MODERN METHODS FOR EVALUATION OF INVESTMENT EFFICIENCY IN ENGINEERING

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Abstract

The paper presents the proposed methodology for project portfolio evaluation. The methodology is based on theoretical knowledge gained in the literature and consultations with experts from academic and business practice. The proposed methodology is focused on the evaluation of investment plans with respect to the entire portfolio of projects. The methodology can be adapted to the changing requirements and needs of the company. It is based on the methods DEMATEL, ANP and linear programming. The DEMATEL method is used to formulate the structure of relationships between system criteria and gain the importance of criteria in the system. The ANP method is used to analyze the structure of the project portfolio and to determine the proposed order of project implementation. Linear programming already includes limited resource capacities in the solution. The functionality of the methodology is verified by a practical assessment of the project portfolio of a particular engineering company. A default set of criteria has been set for the methodology. Several experts were approached to find out the mutual links between the criteria and performed a pairwise comparison of all considered criteria. In total, 6 projects with mutual links were selected in cooperation with the company. The paper also describes the principles of the LCC method, which determines life cycle costs and their application to investment in machinery. The LCC method can be used as a method of financial evaluation of an investment as well as the more commonly used method of NPV today. The method includes the development and production costs of the machine, which are reflected in the purchase price, the cost of operating the machine over its entire life and disposal costs. The basis of the LCC method, is primarily knowledge of the reliability and durability of the individual units. Attention is also paid to the effectiveness of reconstruction and modernization.

Keywords: *the DEMATEL method, the ANP method, the linear programming, the life cycle costs, project portfolio selection*

1. INTRODUCTION

Objective article is presentation of modern methodology of project portfolio selection corresponding with theoretical foundations of PPM. The DEMATEL method (the Decision Making Trial and Evaluation Laboratory) is an effective method to (Altuntas. 2014) propose the use of a methodology for setting priorities in the portfolio of investment projects from the perspective of the government as the creator of incentives for investors. DEMATEL method is used for determination and quantification of direct and indirect links among projects in methodology of projects selection. Simultaneously is method successfully applied to analyze criteria in the system. The linear programming is defined as a problem of maximizing or minimizing a linear function under fixed constraints (Lewis, 2008). Linear programming is used to formulate the task finding the optimal solution projects with resource limits. LCC is an economic analysis tool to assess the costs and/or benefits directly impacting the decision-maker across the life cycle of project. One of the major benefits is the identification of factors which have the largest effect of the total life cycle cost (Korpi. 2008).

The first chapter introduces the basic methods entering to the methodology, including the LCC method. This is the subject of further investigation of its use in methodology. The following chapter is focused on the methodology itself and is a practical application. Especially the part dealing with project selection for portfolio. Chapter 3 introduces the case study to which the methodology was applied. The article focuses mainly on the selection of projects under lack of resources. The

methodology is based on the theoretical basis of linear programming. The status of work on the methodology and future outlooks are summarized in conclusion.

2. METHODS AND METHODOLOGY

2.1. Methods

In this chapter are introduced methods entering the methodology.

2.1.1. The DEMATEL Method

The DEMATEL method (the Decision Making Trial and Evaluation Laboratory) is an effective method to analyze relations (direct and indirect) between different parts of the system in relation to the type and severity). The DEMATEL method is applicable to the evaluation of many factors entering into portfolio assessment and to identify their relationships and evaluate their importance. (Altuntas, 2014) propose the use of a methodology for setting priorities in the portfolio of investment projects from the perspective of the government as the creator of incentives for investors. (Yang, 2011) combines DEMATEL and ANP method. The result is to capture the structure of complex relationships between system criteria and capture the level of influence of these criteria. These levels are then used to calculate the supermatrix ANP. Solution procedure is based on knowledge of the literature such (Fiala, 2013).

The DEMATEL method can be summarized in the following steps:

Step 1. Finding the initial direct relation matrix. Suppose we have m experts in this study and n elements to consider. Each expert is asked to indicate the degree to which he believes an element i affects an element j.

The scores give us a (n, n) non-negative answer matrix $X^k = \left[x_{ij}^k\right]$, with $1 \le k \le m$. The diagonal elements of each answer matrix Xk are all set to zero. We can then compute the (n, n) average matrix A for all expert opinions by averaging the m experts' scores as follows:

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{m} x_{ij}^k, \quad (1)$$

The average matrix A = [aij] is called the initial direct relation matrix. Matrix A shows the initial direct effects that an element exerts on and receives from other elements.

Step 2. Calculating the normalized initial direct-relation matrix. The normalized initial direct-relation matrix D is obtained by normalizing the initial direct-relation matrix A in the following way:

Let

$$m = \min\left[\frac{1}{\max\sum_{j=1}^{n}|a_{ij}|}, \frac{1}{\max\sum_{i=1}^{n}|a_{ij}|}\right], \quad (2)$$

Then $D = \frac{1}{s}A$.

