

Article

Support for the Development of Technological Innovations at an R&D Organisation

Beata Poteralska 

Department of Management, Faculty of Law and Social Sciences, Jan Kochanowski University of Kielce,
25-406 Kielce, Poland; Beata.Poteralska@ujk.edu.pl; Tel.: +48-600-280-215

Abstract: Effective development of technological innovations requires efficient management at the stages of their generation, realisation, and their implementation. For this aim, concepts such as foresight, technology assessment, and organisational capabilities assessment can be applied; however, so far they have been used mainly individually or sometimes combined but to a very limited extent. Moreover, they are not used comprehensively, but only selectively, e.g., at some stages of the innovation processes. The research problem undertaken in the paper concerns the effectiveness of the integration of these concepts: future research (mainly foresight), technology assessment, and organisational capabilities assessment for the needs of supporting innovation processes. The paper is aimed at presenting an original approach assuming the integration of the aforementioned triad. The proposed approach has been developed individually by the paper's author on the basis of (1) state of the art analysis comprising both theoretical approaches and practical examples of individual and combined application of the concepts analysed, and (2) the author's practical experience resulting from research projects conducted collectively. The research result comprises an original matrix approach where the individual concepts of the triad are applied in a way enabling their mutual complementation at all successive stages of the innovation process. The approach proposed comprises modules referring to the succeeding stages of the innovation process, namely generation, realisation and application of technological innovations. The areas of the approach application and possible directions of its further development are presented.

Keywords: R&D organisation; technological innovations; foresight; technology assessment; organisational capabilities assessment



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1. Introduction

The development and implementation of innovative technological solutions is the basis for the growth of any economy. At the same time, the execution of the processes of creating and applying innovations must take into account the conditions of sustainable development, which include, among others, the issues of effective use of resources, energy savings, technical safety, and environmental protection against the effects of industrial activity. To fulfil these conditions, innovative technological undertakings require effective management at the subsequent stages of the innovation process.

Among the classics in the area of management, innovation management was dealt with by, among others, Adamiecki [1], Ansoff [2], Drucker [3], Fayol [4], Obłój [5], Taylor [6], and Webber [7]. Strategies concerning the application of innovations in the management of organisations have been the focus of various management schools, starting with Ansoff [8], who is considered to be the forerunner of the concept of enterprise development strategy. The importance of innovations was emphasised in the 1960s by Drucker [9] and in the 1980s by Peters and Waterman [10]. The idea introduced into the science of management by Drucker [11] that it is innovation, and not the increase in efficiency or quality, that constitutes the competitive advantage, has gained popularity as a result of the changes taking place in the 1990s, when the importance and need for innovation increased. Currently,

innovation management is a key element of management at the level of enterprises, reflected in the strategy of their operation and contributing to the achievement of competitive advantage [12–14].

Despite the very rich literature on innovation management, many specific issues in this area remain unresolved. Among them, one can indicate, for example, the issue of the relationship between innovations, resources and the obtained efficiency of operation [15,16]. Despite a few decades of analysis on innovation management, there is still a lack of clear and consistent results that would provide convincing examples of good practice for the application by entrepreneurs and R&D organisations [13].

The sources of numerous innovations are activities carried out in specialised R&D organisations. They develop innovations with a focus on their implementation in economic practice. Effective development of innovations requires efficient management at the stages of generating, realising, and implementing innovations, including the identification and overcoming of barriers and challenges as part of those innovation processes [17,18]. “Innovation management is the discipline of managing processes in innovation” [19]. Among the methodologies, concepts or approaches (various terms are used in the literature) effectively supporting innovation processes, according to the author, future research, with particular emphasis on foresight as well as technology assessment and organisational capabilities assessment should be applied. Foresight means a systematic look into the future, enabling the identification of strategic research and drawing conclusions for the present [20,21] and as such can be used for supporting the stage of generating ideas within the innovation process. Technology assessment tackled in the paper refers to business and non-governmental applications [22] and is focused on the assessment of technological readiness, commercial and innovation potential, the results of which are used in the course of the innovation development. Organisational capabilities are defined as the state of the organisation’s resources and skills assessed from the point of view of its development capability [23]. The author proposes a triad approach integrating elements of the indicated three partial methodologies. In order to facilitate the perception of the paper, they are called concepts. This term is used by other authors both in relation to foresight [24], technology assessment [25,26], and organisational capabilities assessment [27].

The research problem undertaken concerns the effectiveness of the integration of the analysed concepts, i.e., future research (foresight), technology assessment, and organisational capabilities assessment in supporting innovation processes.

The scientific goal is to develop an approach of supporting processes of the generation and realisation of technological innovations in an R&D organisation. It proposes to use a triad of concepts in an integrated and comprehensive way for the purpose of effective support for the development of technological innovations. They are used at the succeeding stages of the innovation process in an integrated and complementary way.

