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Measuring and Assessing Application-Specific Technology Readiness

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***Abstract*— Technology readiness is a crucial issue for decision-makers in technology-driven enterprises, determining whether the technology will or won't be adopted for use in products or as a process technology. We know that, in some cases, lower technology readiness will be accepted by the users; these could be end-users, but, more often, it will be used in companies. The impact of a too early or too late adopted technology can be huge for companies and can even threaten market position or the existence of the company itself. Research institutes and technology developers, in particular application-oriented research organizations, might be also interested in which parameters or technology attributes should be improved or extended, according to the addressed application field, so that the technology fulfils the market-requested functions and a fast diffusion in the market can be achieved. Existing technology readiness models cover the various usages of the technology. In many cases, they assess the technology's use in across different industries and application fields. However, the requirements in many fields are mostly different and very specific; thus, evaluation at such a high level can't conclude whether the technology should be considered and adopted in the applications involved. This paper introduces an approach on how to determine and map the application-specific readiness of technology by decomposing both the application and the technology into its requested functions, as well as dynamically mapping the individual technology performance criteria. The applicability of this model will be demonstrated and discussed by a use case in the area of OLED-technology.**

***Keywords*— technology readiness measurement; technology readiness assessment; technology lifetime-management; technology commercialization; technology monitoring.**

I. INTRODUCTION

Evaluating the readiness of technologies and their future developments should be categorized as a crucial strategic management task in technology-driven companies at the very least, but also through many more companies. Technologies are often the source of radical changes in the markets and, in particular, companies which haven't recognized this change at an early stage are often struggling when radical technological innovation occurs. However, besides technology-influenced companies, technology readiness is also important for investors, governments and technology developers themselves in order to control their activities and focuses and to know whether they are on the right track [1].

The existing technology readiness models map technology readiness in an undifferentiated manner without concern for their different applications. In particular, with regard to the rising complexity of technologies (system technologies) and cross-sectional technologies with a broad application scope in very different fields, the conventional technology readiness models can't figure out dependencies and sophisticated analyses. Although, they provide an appropriate overview of the technology development statuses to the companies (exploiting competitive potential, market penetration, diffusion, etc.) [2]. However, in R&D and product and production planning decisions the company's require a deeper description of the technology readiness on a branch or application-specific level, which the existing technology readiness models don't provide.

This paper aims to introduce a model which analyzes the actual state of the attributes of a technology by decomposing the technology into its functions and attributes, as well as specifically comparing its attributes with the requirements of the application. The interaction with other technologies implemented in the application is regarded as a subsequent step and, thus, is not part of this work. Further, the model enables anticipation of the application-specific technology readiness of the single attributes by comparing the application-specific requirements with the performance development of the technology. For this purpose, quantitative and qualitative forecasting methods will be included [3], [4]. The model enables companies to anticipate from the attribute-specific development of the entire technology as such/ in itself, or as an entity by mapping the predicted progresses of the individual attributes.

II. Literature Review

A. Definition of and deriving a technology readiness model classification

Generally, readiness or maturity can be defined as "the state of being complete, perfect or ready" [5]. Maturity implies an evolutionary progress in the demonstration of a specific ability or in the accomplishment of a target from an initial to a desired or normally occurring end stage" [6]. In the literature, the term technology readiness is only defined with regard to its characteristic or to the state of the life cycle. In this paper, technology readiness is defined as the chronological evolution of a technology with regard to its application field(s). It relates the current technological performance, market and competitive characteristics of a technology (actual state of the technology) with the requirements of the application field(s) (target state of the technology).

For evaluating technology readiness, different concepts in literature and practice can be found. We classified these (as described in the following chapter) and distinguished between state and time-based approaches. Regarding the state-based models, the dynamics of the relevant state variables are considered to describe technology readiness. Nevertheless, technology readiness is a time-dependent factor; also, if it is described by state-based models, the time dimension is taken as inherent without showing it explicitly [7]. In contrast, the time-based approaches describe the retention time of the technology in relation to the market [8] or the performance of the technology. Thereby, the progress in technology development is mapped on a timeline within a time-correlated variable (e.g. R&D effort).

