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Review of Methodologies for the Assessment of the Technological Capability of RTOs

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I. INTRODUCTION

In a continuously fluctuating, dynamic environment, organisations in all areas must quickly adapt to changes, such as the digital transformation, in order to ensure their sustainable development and growth. Furthermore, the capability of generating and using new technologies effectively and efficiently has a direct impact on the organisations competitiveness and long-term success. Organisations with a high technological capability are able to achieve a higher differentiation through more innovative products and increase efficiency or reduce costs through process innovations.

Moreover, an advancing liberalisation of markets intensifies competition not only for regular businesses, but also for Research and Technology Organisations (RTOs) that cooperate with these businesses. RTOs face the challenge of shorter innovation cycles while at the same time the demand for advanced and market-ready product and process solutions rises.

In order to be successful, RTOs have to pursue technical solutions that eventually lead to state-of-the-art products and services. It is therefore necessary for RTOs to use technological resources and therefore acquire or maintain technological capabilities that make it possible to achieve the aforementioned technical solutions, which ultimately end in high-quality and innovative products. Hence, sustainable success and a competitive edge are the consequence of technological capabilities that are being optimally cultivated and used. [15]

Subsequently, RTOs have to be able to analyse and assess their technological capability, given that an advanced technological capability is imperative for their competitiveness. A tool or method that assesses the technological capability of RTOs in an objective and practical way, while being suitable to the special requirements of RTOs, is needed. While several other authors have previously developed models for the assessment of technological capability in organisations, there is yet to be developed a method that fully meets the specific requirements of RTOs. Therefore, in this paper, existing methodologies will be analysed and reviewed to identify the necessary requirements that a methodology needs to fulfil in order to be applicable for the analysis and assessment of the technological capability of RTOs.

II. RELATED RESULTS IN THE LITERATURE

Having motivated the necessity of a methodology for the analysis and assessment of the technological capability of RTOs, an overview about other existing research in the areas of RTOs in general as well as technological capability of organisations and the assessment of technological capability will be outlined in the following chapter.

RTOs are generally defined as organisations "that mainly provide research and development, technology and innovation services to enterprises, governments and other clients" [4]. Therefore, RTOs carry out activities between the "Technology Readiness Levels" 3 (detection concept of critical functions and/or properties) to 6 (model demonstration of critical functions in relevant environment) [17]. While universities concentrate on teaching and fundamental research, RTOs conduct applied research and use the generated knowledge in industrial innovation and development projects. Moreover, three key work areas of RTOs can be defined [1]:

- Satisfying the demand of public institutions for knowledge-related services
- Providing user- or problem-oriented research to solve societal challenges
- Supporting and developing the technological capacity of the industry

In contrast to the unambiguously definition of RTOs, there is no clear and consensual definition of technological capability in the literature. Thus, various definitions of technological capability and its embedding in a business or RTO context are prevalent. A reason for this may be the different currents within competence research [18]. Moreover, the analysis of related research work found that authors often define the term as a function of their

respective research goals. However, it is noticeable that the definitions mostly use the central terms "ability", "skill", "knowledge" and "resource". For example Figueiredo [5] defines technological capability exclusively as resources needed to generate and manage improvements in product and process organization, equipment and technical projects. Wang et al. [16] also refer to the ability of technological capability to develop and design new products and processes. Other authors such as Panda and Ramanathan [13] define technological capability more comprehensively as a set of functional capabilities that are reflected in the company's performance through various technological activities. In this paper various definitions will be considered.

Currenty, there are multiple methodologies and models for the assessment of technological capability in existence. However, they mainly focus on the application in production companies. An unreflected application of these methologies for the analysis and assessment of the technological capability of RTOs is not possible without adaptation to the specific requirements.

In addition, some of the methodologies mainly focus only on selected aspects (e.g. focus on resources - example: „Technology ATLAS" [2] or focus on technological capabilities in a sense of intangible skills and knowledge and largely disregard resources [14] – example: Phaal's „Technology Management Process Assessment"). The existing methodologies will be analysed and assessed according the the requirements of RTOs in this paper.

