The Analytic Hierarchy Process for new Product Screening Decisions: A Knowledge Management Perspective

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Abstract: The selection of the most promising new product development projects is one of the most important decisions in a company. This decision affects the cost of failed projects, company's profitability, and its survival. The selection of new product development projects with the greatest potential requires the evaluation criteria that reflect the adjustment of a new product to customer requirements, company's strategy, manufacturing, and knowledge management issues. There are specified sub-criteria to identify the impact of a new product on a single area of the company's activity, for example, on the knowledge management area. The criteria and sub-criteria are evaluated by managers, engineers (including knowledge engineers), and IT specialists, who work in departments such as research and development, sales and marketing, manufacturing, IT, and top management. Company professionals have the most updated information of the ongoing processes related to new product development. This paper is concerned with using the analytic hierarchy process (AHP) methodology to a new product screening problem, paying attention to the knowledge management perspective. So far, this perspective is neglected in the context of the decision problem of new product screening. This research develops the field of knowledge acquisition from experts towards selecting and evaluating criteria related to the potential of a new product. Knowledge acquisition refers to issues related to a new product, customer requirements, and uncertainties of project performance. Using criteria related to various areas of the company's activity, the decision maker can identify factors significantly impacting performance of new product projects, and compare these projects with each other. Moreover, the AHP approach prioritizes criteria and sub-criteria, and as a result, it can identify areas of the company's activity that could be improved.

Keywords: knowledge acquisition, evaluation criteria, multi-criteria decision-making, new product development, project selection problem

1. Introduction

Nowadays, companies are continually searching for ways to be closer to customer needs, improve their business processes, develop products more effective, and accelerate their launch. New product development (NPD) is one of the most important processes in maintaining business success. The NPD process includes several phases from market analysis, idea generation, and concept selection, through product design and prototype tests, to production and commercialization. The goal of the concept selection phase is evaluation of different NPD projects and selection of the most promising project(s) to reduce the risk of developing non-profitable ones. Consequently, project portfolio selection belongs to key decisions in project-oriented companies, decisions that affect business survival.

Project portfolio selection can be based on financial measures related to costs, sales, and cash flows in the expected product life cycle, or on non-financial measures related to, for example, customer requirements. The total costs of a new product refer to its development, promotion, production, and the removal from the market, and it can be estimated using analogical, analytical, or parametric techniques (Relich, 2016). The sales volume and the product life cycle depend on the market and are harder to predict than costs that can be controlled, to some extent, by the company. However, decision makers should tend to prepare predictions about new product performance and profitability, considering the highly expenses related to unsuccessful new product projects.

The NPD literature emphasizes the impact of introducing new products on employment, economic growth, technological progress, high standards of living, and on continuing business success (Nielsen et al., 2010; Fish, 2012; Relich and Bzdyra, 2015). There are many approaches to describe and solve a multi-criteria decision problem within, for example, finance (Dobrovolskienė and Tamošiūnienė, 2016), production and distribution (Sitek and Wikarek, 2018; Rudnik et al., 2021), or maintenance sustainability (Jasiulewicz-Kaczmarek et al., 2021). One of these approaches is the AHP methodology that is a suitable tool to present a hierarchical structure of criteria involved in the evaluation process (Velasquez and Hester, 2013).

This study is addressed to project-oriented companies that are interested in evaluating the potential of a new product and selecting the most promising projects at the early phase of new product development. This evaluation is based on expert judgments and the AHP methodology. The approach proposed in this study

develops previous approaches towards incorporating the knowledge management perspective into a model of new product screening.

The paper is organised in the following parts: Section 2 presents a literature review, including description of evaluation criteria for new product development projects, the analytic hierarchy process in new product screening, and acquiring knowledge related to new product development. Section 3 describes the proposed method for evaluating the potential of a new product. The applicability of the proposed approach is illustrated in Section 4. Finally, conclusion and further research are presented in Section 5.

2. Literature review

2.1 Evaluation criteria for new product development projects

Evaluation criteria are often dedicated to a specific stage of an NPD project such as idea generation, concept development, business analysis, product development, market testing and launch. For example, the phase of concept screening can be evaluated according to technical feasibility, customer acceptance, and product performance, whereas the stage of business analysis can include criteria such as sales in units, margin, and market potential (Hart et al., 2003). Evaluation criteria can also be considered from the perspective of financial and nonfinancial dimensions or quantitative and qualitative measures. The financial dimension is particularly important at the phase of business analysis and after-market launch, and evaluation criteria can include profit or sales objectives, and return of investment (ROI) (Hart et al., 2003). The nonfinancial dimension is usually dedicated to the NPD phases such as idea screening, product testing, and testing customer acceptance/satisfaction, in which opinions from the research and development (R&D) employees and customers are analysed. An example of nonfinancial criteria can be the quality of a new product, intuition, market potential or product uniqueness.