As well as the differentiation in time and state-based approaches, the aggregation level of the observation field for the application of the technology is an additional relevant differential element of these models. Hereby, the following aggregation levels can be distinguished:

- Industry: Herein, technology requirements can only be defined roughly and. thus, technology readiness can only be determined on a very generic level.
- Branch: Technology requirements can be stated more precisely than on an industry level and, therefore, technology readiness can also be defined on a more quantitative level.
- Application: As the technology requirements can be formulated very specifically through the application, technology readiness can be determined exactly.

Further, we will use this classification to align the described existing technology readiness models and give an overview as to which areas are covered by the existing models and what is the focus of the newly developed technology readiness model. In the following section, some of the often used and cited readiness model will be briefly introduced.

B. Existing technology readiness models

1) *The Hype Cycle Model:* The Hype Cycle Model, developed by Gartner [9], is based on the assumptions that the course of the public interest in new technologies is depicted by the dimensions "time", "maturity" and "visibility" ("expectations" as degree of public attention).The hype cycle runs through five phases. In the first phase ("technology trigger"), public attention is initially triggered by experts and an eagerly interested community and decreases to the "peak of inflated expectations" represented by the second phase. If the initial exaggerated expectations aren't fulfilled by the technology, public interest, therefore, fades during the third phase, the "trough of disillusionment". Nevertheless, some companies continue with the technology development and the fourth phase, the "slope of enlightenment", will be reached. Finally, in the fifth phase, the development results in the "plateau of productivity". Now, the diversity of the potentially possible application options is recognized by the general public. Gartner's hype cycle model is only suitable to a limited extent in representing the state of development for the above mentioned objectives, because the readiness of a technology for the implementation of a specific application cannot be conducted. Rather, the readiness is described on a qualitative level, across different industries. The allocation of the technology into the hype cycle and the prognosis of future development are built-up more subjectively. The periods before the first / after the last phase and possible iteration or jumps during the technology development are not considered.

2) *Technology Readiness Levels-Model:* Technology Readiness Levels (TRLs) were defined by NASA in the late 1980s to support technology maturity assessments as an integral part of the technology planning process [10]. There are nine TRLs defined in [12], whereat the first Technology Readiness Level (TRL 1) signifies the lowest and the ninth Technology Readiness Level (TRL 9), the highest degree of readiness. To start the acquisition of a new technology, at least TRL 6 is recommended; for system development, TRL 7 should be achieved. The Technology Readiness Levels-Model is a quite simple and clear procedure for the determination of technology readiness. However, the benefit for companies is limited, because the classification of a technology in a TRL does not say anything about the applicability of the technology within the company environment. For example, TRL 6 only implies, that "…a representative prototype system exists, which is well beyond that of TRL 5, is tested in a relevant environment and represents a major step up in a technology's demonstrated readiness..." [12]. Furthermore, "…TRLs leave out such considerations as the degree to which the technology is critical to the overall success of the system (including how difficult it would be to replace it, or assume some fallback posture, should the technology in question prove unacceptable), or the suitability of the technology in question to its intended use within the system…" [13]. Another relevant disadvantage of deploying the TRL model at the application level is mentioned by Smith: "…TRLs blur several aspects of technology and product readiness into a single number…" [13].

3) *Technology Readiness Space-Model:* The technology readiness space is based on the TRL as well as on other approaches from the automobile and aviation industries [14]. This model determines the degree of readiness independently from market and company-specific aspects and, therefore, from the technology developer's point of view, not from the technology applicant's point of view. By the means of a standardized questionnaire, the degree of technology readiness is determined. The questionnaire considers the following parameters, which can be assigned to three elements:

- Technical Parameter (product): characteristic of the product, complexity of the product and similarity of the product,
- Technological parameter (manufacturing process): product quality, process stability, process safety, system integration, properties regarding cycle time/rate and maturity of the production process,
- Method: degree of development concerning the model, concerning the simulation tool and the existence of and knowledge about critical parameters.

