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A TWO-STEP APPROACH FOR SELECTION OF RAILWAY MODERNIZATION PROJECTS BASED ON ANALYTIC HIERARCHY PROCESS

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Abstract. This paper presents a simulation of the Project Portfolio Management (PPM) model usage in evaluation and selection of modernization projects of Serbian Railways. Performance review of the selected projects is conducted in regards to the strategic goals of the company, which have been established during the process of strategic planning. The project selection model is methodologically set up as a two-step selection model. The number of portfolio projects is narrowed down by ranking their importance in regards to the success of the modernization program (benefits, risks, and resources), which is followed by the ranking of the projects on the basis of their contribution to the realization of previously chosen liquidity and rentability goals, which are always a challenge when it comes to railway companies. This selection procedure is simulated by applying the Analytic Hierarchy Process (AHP), a mathematical model of linear programming, embedded in the software package "Expert Choice". The simulation results show that, in this way, it is possible to achieve a considerable drop in the amount of necessary financial resources for the realization of modernization projects, which is also the main contribution of this paper. This proves the efficiency of the PPM concept application as a modern model of strategic management. The showcased model of project portfolio selection can find a significant usage among the current processes of railways restructuring, especially in financing of the projects of public–private partnerships.

Keywords: project portfolio management, two-step selection model, AHP, railway.

Notations

AHP – analytic hierarchy process;
ANP – analytical network process;
DEA – data envelopment analysis;
DMU – diesel motor unit;
DRSA – dominance-based rough set approach;
ELECTRE – elimination and choice translating reality (in French: *ÉLimination Et Choix Traduisant la REalité*);
EMU – electric motor unit;
ERP – enterprise resource planning;
JSC – join-stock company;
MCDM – multi-criteria decision-making;
PPM – project portfolio management;
PROMETHEE – preference ranking organization method for enrichment evaluation;
ROI – return on investment;
SMAA – stochastic multi-criteria acceptability analysis;
TOPSIS – technique for order of preference by similarity to ideal solution;
VIKOR – multi-criteria optimization and compromise solution (in Serbian: *Višekriterijumska optimizacija I KOmpromisno Rešenje*).

Introduction and research area overview

Current changes in the organizational structures of Europe's railway systems are conducted because of the need to make the railway companies efficient and competitive in the long-term. However, the next phase of railway restructuring must be related to the questions of managing the limited resources, as the goal of accomplishing an expected quality in business. This request opens the room for the application of PPM, as one of the modern solu-

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tions for reaching economic efficiency (Markowitz 2009; Martinsuo, Lehtonen 2007). In this phase, defining the portfolio is a "periodic task" that considers the projects suggested to enter the portfolio from the standpoint of resource utilization efficiency, as well as targeted liquidity and profitability parameters – and these are always targeted high in railway business systems (Anisseh *et al.* 2018). This request opens up a space for the utilization of PPM, as a modern solutions to economic efficiency, which has become "the key element of service provision of large organizations" (Danesh *et al.* 2018). PPM research today is especially focused on considering project specificities and key success factors of PPM, as the elements that contribute the most to the choice of different selection techniques when it comes to project portfolio.

In this paper, the business portfolio of railway companies is conceptualized and presented in correspondence with the holistic understanding of a railway company as an open system, whose organizational structure redesign is influenced by external changes. These changes are characterized by the usage of informational and communicational technologies, new knowledge, and intellectual capital as the main strategic resources. Managing the changes in the company is achieved through multiple projects, with segmentation of strategic goals into operational goals through PPM.

From the aspect of strategic goals of a company with limited business resources, the choice of project portfolio has been one of the biggest theoretical and practical challenges in the area of modern project management (Blichfeldt, Eskerod 2008; Aubry *et al.* 2007; Dietrich, Lehtonen 2005). PPM efficiency estimation is not dependent just on multi-criteria analysis, but also on the usage of portfolio assessment methods (Danesh *et al.* 2017; Sandstrom, Bjork 2010; Kester *et al.* 2009). Multiple studies argue about the decision-making and challenges included in PPM (Cooper *et al.* 2002; Elonen, Artto 2003), but none has been able to establish the "frame for their correct connection" (Danesh *et al.* 2018). The solution to this problem requires aggregation of performances from different projects with multiple aspects, and with a mathematically sound approach – through the application of differing methods of different MCDM.