Since the sum of each row j of matrix A represents the total direct effects that element i gives to the other elements, $\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}$ represents the total direct effects of the element with the most direct effects on others. Likewise, since the sum of each column i of matrix A represents the total direct effects received by element i, $\max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}$ represents the total direct effects received of the element that receives the most direct effects from others.

Step 3. Computing the total relation matrix. A continuous decrease of the indirect effects of problems along the powers of matrix D guarantees convergent solutions to the matrix inversion similar to an absorbing Markov chain matrix. Note that $\lim_{k\to\infty} D^k = 0$ and

$$\lim_{k\to\infty}\left(I + D + D^2 + \cdots + D^k\right) = (I - D)^{-1}, \quad (3)$$

where 0 is the (n, n) null matrix and I is the (n, n) identity matrix. The total relation matrix T is an (n, n) matrix $T = [t_{ij}]$, i, j = 1, 2,...,n, and is defined as follow:

$$T_k = D + D^2 + \cdots + D^k = D(I + D + D^2 + \cdots + D^{k-1}),$$

$$T = \lim_{k\to\infty} T_k = D(I - D)^{-1}, \quad (4)$$

Vectors r and c are defined representing the sum of rows and sum of columns of the total relation matrix T as follows:

$$r = (r_i), \quad (5)$$

where r_i is the sum of i-th row in matrix T. Then r_i shows the total effects, both direct and indirect, given by element i to the other elements, and

$$c = (c_j), \quad (6)$$

where c_j denotes the sum of j-th column in matrix T. Then c_j shows the total effects, both direct and indirect, received by element j from the other elements.

Thus when j = i, the sum $(r_i + c_j)$gives an index representing the total effects both given and received by element i. In other words, $(r_i + c_j)$ shows the degree of importance that element i plays in the system. In addition, the difference $(r_i - c_j)$ shows the net effect that element i contributes to the system. When $(r_i - c_j)$ is positive, element i is a net causer, and when $(r_i - c_j)$ is negative, element i is a net receiver (Vysloužilová, 2015).

2.1.2. The ANP Method

The ANP method (Analytic Network Process) network is a generalization of AHP (Analytic Hierarchy Process) method. The analytical network process (ANP) is a method that allows the system to include all possible interdependence and feedback. Structure of ANP model is described by clusters of elements and their interdependencies. Model ANP might reach several levels; the individual elements might be clusters of clusters of the next level etc. It is suitable for expressing dependencies within the network structures. Clusters model may represent variants, decision-makers, evaluation criteria and resources needed for implementation.

Within the portfolio of projects it can be very often seen that the order of the criteria and therefore their importance is given to the project itself (or its variants). It is possible to say that the criteria affecting the variants and variants also have a significant influence on the criteria. ANP method uses a network structure with bonds between system components. The network consists of nodes (elements), which are individual criteria or variants or clusters. A cluster is a group of several nodes connected by a common property, or are similar to each other.

The model contains the clusters with the individual elements which are connected loops. Model bonds can be divided into external and internal. External bonds compare the relationships between elements of one cluster to another one. Internal bonds contrary, comparing relationships between elements in the cluster. Bonds are shown in Fig. 1. C1, C2, C3 and C4 represent the individual clusters in the model. Between C2 and C3 is illustrated feedback. Cluster C1 contains internal bond (indicated loop). Between the nodes C4 and C2 is indicated by arrow outer bond. Description of methods and applications is based on the literature (Saaty, 2008).

2.1.3. The Linear Programming

The linear programming is defined as a problem of maximizing or minimizing a linear function under fixed constraints. The constraints may be equalities or inequalities. For more information read e.g. (Lewis, 2008). The result of linear programming is an optimal solution.

The linear programming method looks for the extreme (maximum or minimum) of linear purpose functions

$$f(X)=\sum_{j=1}^{n} c_j x_j, \quad \text{kde } X = [x_1, x_2, x_3, \ldots x_n], \tag{7}$$

Under conditions:

$$\sum_{j=1}^{n} a_{ij} x_j = b_i, i = 1,2,\ldots,k \tag{8}$$

$$\sum_{j=1}^{n} a_{ij} x_j \le b_i, i = k+1, k+2,\ldots,m, \qquad x_j \ge 0,\ j = 1,2,\ldots n \tag{9}$$

where $a_{ij}, b_i, c_j \in R$ aij , bi , cj $\in$ R, quantities a_{ij} are called structural coefficients, quantities b_i represent constants showing the available amount of resources, quantities c_j are called function coefficients,, j = 1,2 ... n ; i = 1,2 ... m; m < *n*. The optimum solution is a permissible solution that maximizes the purpose function under the given conditions.

Linear programming is used to formulate the task finding the optimal solution projects with resource limits. Resources, which are not available in the enough quantity, that means they will not cover the implementation of all projects selected, are entering into the solution of this problem as individual constraints. Conversely, the resources that are available in sufficient quantity for all selected projects do not enter into the problem at all.