In this technology readiness model, the technical requirements of a product are defined as product technology, whereas process technology describes the manufacturing capabilities. Due to the focus on manufacturing technologies, the usability of this method is very limited. Furthermore, the system integration is just one of several parameters that affect the applicability (and, thus, the readiness) of a technology within an application. The model is defined as independent from company-specific factors, which, therefore, hinders a company-specific determination of technology readiness.

4) *Technology S-Curve-Model:* An often cited readiness model in technology management is the Technology S-Curve-Model [15]-[17]. Herein, the performance of a technology is mapped over the cumulated R&D efforts. The related model, which is called the Double S-Curve-Model, adds emergent technologies within the analysis and seeks to find the most convenient time to switch the technology and jump onto another S-Curve. The benefit of this concept is the possibility to consider the potential of a technology – based on the knowledge about alternative substitution technologies – in investment decisions. The S-Curve-Model reflects only an idealistic development course and, therefore, ex-ante decisions – based on this model – are characterized by a high degree of uncertainty. Furthermore, the procedure of how to determine the performance of a technology is not described and the timeframe for the skip from old technology to new technology (regarding the re-allocation of resources) is not described, either. However, in the case of technology substitution, the criteria for technology assessment can change due to changing performance parameters and environmental conditions. We recognized, in an analysis of different process technologies over three decades, that the focussed parameters mostly were changed during that period.

C. *Classification of technology readiness models*

Having described some of the often cited and used existing technology readiness models and deriving a classification in the previous section, we now arrange all described concepts, as well as the new approach in this classification. This overview should facilitate to fill the existing gap in the technology readiness model landscape and also set up requirements for the requested approach. For instance, according to this overview, the new approach won't consider demand cycle orientated aspects due as the deployment of the technology within an application isn't relevant in this case.

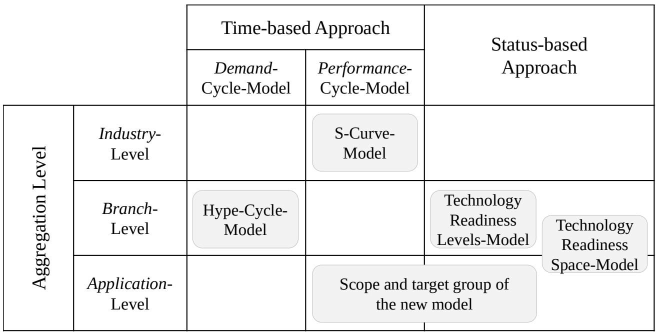

Fig. 1 Classification of the existing technology readiness models and the new approach

III. Requirements For An Application-Specific Technology Readiness Model

In this section, we will establish four hypotheses from what we have learnt from the literature review and the analysis of the existing models, and which requirements should be fulfilled by the new application-specific technology readiness model.

D. *Hypothesis 1: Technology readiness is dependent on the application*

The performance (and therefore the readiness) of a technology is related closely to the requirements of the application field. In order to be able to transfer a technology into an application, several attributes must be fulfilled simultaneously (e.g. for the OLED-technology, attributes such as lifetime, brightness, energy efficiency, volume, etc.). Hence, the attributes can be divided into "must-meet" and "should-meet" criteria; must-meet-criteria have to be met by the technology in order to be implemented into an application (e.g. lifetime >= 36 months), whereas the fulfillment of should-meet criteria are not vital for the implementation - as long as their fulfillment remains at a reasonable level - but are more a "nice-to-have" (e.g. as energy-efficient as possible). As different applications evince different attribute profiles, technology readiness can be determined only for a specific application. The following example explains this: Assuming that the OLED-technology has a lifetime of 36 months, the technology is pretty mature for implementation in a mobile phone (as the lifetime of a mobile phone also amounts to 36 months), whereas the technological maturity of OLED for the implementation within automobile or building applications (lifetime-expectancy > 10 years) is quite low. As a result, the approach should consider the different application requirements.

