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OPERATIONAL SYSTEM FOR THE ASSESSMENT OF THE IMPLEMENTATION MATURITY LEVEL OF TECHNICAL INNOVATIONS

Key words

Technological innovations, Technology transfer, Implementation Maturity Level Assessment (SDW).

Abstract

The article presents a method for the assessment of the implementation maturity of innovative technological solutions. The method in question constitutes a crucial support element for knowledge transformation and technology transfer processes. It can be used at different stages of innovation creation and enables a systemic evaluation of the implementation maturity and the practical application readiness of new technologies. When used for the evaluation of newly created innovative products, the method improves a country's innovation performance and boosts the level of its competitiveness, because it constitutes an effective system for the monitoring of the implementation of the results of research into practice. The advantages of the method in question have been proved by numerous practical applications of products stemming from R&D undertakings.

The in-depth analyses of the national and the EU innovative and research strategies conducted so far show that there still are huge gaps between the stages of scientific research, the design of prototypes, the practical application of models, and the commercialisation of final technological solutions [1, 15, 16]. The importance of activities for the improvement of the competitiveness and innovation performance of national economies was emphasised in the guidelines of the new strategy – Europe 2020 [14]. It is quite common that projects carried out within R&D programmes frequently do not even take into consideration the stage of the practical application of technological solutions and their results are not assessed with reference to their implementation potential or the effectiveness of their industrial application. Therefore, the effectiveness of the technology transfer process in Poland is far from satisfactory [9]. This results from both the inefficiency of mechanisms supporting the stages of application and commercialisation and the low level of implementation maturity of new technological solutions. That is why the assessment of the technological advancement and the implementation readiness of any novel solution should be incorporated into knowledge transformation and technology transfer models [10]. Due to its great importance, the issue of technology transfer management has become the scope of numerous scientific studies [2, 8, 17]. The creation of a set of metrics applied to measure the effectiveness of R&D projects is an important problem in research [19]. The analysis of the diffusion of the results of scientific research and the improvement of procedures for their practical application were the subject of R&D activities that were conducted by the Institute for Sustainable Technologies – National Research Institute within previous research projects and programmes [9, 18], or within the *Innovative Systems of Technical Support for Sustainable Development of Economy*, 2010–2014 Strategic Programme currently executed in the Innovative Economy Operational Programme and co-financed by the European Regional Development Fund. The conducted analysis facilitated the creation and a practical verification of the methods enabling the monitoring of both the individual stages of the new product development process, and the level of implementation readiness of innovative solutions resulting from the undertaken R&D activity. The method for the assessment of the implementation maturity of innovative products was designed based on the globally recognised methods including the Technology Readiness Levels (TRLs) [5], the Engineering Manufacturing Readiness Levels [3], and the complex method of Technology Readiness and Risk Assessment [7]. Such methods are more commonly applied to assess the maturity of new solutions at the stage of scientific research and the development of final technologies [20]. Therefore, the application of methods for the assessment of implementation readiness should be a common practice [6]. Although TRLs are very popular, alternative approaches to support the assessment of R&D projects at an early stage of product development are proposed, e.g. the method of roadmapping of values

[4]. The original implementation maturity assessment method (SDW) is the result of research conducted by the authors of this article.

1. Method for the assessment of implementation maturity of novel technological solutions

The developed methodology is used for the assessment of the technological readiness of innovative products. By taking into consideration the specific properties of the developed product and enabling its complex multistage assessment, the method facilitates the project's operational management and enables the evaluation and control of the advancement of undertaken tasks. The assessment is conducted by a panel of experts who are competent in the SDW methodology and experts who are knowledgeable in the field the solution represents.

The SDW method takes into consideration both the type of an innovative product under assessment (e.g. device, material, technology, system, etc.) and the achieved level of advancement of the innovation development process. There are two algorithms used in the method, which are applied at the stages of the general (initial) and the detailed assessment of technological solutions (Fig. 1).