Evaluation criteria can also be grouped into factors that significantly impact the success of an NPD project. These factors can be related to technical feasibility, strategic fit, customer acceptance, financial performance, and market opportunity (Carbonell-Foulquié et al., 2004). The technical feasibility dimension includes the following criteria: estimation of the project total cost, availability of resources, and leverage of company's R&D, engineering, and manufacturing skills. Strategic fit refers to alignment of an NPD project with company's strategy and window of opportunity. Evaluation criteria for customer acceptance are related to customer satisfaction, product quality, including its reliability and performance. The dimension of financial performance contains criteria such as expected margin rate, internal rate of return (IRR), and sales volume. Criteria related to market opportunity refer to market share and market growth (Carbonell-Foulquié et al., 2004). Another classification of evaluation criteria refers to dimensions related to market (e.g., customer acceptance/satisfaction, sales growth, market share, market potential), finance (e.g., break-even time, profit, margin, IRR/ROI), product (e.g., quality, technical feasibility, product performance, product uniqueness), process (e.g., time-to-market, stay within budget), and intuition (Tzokas et al., 2004). In turn, Martinsuo and Poskela (2011) proposed a few models to verify the impact of strategic, market, and technical criteria on competitive and future business potential. Moreover, they compared the proposed models in the context of using quantitative measures (sales revenue, R&D investments, number of employees, number of front-end projects), and product complexity (including concept novelty).

Another perspective of classifying evaluation criteria is related to the level of novelty regarding a new product. Evaluating innovations can use other criteria compared to modifications of existing products. The comparison of evaluation criteria in the context of the NPD stage and highly, moderately, and low innovation strategy is presented in (Wang and Lee, 2011). Financial criteria of evaluating NPD projects can be based on metrics related to the expected values of sales, costs, profits, and cash flows in the expected product life cycle. The discounted cash flows are used in the net present value (NPV) method to evaluate and compare NPD projects over the whole period of the investment. The expected performance of the NPD project can be provided by experts (if product-related data is not available, e.g. during development of innovations) or acquired from a product management system (e.g., during development of modifications of existing products (Relich, 2017)). The evaluation of NPD projects aims to compare them and select the most promising ones. This problem belongs to the class of decision problems and can be solved using a multi-criteria decision-making method, for example, the analytic hierarchy process.

2.2 The analytic hierarchy process in new product screening

The analytic hierarchy process is a multi-criteria decision-making approach, in which a pairwise comparison procedure is used to range a set of alternatives at a scale of preferences. The word "analytic" means that the object of the decision is described in the form of criteria to compare the possible options (alternatives). Criteria can be specified in a quantitative and qualitative manner and ranked according to the weights. The word "hierarchy" in the name of this approach refers to the manner, in which the criteria and alternatives are presented. In turn, the word "process" is related to the use of a sequence of steps to solve a decision problem. The AHP procedure is based on three following principles: (1) decomposition of a complex unstructured problem, (2) comparative judgments related to components of a problem, and (3) synthesis of priorities derived from the judgments (Pun et al., 2010). The decomposition of an unstructured problem into a systematic decision hierarchy is determined using a qualitative method. The AHP methodology aims to specify both objective and subjective judgements of the evaluators in order to make trade-off and determine priorities among the hierarchy. It requires a pairwise comparison to execute the consistency test, and finally, to validate the consistency of responses (Saaty, 2001; Pun et al., 2010).

An AHP approach enables enterprises to involve their own experts in the process of selecting the criteria and evaluating them. Moreover, the AHP bases on judgments related to the most updated information of the current state of a decision problem rather than on historical statistical data. This approach is also a tool of choice and prioritization, as well as it enables companies to develop a set of criteria according to their needs, a set that can be modified when the situation is changed. In addition to this, the AHP is a group approach to decision making and obtains an overall score to reflect group judgments, what makes this approach suitable for product project screening (Chin et al., 2008).

As the evaluation process of an NPD project involves several criteria related to different areas of the company's activities and employees to evaluate these criteria, new product screening is an example of a multi-criteria decision-making problem. Calantone et al. (1999) presented that the AHP is an important management tool for NPD project screening that provides the potential towards improving decisions within the considered problem. The weaknesses of the AHP approach can be seen from the perspective of the ranking reversal problem and the limited capability in dealing with the issue of uncertainty (referring to incomplete data and imprecise judgments), what is a common problem at the early stages of new product development (Chin et al., 2008).