The paper is structured as follows: At first, it draws on the literature review and discusses the theoretical and practical approaches of both individual and combined use of concepts analysed (foresight, technology assessment, and organisational capabilities assessment) for the needs of supporting innovation processes and it analyses possible directions of their further development. Against the conducted literature review, on the basis of the author’s own experience in the execution of innovative projects, a proposal of an original approach for supporting processes of the generation and realisation of technological innovations in an R&D organisation is presented. The paper is summed up with conclusions indicating the possible directions of the proposed approach development in the future.

2. Literature Review

The scope of the state of the art analysis covers the aspects of individual application of future research methods, mainly foresight, of technology assessment and organisational capabilities assessment to support the development of innovations. Since this has been the subject of the author’s scientific interests for several years [28–30], the analysis covers

several hundred publications in this field analysed over the years (academic literature (including mainly two databases: ISI Web of Science and Scopus) and grey literature (mainly reports and working papers)) and the results of a few dozen projects executed with the participation of the paper's author. In-depth literature reviews and the author's experience allow the drawing of conclusions on the reasonableness of the individual use of these concepts for the needs of supporting the innovation processes and to indicate advisable directions of their further development. Apart from the analysis of the individual application of particular concepts, the next stage of the literature review consists in the analysis of theoretical and practical approaches regarding the combined use of the indicated concepts in the formula of complex models supporting the generation and realisation of technological innovations. In the course of the literature review, a joint use of groups of keywords, i.e., 'future studies/future research/foresight', and 'technology assessment', and 'organisational capabilities/intellectual capital/resources/organisation's potential assessment' were used. The integrated application of the concepts in question is a rare topic in the literature. In total approximately 50 publications were collected, out of which, after reading whole papers, 25 were acknowledged as presenting some aspects of joint application of the concepts in question that were assumed as worth further analysis. The detailed analysis enabled the confirmation of the need of their complex use. The literature review comprises the concepts that constitute the triad proposed by the author, (foresight, technology assessment, and organisational capabilities assessment) supporting decision-making processes in the field of generating, realising, and implementing technological innovations. The analysis conducted refers to concepts used individually and integrated with one another (Table 1).

Table 1. Literature review on individual and integrated use of tools analysed.

Individual Use of Concepts Supporting Innovation Processes			
Foresight	Technology Assessment (2nd Stream)	Organisational Capabilities Assessment	
Irvine and Martin 1984 [20] Coates 1985 [31] Martin 1995 [32] Grupp and Linstone 1999 [33] Tubke et al. 2001 [34] Kuhlman 2002 [35] Hines 2002 [36] Barré 2002 [37] Georgiou 2003 [38] Cuhls 2003 [39] Harper 2005 [40] van der Duin 2006 [41] Giaoutzi and Sapio 2013 [42] Sacio et al. 2015 [43] Miles et al. 2016 [44] Dadkhah et al. 2018 [45] Brown and Barnard 2019 [46] Gordon et al. 2020 [47] Gariboldi et al. 2021 [48] Robinson et al. 2021 [49]	Brandscomb 1993 [50] Mankins 1995 [51] van den Ende et al. 1998 [52] Berloznik and van Langenhove 1998 [53] Rezagholi, Frey 2000 [54] Hsu et al. 2003 [55] Bhatnagar, Jancy 2003 [56] Fleischer et al. 2005 [57] Assefa et al. 2005 [58] Davila et al. 2006 [59] Kim et al. 2007 [60] Lucheng et al. 2007 [61] Hongjun et at 2007 [62] Rui et al. 2007 [63] Tran and Daim 2008 [22] Kulkarni, Ramachandra 2009 [64] DTAG 2010 [65] Mazurkiewicz et al. 2015 [66]	Barney 1991 [67] Romanowska 1998 [68] Barney, Mackey 2005 [69] Lichtarski 2007 [70] Seppänen, Mäkinen 2007 [71] Seppänen 2009 [72] Gierszewska, Romanowska 2009 [73] Penc-Pietrzak 2010 [74] Kałkowska et al. 2010 [75] Godziszewski et al. 2011 [76] Jokiel 2012 [77] Masłyk-Musiał et al. 2012 [78] Zakrzewska-Bielawska 2012 [79] Stabryła 2015 [80] Sobieraj 2017 [81]	
Integrated Use of Concepts Supporting Innovation Processes			
Foresight and Technology assessment	Foresight and Organisational Capabilities Assessment	Technology assessment and Organisational capabilities assessment	Foresight, Technology assessment and Organisational capabilities assessment
Grupp 1993 [82] Porter 1995 [83] Loveridge 1996 [84] Kuhlmann 2002 [35] Rip 2002 [85] Kameoka et al. 2004 [86] Meyer et al. 2021 [87]	Sripaipan 2006 [88] Popper 2008 [89] Szewczyk et al. 2008 [90] Fleisher, Bensoussan 2015 [91] Nazarko et al. 2017 [92]	Daim et al. 2011 [93]	Lucheng et at. 2010 [94] Nazarko 2013 [95] Ziółkowski 2014 [96]

Source: Author.