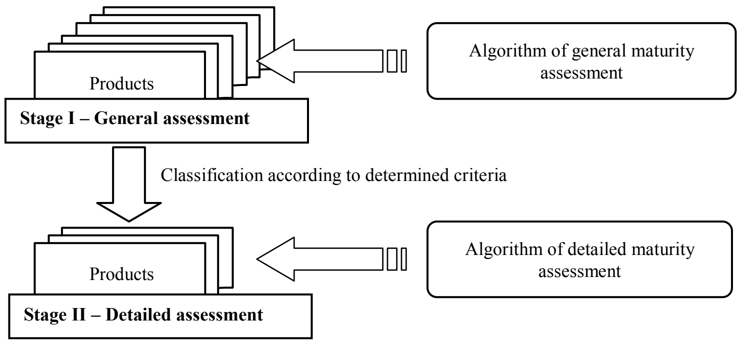

Fig. 1. Outline of the two-stage implementation maturity assessment of an innovative solution

The first stage is composed of a general assessment (based on TRL methodology), whose purpose is to qualify a given solution to one of the advancement levels. The detailed assessment (authors' original achievement), on the other hand, is based on the list of specific questions and requirements that are characteristic for the solution's advancement level identified during the general assessment stage of the evaluation procedure. The knowledge of independent experts is applied in the general assessment. However, the detailed assessment, due to its focus on the very specific and particular issues, requires a direct participation of the authors of the solution under assessment.

1.1. General SDW assessment algorithm

The algorithm for the initial identification of the maturity level of an innovative technical solution has been proposed and designed (Table 1). The general maturity level assessment procedure starts from the highest advancement level. If its criteria are not fulfilled by the assessed solution, the evaluators move to lower levels and stop when the level at which the criteria are fulfilled is reached. This enables the quickest identification of the solution's technological and implementation readiness level.

Table 1. General algorithm of the SDW assessment delineating a set of detailed assessment criteria for level 7

SDW level	Development phase	General level description and basic qualification criteria
10	Transfer	**Final product preparation to commercialisation** – Organisational and technical levels assuring the realisation of a repetitive production process achieved – Financial analysis and the creation of product commercialisation procedures – Development and implementation of product quality monitoring procedures
9	Verification	**Product samples produced and certified** – Production of samples for certification testing – Certification testing – Final technical and operational documentation completed
8		**Final product version made** – Final product made – Cost analysis of production – Product tests and verification of technical and operational parameters
7		**Prototype demonstration and verification in an operational environment** – Development and production of prototype near or at planned operational system – Full hardware and software integration – Full check of product functionality in the operational environment – Initial technical and operational documentation prepared ***Examples of detailed assessment criteria for level 7*** Criterion description 1. Prototype of a device developed with the use of the adapted apparatus 2. Prototype verified in an operational environment 3. Operation of algorithms checked in an operational environment 4. System interfaces tested in an operational environment with increased requirements 5. Test versions (beta versions) of software developed 6. Software verified 7. Target level achievement confirmed for product elements 8. Initial technical and operational documentation prepared

SDW level	Development phase	General level description and basic qualification criteria
		9. Full check of product functionality (machines, software, quality control equipment) in an operational environment 10. Materials for the manufacture of the product checked and accepted, production processes and organisational procedures verified 11. High level of advancement of material selection and production process development and verification tasks achieved 12. Cost analysis of the project conducted 13. Production plan finalised 14. Small scale production readiness achieved
6	Prototype	**Prototype demonstration and validation in relevant environment** – Design and production of the prototype – Prototype tested in relevant environment
5		**Model validation in relevant environment** – Design and production of basic elements of the model – Model integration and validation in relevant environment – High level of functional parameters credibility (high-fidelity)
4		**Component and model validation in laboratory environment** – Basic model elements and sets validation – Ad-hoc laboratory integration of model elements – Low level of functional parameters credibility (low-fidelity)
3	Idea	**Analytical and experimental function and characteristic proof-of-concept** – Theoretical analysis with the application of modelling and simulation – Laboratory studies to physically validate theoretical models – Experiments and research to physically validate analytical predictions of separate elements of the solution
2		**Technology concept formulated** – Technology concept and its technical realisation possibilities formulated – Analytical analysis – Analysis of the possibility of practical implementation of the solution
1		**Basic principles identified and described** – Research into the basic concepts of the problem – Design of a descriptive model – Initial analysis of the concept formulated – Identification of basic principles of the solution – Solution variants formulated