III. DESCRIPTION OF THE METHOD

To identify the requirements for the analysis and assessment of the technological capability of RTOs, the following approach will be followed within this paper. Firstly, research and development (R&D), technology, technological capability as well as RTOs will be defined on the basis of previous research work. Secondly, requirements of a methodology that could be used in the context of RTOs and was also developed in previous research will be presented. Thirdly, existing methodologies and their assessment according to the pre-set requirements will be elaborated. Lastly, the results will be discussed and a conclusion whether the existing methodologies are suitable for the use in RTOs will be given.

IV. RESULTS AND DISCUSSIONS

As mentioned above, requirements to the specific use of technological capability methodologies have been derived in a previous paper. Therefore, these requirements are introduced in the following table 1. Existing methodologies will be analysed and reviewed on the basis of these requirements.

Table 1: Requirements for a methodology for the analysis and assessment of the technological capability of RTOs

Require-ments	**Description**
Applicability in Research and Technology Organi-sations	
Project focus	RTOs perform their work in projects, so that it must be possible to analyse and evaluate projects using the method.
Openness	Various RTOs work on a very broad spectrum of topics, which must not restrict the application of the method.
Applied re-search	RTOs carry out activities between the "Technology Readiness Levels" 3 (detection concept of critical func-tions and/or properties) to 6 (model demonstration of critical functions in relevant environment), which have to be analysed by using the method.
Analysis & evaluability of technological capability	
Technology-independent	Different technologies are used in ap-plied research, so that the application of the method cannot be limited to in-dividual technologies.
Focus on technological resources & capabilities	The implementation of applied re-search activities requires technologi-cal resources and capabilities which must be analysed and evaluated using the method.
Targeted application	
Comprehensi-bility	The method must be understandable so that it can be applied with little preparation time.
Low effort	The application of the method must be accompanied by little effort, so that the daily business of the organi-sation to be analysed and evaluated is not disturbed more than necessary.
Degrees of freedom in application	Due to the wide range of topics that RTOs deal with using a variety of different technologies, a certain de-gree of freedom in the application of the method must be possible without distorting the results.
Practical results	
Comparability	The method of evaluation must be standardised in order to ensure the comparability of evaluation results between RTOs.

Implementation- oriented	The application of the method is intended to identify weaknesses in the RTOs, identify potential for improvement and provide practical assistance.

The existing methodologies that could be considered as suitable approaches for the analysis and assessment of the technological capability of RTOs will be described in the following paragraphs. As a conclusion the following methodologies will be assessed according to the above mentioned requirements that need to be fulfilled.

The *Technology ATLAS*, developed by the Asian and Pacific Center for Technology Transfer [2], assesses technological capability on the basis of four factors that are ranked according to their degree of maturity from 1 to 6. The factor "Technoware" assesses physical resources such as machines and tools. The factor "Infoware" assesses the existing knowledge of using hardware for the organisation's activities and processes. "Humanware" assesses the human capabilities and skills level that is needed to use hardware and infoware for the organisation's activities. "Orgaware" describes organisational and managerial structures to coordinate the aforementioned factors and the organisation's activities. This model is inappropriate for the use in RTO's due to the lack of concise definitions of each degree of maturity. It can therefore not be used to compare RTO's.

The *Technology Audit Model* by Garcia-Arreola [8] is an extensive three-layer (categories, valuation area, elements) model for the assessment of technological capability. On the highest layer, six categories are defined:

- Technological Environment
- Technologies Categorization
- Markets and Competitors
- Innovation Process
- Value-added Functions
- Acquisition and Exploitation of Technology

These six categories comprise 20 valuation areas which are then subdivided into 43 elements. A questionnaire serves the sake of assessment and is conducted by internal experts or auditors by the use of a five-step likert-scale.

Despite its extensiveness, the Technology Audit Model exhibits several weaknesses. As the model tries to assess the technological capability of organisations, it must incorporate all elements that are directly or indirectly involved in the relation of organisations and the use of technology. This is very complex in the case of large-scale organisations and therefore results in a disproportionally high effort. Furthermore, non-technological assessment criteria that contribute to an organisation's success such as markets and competitors, innovation processes etc. are also analysed. As those elements are not in the focus of the methodology for the analysis and assessment the Technology Audit is not meeting the above mentioned requirements.