In proposed methodology, we can use the size of the net present value of the selected projects as coefficients of the objective function. In this case we will maximize linear function. It can also be used the size of the life cycle costs of the selected projects as coefficients of the objective function too.

2.1.4. Life cycle costs

For deciding on the effectiveness of investments, especially for heavy and transport engineering, it is also important to determine and evaluate the total life cycle cost of a product. This method has already been introduced in our previous article (Sellner, 2018).

The principle of the method of life cycle costs LCC - Life Cycle Costs - is possible objective determination of costs during the various phases of the product life cycle – based on the calculations or measurements. These costs include two major time phases of the product: the first - development and production and the second - the proper product use and disposal. From the user‘s views the results of the first stage depends on the purchasing price of the product. The results of the second stage depends on of the costs of the operation including the costs of operation and maintenance, as well as any additional costs associated with lower security and reliability, and the end of life disposal costs. They are usually higher in large engineering products and vehicles.

The life cycle of a vehicle and the related determination and costs allocation can be divided into two main stages. The first includes the costs of market research, development and product design, manufacturing and eventual preservation, sale, installation and commissioning. The second stage presents using the product costs, operation, maintenance and product repairment, including the costs of any reconstruction and modernization, decommissioning and product disposal.

The interest of users of the product is that total cost of the machine life cycle should be minimal, and that their size is reliably and demonstrably verifiable. Then it is possible to compare with the same or similar basic technical, safety and operational parameters of the products of their effectiveness and profitability. Basic risks when determining the life cycle costs consist of reliability and provability costs of the various phases and their components, and the difficulty of comparing machines with different basic technical and operational parameters.

Very important operating parameters significantly affecting the operation of products are safety, reliability and also conditions that are necessary for their achievement in service to provide. It is necessary to establish requirements for these parameters during the development, design and

manufacture of products already at the beginning of development, and to provide a testing and operation for verification. Similarly, it is necessary during the life cycle to enter pre-defined requirements for environmental effects. It is obvious that the more demanding requirements for the reliability, safety, environmental effects, and for the life of the product, the higher the cost will be, mainly in the stage production, which will be reflected in the cost of transport. Even more important component of the costs associated with the operation.

Figure 1 is a scheme cost depending on the time for the product with the length of the life cycle costs t6 which for the life not undergone reconstruction (red) and for a product which, after operating time t3 reconstructed (blue). This life cycle extended by the time t5 growth while reducing costs and operation and maintenance. The cost in time t2 and t3 are formed in a manufacturing company and after adding the manufacturer´s profit forms the basis of the cost for the operator of the products. Costs in operation in most cases are not constant, but grows with time due to operational wear and increasing the cost of operating materials and wages of employees operating and maintenance costs. Has a certain effect and technological progress, the development of new materials and technologies on the one hand and changes in legislation bringing to outdated technical solutions, higher costs, especially in the field of environmental protection. It is therefore necessary during operational use of the product follow the actual reliability of the product and the associated maintenance costs and other costs of operation and to consider the effectiveness of any reconstruction or modernization machines Nr. In many cases, after a suitable reconstruction the lifetime of the machine will be extended. Decisions on the effectiveness of reconstruction and determine the appropriate timing and extent of reconstruction is one of the most risky decisions during use.