Existing PPM research is defined by two directions (Yang *et al.* 2015). The 1st is based on different programming methods and project selection techniques, such are linear, non-linear, integer, dynamic, goal-oriented, unclear and stochastic. Additionally, some other mathematical models are also applied – decision tree, game theory, simulation and heuristic methods. The other research group primarily selects the project portfolios in specific areas, using the information about their specifications, along with the external factors. It is mostly used in public infrastructure projects and complex organizations sensitive to business environment (Song *et al.* 2019).

Modern literature presents a number of studies researching the performances and cross-analysis of more than 100 different MCDM methods. From the aspect of decision-making suitability techniques, Danesh *et al.* (2018) and Sala *et al.* (2013) suggest different project selection criteria. The prominent criteria are: project quantity, connections to strategic goals, quantity and quality parameters, sensitivity, co-dependence, simplicity, decision ordering, conflict between goals, possibility of group decision-making, and other (Danesh *et al.* 2018; Sala *et al.* 2013). Danesh *et al.* (2017) reveal 8 methods "most suitable" for PPM: (1) AHP; (2) ANP; (3) DEA; (4) DRSA; (5) ELECTRE; (6) PROMETHEE; (7) TOPSIS; (8) VIKOR.

The comprehensive literature regarding the cross-analysis of MCDM, Danesh *et al.* (2018) and Sala *et al.* (2013) conclude that "no single method is ideal for application in portfolio management", and propose combining them and producing hybrid applications adaptable to the given business areas. Still, they do recommend two methods: AHP and DEA. They note that complex portfolio management is confronted with many risks and, by itself, is harder than the classic project management. Every management phase, such as management technique selection, factor selection, evaluation, and the determination of criteria weight, has a certain level of uncertainty. This notion establishes the assertion that the "efficient uncertainty management is the most important challenge in the decision-making process" (Danesh *et al.* 2018; Steffens *et al.* 2007; Janssen *et al.* 1990). Seeing how "there is no ideal approach to PPM application" (Dawidson 2006; Cooper *et al.* 2001, 2002), modern literature concludes that combining the MCDM techniques is becoming ever more necessary, considering the specificity, quantity, complexity and high co-dependence between projects, especially in regards to large unique technological systems (Anisseh *et al.* 2018; Danesh *et al.* 2017).

PPM success is directly related to decision quality. Decision-making is a mental process based on tangible and non-material criteria, which established by decision-makers themselves (Saaty, Sagir 2009). Decision-making requires "wider and more complex understanding of the context, rather than any specific technique" (Vargas 2010). In the conditions of turbulent environment, the number of factors influencing the business of a single organization is increasingly larger, and the risks of decision-making become one of the toughest challenges (Triantaphyllou 2000). The project selection is based on calculation of gains and expenses, which cannot always be quantified through financial metrics.

"The Standard for Portfolio Management" (PMI 2017) emphasizes the connection of project portfolio to strategic goals that are specific for each separate organization. This stance implies that there is no universal, perfect model for ideal portfolio project selection, but that it depends on the condition of each separate organization and its decision-maker. Every portfolio-related decision is "a thing of negotiations, human aspects and strategic analysis", so MCDM (AHP included) "cannot and must not be used as universal criteria" (Vargas 2010). When it comes to portfolio success, correct quantifying data and measured qualitative estimations are key.

The usage of AHP in PPM decision-making implies the identification of specific projects functionalities and presentation of collected results in a mathematically impactful way, which connects the significance of a project and the strategic goals of an organization. Modern research papers consider theoretical and practical possibilities for outcome improvement by using the AHP method and examine usability, security, and quality of this decision-making technique. "Human mind uses hierarchies as the dominant method when it comes to classification of what we observe" (Whyte *et al.* 1969). AHP is a method that translates key decision into goal hierarchy, based on the decision-maker's estimation. AHP is the most popular of MCDM techniques primarily because of its simplicity in usage of multi-levelled hierarchy (Danesh *et al.* 2015). AHP is an organized structure of cross-analysis on hierarchical levels of strategic goals, criteria and alternatives, which are targeted by the decision-maker (Singh *et al.* 2007). In the PPM model, organizations create business strategy, and connect projects to strategic goals, as a way to determine priorities.