2.3 Acquiring knowledge related to new product development

The processes of creating and accumulating knowledge can be seen as common ground between projects, companies, and networks, in which projects are operated (Scarbrough et al., 2004). The role of knowledge creation and learning in managing complex projects has been analysed and presented from a problem-solving perspective by Ahern, Leavy and Byrne (2014). Evaluation of project suitability from a knowledge perspective is related to experts and identification of dimensions regarding the knowledge contribution. This term refers to the impact and outcomes of a project-based learning. A model of the knowledge management process presented by Botha et al. (2014) classifies learning activities into three groups: knowledge creation and sensing, knowledge organizing and capture, and knowledge sharing and dissemination.

The specification of the knowledge contribution results from the knowledge taxonomy used in a company, and it can be considered from the following perspectives: (i) individual learning, (ii) organizational level learning, and (iii) organizational culture change (Botha et al., 2014; Geng et al., 2018). The first perspective is related to knowledge and skills of team members who are involved in meeting project objectives. Complex projects may affect continuous learning by team members over the project life cycle (Ahern et al., 2014). According to the second perspective, decision makers may decide whether a company has the capability (including knowledge competency of knowledge workers) of accomplishing the project. Challenging requirements occurring in a project can provide motivation for project-based learning by team members. According to the third perspective, projects significantly impact organizational culture change, as they require communication among employees within and across structural units of an organization (Geng et al., 2018).

There are many models related to incorporating knowledge issues into the NPD project perspective. Akgün et al. (2005) proposed a model dedicated to identify the impact of factors related to project team (interpersonal trust, team stability, team member proximity, team member familiarity, and team communication) on project outcomes (team learning, speed-to-market, and new product success). Peng et al. (2014) investigated the associations between an aspect of NPD collaboration (including cross-functional, customer, and supplier

perspectives) and IT tools related to communication, product design, project management, and product data and knowledge management. Relich (2016) proposed a knowledge-based system for the new product portfolio selection problem, in which financial and nonfinancial criteria are considered. Hellebrandt et al. (2018) presented a model of selecting a suitable knowledge management solution for complaint knowledge transfer, in which a set of admissible solutions includes, for example, lessons learned and best practices, knowledge communities, education and training, expert search and investigation.

A knowledge management perspective is also considered in the context of supporting the innovation processes in companies. For example, Grimaldi and Rippa (2011) investigated the impact of improvement in the areas related to knowledge, performance, and network on sustaining the innovation process. Mannan and Haleem (2017) proposed a hierarchical model of dimensions and determinants for the successful diffusion and adoption of product innovation. Their model consists of dimensions such as innovativeness, social system, communication, and time. In turn, Frederiksen and Knudsen (2017) presented innovation performance from the perspective of the following criteria: product novelty, product usefulness, and commercialization (market potential). These three criteria can be considered in the context of knowledge related to a new product, customer requirements, and uncertainties regarding NPD project performance. These knowledge-related factors are further considered in the proposed model of NPD screening.

3. The proposed method for evaluating the potential of a new product

The proposed method bases on an AHP approach, and it mainly consists of the following steps:

1. Specification of the project selection problem into a hierarchical structure.
2. Information collection and pairwise comparisons.
3. Calculation of standardised weights.
4. Selection of the most promising NPD project.

3.1 Specification of the project selection problem into a hierarchical structure

A hierarchical structure of the considered problem usually consists of four levels. The first level refers to the goal associated to a decision problem, the second and third levels of this structure represent the criteria and sub-criteria related to the considered problem, whereas the lowest level includes the decision alternatives (Grimaldi and Rippa, 2011). The hierarchical structure is developed through specifying a list of criteria and sub-criteria that are selected using a literature review and expert experiences. In this study, the hierarchical structure is as follows:

***Goal*:** solving the NPD project selection problem, considering fit of an NPD project to issues related to market (customers, competitors, suppliers) and company (its strategy, technology, knowledge management).

***Criteria*:** customer, manufacturing, company's strategy, and knowledge acquisition.

***Sub-criteria*:**

Customer perspective:

- The ability to design a product according to the customer requirements (CUST_REQ)
- The ability to set product price that is acceptable for target customers (PROD_PRI)
- The ability to distribute the product to customers (PROD_DIS)

Manufacturing perspective:

- The adjustment of a new product to current technology (CUR_TECH)
- The adjustment of a new product to current supply chains (CUR_SUPP)
- The adjustment of a new product to manufacturing capacity (MANU_CAP)

Strategy perspective:

- The adjustment of a new product to current product lines (CUR_LINE)
- The adjustment of a new product to current business processes (CUR_PROC)
- The adjustment of a new product to the preferred product life cycle (PREF_CYC)

Knowledge perspective:

- The ability to acquire knowledge related to a new product (KNOW_PRO)

- The ability to acquire knowledge related to customer requirements (KNOW_CUS)
- The ability to acquire knowledge related to uncertainties of NPD project performance (KNOW_UNC)

***Alternatives*:** new product development projects.

Figure 1 presents the hierarchical structure proposed for solving the NPD project selection problem.