At first, individual use of each concept is analysed. Review of the rich literature on foresight shows that foresight is a recognised concept used to model, explore, and test variant visions of the future, those which are desirable and unexpected, possible and probable [33,97]. Foresight supports decision-making processes, because it enables one to create strategies that anticipate possible opportunities and threats, and, in this way, contributes to increasing the flexibility of business organisations and increasing the effectiveness of the execution of development plans in the public sector [34,39,44].

The observed changes in foresight research over the years and the ongoing process of developing the research methodology in this area are, among others, a consequence of changes in recent decades in the world, comprising economic, social, cultural, etc., aspects [98]. Some researchers point out [36] that, despite the unquestionable need to increase the innovation level, the tools used in foresight projects remain predominantly traditional and need to be changed. The methods used are not effective enough. Methods used in the past may no longer be relevant for tackling contemporary problems today [99]. It is necessary to search for new methods and new approaches [98–101]. For example, many foresight activities include horizon scanning [102] and in recent years horizon scanning has become more and more automated. In the case of the prospective and anticipatory phases of foresight they can be “fully intertwined with the Horizon Scanning activities” [24]. New methodological concepts currently under development in this area comprise combining horizon scanning with a set of indicators proposed for particular radical innovation breakthrough [103].

Furthermore, in foresight projects described in the literature, it is indicated that there is a need to take into account aspects for the analysis of which, in the author’s opinion, the method of technology assessment can be used. These aspects comprise the characteristics of technology, market needs, and non-market needs, e.g., concerning environmental requirements or social issues. Their analysis for the needs of foresight is carried out in an expert manner. The use of the results of technology assessment of innovations developed in the past or currently under development, with respect, among others, to their commercial and innovative potential, allows one to enrich the foresight process, thanks to taking into account the experience of previously conducted innovation processes which can be very useful while generating new innovative topics. On the other hand, attempts are made to use technology assessment for shaping the future, which is an aim of foresight [21]. It can be carried out “through critical and constructive assessment of existing visions and the assumptions underlying them” [104].

Moreover, executors of foresight projects point out, on the one hand, the need to take into account the existing organisational capabilities as one of the elements influencing the selection of foresight methods to be used in a particular project, and on the other hand, the need to develop the capabilities as a condition indispensable for effective conduct of the process of developing innovations generated with the use of foresight. However, there is a lack in the literature of complex approaches to solve the issue of linking foresight with organisational capabilities assessment.

The paper’s author indicates the need to use concepts supplementing foresight with aspects related to technology assessment and organisational capabilities assessment. Such an approach, assuming the use of the indicated triad of concepts, allows one to generate future-oriented technological solutions while taking into account the previous experience resulting from the development of technological innovations, and to generate innovations planned to be created in the future, where specific organisational capabilities are necessary for their development.

A growing importance of technology assessment is directly related to the significance of technology as a key factor facilitating a country’s economic and social development, and the development of enterprises and public institutions [105,106]. Technology assessment can be conducted within two basic streams [22]: (1) the traditional and mainstream technology assessment that is linked to the support of decision-making in the public sphere and focused on the social aspects of technology; and (2) an additional, fast-growing stream

in technology assessment for the business and non-governmental sphere, including the use of technology assessment in academic and industrial circles, and by individual researchers developing technologies.

The author of the paper focuses on the second stream and defines technology assessment as “a process of comprehensive analysis of a technological innovation, understood as a technologically new or improved product or process, at the stage of its generation, realisation and application, supported by the use of future research methods, mainly foresight, and methods of organisational capabilities assessment” [107] (p. 82). Technology assessment is carried out in many ways using methodologies that take into account techniques and methods adjusted to specific research or business needs [52,53]. Although technology assessment methods have been developed since the 1960s, there is still a strong need to further develop them and increase the effectiveness of their use [22]. New methods and models for technology assessment are still being developed and their applicability in different contexts is being explored [108]. Despite the existence of many different methods and tools and their continuous development, there are no universal methods to be used. This is due, among others, to the fact that technology assessment is an evolving area that is subject to constant change in which new challenges arise for researchers. These challenges are, among others, connected with a need to include in technology assessment specific aspects, e.g., those related to sustainable development. It results in the necessity to develop new methods and approaches [93]. The introduced new tools and methods, complementary to the already known methods and used in management, contribute to further dissemination of technology assessment.

Technology assessment carried out by means of the analysed methods is not integrated with the organisational capabilities assessment, although the possibility of developing and implementing technologies is inherently related to organisational capabilities—both the existing capabilities and those planned to be expanded or created. The currently used theoretical and practical approaches take this interconnection into account only to a marginal extent. At present, some aspects concerning organisational capabilities (e.g., available infrastructural, human and financial resources, the existing technological base) constitute criteria in technology assessment only incidentally in some of the projects analysed.