AHP developed during the 1980s (Saaty 1980), is still the most popular and most frequently used MCDM technique, when it comes to resource management, business policies establishment and strategic planning in large organizations (Danesh *et al.* 2017). AHP is one of the most widely used mathematical models in decision-making process (Vargas 2010). The main contribution and the main characteristic of AHP is its ability to translate empirical data into numerical values, which can then be compared. It is a mathematical model that enables comparison of two elements, usually through the so-called scale of relative importance between two alternatives, 1st suggested by Saati in 2005 (Vargas 2010). AHP is a simple technique for project selection, which uses precise mathematical tools in a software application to support the validity of a decision and enable decision-makers to create a results simulation and justify their choice. Some authors note the suitability of AHP in area of complex project management, risk assessment and sensitivity analysis, as well as ERP (Benítez *et al.* 2012).

In 1996, a form of developed AHP, now known ANP appeared and quickly became suitable for large business systems with numerous projects. It enables quantification of co-dependence between projects in a portfolio, but also clustering and prioritization of projects based on binary analysis of quantitative parameters, which requires an approach through software (Wang 2012; Zhong *et al.* 2012; Verdecho *et al.* 2012). From the angle of restructuration and modernization of large system, such as railways, ANP can be of particular use during organizational performances establishment, business resources structure optimization (ERP), large infrastructural projects complexity measurement, and chain of supply efficiency increase (Boj *et al.* 2014; Gürbüz *et al.* 2012; He *et al.* 2015).

AHP and ANP use only quantifiable parameters, the number of criteria is usually limited to 10, and it's not possible to compare more options. Yeh (2002) estimates that AHP can be an efficient decision-making technique when a portfolio consists of less than 10 alternatives and criteria. When that number is above 10, it is suggested that AHP is combined with a method that can process uncertain and non-precise information, as well as missing information (Yeh 2002). AHP can only support quantified values and is not applicable when there are multiple requirements and options. Danesh *et al.* (2015) recommends combining AHP with other MCDM techniques or developing hybrid models, so that both quantitative and qualitative data can be used in project evaluation.

Because of these imperfections, these methods are often combined with a mathematical technique of linear programming (DEA), as a way of minimizing mistakes and subjective estimations (Thanassoulis *et al.* 2012; Giannoulis, Ishizaka 2010). Through this technique, projects can be evaluated by resources (Sudhaman, Thangavel 2015; Ghapanchi *et al.* 2012), efficiency (Hadad *et al.* 2013), risk (Shi *et al.* 2014). Considering the limitations on type and number of parameters, Danesh *et al.* (2017) do not recommend exclusive usage of AHP and ANP methods, but their combination with DEA, which supports unlimited criteria.

The selection of portfolio projects based on multiple criteria often cannot be performed without biases and conflicts (Tavana *et al.* 2015), so many researches use decision-maker's preferences as a criterion (Song *et al.* 2019). In order to produce information regarding the uncertain preferences of the decision-maker, AHP models or TOPSIS techniques (Anisseh *et al.* 2018; Collan, Luukka 2014) are used. In situations where resources are limited and estimations are off, AHP can be used in an uncertain environment. The project selection decisions can be seen as a risk problem, and they include different risk factors (Chatterjee *et al.* 2018). However, when the preferences of a decision-maker are not known, it is difficult to measure the criteria's weight, so these methods become unusable. The solution can be found in the usage of the theory of uncertain sets and the stochastic theories (Song *et al.* 2019; Perez, Gomez 2016), but it needs to be noted that the theory of fuzzy sets is a method that produces approximate answers.

The researchers mentioned above are increasingly approaching the problem of portfolio project selection through SMAA. This approach does not require the decision-maker's declaration of preferences, or precise criteria data. Based on an established algorithm, all acceptable portfolios are identified, which produce an optimal combination of projects that satisfy the most criteria. Even though it requires difficult calculations, the dynamic model of SMAA software can be very useful in corporative strategic planning and management of large public projects (Song *et al.* 2019).

Benaija and Kjiri (2014) look for solutions in decomposing of PPM processes, focusing on the phase of project selection. They suggest 3 steps of selection, where the 1st step is the most important – classification of projects based on 3 established decisive criteria: (1) value maximization; (2) risk minimization; (3) compatibility of projects with strategic goals. In the next steps, this approach introduces interactivity by including the intervention of the decision-maker in the further process. Additionally, of note are also other aspects of project portfolio research, which value the allocation of available financial resources from the aspect of project sustainability, weighting between internal level of returns and key risk factors (Markowitz model) (Dobrovolskienė, Tamošiūnienė 2016).