The consecutive levels (from Level 1 to Level 10) present the advancement of works on an innovative product from the initial level including concept formulation, through the stage of model and prototype creation, the verification phase and the product manufacture, up to the final level of industrial implementation. Level 6 (prototype design and production) is critical for the development of the undertaking, because it connects the stages of research completion and the initialisation of the implementation process. This level is a milestone, whose achievement determines the final success of the project. The next stage (Level 7) enables full verification of the developed prototype in an operational environment. The qualification of the assessed solution to this level significantly limits the risk of failure to commercialise. The decision to begin the production at a targeted scale should be made at Level 8 or even Level 9 (including certification testing). Level 10 characterises final product preparation to commercialisation.

1.2. Detailed SDW assessment algorithm

The original methodology, enabling the assessment of innovations with the use of the sets of detailed criteria ascribed to particular product categories and subcategories, was developed to enable the detailed implementation maturity assessment. Each product subcategory has its own set of detailed assessment criteria. The developed methodology enables new groups and subgroups of products to be created according to the trends in the global technological progress. It also makes the definition of their specific detailed assessment criteria easier. Products under assessment were classified according to the following main categories: Materials (M), Technologies (T), Devices (U), and Systems (S), which can be further divided into relevant subcategories (Fig. 2).

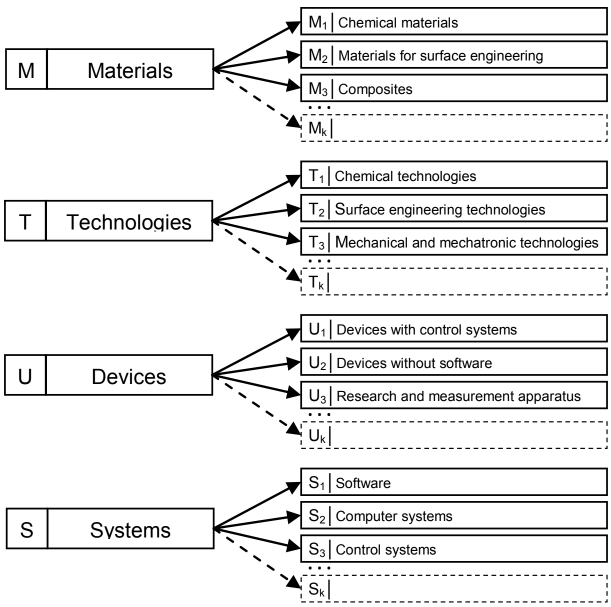

Fig. 2. Innovative products classification into specialist categories and subcategories

The proposed categorisation forms the basis for the algorithms of detailed implementation maturity assessment (Fig. 3). Products, that achieved Level 6 during the general assessment, should undergo a detailed assessment. This procedure includes nearly 200 control questions tailored to each category of novel solutions and enables the standardisation of the results obtained and the comparison of the assessed solutions within a given category with regard to their technical advancement. The qualification of the solution to a given level takes place after a positive verification, 80% minimum, of the assessment criteria ascribed to that particular level.