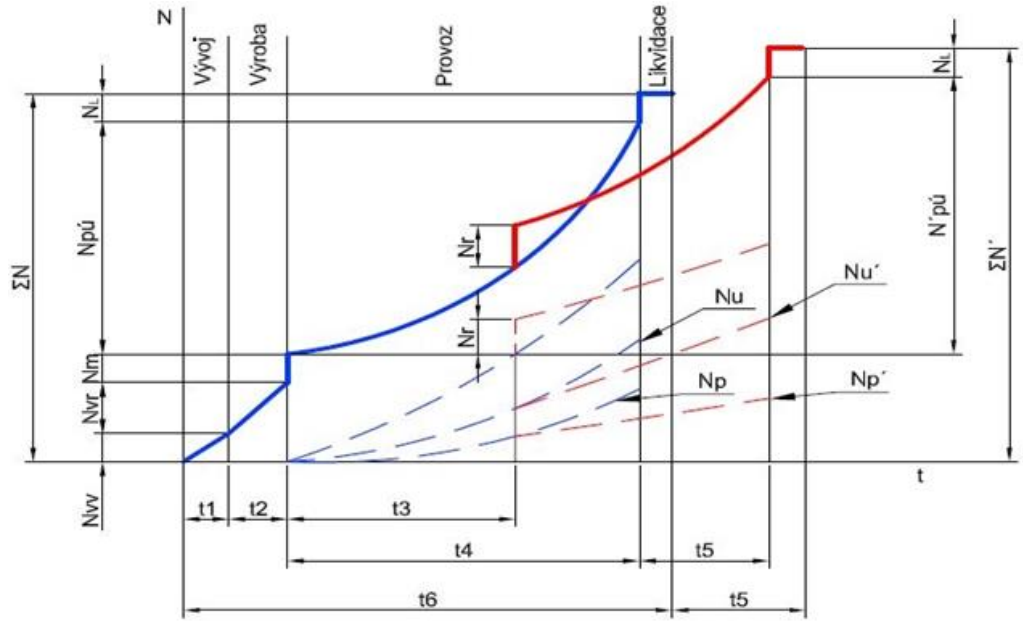


Fig. 1. Scheme of dependence life cycle costs on time (Vývoj – Development, Výroba – Manufakturing, Provoz – Operation, Likvidace – Disposal)

Source: Sellner, 2018.

There Nvv shows costs for research and development; Nvr production costs; Nm manufacturer´s profit; Npú operation and maintenance costs; Np operation costs; Nú maintenance costs; Nl disposal costs; Nr the costs of reconstruction and modernization; N´pú operation and maintenance costs after reconstruction; Np´ operating costs after reconstruction; Nú´ maintenance costs after reconstruction; ∑N live cycle costs; ∑N´ live cycle costs after reconstruction; t1 time in research and development; t2

production time; t3 time increase uptime reconstructed; t4 operating time machine; t5 increase the operating time after reconstruction and t6 live cycle after reconstruction.

The ratio between the costs of acquisition of products (i.e. the costs of the development, design, manufacture and possible commissioning) and operation and disposal costs from the customer's perspective is very important. For complex engineering products, which include high – capacity transport means the costs are usually important during the second stage of a product, ie the costs of operation and maintenance and subsequent destruction exceeds the costs of the first phase.

The method of defining life cycle costs is especially important when deciding on the order of a particular machine with the predefined requirements.

2.2. Introduction of methodology

In Portfolio projects selection, we are deciding about the inclusion or non-inclusion of project into portfolio. We provides: criteria identification and determining their weight in the overall assessment; identification of the linkages and factor them in the assessment; projects selection in the portfolio according to sufficiency of resources; projects classification through portfolio.

All above mentioned phases come under the Project portfolio management. It secures besides others aftercare and management of project portfolio.

The methodology is introduced in detail in (Vysloužilová, 2015). The goal of our methodology is to choose the best projects into portfolio and to consider all source distribution among project to achieving excellent efficiency.

The portfolio projects selection includes a comparison between all the projects that have been evaluated as appropriate. The portfolio is selected based on the evaluation criteria and depending on the availability of resources. The portfolio projects selection comprises a combination of objective and subjective criteria. The sequential steps of the methodology are summarized in Fig. 2.

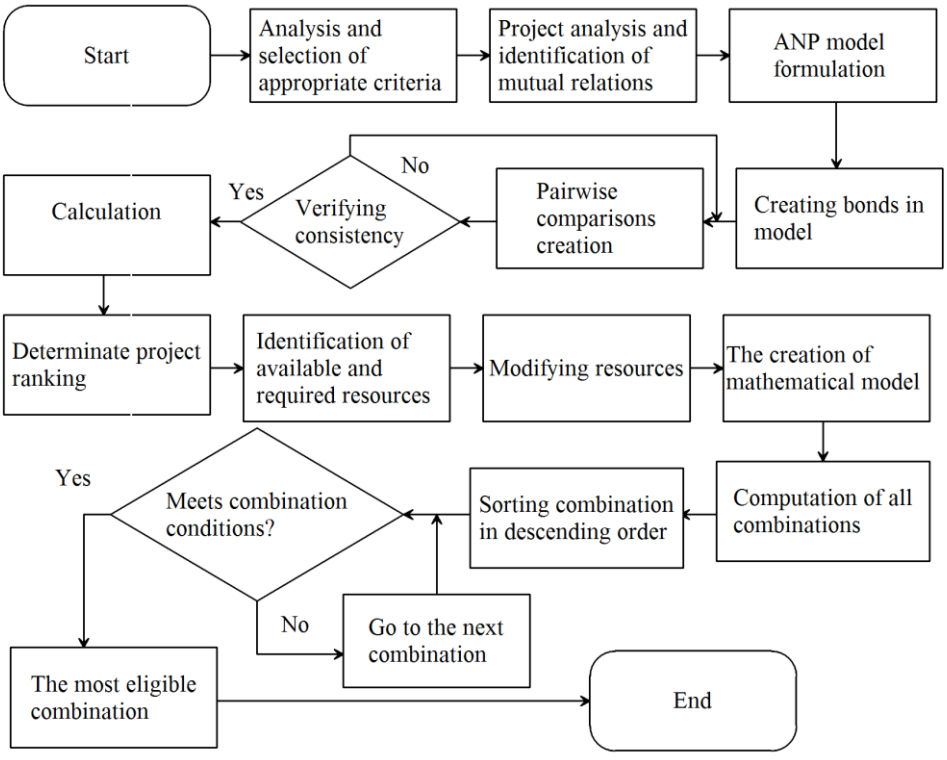


Fig. 2. Flow chart Projects portfolio selection

Source: Own work, 2017.