On the other hand, it is necessary to use technology assessment results for the needs of foresight. This approach is not applied in practice, although it seems natural to use it, even considering the fact that at its beginning technology assessment was associated with forecasting considered to be the precursor of foresight [105] and still considered to overlap with foresight [21]. Technology assessment results should be utilised in the course of generating research topics, as they provide information on the innovation potential, market demand, and possibilities of practical implementation of innovations that have already been developed and can constitute a source of the next technological innovations.

The mobilisation of organisational capabilities is an indispensable element for conducting foresight and implementing its results in a form of technological innovations [109–111]. Although the application of foresight methods allows one to generate future directions of technological, economic, or social development, decision-makers also need information about the existing organisational capabilities that are necessary to execute the indicated future research directions [112]. Furthermore, the existing organisational capabilities also determine the scope of possible activities that can be undertaken in the future. Access to information on the available organisational capabilities is also necessary in the course of making decisions—while taking into account the technology assessment results—on the continuation or termination of the development of a particular technological solution.

Organisational capabilities are understood as the state of strategic and operational resources and competences of an organisation enabling execution of already undertaken activities and shaping the development of the organisation in the future [107] (p. 104). The analysis of organisational capabilities includes the diagnosis and assessment of all elements of an organisation’s tangible and intangible resources and competences in order to assess its ability to meet the requirements of a competitive environment and to expand

in the future [79]. The literature provides information on the methods used primarily to assess the capabilities of an enterprise [73,74,79,81]. According to the paper's author, many of these methods can also be used for the needs of assessing other types of organisations, apart from enterprises, including R&D organisations. It should be noted, however, that the use of methods of organisational capabilities assessment proposed in the literature does not assume their interconnection with the use of technology assessment and foresight methods. Moreover, the need to develop methods for organisational capabilities assessment of R&D organisations to be used in the context of supporting the execution of innovation processes should be emphasised, including the need to develop such methods in conjunction with foresight and technology assessment methods.

The next step of the literature review concerned the joint application of the analysed concepts. Foresight, technology assessment, and organisational capabilities assessment activities undertaken by scientific communities in a range of countries are commonly independent one from another [84], although these areas of innovative activities are inter-related. On the other hand, industrial organisations have the practical ability of combining individual concepts in order to select technological solutions of a potentially high significance, both commercial and social [113]. In enterprises, actions for idea generation, assessment of technological solutions developed, and the utilisation of the potential in place are frequently integrated [84], and the need for their interlinking is understood.

The state of the art analysis, comprising theoretical approaches, models, and practical examples of combining the concepts in question supporting the processes of generating, realising, and implementing innovations helps to identify, both in the literature and in practice, only a limited number of instances of such integrations. The majority of them concern combinations of two out of the three concepts analysed, mainly foresight combined with technology assessment. The concepts are not applied in a complex way, but only selectively, e.g., in relation to selected stages of innovation processes. There are identified examples of combining foresight with technology assessment [35,83–86], especially while conducting Delphi surveys [87,114] in order to support the decision-making process regarding the selection of technological solutions that should be developed or adopted; however, there is a lack of a crucial stage, in the author's opinion, namely, the analysis of the availability of organisational capabilities necessary for the development of technologies and their implementation. Moreover, the literature review conducted allows only identifying individual examples of projects in which aspects of the analysis of organisational capabilities are taken into account in the framework of technology assessment, but this is applied exclusively as individual criteria for technology assessment [93,94]. The attempts to take into account the existing organisational capabilities in foresight projects were also made within research projects co-executed by the paper's author [28,115]; however, within them, organisational capabilities assessment was carried out fragmentarily, e.g., concerned only human resources, or was carried out to a large extent in an intuitive way or with the use of a very limited set of criteria. Given the unquestionable importance of organisational capabilities in the processes of the development and implementation of technological innovations, there is a need to develop an approach to assess both the existing and potentially necessary extended organisational capabilities in conjunction with other concepts, i.e., foresight and technology assessment.

The analysis shows that the joint use of concepts, i.e., foresight, technology assessment, and organisational capabilities assessment in R&D organisations aimed at support for the innovation process, is a subject of few scientific analyses and only a limited number of practical applications.

However, due to the mutual complementarity and the possibility of complex application of the indicated concepts, it is reasonable to use them as a triad, including them in the process of generating, realising, and implementing innovative technological solutions. The conducted state of the art analyses (theoretical analyses and practical undertakings) and the author's own experience resulting from the execution of research projects confirm the legitimacy of applying such an approach.