Based on this short summary, it can be concluded that the project portfolio decision-making is always complex and requires a setup of multiple criteria and goals, which are often non-material and in conflict with each other, and include different risks (Closs *et al.* 2008). PPM is a process in which a group of projects maximizes success and strategic goals achievement. In this paper, a practical example of selection of the supplier for Serbian Railways modernization projects presents the usage of AHP methods of MCDM, with 4 project selection criteria and with several quantified parameters used for rating the suppliers, based on liquidity and rentability. In supplier selection, a two-level choice AHP method has been used, adapted for complex projects of railway systems modernization (Ković, Djuranović 2011).

The paper is organized as follows. After the introduction, which gives the short overview of the current PPM research, the Section 1 shows the evaluation algorithm schematic the portfolio project selection. In the Section 2, a case study was developed, which, through the software package "Expert Choice", shows a two-stage model of selection of procurement projects in Serbian Railways, with the aim of harmonizing the project value in relation to limited financial resources for railway modernization. This section discusses the two-step project selection process and showcases the visual presentation of the selection results based on the used software application. The last section gives the conclusion regarding the paper contribution and discusses the direction of succeeding research.

1. Selecting the projects for portfolio

Development of a project portfolio is tied to the project selection – the portfolio candidates. The project selection is the 1st phase of the PPM process and it starts with a clearly defined organizational mission, a limited list of general goals and aspirations that specify the company's purpose; and organizational vision, a mental roadmap, which streamlines the organization's mission. This is followed by the setup of strategic goals, a set of clear and quantifiable output performances related to the expected results in a certain time frame (Levine 2005).

In the chronically non-liquid companies, a common strategic goal is usually the increase of liquidity levels (e.g., decreasing the debt level by 50%, settling obligations in 45 days from the loan inception). In the companies, which conduct business on a loss, the strategic goal is to increase rentability.

Looking at the strategic goals, the company makes an inventory of available resources and undertakes strategic planning, which also covers strategic analysis of the market. Strategic goals enable the formation of the previous image of the project portfolio, the one defined by available resources, which a railway company can procure from their own or external sources (credits, loans, public–private partnerships, outsourcing, etc.).

Strategic planning connects the strategic goals and strategic resources. On the other hand, project portfolio organizes strategic resources in a way that enables them to perform strategic goals. Organization of available strategic resources of a company through project portfolio is conducted by evaluating separate projects, selecting them, and determining the size of portfolio (Arnold, Schmidt 2010).

Selection of portfolio project is conducted with a goal of reaching a mix of project, which will, in time, contribute the most to the goals of the company. In other words, the selected projects should be aligned with the strategic priorities and the limited resources of the company. Selection has two basic sub-phases: (1) evaluation of projects – portfolio candidates, and (2) project approval and their subsequent addition to the portfolio. In this paper, a special attention is given to the financial aspect of evaluation, because the projects are evaluated from the point of liquidity and rentability.

1.1. Evaluation of projects – portfolio candidates

Starting with the indicators, which quantify strategic goals, the candidate projects go through 3 evaluation filters during the process (Greer 2006):

- project rating according to value and usefulness criteria;
- project realization risk assessment;
- project rating relative to the available strategic resources (Figure 1).

Value and usefulness criteria are usually represented as the quantified results of business success (revenue, profit, savings, etc.). Usefulness can also be showcased as a quality achievement (of a product, for instance), as time-based usefulness (e.g. time saved on production or delivery), or it can be related to the strategic position on the market (achieving a certain market share, for instance).

Criteria for risk assessment are connected to project duration, its costs, and the structure of the financing (means, sources, and dynamics), as well as to the need and the scope of engaging other strategic resources of the company. The information sources of these criteria are the strategic plans of the company or supplier's offers, including the suppliers of external financial sources, as well as the outsourcing companies.