The project portfolio is selected on the basis of evaluation criteria and depending on the availability of resources. The selection of projects for the portfolio involves a combination of objective and subjective criteria.

The initial set of criteria was determined based on the results of the questionnaire survey and structured interviews. The set of criteria is shown in Table 1.

Financial criteria	Net present value	K1
	Labor cost savings	K2
	Saving energy and materials	K3
	Possibility of subsidies	K4
Technical criteria	Reduce wastage rat	K5
	Equipment usability	K6
	Assortment change requirements	K7
	Increasing production capacity	K8
Economic criteria	Increasing economic efficiency	K9
	Increase labor productivity	K10
Social criteria	Ecological criterion	K11
	Social area	K12
	Increase safety at work	K13
Project criteria	The probability of completing the project on time	K14
	Type of project	K15
	Project risks	K16

Table 1. Criteria entering the analysis

Source: Own work, 2017.

The selection of projects for the portfolio thus begins with an analysis of the applicable criteria using the DEMATEL method and the subsequent selection of the most suitable ones. At the same time, it is necessary to analyze all projects entering this evaluation phase, especially in terms of their mutual links and relationships. The DEMATEL method is able to detect and quantify both direct and indirect links between individual projects.

Based on information from the previous stages is created ANP model. This model is based on four basic clusters: criteria, resources, time and projects. Depending on the results of the DEMATEL method and the available information, the relationships between the clusters and nodes are formulated. The responsible experts will then make pairwise comparisons. After consistency verification, the calculation is performed and the order of projects is determined.

For a more accurate comparison of the various options of investment in machinery, it seems advantageous to use the LCC method instead of the NPV in terms of financial evaluation. The LCC method includes the total lifetime cost of each machine. Further, it takes into account the costs of development and production of the machine included in the sale price, as well as the operator's costs of operation, operation and maintenance as well as the costs of ecological disposal after the end of operational use.

2.2.1. Practical use of Live cycle costs

The LCC method is important and practically used in deciding on investing in complex mechanical engineering, transport and energy equipment with a long service life. With clear and specific assignment of operational use and knowledge of reliability parameters of individual components, it is possible to objectively determine the costs of individual stages of the life cycle from development and construction through operational use to disposal. This knowledge is then one of the most important criteria for a final decision about a particular investment and its suppliers. It can also be important for decision-making about the system and the maintenance of the investment (Daněk. 2009).

The second area of practical use of this method is to decide on the suitability, scale and effectiveness of modernization or major reconstruction of the product before it expires. The reason for such a modernization or reconstruction may be either to prolong the life of the product or to increase by reducing operating and maintenance costs, or a combination of these reasons. A prerequisite for the objective result and a basis for a correct decision is the thorough knowledge of the current operating and maintenance costs, the reliability characteristics of the newly installed units and the energy demands.

In deciding on investments and suppliers of the machines is appropriate to use the method LCC and the method of determining the RAM reliability parameters includes, in particular, an objective determination of the reliability, readiness and maintainability time. Reliability is due in particular to the intensity of failures of machines. Emergency is expressed as a standby factor and the concept of sustainability expresses the personnel and material demands to the costs. The basic step preceded by RAM analysis as one of the bases for the LCC machine method is the decomposition of the machine by dividing it into structural groups and units. Each item defines the maintenance costs and reliability characteristics of individual components (Netočný J. 2004).

In order to determine LCC using a machine-specific RAM method, especially with regard to a new product, it is in many cases necessary to use individual cost estimates and reliability characteristics. This procedure is applied when there is no complete data available or missing completely for individual components. This process is being used by leading global manufacturers in mechanical engineering.

The diagram of the LCC assay procedure using the RAM method is shown in Fig. 3. The result is the determination of the machine life cycle cost and its reliability and operability data.