3. Methodology

The approach of integrating foresight, technology assessment and organisational capabilities assessment for the needs of supporting innovation generation, realisation and implementation by an R&D organisation has been proposed as a result of the individual process carried out by the author while taking into account the existing body of knowledge, namely:

- Literature in the area of research methods used within foresight, technology assessment and organisational capabilities assessment,
- Literature concerning the possibilities of integrating the concepts of foresight, technology assessment and organisational capabilities assessment,
- Practical examples of combining the concepts in question, and
- The author's own experiences resulting from participation in the processes run in a collective way within projects applying the methods of foresight, technology assessment and organisational capabilities assessment indicating the weaknesses of an individual use of the concepts in question, and the need and advantages of their integration and application at all stages of the innovation process.

The process of creating the proposed approach aimed at supporting activities comprising the generation, realisation and implementation of technological innovations covered the stages as follows:

- Defining the objectives,
- Adopting the assumptions,
- Developing detailed modules referring to the particular stages of innovation processes: generation, realisation, and implementation, while taking into account the use of the triad of concepts: foresight, technology assessment and organisational capabilities assessment, and
- Implementing the approach in an R&D organisation.

The main objective of the proposed approach is to ensure effective support for the processes of generating, realising and implementing technological innovations by an R&D organisation.

The assumptions were made as follows:

- The proposed approach is meant for supporting strategic and operational decision-making processes in an R&D organisation referring to the generation, realisation and implementation of technological innovations,
- Three modules are distinguished, namely referring to the stages: generation, realisation and implementation of technological innovations,
- Within the detailed modules, the triad of the concepts: foresight, technology assessment and organisational capabilities assessment, is used in an integrated manner,
- Foresight is used for generating technological innovations; technology assessment comprises an analysis of innovations under development; and organisational capabilities assessment refers to the assessment of (1) operational capabilities used for the ongoing execution of tasks in the course of developing and implementing innovations and of (2) strategic capabilities aimed at building a stable position of an R&D organisation in the future,
- The modules are interrelated and the results of using the module at one stage constitute the necessary input for the application of the module at the next stage, namely, generating innovations as the basis for conducting the process of their development, and the end of the process of their realisation—the basis for starting activities aimed at their implementation,
- Interconnection of modules also takes place in the opposite direction to the course of the innovation process. This is the case with the innovation generation module—it is powered by both the results of the application of the innovation realisation module and the results of the use of the innovation implementation module, which provide input data to be used in the innovation generation process,

- On the operational layer, a project generator and algorithms relating to organisational capabilities assessment, identification of technological innovations, assessment of the implementation maturity level of technological solutions, and assessment of their commercial and innovation potential are used, and
- The proposed approach may be supplemented with additional elements (methods, procedures), if they are considered important in the process of its verification or practical application.

With regard to the individual modules of innovation generation, realisation and implementation, their objectives, assumptions, stages of executing activities within the module, and the applied algorithms were indicated.

4. Results

The literature review has affirmed the rationality of employing the proposed triad of concepts to support the realisation of innovation processes and has helped to identify very few attempts at combining them as part of theoretical models and practical instances of application. Recognising the rationality of applying these concepts as a fully integrated triad, the author has proposed an approach comprising the triad to support processes of generating, developing, and implementing technological innovations (that constitute new or substantially improved or modified products: devices, technologies, systems, materials) in R&D organisations.

An original matrix approach was applied, in which particular individual concepts are used at the subsequent stages of the innovation process (Figure 1).

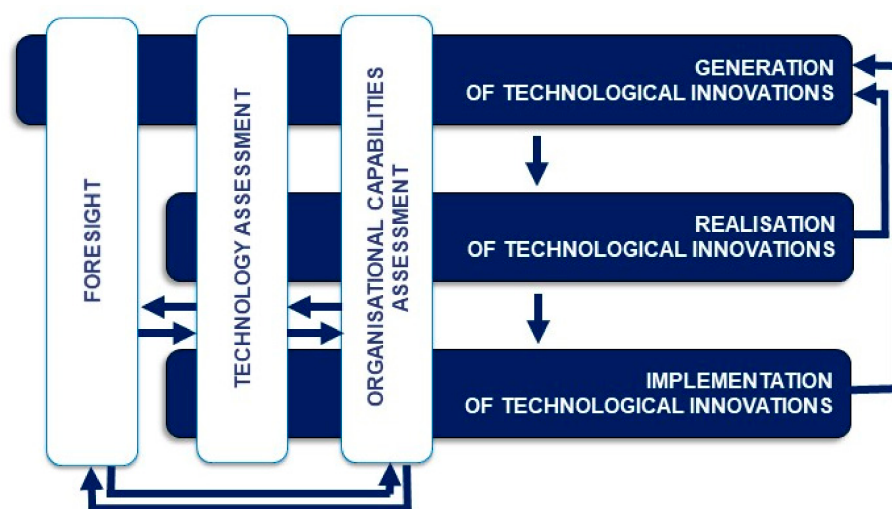


Figure 1. Application of the triad of concepts at the successive stages of the innovation process. Source: Author.