Rating a project relative to the available strategic resources requires making an inventory of available strategic resources and their allocation. During this phase, the eval-

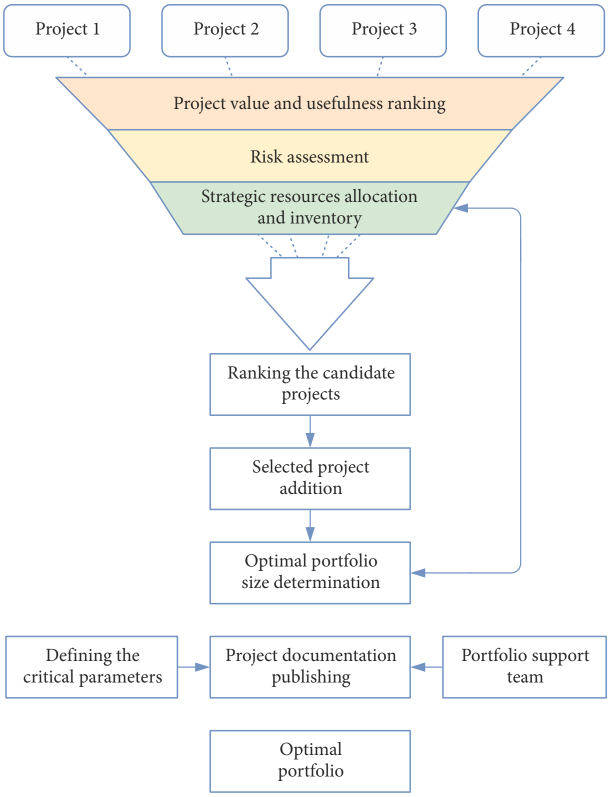

Figure 1. Portfolio project candidates selection algorithm (created by authors)

uation of projects is performed by measuring the relations of strategic potentials of the company and the parameters from the supplier's offers. When it is estimated that a project is useful for a company and that the risk is small, that project can be included in the portfolio only if the company has the resources to realize it. If the company does not have the necessary resources, but the estimated usefulness is great, the company can make the decision of borrowing the resources from external sources. This is usually the case with financial resources, which is connected to sources, forms, prices, conditions, and the structure of financing, which opens the question of transactional costs.

Evaluation of portfolio project candidates in 3 steps – (1) usefulness; (2) risk; (3) resources – determines the acceptable scope of portfolio. The portfolio scope is not rigid or pre-determined, but entirely connected to company's strategic goals.

1.2. Project approval and addition to portfolio

Project approval and addition to portfolio represents the 2nd phase of the evaluation process. During this phase, the approved project is formalized, and the company defines the key parameters of project's success, as well as the team that will manage the project.

Portfolio formation is conditionally finished when the project document is published. Modern companies tend to define their total business through different portfolios, based on availability of strategic resources. Considering that the portfolio process is iterative, with evaluation and selection being continuous, it is possible for some projects to be redesigned or suspended, and others to be included (Greer 2006).

In this paper, project evaluation and selection, as well as the determination of the portfolio scope, are showcased through the choice of a supplier (Arnold, Schmidt 2010). Supplier offers are translated into project suggestions, which compete for entry into procurement project portfolio. Choice criteria are set up relative to Serbian Railways, which have rentability and liquidity as its biggest business challenges. These challenges are analogous to most of the European railway companies.

2. Case study: a two-step project selection model in Serbian Railways

2.1. Criteria selection setup and project inventory

Defining the portfolio project selection criteria is represented through the definitions of the business mission and vision, as well as the strategic goals of the railway company. After that, an inventory of modernization projects is made, which is used as the basis for the selection of projects based on their ability to satisfy the established strategic goals.

Mission statement:

- »» JSC "Serbian Railways" is a modern European railway company with the competences to satisfy the user's needs in the area of goods and passenger transport.

Vision statements:

- »» JSC "Serbian Railways" can conduct business independently from the state's budget donations by achieving rentability, which will secure the permanent ability to settle the claims from various business partners (suppliers, overhaulers, contractors);
- »» JSC "Serbian Railways" should pay special attention to develop the transit transport of goods and passengers through Serbia in order to become a part of the major European transcontinental railway passage: Northwest–Southeast (Railway Corridor X).

Strategic goals:

- »» conduct capital repairs with modernization of major railway tracks along Railway Corridor X;
- »» conduct capital repairs with modernization of the existing transportation capacities, along with the procurement of modern railway traction and haul vehicles, with emphasis on electromotors and diesel motors intended for intercity and city–suburb passenger transport, as well as on special cargo wagons;
- »» achieve long-term ability to settle any incoming obligations towards business partners (liquidity);
- »» achieve the level of business, which will turn profit, shorten the ROI periods, and enable the change in structure of the engaged resources in favour of own resources, lowering the debt levels (rentability).

The 1st 2 strategic goals enable the prioritization of project that service these goals, which means that any other projects will be suspended. The PPM team of JSC "Serbian Railways" is making an inventory of projects, allocating the available strategic resources needed for portfolio realization.

