make the target platform technologically competitive.

The second topic was studied using a bottom–up process which also addresses the technology pull. Researchers of universities and research establishments were invited to make presentations on their research and technology projects and their technology expectations. Although the projects undertaken by universities and research establishments differ substantially from the requirements of the target platform, by using technology taxonomy it was possible to compile enough information on the nation's potential on enabling and emerging technologies. Preliminary technology priorities were identified by matching the information coming from the top–down and bottom–up studies.

5. Critical Systems

Critical technologies and/or systems/subsystems should be addressed in determining priorities. Critical technologies may be described as technologies that support systems/subsystems having very high life cycle costs or cannot be purchased. Subsystem's cost and availability are two essential characteristics, which make a subsystem critical. Critical subsystems either cannot be purchased or if they can, inflict very high life cycle costs. Such subsystems or systems can be characterized as "procuring critical". The information in this regard can be obtained from procuring specialists. At the conceptual design phase, technical specifications may not be mature enough. Therefore, assessment of "procuring critical" subsystems should be re-evaluated at the preliminary design phase. Uncertainty affects selection of suppliers and therefore associated technologies. Selection outcomes in terms of commitment to one supplier should be avoided and flexibility should be maintained [Malender and Tell (2014)].

6. The Need for Technology Readiness Level Measurement

At the conceptual design phase, technical specifications of systems and subsystems are determined conforming to the identified requirements. The "degree of readiness" of systems and subsystems has to be determined to assess their level of criticality. Systems and subsystems which are not mature enough for integration into the platform, are considered as "technology critical". In order to decide the readiness of a system or subsystem, a measuring method must be used. An adapted form of technology readiness level (TRL) metric with its nine levels was utilized for this purpose [Ender *et al.* (2009); ESA[a] (2008); Mankins (1995); Banke (2010); US DOD[b] (2011); Collins *et al.* (2008)]. Figure 4 shows the maturity path of a subsystem in terms of TRL levels as it is transitioned to a platform.

The first three levels of the TRL metric cover concept development and proof of concept. Next three levels include technology development and demonstration of the prototype in the relevant environment. Level 7 corresponds to the test of the engineering model in the operational environment. Level 8 represents the use of the actual system or subsystem on the actual platform. Finally, the last level corresponds to the use of the system or subsystem in operations.

[a] European Space Agency.
[b] United States Department of Defense.

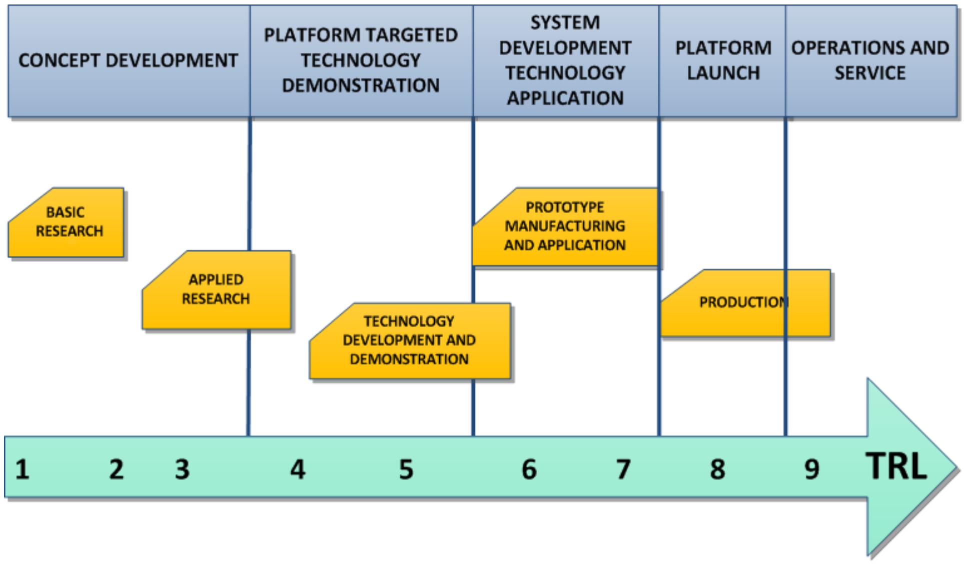

Fig. 4. Developments in systems and subsystems and transition to platform.