E. Hypothesis 2: Technology readiness is dependent on the attributes

Depending on the application-specific requirements, a technology must fulfill different requirement profiles (see Hypothesis 1). Consequentially, technology readiness depends on the attributes (for definition, see Chapter 1). Generally, there are three different ways to describe technology readiness:

- Concerning an overall-related value (e.g. as mean value over all attributes),
- Based on some (pretended) key performance attribute (e.g. brightness within the OLED-technology),
- Concerning the worst-performed attribute.

To map technology readiness concerning both the specific application(s) and their relevant attributes, is a practical and transparent way for enterprises to assess the readiness of a technology. In this paper, we assume, that an attribute will be influenced only by the technology/ies of a single function (e.g. the attribute "brightness" will be influenced only by the function "light emitting" and, therefore, form the light-emitting technologies). As a result, we need an attribute-specific technology readiness model.

F. Hypothesis 3: A technology is, rather, a technology system

A technology is a system consisting of a set of sub-technologies derived from a system theory view [18]. According to the Academic American Encyclopedia "…In the broader sense, technology refers to all processes dealing with materials…" [19]. Based on this definition of the term technology as used in this paper, it can be assumed that the performance of a technology can be influenced by the applied materials, the processing of those materials, or both. For instance, if the lifetime of the OLED-technology is to be increased, sub-technologies for the function "Enhancement of the barrier properties" should be investigated concerning new materials and/or new processes. The following combinations will be possible:

- New materials with existing processes: taping of new coated hybrid polymer-foils,
- Existing materials with new processes: sealing of existing barrier-foils,
- New materials with new processes: sealing of new coated hybrid polymer-foils.

Thus, different (sub-) technologies influence the performance of a technology (on an attribute-level), so, the observed technology must be decomposed into its sub-technologies. As a result, the technology readiness model should ensure to decompose the analyzed technology and its sub-technologies systematically.

G. Hypothesis 4: Anticipation of the future readiness of a technology

By breaking down the technology into sub-technologies and by assigning functions and attributes to them, a transparent picture of technology readiness can be drawn. This decomposition eases the anticipation of the future readiness:

- Experts can be addressed with much more detailed and answerable questions, as the attributes will be parameterized. For instance, "…How does the lifetime of OLED develop with the implementation of coated hybrid-polymers in future?..." vs. "How does the barrier property of coated hybrid-polymer develop in future (in $cm^3/m^2.24h.atm$)?..."
- Technology research can be undertaken in other technology fields (e.g. transparent aluminum, $MgAl2O4$ as barrier film for OLED)
- Through consecutive mapping of the technology attributes performance development across time (post-ex until now), the dynamic of the development can be extracted. This can give an indication of the future development (e.g. asymptotic approximation to a value)

The technology readiness model has to consider that readiness changes over time. This fact can be used, to a certain extent, for anticipating the development of the technology readiness concerning single attributes. As a result, dynamic technology readiness is required.

H. General requirements

Technology development and strategic decision in production, market and/or areas depend heavily on each other. Reducing complexity to show dependencies and impacts is often quite important; therefore, the model should be designed as phases and sub-phases concepts, supporting the user to understand how to go forward within the analysis project. Each step should be consistent and logical. The used methods must be compatible with each other. The approach should be structured in modules, so that different parts or phases can be combined and passed through several times, as well as additional methods can be used, while the generic structure remains unaffected. The user should be guided by the model to ensure efficiency in the application, effective results and gain experience in working with this approach and transferring the ascertained model deliverables. As a result, the new model should address the following general requirements: reduce complexity, ensure consistency and maximize applicability in practice.