The other 2 strategic goals are key to candidate project selection. Rating of the candidate projects is performed by determining the usefulness/value, and through risk assessment. The measured factors are the available company resources and the conditions set by the suppliers' offers (delivery value, method and dynamics of payment, and others), from the point of liquidity. Factoring the rentability in, certain profit criteria are used: level of internal project rentability, ROI intervals, and others. Additionally, the company performs risk assessment: deadlines and dynamics of deliveries, logistics, supplier references, and others.

Creating a railways modernization projects inventory is usually conducted in regards to national strategies related to transportation and economy development, as shown in Table 1.

2.2. Modernization project selection model setup in regards to strategic goals

The selection process is conducted according to the defined modernization project inventory and established mission, vision and strategic goals of a railway business system. In a practical model, the project selection is conducted as a two-step selection model.

2.2.1. The 1st selection phase

Selection criteria. As soon as JSC "Serbian Railways" pick a specific modernization project (inventory of projects) (Table 1), the 1st selection phase checks the projects in accordance to their usefulness in conducting the modernization. The importance of technical solution for the project success is determined 1st and then the estimated value of the projects is considered in relations to the available financial resources. In the 1st phase, the following modernization projects are selected:

- the projects that can contribute considerably to strategic goals: (1) Railway Corridor X modernization; (2) the procurement of modern passenger trains and cargo cars (strategic goals 1 and 2);
- the projects that can be realized within the critical sum of available financial resources (800 mln EUR). This criterion should indicate if projects, which satisfy in terms of content and technical performances, can be realized considering the available financial resources or is it necessary to obtain additional financial sources.

The criteria measuring the project's contribution to success of the modernization program should answer the question asking which of the 15 projects (according to their content and technical performances) matches mission, vision and strategic goals (1 and 2) the best. Project value criteria in relation to the available resources should showcase if the project require the resources handled by JSC "Serbian Railways" (strategic goal 3) or if they require additional financing sources (strategic goal 4). Applying the value criteria to modernization program success, the inventory was narrowed down to 6 projects, each becoming a candidate for the portfolio (Figure 2) (Ishizaka, Labib 2009).

Figure 2 showcases the 1st phase selection algorithm. During this phase, 15 modernization projects are narrowed down to 6 project that can contribute the most to achieving the mission, vision and strategic goals of JSC "Serbian Railways". The results of the 1st selection phase are given in the Table 2. According to the determined criteria and the following selection, the projects chosen are 3, 6, 7, 9, 12 and 14.

Table 1. Modernization projects inventory of JSC "Serbian Railways"

No	Modernization project name*
Project 1	Valjevo – Loznica track development
Project 2	Belgrade railway junction completion
Project 3	Railway Corridor X restructuring**
Project 4	Belgrade – Bar track restructuring**
Project 5	Pančevo – Vršac track electrification
Project 6	Electric trains (EMU) procurement
Project 7	Diesel trains (DMU) procurement
Project 8	Modernization of diesel locomotives series 641-300
Project 9	Modernization of diesel locomotives series 661 (GM)
Project 10	Restructuring of electrolocomotives series 444
Project 11	Restructuring of electric trains series EMU 412-416
Project 12	Restructuring and new construction of 5000 cargo wagons
Project 13	Procurement of new Z-1 wagons for international passenger transport
Project 14	Maintenance modernization of transit routes (mechanical maintenance)
Project 15	Maintenance modernization of vehicular resources (modular maintenance)

Notes:
* project inventory serves only as a model for the needs of this paper;
** overhaul of upper and lower railway set, contact network, safety, signal, telecommunication and control systems.

Table 2. Modernization project selected as portfolio candidates

No	Modernization project name
Project 3	Railway Corridor X restructuring
Project 6	Electric trains (EMU) procurement
Project 7	Diesel trains (DMU) procurement
Project 9	Modernization of diesel locomotives series GM 661
Project 12	Restructuring and new construction of 5000 cargo wagons
Project 14	Maintenance modernization of transit routes (mechanical maintenance)