The system/subsystem under investigation may be hardware or software. Several in-house tests revealed that definitions of TRL levels must be verbalized very carefully achieving consensus among technical personnel of the nation. For hardware, "manufacturing readiness" was also evaluated. Therefore, nine hardware readiness levels (HRLs), nine levels for software readiness levels (SRLs) and seven levels for manufacturing readiness levels (MRLs) were reformulated. Several proposed definitions of each level in the literature and specifics of the target platform were used for this purpose [Bilbro (2007); Sauser *et al.* (2008, 2010)]. In order to increase the accuracy of the level of TRL assessment, a calculator proposed by Bilbro [2009] was evaluated and adapted for local use. The revised version was obtained by introducing aircraft specifics and terminology of local technical personnel.

The typical situation confronted in countries with less technological capability is that many of the subsystems had not been developed in the country. However, there may be some knowledge regarding necessary enabling technologies of subsystems. This knowledge may mostly be used to prepare specifications for procurement of subsystems. There are cases in which the subsystems are being developed with a foreign partner. Therefore, before answers to the TRL calculator questions are pursued, several introductory questions are necessary to reach a sound understanding of the "existing subsystem's" historical background. For the assessment of TRLs of existing subsystems, experience showed that reliable results could be obtained if TRL calculator are used by program managers and technical experts. In analyzing the results, the reliability is checked by assessing consistency of answers to the introductory questions and answers to the TRL calculator questions. Following are the introductory questions:

(i) Is the subsystem used in the operational environment of the target platform?
(ii) Is there a test program available for the subsystem?

(iii) What does the subsystem comprise? Hardware, software or both?
(iv) Is the subsystem developed starting from basic research?
(v) Is the subsystem developed using reverse engineering?
(vi) Is the subsystem developed by modifying an existing subsystem?
(vii) Is the subsystem developed in cooperation with one or several partners?
(viii) Is the subsystem purchased from a company and integrated into a platform?
(ix) List all the components of the subsystem for which the TRL assessment is to be performed.

At this stage, a survey is needed to determine the possible system/subsystem suppliers. For this purpose, all possible suppliers of the country that may contribute to the subsytem technology development, design and manufacturing were compiled using expert opinions and information gathered from a quick technology survey of probable establishments. A TRL assessment manual including definitions of HRLs, SRLs and MRLs was being prepared and sent to all possible suppliers. The manual also addresses the vocabulary used in the definitions and the TRL calculator questions.

It is important for the probable suppliers to select their suitable existing subsystems for which TRL assessment is to be performed. Conceptual design results, which describe the operational environment of the target platform and technical specifications of the target subsystem, steer the existing subsystem selection. The size and shape of the existing subsystem are almost always different from the target subsystem. However, its properties might be considered as required or very close to required.

In most of the cases, existing subsystems cannot be used directly on the target platform. Therefore, it is necessary to forecast the TRL value of the existing subsystem for the target platform. This assessment was made by subsystem experts using:

(a) Existing subsystem's TRL value.
(b) Difference between the existing subsystem's technical specifications and specifications of target subsystem's.
(c) Difference between existing platform and target platform.

If existing subsystem's TRL value is less than four, it is assumed that the knowledge acquired in the development of existing subsystem can be used in the development of the target subsystem. Therefore, TRL value of the existing subsystem is considered equal to the target subsystem's TRL value. Existing subsystem's TRL value greater than six implies the use of the existing subsystem in an existing platform. The existing platform may have some similarities with the target platform. However, at the conceptual design phase, no reliable information is available which would prove a complete similarity. At this stage, the highest value of TRL can be seven because TRL 8 represents the subsystem integration to (non-existing) actual platform. Therefore, the task of subsystem experts is to estimate the existing subsystem's TRL value between 4 and 7.

At the end of this evaluation, candidate suppliers that would be responsible for developing the subsystems as well as the starting TRL values are determined. MRLs of the subsystems are used as additional information in determining candidate suppliers. Subsystems with TRL values between 1 and 3 indicate high development risk. They are far from ready for transitioning to the target platform, therefore, they are strongly inclined to increase both schedule and cost of the target platform. Subsystems with TRL values between 1 and 3 are named "technology critical". There may be two possibilities for technology critical subsystems. Either these subsystems may be purchased if possible or work on them should start immediately. Technology critical subsystems are supported by a number of fundamental/enabling technologies and system-related technologies. These were determined using technology/subsystem matrix (Sec. 3). Priority levels of fundamental/enabling and system-related technologies are updated using critical subsystem data.