IV. Application-Specific Technology Readiness Model

The approach described in this paper aims at identifying the readiness of a technology (on an attribute-level) for the technology's implementation within a specific application. Furthermore, the gathered data can be used to forecast the development of the technology performance on an attribute-level. The approach for the determination of the application-specific technology readiness is divided into four phases:

- Phase 1: Decomposition of the technology,
- Phase 2: Identification of relevant application-specific attributes and their performance requirements,
- Phase 3: Identification of alternative technologies and concepts,
- Phase 4: Visualization of technology readiness and mapping of the attribute-specific technology performance development.

These phases structure the model and allow application in different work packages and show what is important in order to achieve an application-specific assessment of technology readiness.

A. Phase 1: Decomposition of the Technology

The breakdown of complex issues in terms of the reduction into their components and interactions – hereafter referred to as decomposition – is an appropriate way to reduce complexity of a main-problem and a heuristic approach for decision-makers in numerous disciplines [20]. Taking into account the previous described objectives of this model, decomposition is a suitable prospecting method for technology forecasting [21].

Within this phase, the technology to be observed will be decomposed concerning its functions. The functions will be subdivided into overall-function and sub-functions, which can be defined as follows:

- The overall-function provides the overall effect of all underlying sub-functions.
- Sub-functions are defined as functions whose interactions result in an overall effect.

Between overall and sub-functions, logical, physical, technological and/or organization-related correlations persist, which – in their addition – lead to a functional structure [21]. According to the underlying definition of technology for this paper, a technology can be described by the (set of) material(s) and by the process(es) used to fulfil the function(s). In this paper, a technology-option is defined as a particular material and a process used.

As mentioned, as an example, we applied the model in the area of OLED-technology, as is also described in this paper. Figure 2 shows that the fulfilment of the function "light emitting" rather than the technology-option "Polymer 1 processed with spin coating" or the technology-option "Polymer 2 processed with Ink Jet-printing", can be applied. For each function and sub-function, the already known material and process combinations have to be collected and summarized.

B. Phase 2: Identification of relevant application-specific attributes and their performance requirements

This step covers the identification of the relevant attributes and the specific performance requirements. For each attribute, the function(s) influencing its performance have to be captured (e.g. lifetime of the OLED-Display: min. 24 months; brightness: min. 500 cd/m², etc.). Further, the technological parameters need to be assigned to the attributes. For the lifetime of an OLED, the user-oriented parameter "month" is rather difficult to map on a technological level, whereas the parameter "permeability of oxygen"– which describes the same matter from a technological point of view – is much easier to map. In addition to the requirements of the application (see requirements for application A in Figure 2), the actual performance of the attributes has to be investigated. In our OLED example (see Figure 6), the attribute "brightness" for technology-option 1.1 is 500 cd/m², while, for technology-option 1.2, it is only 400 cd/m².

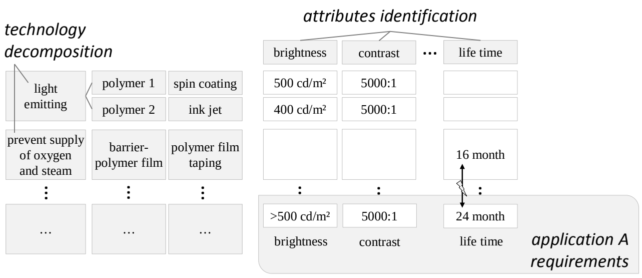

Fig. 2 Identification of relevant attributes and performance requirements

C. Phase 3: Identify alternative technologies and concepts

Both previous phases regard the currently used and known technologies. However, emergent technologies and other relevant technologies, which might better fit the requirements of the attribute(s), have to be identified by scanning the technology landscape. In the analyzed case of the OLED-technology, it could be concluded that the lifetime requirements cannot be yet met with the existing technology. Therefore, for the functions – assigned to the low-performed attribute(s) – new materials and/or processes should be investigated, which potentially are able to increase the performance. Also, relevant technologies and their performance profile and relevant technology experts need to be identified. In the use case, shown in figure x.x, a new material and a new connection technology were identified. Both have the potential to increase the barrier characteristics and, therefore, the lifetime, to the requested 24 months.