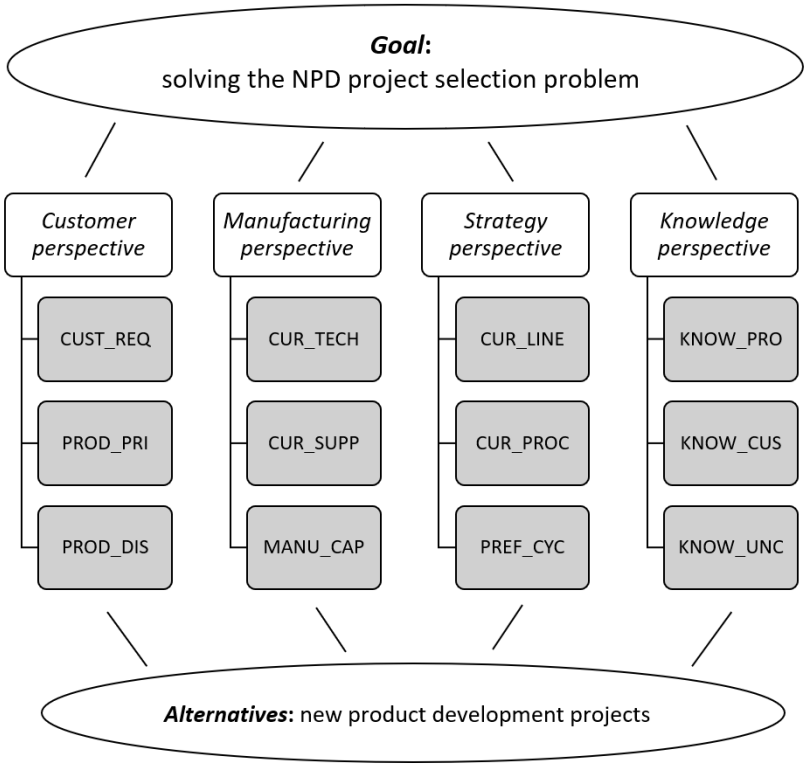

Figure 1: An NPD project selection model

3.2 Information collection and pairwise comparisons

Information is collected from specialists who work in departments such as R&D, sales and marketing, manufacturing, IT, and top management. Pairwise comparisons are given by experts using 1–9 scale proposed by Saaty (2001), where 1 denotes equal importance of (sub)criteria, 3 – moderate importance, 5 – strong importance, 7 – very strong importance, 9 – absolute importance, and 2,4,6,8 – intermediate values. Figure 2 presents a pairwise comparison matrix, which components derive from the structure of criteria (the 4 x 4 matrix) and sub-criteria (the 3 x 3 matrix). If the *i*-th (sub)criterion has one of the above non-zero numbers assigned to it when compared to the *j*-th (sub)criterion, then the *j*-th (sub)criterion has the reciprocal value when compared to the *i*-th (sub)criterion.

	i	j	...	...
i	1/1	a_{ij}		
j	a_{ji}	1/1		
...			1/1	
...				1/1

Figure 2: A pairwise comparison matrix

The fulfilment of the pairwise comparison matrix can result in inconsistencies that commonly appear in making multiple comparisons. These inconsistencies are acceptable within certain limits, what requires the determination of a consistency index.

3.3 Calculation of standardised weights

After the fulfilment of the pairwise comparison matrix, the weights of (sub)criteria are calculated by solving the eigenvector of the pairwise comparison matrix. The relative weights of (sub)criteria are determined by calculating the eigenvalues for their judgments matrices with these relative weights aggregated. If the weights of components of the decision hierarchies are calculated, they are synthesised to obtain the ranking scores of NPD projects. Weights are synthesised from the highest level down by multiplying weights by the weight of their corresponding parent component in the level above and adding them for each component in a level according to the component if affects (Grimaldi and Rippa, 2011).

In order to synthesise the local priorities throughout the hierarchy and compute the global priorities of the alternatives, the principle of hierarchic composition is applied. The local priorities are multiplied by the corresponding criterion weight, and the results are summed up to obtain the global priority of the alternative with respect to the goal stated at the top level. The global priority weight in each level should be equal to a sum of one. A value of the above-mentioned consistency index should be less than 0.1 (at larger values, the decision maker should reduce the inconsistency by revising expert judgements). More details related to theoretical foundations of the AHP approach is presented in (Pun et al., 2010).