The use of foresight was adopted as a key concept in the generation of future-oriented research directions and individual technological innovations. At this stage, it is reasonable to use the results of technology assessment of technological innovations developed in the past (ex-post assessment) and these currently under development (ongoing assessment) as one of the sources of the innovative subject area. It is also of key importance to assess the organisational capabilities necessary to develop innovations, both in terms of the existing and currently available capabilities, and capabilities planned to be developed. Taking into account the information from these three sources: foresight results, technology assessment and organisational capabilities assessment, allows for selecting which technological innovations are to be developed that are consistent with current research priorities and economy needs, are characterised by innovation potential and that for their development the necessary organisational capabilities are available.

The stage of innovative technologies development is supported by conducting, in an integrated manner, technology assessment and organisational capabilities assessment. Systematically conducted technology assessment enables one to track and correct the development process of individual innovations. The analysis of the assessment results of the implementation maturity, the commercial and innovation potential, enables one to assess the correctness of the course of the innovation development process. It is supplemented with an analysis of the assessment results of the organisational capabilities that are involved in the development of an innovation. In addition, ongoing assessment of the innovations being developed can be used as a source of inspiration while generating further innovative technologies with the use of foresight. After completing the process of developing a technological innovation, on the one hand, ex-post technology assessment is carried out, providing information on the level of the innovation's implementation maturity, commercial potential and innovation potential, and on the other hand, assessment of the available organisational capabilities that can be used in the process of implementing the innovation is conducted. Taking into account the assessment results from both sources makes it possible to make a decision which solutions should be implemented, in which economic entities and whether there are necessary organisational capabilities in an R&D organisation that could be used for this purpose. Similarly, the results of technology assessment conducted in the course of the technology development (on-going assessment) and also the results of technology assessment referring to the finally developed technology (ex-post assessment), supplemented with the results of an organisational capabilities assessment, constitute the basis for the subsequent generation of new technologies to be developed, which is then carried out with the use of foresight. In this way, the use of the assessment results of the developed innovations provides information support for the process of generating new innovations.

The proposed approach (Figure 2) comprises modules referring to individual stages of the innovation process: generation, realisation, and implementation of technological innovations. Within the modules, the use of foresight methods (literature review, bibliometric analysis, key/critical technologies, expert panels), technology assessment methods (implementation maturity level assessment, commercial potential assessment, innovation potential assessment), organisational capabilities assessment (Hofer—Schendel matrix, sets of indicators, maps of competences), project generator and operational algorithms are proposed.

In order to effectively support the innovation generation stage, an original idea and IT tool, namely, a project generator [115] was developed and implemented that is used to monitor the process of generating and realising research undertakings. In addition, within the innovation generation module, the following algorithms are used: an algorithm for the identification of technological innovations (possible for the development in an R&D organisation, acknowledged as significant due to their scientific and technological values, compliance with the strategic directions of an R&D organisation and possible potential economic and social benefits), an algorithm for organisational capabilities assessment of an R&D organisation for the purpose of deciding on the rationale of starting work on a technological innovation, an algorithm for the innovation potential assessment, and an algorithm for the commercial potential assessment.

The next phase of the innovation process is the innovation realisation which is supported by the use of technology assessment methods at particular stages of technological solutions development in order to monitor the progress of work. Within the technology assessment, the algorithms are applied as follows: the algorithm for the implementation maturity level assessment, the algorithm for the innovation potential assessment, and the algorithm for the commercial potential assessment. At this stage, organisational capabilities are assessed with respect to the capabilities already utilised for the need of developing innovations, the need of strengthening capabilities on an ongoing basis (operational decisions), and possible indications (e.g., by means of foresight methods) of the areas in which organisational capabilities should be expanded. The assessment is carried out by means of

the algorithm for organisational capabilities assessment of an R&D organisation for the needs of supporting the stage of innovation development.