It is well established that 1–9 TRL string be considered in two parts [US GAO[c] (1999)]. Subsystems with TRL values up to three carry high risk for use on the target platform. They are in the research and technology development phase and the outcome is difficult to predict. Although the cost of this phase is much less than the rest, large errors in cost and schedule are inevitable. TRL 6 describes the state at which technology is demonstrated. Work at the levels of 4–6 of TRL ask contribution from designers. Therefore, at these levels, collaboration between researchers, designers and manufacturers are essential. At TRLs 4 and 5, subsystem is created, and at TRL 6 the subsystem is tested in a relevant environment. If the outcome is successful, product development phase is ready to start. TRLs 1–6 is named as technology development and TRLs 6–9 as product development phases. Although there is a continuous transition between the two, it is advisable to manage them in different programs/projects. Figure 5 shows the technology development and product development phases under TRL context. The transition from 5 to 7 describes the integration of subsystem to the platform.

Technology development phase starts with the use of fundamental/enabling technologies to prove the concept of the target subsystem. Concurrently investigations on the development of the subsystem using emerging technologies may also be

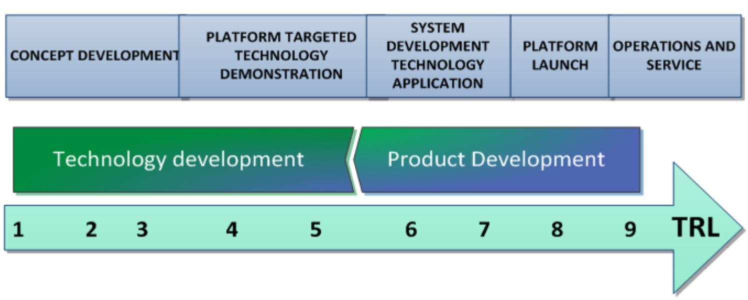

Fig. 5. Technology developments and product development.

[c]United States Government Accountability Office.

considered. The actors of this phase are universities and research institutes. Accumulations of knowledge during TRLs 1–3 have generic nature. Therefore, this knowledge buildup is precious and can be used in many other applications. Thus, the first three levels of TRL is knowledge buildup on the topics listed under relevant technology taxonomy items targeted to the development of the identified subsystem. TRLs 4–6 are based on the previous buildup of knowledge and includes development efforts for the prescribed subsystem. Therefore, assembled knowledge here as well has some generic nature and may be used in the development of future similar subsystems.

7. Methodology

The methodology flowchart (Fig. 6) outlines relationships between activities that are explained in the sections above. The flowchart also depicts required human source that materialize the activities. Users, customers and technical experts state requirements. Acquisition personnel, researchers, academicians and engineers of the subsystem "suppliers" take part in different phases of the methodology.