3.4 Selection of the most promising NPD project

In the last step, the principle of hierarchic composition is applied for computing the global priority weights in each hierarchy level (Saaty, 2001). The global weights are used to prioritise various criteria and sub-criteria considered in the project selection problem. The local priorities are multiplied by the corresponding criterion weight, and the results are summed up to obtain the global priority of the criterion with respect to the stated goal. The AHP methodology determines the consistent nature of the pairwise comparisons (using the consistency index) for all matrices. If there is inconsistency, the procedure should be repeated (Pun et al., 2010).

The results of the AHP analysis may be clearly presented at the radar chart, in which the impact of the considered sub-criteria on different NPD projects is illustrated. The next section presents an example of using the proposed method for selecting the post promising NPD project.

4. An illustrative example

The AHP method has been applied to the evaluation of three NPD projects, considering their impact on factors related to the customer, manufacturing, company's strategy, and knowledge perspective. The expert panel consists of five experts who work as managers, engineers, and IT specialists in the following departments: R&D, sales and marketing, manufacturing, IT, and top management.

Figure 3 presents the relative importance of criteria related to the considered perspectives of selecting an NPD project. According to expert evaluation, the most important perspective is the customer perspective, and further the company's strategy, knowledge, and manufacturing perspective.

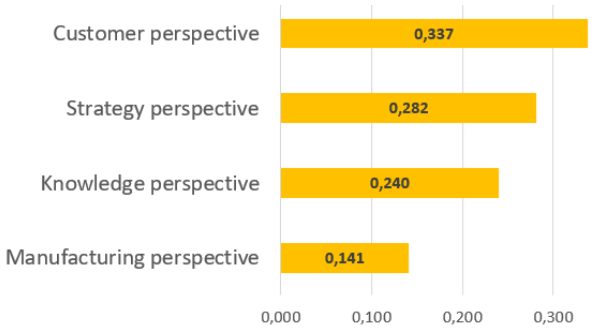

Figure 3: The relative importance of criteria

Figure 4 illustrates the relative importance of sub-criteria within a single perspective. The sum of local weights for a single perspective equals 1.

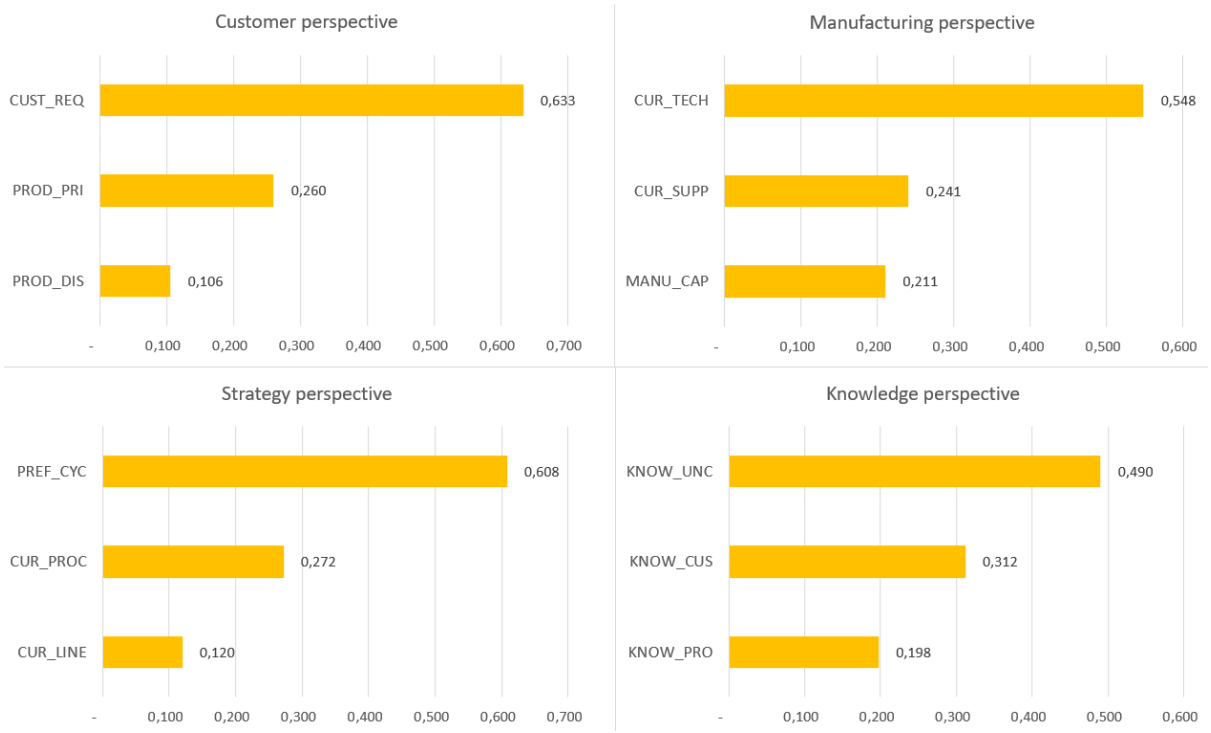

Figure 4: The relative importance of sub-criteria within a single perspective

Figure 5 presents the global weights for sub-criteria within four considered perspectives. The sum of weights for all sub-criteria equals 1. The most important sub-criteria refer to issues regarding the ability to design a product according to the customer requirements, the adjustment of a new product to the preferred product life cycle, and the ability to acquire and codify knowledge related to uncertainties of an NPD project performance.