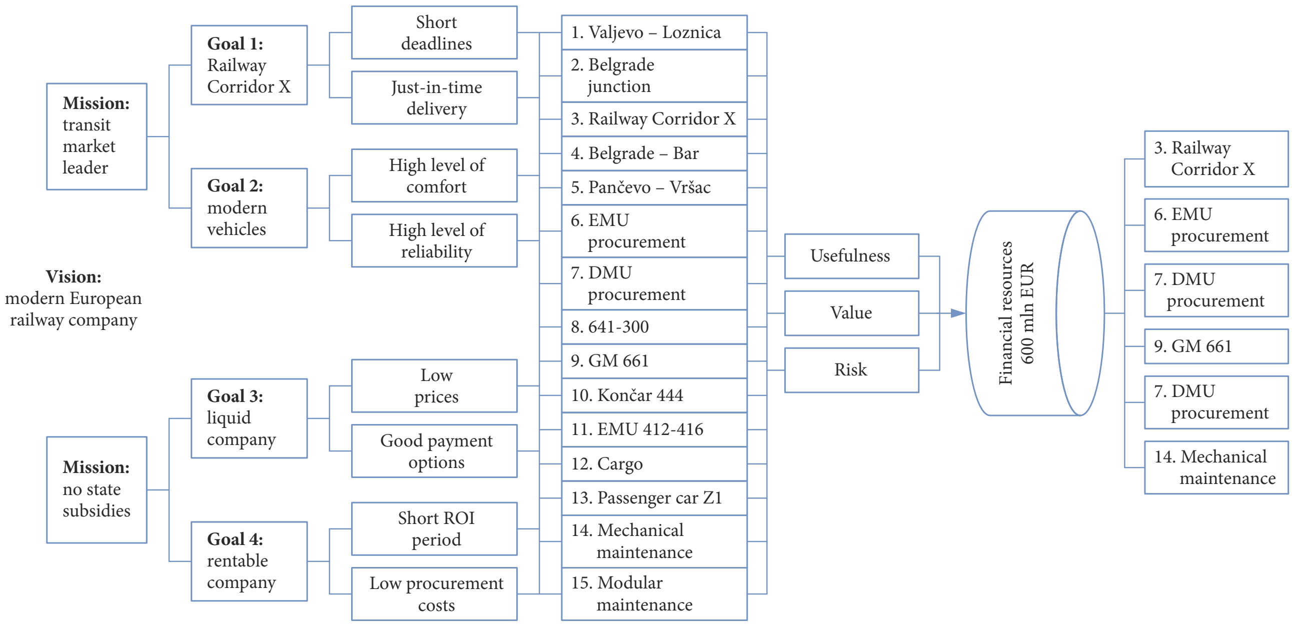

Figure 2. Serbian Railways – modernization projects selection model in relation to the strategic goals (created by authors)

The results of the 1st selection phase are given in Table 2. In the 1st phase of the selection, 15 modernization projects have been narrowed down to 6 projects, which can contribute the most to achieving the business mission, vision, and the strategic goals of "Serbian Railways".

2.2.2. Transforming the modernization projects into procurement projects (material and equipment)

Most of the modernization projects included in the inventory also imply material good procurement projects (material, components, and equipment) (Table 3). Therefore, they need to be broken down into separate procurement projects. For example, Project 3 "Railway Corridor X restructuring", contains the procurement projects of main investment materials: (1) railway tracks procurement project; (2) special concrete support-building steel procurement project; (3) contact network pole U-profile steel procurement project; (4) "artificial objects" armature steel procurement project.

By breaking down the modernization projects into procurement projects, we reach the following suggestion for procurement project portfolio, which includes 11 material and equipment procurement projects (Table 4)[1].

2.2.3. 2nd selection phase

Selection criteria. During the 2nd selection phase, the portfolio candidates are prioritized based on whether they satisfy liquidity and rentability goals (strategic goals 3 and 4). Based on the selection criteria, the project candidates are ranked according to value (main criteria group) and risk (auxiliary criteria group).

The bidding suppliers overview is presented on Table 5. The offer from each supplier is treated as their project suggestion. The choice of supplier is therefore presented as a selection of offered procurement projects. In this example, 5 suppliers are competing for 11 procurement projects, which together realize the 6 chosen railway modernization projects. Figure 4 showcases the supplier selection algorithm – the 2nd phase of the project selection, that is the formation of procurement project portfolio. This phase contributes to project portfolio scope.

The supplier selection process is conducted with the help of the linear programming mathematical model (AHP model), which is embedded in the software package "Expert Choice". Forming the AHP selection model requires establishing the selection goal and determining the main and auxiliary selection criteria, and the appropriate sub-criteria. In the following example, the selection goal is the choice of the most suitable supplier for each of the 11 procurement projects. The choice of the most suitable supplier is conducted with minimization of prices and procurement costs in mind, which leads to favourable procurement financing parameters in conditions of limited financial sources, with liquidity, financial power and profitability accounted for.