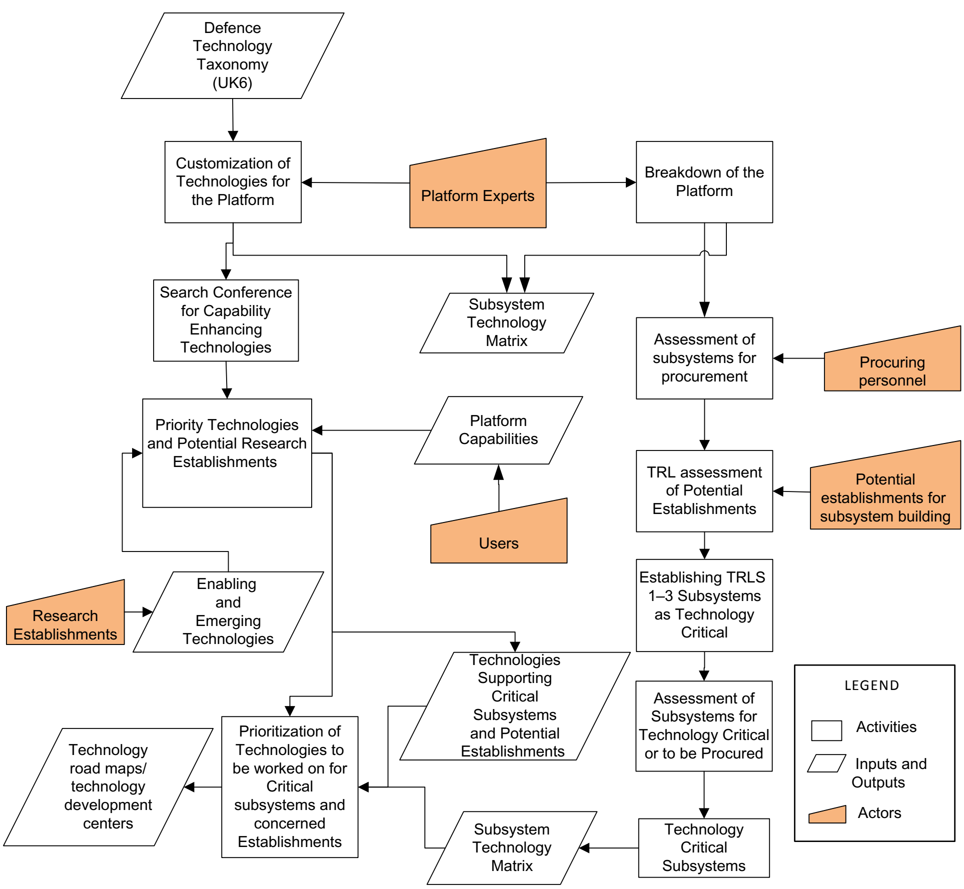

Fig. 6. Methodology leading to critical technologies and systems.

The primary philosophy behind the methodology is to determine priorities by exploring the required capability driving technologies and maturity of subsystems. It is expected that systematically covering all information available in the country would reveal rational results. These results are most valuable for further decision-making and planning.

The proposed methodology uses three tools. Technology taxonomy describes technologies that are required to make up the target platform. It was shown that carefully developed technology taxonomy is necessary because it provides coherent technology definitions for scientists and engineers. Breakdown of the target platform into systems and subsystems is the second tool. It was concluded that careful breakdown at subsystem level sufficiently describes the platform at conceptual design stage. The new tool, which was developed by matching components of platform breakdown and technologies referred as technology/subsystem matrix, proved to be useful. The matrix was used for replacing subsystems with technologies or vice versa, if needed. The third tool is the TRL calculator which determines the readiness levels of subsystems to be transitioned to the platform. It was illustrated that a rigorous TRL assessment leads to objective vendor selections.

The methodology needs information from conceptual design work. Therefore, the team working on technologies must constantly be informed about the progress in conceptual design. Close collaboration between technology management and conceptual design teams is essential. As critical subsystems and technologies and their priorities are established, the two groups take part in the preparation of road maps for technology development for which the survey paper on technology road mapping is considered useful [Vatananan and Gerdsri (2012)].

Figure 6 illustrates two components of the methodology. The component on the left is focused on fundamental/enabling and system-related technologies. The component on the right addresses the maturity of systems and subsystems. The left component compiles expert opinions on possible technological improvements for the platform's capability requirements. The other component assesses feasibility of subsystems. Merging the results of the two components reveal technology priorities.

It is possible to construct two types of organizations/programs using the consolidated information at the end of the methodology.

(i) For subsystems with TRLs 1–3.
(ii) For subsystems with TRLs 4–6.

The first type comprises of universities and/or research institutes as actors of the organizations to be established. A fundamental/enabling technology, which supports a large number of subsystems of the target platform, may be organized as a new research center. A center housing experts on fundamental/enabling technologies working on several subsystems of the platform, would create synergy and speed up the work. If a research center working on identified fundamental/enabling technologies already exists, program of work of the center can be rearranged to take into account the requirements of the target platform's critical subsystems.

Deciding whether to buy or to make is critical: acquisitions requiring research work are full of uncertainty. Eckhause *et al.* [2009] developed a dynamic programming approach for vendor selection based on TRL values. Brem *et al.* [2014] describes the make-or-buy decision-making of German industry using multiple weighted criteria with scoring models and portfolio matrices. There are also linear programming techniques used by decision-makers for selecting R&D projects [Husam *et al.* (2014)].

As TRL values of subsystems increase and reach the 4–6 interval, design and manufacturing establishments become actors of possible organizations. In this case, technology development will best be organized inside establishments responsible for manufacturing the subsystems. A good cooperation is needed between design and manufacturing establishments and responsible research centers. Particular attention should be given to the increase of innovation capacity of small- and medium-sized enterprises (SMEs) as partners, suppliers and/or customers. Chen [2012] explores how high-tech SMEs utilize integrative innovation resource strategy to transform knowledge into action.

One of the crucial questions of decision-makers is the cost and schedule forecasts for critical subsystem development. Decision-makers should always keep in mind that the technology development efforts have significant positive impact on the technological competence of the nation. The main reason for this is that the knowledge generated during the course of the development is generic and can be used for other systems. Therefore, return on investment of this effort is significant.