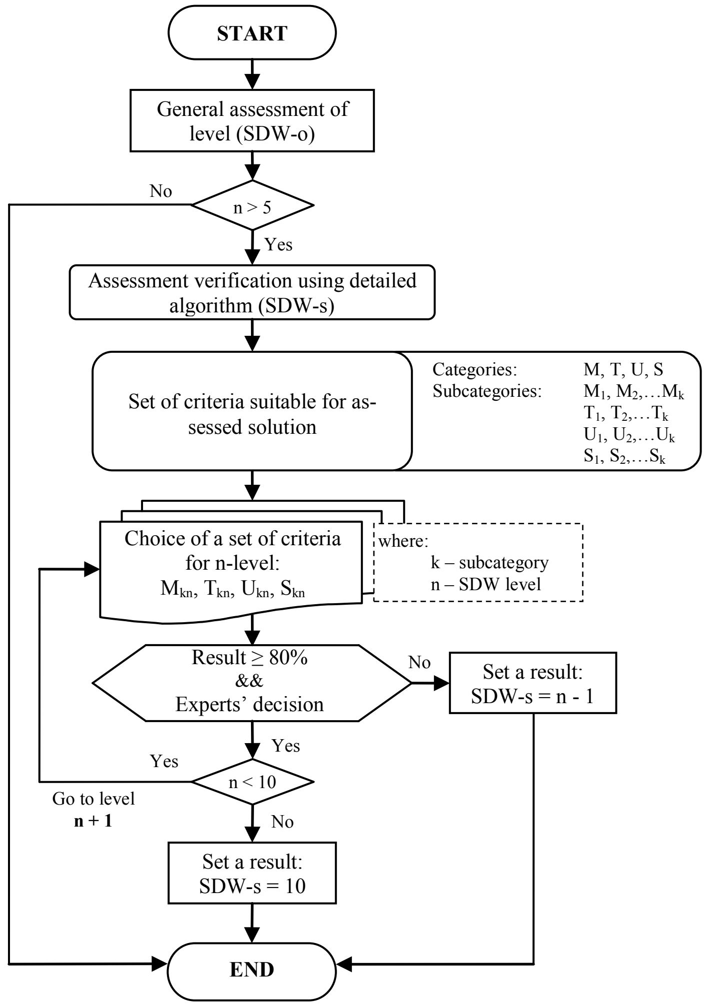

Fig. 3. Detailed implementation maturity level assessment algorithm

The initially adopted zero-one assessment method did not consider the possibility of a partial fulfilment of criteria and did not take into consideration the varied importance each of the criteria has in the development of a given solution, which in many cases, did not reflect the actual level of the advancement of the assessed solution. Therefore, the solution including the weight factor and the percentage indicator of its fulfilment was proposed. The advancement level of the assessed innovative product can be presented in form of the following equation:

$$P_X = \frac{\sum_{i=1}^{n} Z_i \cdot W_i}{\sum_{i=1}^{n} Z_i}$$

where: P_X – the degree of fulfilment of the requirements of the SDW level [%];
Z_i – criterion weight factor;
W_i – level of criterion fulfilment [%];
n – number of criteria;
X – level number.

The developed assessment system is open and its structure and scope can be modified.

2. Computer system

A computer system for the support of the developed implementation maturity level assessment method (SDW) was developed. The programme is available in a desktop and an on-line application (Fig. 4).

Fig. 4. Sample view of the on-line application window of SDW implementation maturity assessment (prepared for the Technology Park in Belchatow)

The system is equipped with tools enabling the generation of reports from the database, including e.g. the product assessment form, the list of the assessed products, or the list of detailed criteria for selected product categories and subcategories. The developed system was designed to enable the acquisition, aggregation, processing and filtering of information about the assessed products (e.g. product categories, product features, assessment results). To gather and process the data, a server based on Oracle relational databases was applied. The user interface is in the form of a desktop application based on the NET Framework 2.0 Platform in the C# programming language. The application enables work with the database both in the Intranet and the Internet networks. In order to be able to use it, the user first needs to install the application and the client software communicating with the Oracle database on their workstation. The system is protected against any unauthorised access. In the basic assumption, the programme is primarily intended for independent evaluators; however, its disclosure to project executors is also possible, so that the level of the advancement of undertaken tasks can also be monitored on the operational level. The methodology of the SDW method, on the one hand, constitutes an autonomous system, but on the other, is a part of a complex technology assessment system [13], which is composed of the following three assessment modules: the implementation maturity assessment module (SDW), the commercial potential assessment module (PK), and the innovativeness level assessment module (PI) (Fig. 5).