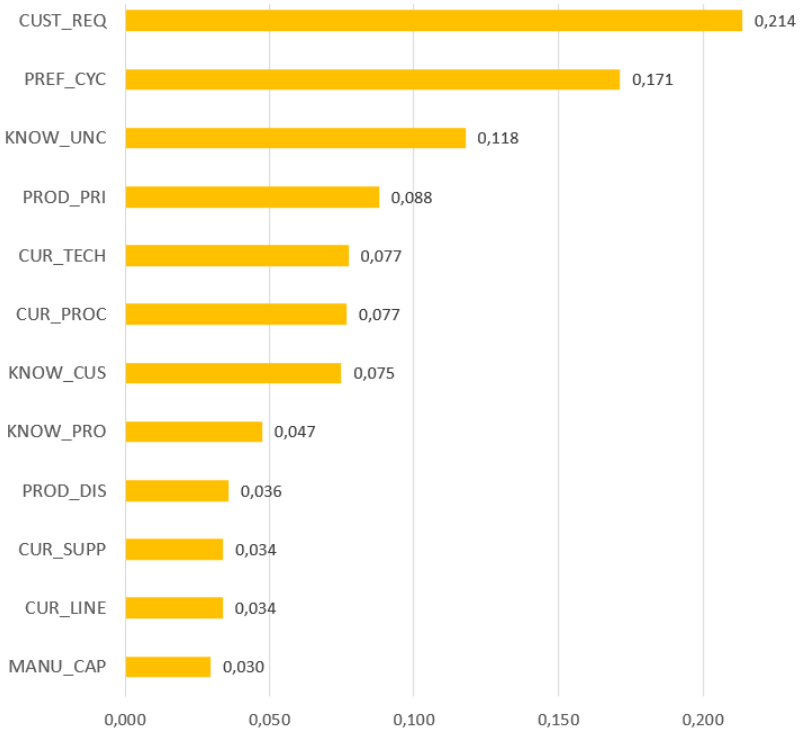

Figure 5: The importance of sub-criteria for all perspectives

Figure 6 illustrates the radar chart related to weights of sub-criteria for three NPD projects.

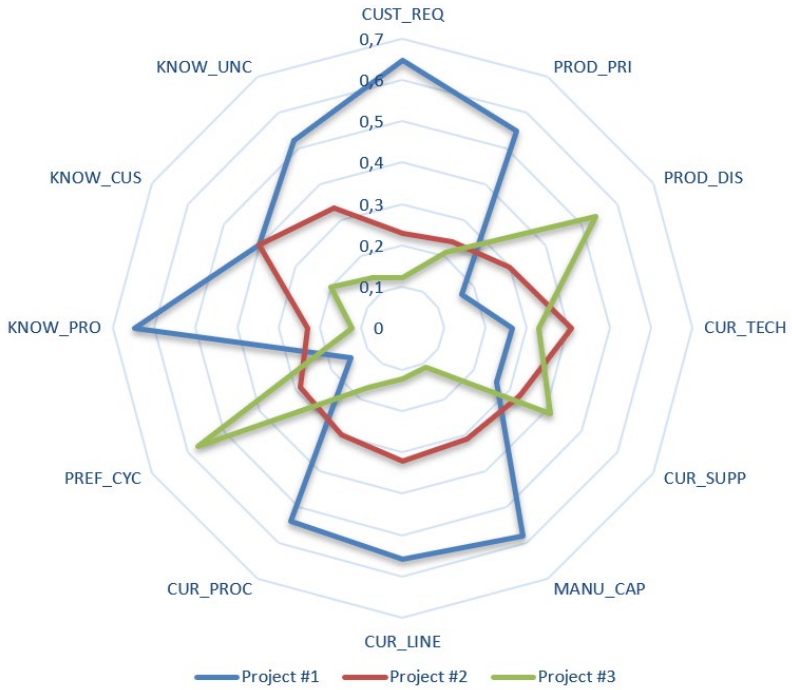

Figure 6: The weights of sub-criteria for NPD projects

Figure 7 presents the global evaluation of the considered NPD projects according to expert judgments. The results of the AHP analysis indicates that the most promising project is Project #1, considering all criteria and sub-criteria.