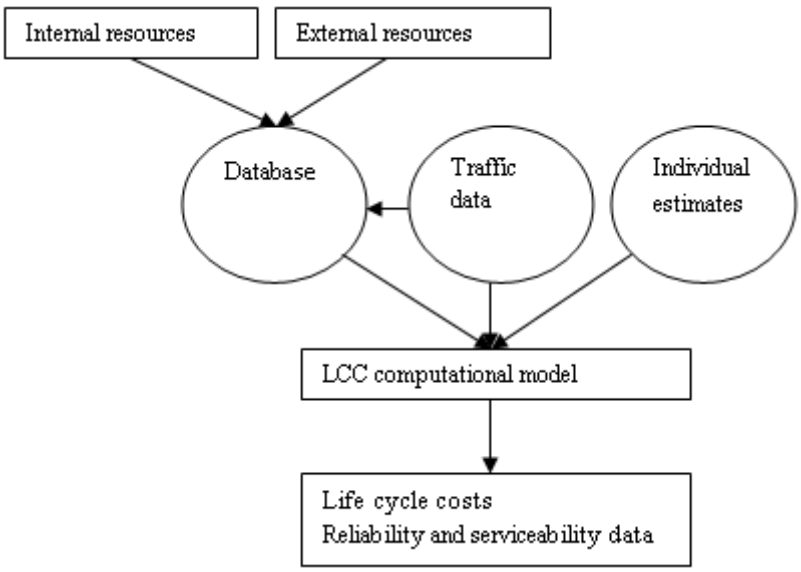


Fig. 3. LCC Assay Procedure Using the RAM Method

Source: Own work, 2019.

Principle of practical application of LCC method of rotary cultivators´ tools and building a database of relevant data for economic evaluation is shown in. (Sujová, 2015)

3. RESULTS

The results are presented on a case study. The study was carried out in the world's leading engineering company engaged in the development, manufacture, sale and service of machine tools.

3.1.1. Assignment of a case study

In total, 6 projects with mutual links were selected in cooperation with the company. Projects are marked with letters P1 to P6 for the purpose of this work. Due to the sensitivity of the data, projects are not described in detail see Table 2.

Project	Project description	Unit
Project P1	New investment in the purchase of a universal center lathe with CNC support replacing the existing center without CNC control	101
Project P2	General repair of universal machine for precision milling, coordinate drilling, boring and threading of box, plate and shape workpieces weighing up to 25 000 kg in order to maintain and partially expand production capacity of the center	102
Project P3	Creating sufficient capacity for machining high-precision parts by purchasing a machine of the character of a machining center with automatic tool and pallet change (new investment to expand the existing capacity of the relevant center)	102
Project P4	Replacement of an existing machine with a machine for precision milling, coordinate drilling, boring and cutting threading of case, plate and shape workpieces weighing up to 25,000 kg	102
Project P5	Implementation of a machining center, so more operations from existing workplaces are concentrated into a few at this center (replacing several machines)	102
Project P6	Strengthening the capacity of special types of machining and eliminating bottlenecks for grinding spindles and tapered bores	103

Table 2. List and basic description of the projects used in the case study

Source: Compiled from internal documentation of the company, 2017.

Within the initial evaluation of individual projects, a variant solution was identified for projects P2 and P4. The implementation of both projects is therefore mutually exclusive. In the next stage of evaluation of individual projects, in cooperation with the company, using the scoring method, it was identified as the best option of P4, which enters the next stage of evaluation.

Projects P1, P3, P4, P5 and P6 can therefore be identified as candidate projects and are entering the project selection phase in the portfolio. This case study deals with this phase of the proposed methodology.

3.1.2. Creation and calculation of mathematical model

Based on the available knowledge and information on projects and their needs, it is necessary identify the resources which are available in insufficient amount.

Sources, which available quantity does not cover the realization of all selected projects, come to the solution of this task as limiting conditions. On the contrary, the resources, which available quantity covers implementation of all selected projects, are neglected in the task. As maximization criterion we can used the ranking of projects.

Also it is necessary to identify resources (inputs), results (outputs) and activities for creation of economical model.

Now it is important to define the custom limitations and convert them into a mathematical model by using linear equations and inequations define proper task limitation. The order of projects in the form of weights enters the purpose-based function of the equation as the optimization criterion. This is maximizations criterion. The sum of the weights of all projects is equal to 1.

It is followed with calculation of possible combinations mathematical model. For the evaluation of projects, the solution is vector xi = 1, 0; where i = 1, ... n (xi defines whether or not the project will be implemented). The proposed calculation procedure uses the above mathematical model. From limitations and purpose function, the matrix C [k + 1, n] is created and then the right side vector b for n projects.

$$C \cdot x = b, \tag{10}$$

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{k1} & \cdots & a_{kn} \\ c_1 & \dots & c_n \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix} \leq \begin{bmatrix} b_1 \\ \vdots \\ b_k \\ 1 \end{bmatrix}, \tag{11}$$

Where:

k...number of limitations [-],

n…number of projects [-].

$$\sum_{i=1}^{n} c_i = 1, \tag{12}$$

It will create a matrix X [n, m] of all possible combinations of projects where n is the number of projects and m is the number of all combinations 0 and 1.

$$m = \sum_{i=0}^{n} \binom{n}{i} = 2^n \tag{13}$$

The elements of the j-th column (j = 1, .., m) of the matrix X are obtained by converting the number (j-1) into the binary system (ie by converting the numbers 0 to m-1).