There are a number of publications in the literature on the estimation of cost and schedule issues [Dubos *et al.* (2007); Malone *et al.* (2011); Conrow (2011); El-Khoury and Kenley (2012)]. A part of these publications take TRL metrics as the basis for estimation. As advancement degree of difficulty increases from one TRL to the next, both cost and schedule are affected directly. Although there are estimations based on TRL, it is believed that estimations strongly depend on the local work habits. It is misleading if data of one nation is used in the other. No comprehensive work is available which addresses the influence of cultural factors in the estimation of cost and schedule.

8. Results

This section illustrates the outputs of "fighter aircraft technology assessment project" which was the driving force behind the work described here. First, fundamental/enabling and system-related technology component of the methodology is explained. The primary motivation of this component was to select critical technologies that would make a positive impact on the capabilities of the target aircraft. About 114 technologies were selected by the experts that support five capability requirements. The priorities of these technologies were established by considering the number of capability requirements that they were supporting. The 114 technologies were grouped under 22 research areas. Some of these research areas were identified as information and signal processing, materials, sensors, human sciences, integrated system technologies and synthetic environments. During the bottom–up process of the technology component, 36 university and research institute laboratory presentations were attended. This effort revealed valuable knowledge on the possible research and technology development centers and the strength of indigenous technology pull. Results were used to update the prioritization of technology areas.

Systems and subsystems of the target aircraft were the gadgets of the methodology's second component. The main incentive here was to find the level of knowledge for producing the aircraft system and subsystems. The level of knowledge was determined by assessing the TRL of subsystems. Main actors of the process were mostly defence industries, however, in several cases research establishments were also involved. Attempt was made to determine the HRLs, MRLs and SRLs of subsystems.

Preliminary assessment of procurement specialists revealed that many systems of the target aircraft are "procuring critcal", showing that TRL assessment of substantial number of subsystems must be undertaken. At this stage, a number of critical systems and their probable suppliers were named by the customer. Here, we shall discuss three cases to demonstrate the different aspects of how readiness of subsystems, and therefore systems, were evaluated.

Case 1 concerns system A that had six subsystems. TRL assessment of system A was accomplished by the developer of the methodology, TAI (Firm X). TRL assessments were performed for all "A" systems which were developed in-house. The TRL evaluations for "A" systems of five possible solution partners were also determined. Altogether, 26 separate TRL measurements were conducted in "face-to-face" sessions.

Case 2 is the TRL assessment of system B that was performed by Firm Y. The system contains 10 subsystems. Firm Y was enthusiastic in using the technique. An exploratory session was conducted in which all aspects of the process were discussed. Firm Y was then operated as the TRL calculator applicator of the Case 2 and performed 19 TRL assessments. Firm Y also identified technological capabilities of the possible solution partners. Three other establishments, which may contribute to the manufacturing of the system, were also assessed. Firm Y tried all the requirements which were outlined in the TRL assessment manual.

Case 3 concerns the system C. Firm Z performed this system's TRL assessment. The system was made up of six subsystems. Firm Z was contented with the TRL assessment manual and demanded no further guidance for TRL evaluation. Firm Z gave limited information on the subsystems for which TRL assessment was performed. Although possible solution partners were identified, no effort was presented by Firm Z to assess their capabilities.

Reliable results were obtained when not only answers to the questions were sought, but also evidence underlying the responses was questioned. Most dependable and comprehensive results were obtained for subsystems that were evaluated by Firm X. It was also seen that close collaboration with the firm that developed the methodology improved the consistency of the results.

While it was possible to compile reliable information from the research establishments about their level of technology readiness, it was indeed a difficult task to obtain coherent information from the industrial sector. Because of the industrial sector's highly competitive environment, obtaining reliable information was found to be challenging. Whereas, precompetitive working environments of research establishments enhanced cooperative relations.

The component of the methodology which determines the readiness levels of systems and subsystems compiles the information on how well the making of the systems/subsystems is known in the country and which institutions can be involved in the making. Small TRL values imply the need for fundamental or engineering research. The fundamental and system-related technologies and organizational data, which were already compiled in the technology component of the methodology, were merged with the data obtained from the system/subsystem component of the methodology. Synthesis of data revealed priorities and organizational framework which could be used in the development of the target aircraft. As a result of the fighter aircraft investigation, several research projects, three research centers of which the program of work was outlined and possible partnerships were identified. The partnership proposals include both national and international collaborations as well as alliances with research centers and firms that will be responsible for the production of systems and subsystems.