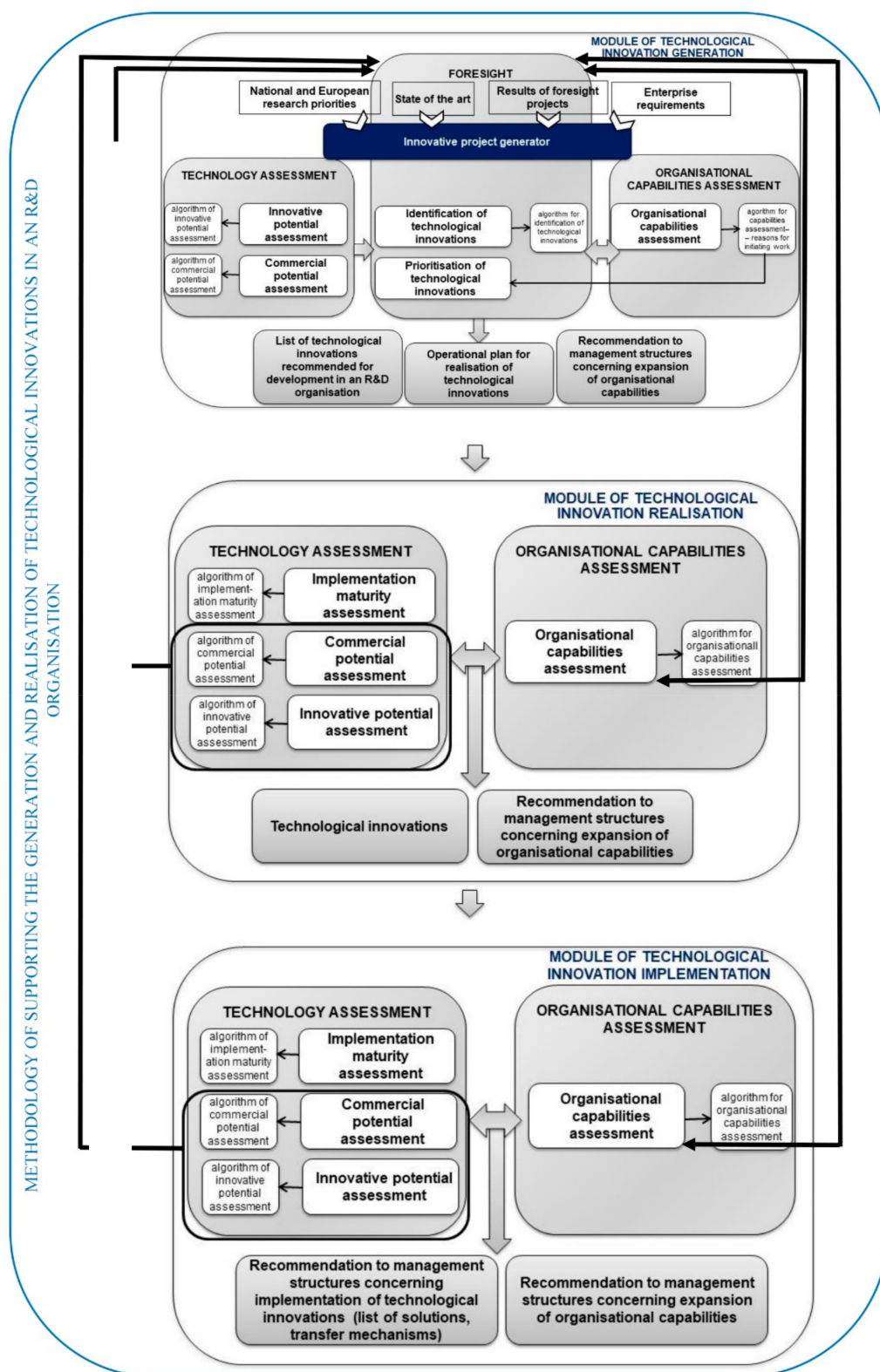


Figure 2. The proposed approach of supporting processes of generation and realisation of technological innovations in an R&D organisation. Source: Author.

The developed innovative solution is a subject of implementation in the economy. Depending on the results of its assessment carried out by means of the algorithms for the assessment of the implementation maturity level, the innovation potential, the commercial potential, and the availability of organisational capabilities (the algorithm for organisational capabilities assessment of an R&D organisation for the needs of supporting the innovation implementation phase), a decision on the feasibility of implementation is made and a technology transfer mechanism is proposed. At this stage, additional decisions may be made, based on the analyses conducted by means of foresight, regarding the areas of expanding the strategic organisational capabilities of an R&D organisation.

In the course of the development process of an innovation and after its completion, the results of ongoing and ex-post technology assessment feed with the data from the module of generating technological innovations.

Integrated application of the triad of concepts (foresight, technology assessment, and organisational capabilities assessment) at the subsequent stages of innovation processes allows for multidimensional support for these processes and increasing their effectiveness. Its use makes it possible to do the following:

- Select technological innovations characterised by high innovation level and market demand, consistent with the research priorities of a particular R&D organisation and for which there already is or where it is possible to acquire the operational organisational capabilities necessary for their implementation,
- Create an operational plan for the development of selected technological innovations,
- Provide the monitoring process in the course of technological innovations development,
- Prepare recommendations concerning the implementation of developed technological innovations,
- Indicate areas that require strengthening of operational organisational capabilities (financial, physical and material, human, information and management) to make possible the development of selected technological innovations, in the situations when the existing operational organisational capabilities are insufficient, and
- Identify areas that require strengthening of the strategic organisational capabilities to make it possible to improve the competitive position of an R&D organisation in the future.

The approach proposed is aimed at ensuring effective support for the processes of generation, realisation, and implementation of technological innovations in an R&D organisation. It is meant for the use by researchers and practitioners representing various fields of science and technology involved in innovation development, and specialists in the field of innovation management.