Than it is necessary to calculate the matrix E [k + 1, m] for all combinations.

$$E = C \cdot X \tag{14}$$

Again, for the purposes of this work was created a source program for this solution in a freely available MAXIMA program for calculation.

Another step is to select the highest weighted combination of satisfying the specified constraints. We are looking for such combination, which would meet requirements. The result is listed at the end of the source program as the chosen solution. Where 1 is indicated, the project will be implemented, instead, the project, where 0 is stated, will not be implemented.

3.1.3. Case study solution

For the formulation of the mathematical model, the following assumptions were known: source constraints were chosen after consultation with the management of the company. The financial constraints are based only on how much the company is willing and able to give funds (due to their content) to the implementation of projects. Every investment (in our case a project) has given service requirements. These are based on the required qualifications, the effective work fund of the facility and the number of shifts considered. Requirements based on project documentation are shown in tab. Entry of the P2 project into the portfolio was excluded. Under these conditions, a total of 13 people would be involved. At the same time, it is necessary to realize that some projects are being

implemented as a replacement for existing facilities. This means that workers from the original workplaces will move to the new workplaces. The movement is possible only with the assumption of the required qualifications. For this reason, no additional human resources requirements are envisaged for projects P1 and P4. Thus, after the closure of some workplaces and the envisaged increase in the number of workers, the company has a total of 7 employees at its disposal for redistribution between projects. For the capacity, it is assumed that the machines will not be able to be used for the duration of the investment. Production capacities will therefore be reduced. This will be replaced by creating sufficient inventory for contracted orders (which are arranged for about 1 year or more in advance). So the project implementation will not interfere in the production of these projects. In case of unexpected order production this will be solved by external cooperation. Projects P1 and P5 are investments replacing existing equipment. According to the company, the existing facilities occupy a larger space capacity than the intended projects. The project will be implemented on the current floor plan of existing machines. From this reason, the technical equipment is not considered as a limiting factor in these projects.

Formulation of the economic model: The economic model for a given case study can be expressed as follows. The company selects between five projects P1, P3, P4, P5 and P6 for lack of some resources. To solve the problem, it has the following resource limitations: available funds totaling 50 million crowns, human capacity in total 7 people and limited space capacity (technical equipment) total 200 m2. The ranking of projects given by their weight and the project requirements for each resource are summarized in Table 41. All values are based on data provided by the enterprise. The resources in parentheses are not considered to be limiting in view of the above. Project weights were determined using the ANP method.

	P1	P3	P4	P5	P6
Financial resources [mil. CZK]	1,97	6,7	8,94	27,4	16,85
Human resources [human]	(2)	3	(3)	2	3
Technical equipment [m2]	(8)	92	84	(40)	60
Project weights	0,210	0,195	0,169	0,256	0,170

Table 3. Initial conditions of the case study

Source: Compiled from internal documentation of the company, 2017.

Formulation of mathematical model: The following mathematical model was created based on the above available theoretical and theoretical data.

The order of the projects in the form of weights enters the purpose function based on equation (7) as an optimization criterion. It is a maximizing criterion. The sum of weights of all projects is 1.

$$Z_{max} = 0{,}210\,x_1 + 0{,}195\,x_3 + 0{,}169\,x_4 + 0{,}256\,x_5 + 0{,}170\,x_6 \quad (15)$$

In Table 3 are defined custom limitations. Each source constraint represents one inequality in the mathematical model . The last inequality is given by the non-negativity of resources.

$$1{,}97\,x_1 + 6{,}7\,x_3 + 8{,}94\,x_4 + 27{,}4\,x_5 + 16{,}85\,x_6 \leq 50 \quad (16)$$

$$3\,x_3 + 2\,x_5 + 3\,x_6 \leq 7 \quad (17)$$

$$92\,x_3 + 84\,x_4 + 60\,x_6 \leq 200 \quad (18)$$

$$x_1, x_3, x_4, x_5, x_6 \geq 0 \quad (19)$$

A total of 5 projects P1, P3, P4, P5 and P6, including known limitations (16), (17), (18) and (19), and special-purpose functions (15) enter the task solution. Based on this data, a matrix X was created with a total of 32 possible combinations. An overview of all combinations arranged by total weight including sources is given in Table 4.