9. Discussion, Conclusions and Recommendations

The purpose of the study was to develop a methodology that may be used to determine technologies that are necessary for a target platform to make it competitive in the market. In general, this study shows that the developed methodology appears to be useful in this regard.

It was expected that the product-based technology management is a pragmatic approach to technology selection and system development suitable for technologically less-developed nations. The high-tech platform at the target is a proper symbol that was expected to motivate the nation. Because target platform constitutes a large number of technologies, it was anticipated that working on its systems and subsystems produce an atmosphere in which valuable knowledge will be harvested. It was foreseen that a well-managed undertaking would be capable of improving the technological competence of the nation. During the course of the study, it was observed that the stakeholders were motivated because a definite target was named. Motivation was however restricted to the making of the platform. The ultimate effect of learned technologies to the technological competence of the country was secondary.

In the process of determining critical technologies and systems, there must be no external influence. Identifying suppliers for systems at the conceptual design/technology assessment phase should be avoided. The analytical approach described in the methodology is designed to obtain critical technologies and systems as outputs of the study. Because for the system/subsystem component of the methodology data gathered from a large number of diverse sources, a coherent set of information was not collected. This situation is expected to have some adverse effect on the results, but leveled, as the outcome of the two components of the methodology is synthesized.

Compiling technological competence level information from firms was challenging due to the firm-level competitive environment. It is, therefore, recommended that the study be managed by an independent team not related to any of the probable firms that may take part in the product development phase. It may be argued that in order to reach the information that is labeled as classified, a team, above firm level, is needed. The importance of an independent team is also emphasized in US DOD [2011].

Representatives of the firms that would be undertaking TRL assessment must be well trained before they start to evaluate their products. Face-to-face TRL assessment workshops was found to be the best way of obtaining reliable results. The second best way was to find partners enthusiastic to apply the techniques to their products.

The two-dimensional (HRL and MRL) assessment for hardware and one-dimensional assessment for software (SRL) were applied to determine maturity levels of hardware and software subsystems. Definition of each maturity level and questions of the calculator were designed to cover performance and integration aspects, integration readiness and system readiness [Sauser *et al.* (2010)] in maturity assessment were acknowledged as techniques that need too much effort for too little gain at this stage of platform development. It was concluded that the developed technique appeared to be adequate for evaluating the readiness of existing subsystems at the conceptual design and technology assessment stage.

The weakest subsystem of the system under investigation becomes apparent when all subsystems' readiness levels are assessed. This information is useful in deciding the priority levels of technologies. It should be noted that no systematic risk evaluation was developed for determining the effect of weakest links to the end product, but weakest links' influence was observed in the priorities.

It was established that product-based technology management should be implemented together with conceptual design work. Technology requirements have to be updated depending on new findings of conceptual design. The process requires two teams among which information should be shared. While one of the teams is working on the conceptual design, the other should work on the ways for acquiring technologies, subsystems/systems, which the design requires. This collaboration is essential during the course of the process.

The support of experienced design specialists who know the target platform's requirements and design concepts is crucial. In each step of the methodology, experienced design specialists play important roles. Their contributions include selection of target platform technologies for a technologically competitive platform, evaluation of emerging technologies, determination of TRLs of target platform subsystems and preparation of technology development plans. Discussions among scientists and design specialists on emerging technologies and technologies that enforce competitive edge to the platform produced valuable outcomes. These debates also enabled to identify weaknesses in fundamental/enabling technologies.

The output of the methodology is a list of required technologies for which knowledge is to be improved and organizational suggestions and road maps for developing subsystems and systems are defined. These findings seem to indicate that accumulated knowledge enables to prioritize research, technology, development and innovation efforts. Although there is not much progress yet regarding the implementation of results, the proposed methodology and the use of TRL assessment techniques were acknowledged by defence industries and described in their manuals.

It is necessary to create research and technology projects for subsystems having TRL values less than six. Because TRL values of subsystems at the start are known, it is recommended that the TRL improvements must be monitored and assessed as the projects progress. Data collected by TRL evaluation teams will help to estimate cost and schedule of new projects. It is recommended that as projects progress, TRL versus cost and schedule data unique to the nation be collected. Since the data depends on the discipline in which of the project is identified, a discipline-based data collection would be necessary.