The *Technology Management Process Assessment* by Phaal et al. [14] is a top-down assessment model that proceeds in three phases that are conducted in employee-workshops. In the first phase, the "Strategic Overview", the organisation is subdivided in technology areas and business units. The impact of each technology area on the business units is then assessed according to its delivered value to the unit, effort that is made and risk using a four-point scale ("high", "medium", "low", "not significant"). Naturally, these factors correlate positively. If they fail to do so, the technology area is then evaluated in the second phase, the "Process Overview". In this phase key technologies as well as current and future technology management activities of the technology areas identified in phase 1 are mapped. In order to facilitate the identification of activities, workshop participants are encouraged to identify significant events over a period of time (e.g. the last five years) related to the respective key technologies. The associated activities will then be categorised using Gregory's Five-process model (identification, selection, acquisition, use and protection of technologies, cf. [8]) and used as a basis for assessing technology management effectiveness on the basis of inputs, processes and outputs. Each of these elements is linked to a statement:

- Input: "The requirements for this activity were always clearly defined".
- Process: "The activity was always well controlled"
- Output: "The results of the activity were always used"

These are then evaluated on a five point scale (1 ="agree entirely",…,5="disagree at all"). In the third phase, the "Process Investigation", specific process areas are mapped in detail to identify good-practices and improvement-worthy areas. The approach is entirely qualitatively and rather concentrates on functions and strengths and weaknesses of technology management than on technology contents. It is therefore only conditionally usable to assess technological capability. [7]

The *Technological Capability Audit Tool* [19] is an assessment tool that aims to combine knowledge of key competences for the realisation of technological innovations with development stages of technological capabilities that enable an organisation to select and deploy technologies to gain a strategic competitive advantage. It uses nine main components: "Awareness", "Searching", "Core Competencies", "Strategy", "Assessment", "Acquisition", "Implementation, Absorption and Operation", "Learning", "Exploiting external linkages and incentives" that are self-explaining to build a survey to assess an organisations technological capability. 4 different statues are used to evaluate the condition of a main component: "Unaware or passive", "Reactive", "Strategic", "Creative". These four types allow each major component to be assigned a specific

number of points. Although the result of the assessment delivers numeric results, the model leads to a highly subjective evaluation. It is therefore not appropriate due to the comparability aspect of the requirements.

The following table 2 summarizes the four analysed methodologies and reviews the suitability of those methodologies for the application for the analysis and assessment of the technological capability of RTOs according to the requirements described in table 1.

Table 2: Summary of analysed methodologies assessed by the requirements for a methodology for the analysis and assessment of the technological capability of RTOs

Requirements	**Technology ATLAS**	**Technology Audit Model**	**Technology Mgmt. Process Assessment**	**Technology Capability Audit Tool**
Applicability in Research and Technology Organisations				
Project focus	◕	◑	◑	◑
Openness	○	●	○	●
Applied research	◔	◔	●	◔
Analysis & evaluability of technological capability				
Technology-independent	◕	◕	◕	◕
Focus on technological resources & capabilities	◕	◑	◑	◑
Targeted application				
Comprehensibility	◔	◑	◕	◕
Low effort	◔	◔	◔	◔
Degrees of freedom in application	◔	◔	◔	◔
Practical results				
Comparability	◕	◕	◔	◑
Implementation-oriented	◔	◔	◔	◔

Legend:

○ The model / method does not meet the requirement.

◔ The model / method hardly meets the requirement.

◑ The model / method partially meets the requirement.

◕ The model / method meets the requirement mostly.

● The model / method completely fulfils the requirement.

V. CONCLUSIONS AND OUTLOOK

In a first step the requirements for the analysis and assessment of the technological capability of RTOs have been identified based on previous research work of the authors as well as the definition and interpretation of the terms "RTO" and "technological capability". In a second step, possible methodologies for the analysis and assessment of the technological capability have been identified and briefly been described. As a summary, the identified methodologies have been assessed according to the identified requirements that needs to be fulfilled. As a result, no of the analysed methodologies fully meet all the defined requirements and therefore, the need for the creation of a new methodology for the analysis and assessment of the technological capability of RTOs could be pointed out within this paper. Further research work of the authors will focus on the creation of a methodology that fully meets the requirements described in this paper.

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