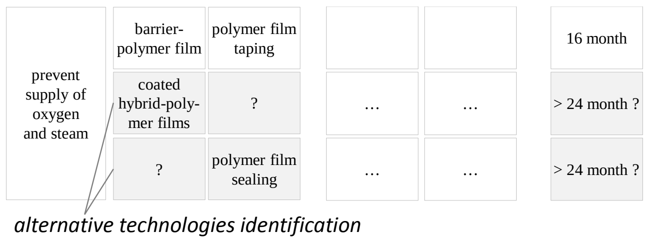

Fig. 3 Identification of alternative and emergent technologies

D. Phase 4: Visualization of technology readiness and mapping of the attribute-specific technology performance development

The visualization occurs concerning every relevant attribute. This means that the performance development will be tracked and mapped for each attribute and visualized graphically.

From the collected data, the application-specific technology readiness can be deduced (a technology readiness value for every relevant attribute of the application). A technology readiness of 100% corresponds to the minimum required attribute performance for the application. The value can lie between 0 (the attribute cannot be reached at all) and theoretically ∞., whereas a technology readiness value of 100% exceeds the minimum required performance.

Principally, the following graphical analysis can be realized:

- Chronological development of the attribute performance for different technologies: the user can picture the chronological performance development for an attribute to benchmark the attribute-specific technology readiness of different technologies

- Chronological performance development of all attributes for a technology: the user can picture the chronological performance development of all related attributes for a technology (based on the existing technology options). The technology readiness values of the relevant attributes can be estimated for different applications. The user can distinguish, for every technology option, which attributes are still underdeveloped.

Based on the transparent decomposition of the technology and the past performance development of the technology attributes, their further development needs to be forecasted. Therefore, experts can be interviewed concerning future technology development using the technological parameters of the attributes, according to the findings of the leading research institutes in a previous step. Also, other methods of technology forecasting should be used to provide a comprehensive presentation of the possible technology performance development and enable a proactive technology management, which might influence technology readiness and enable the technology user to be one of the earliest adopters at the most appropriate time.

V. Conclusions

Defining the current readiness and forecasting the future development of technologies represent a task of high strategic relevance for companies.

The literature review identified the existing gap in the technology readiness model landscape. Detailed analysis on an application level enables companies, as well as technology users, investors and technology developers, to decide in the case of each specific application as to whether the technology has reached the readiness to apply in the defined purpose and if the current technology performances match the requirements from the market and usage side.

The crucial step to achieve precise deliverables is the decomposition of the technology into its functions and attributes. This analysis step provides a sophisticated comprehension of the technology parameters and its limits. In particular, technology developers could use these findings to identify white spots in the research and development and these should be taken into account in their technology strategy.

The technology readiness model is divided into four phases to support applicability in practice and guide the involved parties to understand the aim of each phase. For a better understanding, the model was described in a use case of OLED- technology, even though the model was tested in quite a few more cases. As such, the application and attribute-specific technology performance development analysis and readiness assessment can support different departments in companies and reduce the risk of adopting too early or missing some technology development in order to be competitive and market leading.

The limitations of the model lie in the assumption that an attribute will be influenced just by the technology/ies of a single function (e.g. the attribute "brightness" will be influenced just by the function "light emitting" and, therefore, just form the light-emitting technologies). The occurring interrelation of attributes and their influence upon technology readiness should be considered in further research activities. Further, the model should be extended to software-related and/or non-physical technologies and be proven in more, and especially different, technology areas, so that the model can be continually improved. of a technology (on an attribute-level) for the technology's implementation within a specific

References

[1] L. F. Leite, F. M. Lins Mendes, V. M. Antunes Parreiras, F. A. Machado Gomes, and J. G. Gomes Wiezel, "Developing a technology readiness assessment methodology for an energy company," in *IAMOT 2015 Conference Proceedings*, 2015, paper 276, pp. 2026-2039.