5. Discussion

The proposed approach can be used for a complex, integrated support of innovation processes management. It is based on (1) the ideas discussed by a limited number of scholars indicating the need and possible areas for the integrated use of the analysed concepts (foresight, technology assessment, and organisational capabilities assessment) [35,83,84,86,93] and on (2) the practical experience resulting from research and implementation projects [82,95,96,116,117]. These underpinning ideas are further developed in a form of combining all the concepts in question in a complex way. The proposed approach assumes the use of a triad of concepts, namely, foresight methods (e.g., literature review, bibliometric analysis, key/critical technologies, expert panels), technology assessment (implementation maturity level assessment, commercial potential assessment, innovation potential assessment) and organisational capabilities assessment (Hofer—Schendel matrix, sets of indicators, maps of competences) at all stages of the innovation process—generating innovations, their development, and preparing implementation. Such an approach is not present in complex models supporting the generation and implementation of technological innovations; however, this approach is derived from the body of knowledge in the area of (1) innovation process models and (2) the practice of project management in the area

of innovative technologies generation, development and implementation. Although the existing innovation models differ in structure, the majority [118–122] (1) include some form of searching for and generating ideas (inside and/or outside the organisation), selecting an idea with the criteria of feasibility and the possibility of bringing potential profits, (2) indicate the stages of an idea development into a product, process or service, and then (3) emphasise the stage of practical application related to marketing, distribution, logistics and other activities for the benefit of the client. Although the majority of models include the stage of generating ideas, it is mostly in a very general way. Only in single models are some details at this stage included, e.g., by stating that it concerns the identification of future-oriented research areas or the creation of strategies [123,124]. The analysed innovation process models also comprise the stages of innovation development and implementation. With reference to these phases, many aspects concerning the characteristics of technologies and the market [119,123–125], and different types of organisational capabilities needed for the development and implementation of the technology [119,123,124,126] are identified. Although the selected models indicate detailed aspects of the execution of innovation processes, in most of them, no methods of estimating these aspects are proposed. An exception, among those analysed, is the TDAC model [126], which proposes methods for assessing selected aspects, carried out individually with reference to each of them. The application of the proposed triad approach makes it possible to assess individual aspects affecting the innovation process at its succeeding stages.

Moreover, this approach proposed stems from the practice of executing projects aimed at innovation development. In the case of projects executed, their phases and detailed solutions depend a lot on the character of individual projects. Some are focused on the whole innovation process and some on its particular stages. The effectiveness of the use of the proposed approach is confirmed by the results of its application within projects carried out in an R&D organisation concerning technological solutions in the field of machine construction and maintenance [107]. In order to increase the effectiveness of the use of the approach, it is possible to introduce modifications and additions both in the substantive (conceptual) and operational dimensions. The proposed modifications in the conceptual area result, on the one hand, from the need to take into consideration the processes taking place in the economy that condition the functioning of R&D organisations and enterprises that apply the innovations developed by R&D organisations. They, among others, include the need to consider the conditions of sustainable development, the societal impact of the use of technology, and the growing importance of marketing and organisational innovations. Possible modifications also result from the need to consider trends in the evolution of methodological tools, e.g., related to the increasing importance of participatory approach in research. On the other hand, the possible further directions of the proposed approach development of operational character are associated with the need to increase the effectiveness of its application by improving and expanding the methods and operational algorithms proposed. In this respect, it would be justified to include methods allowing for risk assessment and for financial analysis. Furthermore, the algorithms should be updated and developed depending on the need to include additional factors affecting the conducted innovation processes.

6. Conclusions

The processes of generating, realising, and implementing innovations in an R&D organisation are of a continuous nature. Some technological solutions are at the stage of their generation, others are at the stage of execution, and others are being implemented. At all stages the proposed triad of concepts, i.e., foresight, technology assessment, and organisational capabilities assessment, can be used in an integrated way, within the proposed approach supporting the processes of the generation and realisation of technological innovations.

The application of the integrated triad of concepts facilitates the strategic decision-making processes carried out in an R&D organisation comprising an indication of (1) future research directions to be executed in the R&D organisation and (2) areas for expanding

its strategic organisational capabilities. Moreover, it also facilitates the decision-making processes of an operational nature, among others, concerning (1) the launch or suspension of innovation development processes, (2) support for the ongoing work on innovations development, and (3) their implementation, including the selection of technology transfer mechanisms.

In the longer term, the consistent application of the proposed approach in relation to innovation processes carried out in an R&D organisation contributes to an improvement in effectiveness of its operation. It is possible thanks to increasing, in a set of products and technologies developed, a share of technological solutions that are characterised by a high level of innovation, compliance with market needs, and significant implementation opportunities, and thanks to a better use of the organisational capabilities at the disposal of a particular R&D organisation.

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