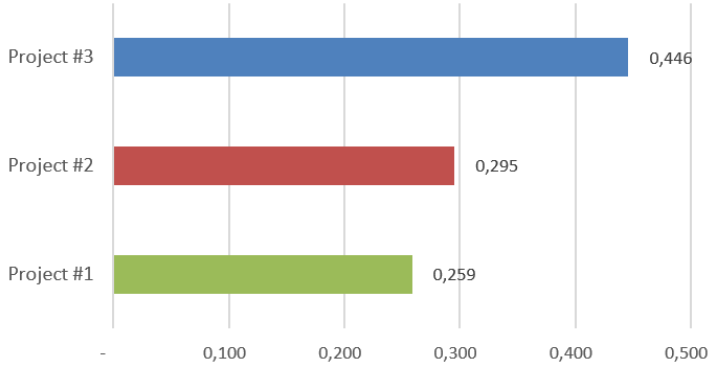

Figure 7: The evaluation of NPD projects

5. Conclusion

The presented research has been based on the AHP methodology dedicated to the selection of the most promising NPD project, incorporating the knowledge-related issues into this problem. NPD projects should be evaluated using various criteria regarding different areas of the company's activity. This research investigates the impact of customer, company's strategy, manufacturing, and knowledge-related factors on evaluating the potential of a new product. Each area includes three components selected through the literature review. A customer perspective refers to issues regarding customer requirements, product price, and distribution. A manufacturing perspective includes the adjustment of a new product to current technology, current supply chains, and manufacturing capacity. A company's strategy perspective contains issues regarding the adjustment of a new product to current product lines, current business processes, and the preferred product life cycle. In turn, a knowledge perspective refers to issues such as the ability to acquire knowledge related to a new product, customer requirements, and uncertainties of NPD project performance. The knowledge perspective is rarely considered in the context of a new product screening problem, and the above-mentioned knowledge-related issues have been specified to acquire knowledge regarding product novelty, product usefulness, and commercialization (market potential). Compared to previous research, the proposed structure of project evaluation allows the decision maker to get information to what extent knowledge acquisition (within a new

product, customer requirements, and uncertainties of project performance) impacts the attractiveness of a new product project.

The AHP approach is a suitable tool for solving a multi-criteria decision problem, including new product screening. The use of criteria related to various areas of the company's activity enables the decision maker to check what factors significantly impact the NPD project performance, and compare NPD projects with each other. A set of criteria and sub-criteria is set by a knowledge engineer, and it can be adjusted to current situation and company needs. Another advantage of using the AHP refers to expert judgments, who work in the company and have the most updated information of the ongoing processes related to new product development. Moreover, the AHP approach enables prioritization of criteria and identification of areas that could be improved.

A drawback of using the AHP is pairwise comparisons within criteria and sub-criteria, also in the context of alternative NPD projects. Further research includes the use of the best-worst method to reduce the above-mentioned drawback of using the AHP. Moreover, further research will investigate the extent of using knowledge management towards diffusing an adapting product innovation.

References

Ahern, T., Leavy, B. and Byrne, P. J. (2014) "Knowledge formation and learning in the management of projects: A problem solving perspective", *International Journal of Project Management*, Vol 32, No. 8, pp 1423–1431.

Akgün, A. E., Byrne, J., Keskin, H., Lynn, G. S. and Imamoglu, S. Z. (2005) "Knowledge networks in new product development projects: A transactive memory perspective", *Information & Management*, Vol 42, No. 8, pp 1105–1120.

Botha, A., Kourie, D. and Snyman, R. (2014) *Coping with continuous change in the business environment: Knowledge management and knowledge management technology*, Elsevier, Amsterdam.

Calantone, R. J., Di Benedetto, C. A. and Schmidt, J. B. (1999) "Using the analytic hierarchy process in new product screening", *Journal of Product Innovation Management*, Vol 16, No. 1, pp 65–76.

Carbonell-Foulquié, P., Munuera-Alemán, J. L. and Rodrıguez-Escudero, A. I. (2004) "Criteria employed for go/no-go decisions when developing successful highly innovative products", *Industrial Marketing Management*, Vol 33, No. 4, pp 307–316.

Chin, K. S., Xu, D. L., Yang, J. B. and Lam, J. P. (2008) "Group-based ER–AHP system for product project screening", *Expert Systems with Applications*, Vol 35, No. 4, pp 1909–1929.

Dobrovolskienė, N. and Tamošiūnienė, R. (2016) "Sustainability-oriented financial resource allocation in a project portfolio through multi-criteria decision-making", *Sustainability*, Vol 8, No. 5, pp 485.

Fish, A. N. (2012) *Knowledge automation: how to implement decision management in business processes*, John Wiley & Sons, Hoboken, New Jersey.