[2] M. T. Martin, M. V. Román, and M. Recio, *Definition and Measurement of the Technology Readiness*, in Encyclopedia of Healthcare Information Systems. Hershey, PA: IGI Global, 2008.

[3] S. R. Walk *Quantitative Technology Forecasting Techniques*, in Technological Change, InTech, 2012, DOI: 10.5772/38024.

[4] A. T Roper, S. W. Cunningham, A. L. Porter, T. W. Mason, F. A. Rossini, and J. Banks, *Forecasting and Management of Technology*, 2nd ed., Hoboken, NJ, USA: John Wiley & Sons Inc., 2011.

[5] *The Oxford English dictionary,* [Online]. Available: http://www.oed.com.

[6] T. Mettler, "Maturity assessment models: a design science research approach," *International Journal of Society Systems Science*, vol. 3, no. 1/2, pp.81-98, 2011.

[7] B. Hicks, A. Larrson, S. Culley, and T. Larrson, "A methodology for evaluating technology readiness during product development," in *17th International Conference on Engineering Design, ICED'09*, 2009, p. 3-157--3-168.

[8] L. Aiman-Smith, N. Goodrich, D. Roberts, and J. Scinta, "Assessing your organization's potential for value innovation," *Research Technology Management*, vol. 48, no 2, pp. 37–42, 2005.

[9] J. Fenn and M. Raskino, *Mastering the Hype Cycle: How to Choose the Right Innovation at the Right Time*, Boston: Harvard Business Review Press, 2008.

[10] J. C. Mankins (1995) "Technology Readiness Levels," [Online] Available: http://www.hq.nasa.gov/office/codeq/trl/trl.pdf.

[11] EARTO (2014) "The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations," [Online]. Available: http://www.earto.eu/fileadmin/content/03_Publications/The_TRL_Scale_as_a_R_I_Policy_Tool_-_EARTO_Recommendations_-_Final.pdf.

[12] M. Eisman, and D. Gonzales (1997) "Life Cycle Cost Assessments for Military Transatmospheric Vehicles," [Online]. Available: http://www.rand.org/content/dam/rand/pubs/monograph_reports/2009/MR893.pdf.

[13] J. Smith, "An Alternative to Technology Readiness Levels for Non-Developmental Item (NDI) Software," Carnegie Mellon University, Pittsburgh, CMU/SEI-2004-TR-013, 2004.

[14] M. Nedele and B. Drapp, "Messung des Reifegrades von Technologien," DLR and Fraunhofer TEG, Stuttgart, 2006.

[15] R. Burgelman, C. Christensen, and S. Wheelwright, *Strategic Management of Technology and Innovation*, 5th ed., Boston: McGraw-Hill Irwin, 2008.

[16] G. H. Gaynor, *Handbook of Technology Management*, 1st ed., Boston: McGraw-Hill Irwin, 1996.

[17] G. Tesar, S. W. Anderson, S. Ghosh, and T. Bramorski, *Strategic Technology Management: Building Bridges between Sciences, Engineering and Business Management*, 2nd ed., World Scientific Publishing, 2008.

[18] O. L. de Weck, D. Roos, and C. L. Magee, *Engineering Systems: Meeting Human Needs in a Complex Technological World*, Cambridge, MA: MIT Press, 2011.

[19] *Academic American encyclopedia*, Danbury, Conn: Grolier, 1986.

[20] E. Szczerbicki, and N. T. Nguyễn, *Smart information and knowledge management: Advances, challenges, and critical issues,* Berlin, Germany: Springer, 2010.

[21] F. Albar, *Technology assessment: Forecasting future adoption of emerging technologies*, Berlin, Germany: Erich Schmidt, 2011.