As a last note, the methodology has an inclusive character that draws together all related institutions around a jointly-defined high-tech product. Therefore, it is claimed that the process not only has the ability to touch the technological priorities of the nation, but also to enhance the values related to the comprehensiveness of the technology management techniques.

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References

Archibugi, D. and Pietrobelli, C. (2003). The globalization of technology and its implications for developing countries: Windows of opportunity or further burden? *Technological Forecasting and Social Change*, **70**, 9: 861–883.

Banke, J. (2010). Technology readiness levels demystified. Available at http://www.nasa.gov/topics/aeronautics/features/trl_demystified.html [accessed on October 2015].

Betz, F. (2011). *Managing Technological Innovation: Competitive Advantage from Change*, 3rd edn., John Wiley and Sons, New York.

Bilbro, J. W. (2007). A suite of tools for technology assessment. In *Technology Maturity Conference: Multi-Dimensional Assessment of Technology Maturity*. Air Force Research Lab, Virgin Beach, VA.

Bilbro, J. W. (2009). Technology assessment calculator. Available at http://www.google.com.tr/webhp?sourceid=chrome-instant&ion=1&espv=2&ie=UTF-8#q=Bilbro%2C+J.+W.+(2009).+Technology+assessment+calculator [accessed on October 2015].

Brem, A., Daniel, A. G. and Kia-Ingo, V. (2014). Strategic technological sourcing discussions in the context of timing and market strategies: An empirical analysis. *International Journal of Innovation and Technology Management*, **11**, 3: 1–23.

Cetindamar, D., Phaal, R. and Propert, D. (2009). Understanding technology management as a dynamic capability: A framework for technology management activities. *Technovation*, **29**: 237–246.

Chen, T. F. (2012). Transforming knowledge into action to reach innovation capacity in high-tech SMEs. *International Journal of Innovation and Technology Management*, **9**, 1: 1250005.

Collins, J. W., Back, J. M., Opare, E. O. and Pincock, L. F. (2008). NGNP — Creating validated TRL and TDRMs for critical systems, subsystems, and components. Report No. INL/EXT-08-14842, Idaho National Laboratory, Idaho Falls, Idaho.

Conrow, E. H. (2011). Estimating technology readiness level coefficients. *Journal of Spacecraft and Rockets*, **48**, 4: 148–152.

Dubos, G. F., Saleh Joseph, H. and Braun, R. (2007). Technology readiness level, schedule risk and slippage in spacecraft design: Data analysis and monitoring. *AIAA Space 2007 Conference and Exposition*, 18–20 September 2007, Long Beach, California. In AIAA, Reston, VA.

Eckhause, J. M., Hughes, D. R. and Gabriel, S. A. (2009). Evaluating real options for mitigating technical risk in the public sector R&D acquisitions. *International Journal of Project Management*, **27**: 365–377.

El-Khoury, B. and Kenley, C. (2012). *Analytic Framework for TRL-Based Cost and Schedule Models*. Report No. NPS-AM-12-C9P21R02-086, Acquisition Management Series, Naval Postgraduate School, Monterey, CA.

Ender, T. R., McDermott, T. and Mavris, D. (2009). Development and application of systems engineering methods for identification of critical technology elements. In *7th Annual Conference on Systems Engineering Research (CSER 2009).* University of Southern California, Loughborough.

Ertem, O., Cezayirlioglu, U., Temiz, A. and Üçer, A. S. (2009). Technological competency in defence industry. In *Proceedings of the 5th Ankara International Aerospace Conference AIAC-2009-122*, 17–19 August 2009, Metu, Ankara, Turkey.

European Defence Agency (EDA) (2014). EDA Technology Taxonomy. Available at: http://www.eda.europa.eu/docs/default-source/procurement/eda-technology-taxonomy.pdf [accessed on October 2015].

European Space Agency (ESA) (2008). *Technology Readiness Levels Handbook for Space Applications.* ESA Document No. TEC-SHS5551/MG/ap, ESA, France.

Damanpour, F. and Wischnevsky, J. D. (2006). Research on innovation in organizations: Distinguishing innovation-generating from innovation adopting organizations. *Journal of Engineering Technology Management*, **23**: 269–291.

Halkosa, G. E. and Tzeremesa, N. G. (2013). Modelling the effect of national culture on countries' innovation performances: A conditional full frontier approach. *International Review of Applied Economics*, **27**, 5: 656–678.

Hofstede, G. (1980). *Culture's Consequences, International Differences in Work-Related Values.* Sage Publications, The International Professional Publishers, Newbury Park, London and New Delhi.