Frederiksen, M. H. and Knudsen, M. P. (2017) "From creative ideas to innovation performance: The role of assessment criteria", *Creativity and Innovation Management*, Vol 26, No. 1, pp 60–74.

Geng, S., Chuah, K. B., Law, K. M., Cheung, C. K., Chau, Y. C. and Rui, C. (2018) "Knowledge contribution as a factor in project selection", *Project Management Journal*, Vol 49, No. 1, pp 25–41.

Grimaldi, M. and Rippa, P. (2011) "An AHP-based framework for selecting knowledge management tools to sustain innovation process", *Knowledge and Process Management*, Vol 18, No. 1, pp 45–55.

Hart, S., Hultink, E. J., Tzokas, N. and Commandeur, H. R. (2003) "Industrial companies' evaluation criteria in new product development gates", *Journal of Product Innovation Management*, Vol 20, No. 1, pp 22–36.

Hellebrandt, T., Heine, I. and Schmitt, R. H. (2018) „Knowledge management framework for complaint knowledge transfer to product development", *Procedia Manufacturing*, Vol 21, pp 173–180.

Jasiulewicz-Kaczmarek M., Żywica P. and Gola A. (2021) "Fuzzy set theory driven maintenance sustainability performance model: A multiple criteria approach", *Journal of Intelligent Manufacturing*, Vol 32, No. 5, pp 1497–1515.

Mannan, B. and Haleem, A. (2017) "Understanding major dimensions and determinants that help in diffusion & adoption of product innovation: Using AHP approach", *Journal of Global Entrepreneurship Research*, Vol 7, No. 1, pp 1–24.

Martinsuo, M. and Poskela, J. (2011) "Use of evaluation criteria and innovation performance in the front end of innovation", *Journal of Product Innovation Management*, Vol 28, No. 6, pp 896–914.

Nielsen, P., Nielsen, I. and Steger-Jensen, K. (2010) "Analyzing and evaluating product demand interdependencies", *Computers in Industry*, Vol 61, No. 9, pp 869–876.

Peng, D. X., Heim, G. R. and Mallick, D. N. (2014) "Collaborative product development: The effect of project complexity on the use of information technology tools and new product development practices", *Production and Operations Management*, Vol 23, No. 8, pp 1421–1438.

Pun, K. F., Chin, K. S. and Yiu, M. Y. (2010) "An AHP approach to assess new product development performance: An exploratory study", *International Journal of Management Science and Engineering Management*, Vol 5, No. 3, pp 210–218.

Relich, M. and Bzdyra, K. (2015) "Knowledge discovery in enterprise databases for forecasting new product success", In Proceedings of International Conference on Intelligent Data Engineering and Automated Learning, Wroclaw, Poland, pp 121–129.

Relich, M. (2016) “A knowledge-based system for new product portfolio selection”, *Intelligent Systems Reference Library*, Vol 98, pp 169–187.

Relich, M. (2016) “Portfolio selection of new product projects: A product reliability perspective”, *Eksploatacja i Niezawodnosc – Maintenance and Reliability*, Vol 18, No. 4, pp 613–620.

Relich, M. (2017) “Identifying project alternatives with the use of constraint programming”, In Proceedings of 37th International Conference on Information Systems Architecture and Technology, Karpacz, Poland, pp 3–13.

Rudnik, K., Bocewicz, G., Kucińska-Landwójtowicz, A. and Czabak-Górska, I. D. (2021) “Ordered fuzzy WASPAS method for selection of improvement projects”, *Expert Systems with Applications*, Vol 169, No. 114471.

Saaty, T. L. (2001) *Decision making for leaders: The analytic hierarchy process for decisions in a complex world*, RWS publications, Pittsburgh.

Scarbrough, H., Swan, J., Laurent, S., Bresnen, M., Edelman, L. and Newell, S. (2004) “Project-based learning and the role of learning boundaries”, *Organization Studies*, Vol 25, No. 9, pp 1579–1600.

Sitek, P. and Wikarek, J. (2018) “A multi-level approach to ubiquitous modeling and solving constraints in combinatorial optimization problems in production and distribution”, *Applied Intelligence*, Vol 48, No. 5, pp 1344–1367.

Tzokas, N., Hultink, E. J. and Hart, S. (2004) “Navigating the new product development process”, *Industrial Marketing Management*, Vol 33, No. 7, pp 619–626.

Velasquez, M. and Hester, P. T. (2013) “An analysis of multi-criteria decision making methods”, *International Journal of Operations Research*, Vol 10, No. 2, pp 56–66.

Wang, K. J. and Lee, Y. H. (2011) “Criteria deployment at evaluation gates under different new product development strategies”, *European Journal of Social Sciences*, Vol 22, No. 2, pp 165–176.