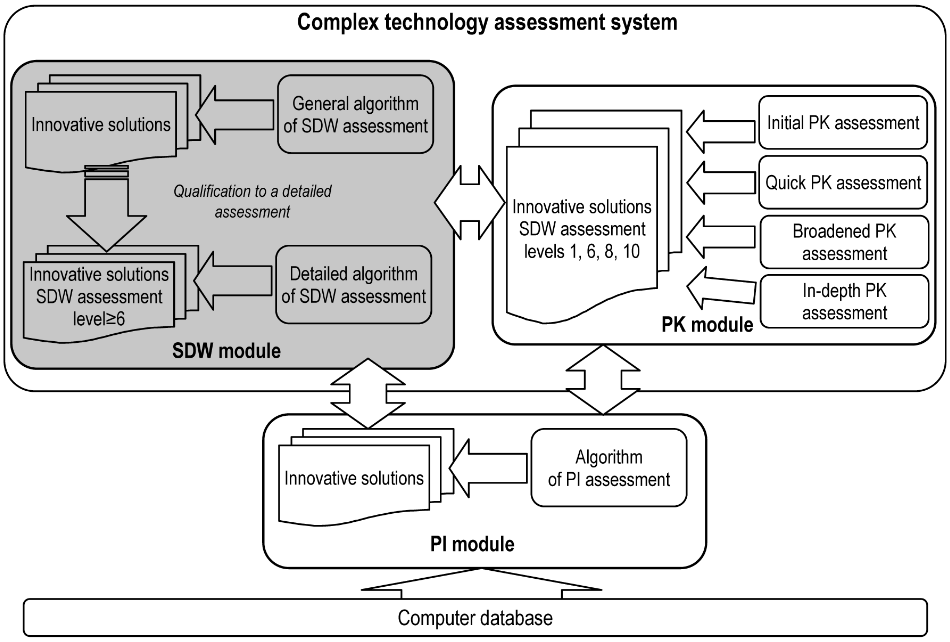

Fig. 5. System of a complex assessment of technological innovative solutions – general structure

3. Verification and application of the method

The developed SDW method for the assessment of the implementation maturity of innovative products and the software enabling its execution were practically verified with reference to numerous innovative products developed within the 2004–2008 PW-004 Multiyear Programme and the currently executed by the Institute for Sustainable Technologies – National Research Institute Strategic Programme. The verification concerned, inter alia, the effectiveness of the developed method, the adequacy of the assessment criteria at the general and the detailed assessment levels, and the selection of weight factors. An example of a solution that underwent the assessment procedure was the prototype Profilometer 3D-XY, falling into category U–Device (according to the Polish nomenclature), particularly category U3 – research and measurement apparatus. The first stage of the assessment of this product was composed of the general assessment with the use of the adopted assessment criteria. According to this general SDW assessment, the Profilometer reached Level 8 (Fig. 6). The joint indicator of the fulfilment of the detailed assessment criteria (min. 80%) indicated the possibility of the higher level of implementation maturity of this solution. However, in the detailed assessment of the product, Level 8 was also reached, which confirmed the results of the initial SDW assessment. The inability to fulfil the crucial criteria of Level 9, those concerning certification, meant that the general assessment of this level reached was only about 57%, which was below the acceptable minimum.

The innovative products developed within the Strategic Programme were evaluated in the four consecutive stages conducted in half-yearly intervals. The results of the first stage evaluation confirmed the initial level of the vast majority of solutions (Levels 0-5). At the next stages of the evaluation, a significant increase in the advancement of the developed solutions could be observed. At the fourth stage of the evaluation, most solutions displayed a high level of advancement (Levels 6-9), which confirmed their implementation maturity and commercialisation readiness. At the same time, the analysis of the results allowed the identification of research tasks that display unsatisfactory progress in the development of innovative solutions. Such information enabled appropriate corrective actions to be undertaken at the project management level.

The advantages of the SDW method have been proven in numerous applications, inter alia, in undertakings coordinated by the Polish Ministry of Economy and aimed at supporting the improvement of the innovation performance of the SME sector in particular [11]. The method is now an inseparable element of the evaluation of projects conducted by the Polish technology parks and executed within publicly and EU financed R&D programmes.