Combination	P1	P3	P4	P5	P6	Financial resources [mil. CZK]	Human resources [human]	Technical equipment [m^2]	Total weight	Combination	P1	P3	P4	P5	P6	Financial resources [mil. CZK]	Human resources [human]	Technical equipment [m^2]	Total weight
1	1	1	1	1	1	61,86	8	236	1,000	17	1	0	0	1	0	29,37	2	0	0,466
2	1	1	0	1	1	52,92	8	152	0,831	18	0	1	0	1	0	34,1	5	92	0,541
3	1	1	1	1	0	45,01	5	176	0,830	19	0	0	0	1	1	44,25	5	60	0,426
4	1	0	1	1	1	55,16	5	144	0,805	20	0	0	1	1	0	36,34	2	84	0,425
5	0	1	1	1	1	59,86	8	236	0,790	21	1	1	0	0	0	8,67	3	92	0,405
6	1	1	1	0	1	34,46	6	236	0,744	22	1	0	0	0	1	18,82	3	60	0,38
7	1	1	0	1	0	36,07	5	92	0,661	23	1	0	1	0	0	10,91	0	84	0,379
8	1	0	0	1	1	46,22	5	60	0,635	24	0	1	0	0	1	23,55	6	152	0,365
9	1	0	0	1	1	38,31	2	84	0,635	25	0	1	1	0	0	15,64	3	176	0,364
10	0	1	0	1	1	50,95	8	152	0,621	26	0	0	1	0	1	25,79	3	144	0,339
11	0	1	1	1	0	43,04	5	176	0,62	27	0	0	0	1	0	27,4	2	0	0,256
12	0	0	1	1	1	53,19	5	144	0,595	28	1	0	0	0	0	1,97	0	0	0,21
13	1	1	0	0	1	27,76	3	144	0,549	29	0	1	0	0	0	6,7	3	92	0,195
14	1	1	1	0	0	17,61	3	176	0,574	30	0	0	0	0	1	16,85	3	60	0,17
15	1	0	1	0	1	24,76	3	144	0,549	31	0	0	1	0	0	8,94	0	84	0,169
16	0	1	1	0	1	32,49	6	236	0,534	32	0	0	0	0	0	0	0	0	0

Table 4. Organized results of all combinations

Source: Own work, 2017.

Gradually, a combination is sought that meets all the constraints. Combination 1 has the highest overall weight (1), but exceeds the limitations for all three sources. Combination 2 meets the limitations in the technical equipment but does not meet the other two limitations. The combination with the highest total weight meeting all limitations is shown in Table 4 on line 3. Therefore, projects P1, P3, P4 and P5 will be implemented. Details are given in Table 5. The mathematical software MAXIMA was used for the calculation.

	P1	P3	P4	P5	Total need for all resources	Need for new resources	New resources left
Financial resources [mil. CZK]	1,97	6,7	8,94	27,4	45,01	45,01	4,99
Human resources [human]	(2)	3	(3)	2	10	5	2
Technical equipment [m^2]	(8)	92	84	(40)	224	176	24

Table 5. Resulting solution under given conditions

Source: Own work, 2017.

Economic interpretation of the mathematical model: Based on the given conditions, a combination of projects to be implemented has been selected. These are projects P1, P3, P4 and P5. A total of CZK 45.01 million will be used, 5 new employees will be required and the new area needed to implement the selected projects is 176 m^2 in total. Based on the defined conditions, it is possible to start the implementation of all selected projects simultaneously. The decision as to whether the projects will be carried out simultaneously or in which order they will be implemented depends on the company and its operating conditions.

4. DISCUSSION

The scientific contribution lies in the creation of a new methodology containing modern methods from the field of operational research and, to a certain extent, linear programming. Novelty is given mainly by a comprehensive view of this problem. It should be noted that the proposed methodology is entirely dependent on the input data, their accuracy and availability. Assuming this is achieved, its use will greatly facilitate the decision making of the project portfolio manager.

Within the methodology formulation, a set of criteria in the field of engineering was identified. Furthermore, the analysis of mutual influences and links in the created system of criteria was performed. The source program for the DEMATEL method was created in the free program MAXIMA. It was also necessary to design an ANP model in program SuperDecisions.

In further research we want to focus on monitoring the practical use of this methodology and its possible adjustments and improvements, as well as on extending the methodology to other project investments. The application of methodology in other areas of the national economy is also worth considering.

5. CONCLUSIONS

Methodology covers the most important factors affecting decision process, e.g. project interactions, resources limits, criteria and their mutual relations etc. It is constructed on methods from the field of operations research. They include risk, multiple criteria and dynamics. The procedure has high rate of flexibility. The DEMATEL method enables to identify and quantify effects receives and received to other parts of system. Method is applied for mutual relations analysis in cluster projects and in cluster criteria. Also it is used for determination of criteria importance. The ANP method make possible to include all linkages counting feedbacks and their significance into evaluation. The projects are chosen and subsequently implemented on the grounds of a set of factors from the fields all over which have the impact on the decision. The linear programming model is in methodology used to redistribution limited resources among chosen project to maximize profitability. The paper also describes the principles of the LCC method, with which can be determined in combination with the RAM method of life cycle cost and application to investment of machinery.

This methodology has been verified in a case study containing real data provided by the engineering company in several steps. First, projects were evaluated using the ANP method and the DEMATEL

method. Subsequently, the allocation of insufficient resource capacities was solved. This was done using a mathematical model containing source limitations and a purpose function occurring in linear programming. All calculations were solved using the MAXIMA and Super Decisions software tools.

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