Husam, A., Nabil, G., Mohammad, K. and Shirley, C. (2014). Integrated technology roadmapping tool to aid the decision-making of R&D investments. *International Journal of Innovation and Technology Management*, **11**, 2: 1–21.

Juma, C., Fang, K., Honca, D., Huete-Perez, J., Konde, V., Lee, S. H., Arenas, J., Ivinson, A., Robinson, H. and Singh, S. (2001). Global governance of technology: Meeting the needs of developing countries. *International Journal of Technology Management*, **22**, 7/8: 629–655.

Karagozoglu, N. (1987). Managing technological dependence in the developing countries: Analysis at the firm level. *Journal of Technology Transfer*, **12**: 65–70.

Kharbanda, V. P. (2001). Strategic technology management and international competition in developing countries — The need for a dynamic approach. *Journal of Scientific and Industrial Research*, **60**: 291–297.

Malender, L. and Tell, F. (2014). Uncertainty in collaborative NPD: Effects on the selection of technology and supplier. *Journal of Engineering and Technology Management*, **32**: 103–119.

Malone, P., Smoker, R., Apgar, H. and Wolfarth, L. (2011). The application of TRL metrics to existing cost prediction methods. In *2011 IEEE Aerospace Conference*, Big Sky, MT, IEEE, Washington DC.

Mankins, J. C. (1995). Technology readiness levels. White Paper, Advanced Concepts Office, NASA Office of Space Access and Technology, Washington DC.

Miles, I. (2002). Mobilising the regional foresight potential for an enlarged European Union. Paper prepared for the STRATA-ETAN Expert Group Action, European Commission DG: Directorate K, Brussels.

Narkus, S. (2012). *Kondratieff, N. and Schumpeter, Joseph A. Long-Waves Theory: Analysis of Long-Cycles Theory.* Master Thesis Universitetet i Oslo, Norway.

Pérez Luño, A., Shanthi, G. and Cabrera, R. V. (2014). Innovation and performance: The role of environmental dynamism on the success of innovation choices. *IEEE Transactions on Engineering Management*, **61**, 3: 499–510.

Porter, A. L. (2010). Technology foresight: Types and methods. *International Journal of Foresight and Innovation Policy*, **6**, 1/3: 36–45.

Rieck, R. M. and Dickson, K. E. (1993). A model of technology strategy. *Technology Analysis and Strategic Management*, **5**, 4: 397–411.

Rush, H., Bessant, J. and Hobday, M. (2007). Assessing the technological capabilities of firms: Developing a policy tool. *R&D Management*, **37**, 3: 221–236.

Rush, H., Bessant, J., Hobday, M., Hanraham, E. and Medeiros, M. Z. (2014). The evolution and use of a policy and research tool: Assessing the technological capabilities of firms. *Technological Analysis and Strategic Management*, **26**, 3: 353–365.

Saritas, O., Taymaz, E. and Tumer, T. (2006). Vision 2023: Turkey's National Technology Foresight Program — A contextualist description and analysis. Working Papers in Economics No. 06/01, Ecnomic Research Center, Ankara, Turkey.

Sauser, B., Ramirez-Marquez, J. E., Devanandham, H. and DiMarzio, D. (2008). A system maturity index for the systems engineering life cycle. *International Journal of Industrial and Systems Engineering*, **3**, 6: 673–691.

Sauser, B., Gove, R., Forbes, E. and Ramirez-Marquez, J. E. (2010). Integration maturity metrics: Development of integration readiness level. *Information, Knowledge, Systems Management*, **9**: 17–46.

Schumpeter, J. (1949). Economic theory and entrepreneurial history. *Change and the Entreprenuer*, Harvard University Research Center in Entrepreneurial History, Change, and the Entrepreneur. Harvard University, Boston.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, **15**, 6: 285–305.

Teece, D. J. (2009). *Dynamic Capabilities and Strategic Management*, Part 2, Chap. 6. Oxford University Press, New York.

US Department of Defense (2011). Technology readiness assessment (TRA) guidance prepared by the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)).

US Government Accountability Office (1999). Better management of technology development can improve weapon system outcomes. Report No. GAO/NSIAD-99-162, US GAO, Washington, DC.

Vatananan, S. R. and Gerdsri, N. (2012). The current state of technology roadmapping (TRM) research and practice. *International Journal of Innovation and Technology Management*, **9**, 4: 1250032.

Biography

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