Fig. 6. Sample view of the SDW assessment of an innovative product (Profilometer 3D-XY)

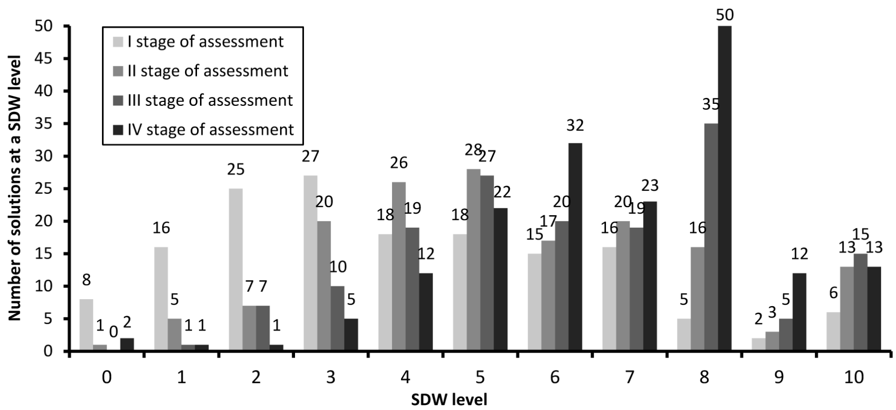

Fig. 7. Results of SDW assessment of solutions developed within the Innovative Systems of Technical Support for Sustainable Development of Economy Strategic Programme

Conclusions and Implications

The developed SDW assessment method and the computer system constitute important elements of knowledge transformation and technology transfer processes supporting the improvement of competitiveness and innovativeness of a knowledge-based economy. The method in question can be applied at various levels of a solution development process, starting from the concept level, through the stage of model and prototype creation, the verification phase and the product manufacture, up to the final level of industrial implementation. The R&D sector and industry (particularly the SME sector) can use the method for the assessment of new technologies and R&D undertakings.

The method also enables a detailed analysis of the advancement of the results of research projects and the level of their adaptation to practical implementation; therefore, it limits the risk of their unsuccessful commercialisation. A significant advantage of the method and the operational procedures is the open structure of the assessment system, which enables the modification and the extension of the applied criteria and the customary categorisation of innovative products. The SDW method can be correlated in the complex technology assessment system with other innovation assessment methods, including the commercial potential assessment method and the innovativeness level assessment method.

The SDW method is used by organisations that financially support innovative undertakings and the commercialisation of research results (e.g. technology parks). It is a basic assessment tool applied within the *Innovative Systems for Technical Support of Economy* Strategic Programme. The authors of the method assume its further improvement and the development of optional solutions for other categories of R&D results, including organisational innovations.

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System operacyjny oceny poziomu dojrzałości wdrożeniowej innowacji technicznych

Słowa kluczowe

Innowacje techniczne, transfer technologii, Stopień Dojrzałości Wdrożeniowej SDW.

Streszczenie

W artykule zaprezentowano metodę oceny stopnia dojrzałości wdrożeniowej (SDW) innowacyjnych rozwiązań technicznych opracowaną w ramach Programu Strategicznego pt. „Innowacyjne systemy wspomagania technicznego zrównoważonego rozwoju gospodarki". Opracowane narzędzie stanowi istotny element wspomagania procesów transformacji wiedzy i transferu zaawansowanych technologii procesowych i produktowych w obszarze wytwarzania oraz eksploatacji maszyn i urządzeń technicznych. Metoda SDW jest przydatna na różnych etapach powstawania innowacji, głównie poprzez ewaluację rozwiązań z ukierunkowaniem na ich dojrzałość wdrożeniową oraz potencjał aplikacyjny. Wykorzystanie metody do oceny powstających rozwiązań przyczynia się do wzrostu innowacyjności i konkurencyjności gospodarki poprzez bardziej efektywną kontrolę procesu wdrażania wyników badań naukowych do zastosowań praktycznych. Walory metody SDW zostały potwierdzone w kolejnych aplikacjach, m.in. do oceny rozwiązań innowacyjnych związanych z zastosowaniem zaawansowanych technologii warstwy wierzchniej w przemyśle.