The main supplier selection criteria, noted in the procurement contract, are: price and quality (K1) and procurement risk (K2). Sub-criteria for the main criteria K1 are: K1.1 – price and K1.2. – design. Sub-criteria for the main criteria K2 are: K2.1 – advance rate, K2.2 – payment inception delay, K2.3 – compensation payment possibility and K2.4 – delivery terms.

[1] Modernization Project No 3 "Railway Corridor X restructuring" is segmented into 4 procurement of strategic materials for the upper railway array projects. Modernization Project No 12 "Restructuring and new construction of 5000 cargo wagons" is segmented into 3 procurement projects (Table 3).

Table 3. Transformation of modernization projects into procurement projects

No	Modernization projects portfolio candidates	No	Procurement projects portfolio candidates
Project 6	Electric trains (EMU) procurement	1	Electric trains (EMU)
Project 7	Diesel trains (DMU) procurement	2	Diesel trains (DMU)
Project 14	Maintenance modernization of transit routes (mechanical maintenance)	3	Track machines
Project 3	Railway Corridor X restructuring	4	UIC-60 tracks
		5	Support steel
		6	U-profile steel
		7	Armature iron
Project 12	Restructuring and new construction of 5000 cargo wagons	8	Monoblock wheels
		9	Technical oil
		10	Wagon axle box bearings
Project 9	Modernization of diesel locomotives series GM 661	11	Locomotive series GM 661 spare parts

Table 4. Procurement projects candidates for the portfolio

No	Procurement project description	Unit	Quantity	Value [EUR]
1	Electric train (EMU)	set	25	120000000
2	Diesel train (DMU)	set	15	63000000
3	Track machines	pcs	12	72000000
4	UIC-60 tracks	t	60000	48000000
5	Steel (concrete support)	pcs	700000	21000000
6	Steel profiles	pcs	10000	4000000
7	Armature iron	t	50000	9240000
8	Monoblock wheels	pcs	40000	24000000
9	Technical oil	t	3000	6000000
10	Wagon axle box bearings	pcs	40000	10000000
11	Locomotive series GM 661 spare parts	pcs	2500	8000000
			Total:	385240000

Additional criteria. The additional criteria (Table 6) used are the analytical project success indicators (ROI terms and annual project income) and project financing criteria, which are sourced by the terms of procurement financing loan contract (interest rate and annuity level).

According to the shown model (Figures 3 and 4), the 2nd phase of the project selection evaluates 51 project candidates (suppliers) and narrows the choice down to 11 suppliers. This, of course, matches the 11 projects, which make the procurement portfolio with satisfactory performances based on liquidity and rentability criteria (Table 7).

Tables 8 and 9 in the show model, the supplier choice is conducted by ranking the 5 suppliers (alternatives) for each project, which belongs to the suggested portfolio (Figure 3). Procurement portfolio management assigns relative importance grades to each supplier according to the determined criteria. For each supplier grade, through usage of "9-point" scale, a decision table is made. The decision table numerically ranks the importance of each criteria and sub-criteria. For example, represented below are the decision tables for the selection of most suitable supplier of diesel engine trains (DMU) from the aspect of parameters established in the procurement contract and the parameters found in financing contract.

Table 5. Supplier selection main criteria and sub-criteria

Criteria		Sub-criteria	
K1	Price and quality	K1.1	price
		K1.2	design
K2	Procurement risk	K2.1	advance rate
		K2.2	payment delay
		K2.3	compensation
		K2.4	delivery terms

Table 6. Supplier selection additional criteria and sub-criteria

Criteria		Sub-criteria	
K1	Price	K1.1	project value
		K1.2	advance rate
K2	Procurement risk	K2.1	ROI date
		K2.2	annuity rate
		K2.3	interest rate
		K2.4	annual income

Table 7. Overview of suppliers that applied for project portfolio procurement selection

No	Procurement project	Supplier				
		A1	A2	A3	A4	A5
1	Electric trains (EMU)	Siemens, Germany	Alsthom, France	Schtadler, Switzerland	CAF, Spain	DMZ, Russia
2	Diesel trains (DMU)	Siemens, Germany	Alsthom, France	Bombardier, Canada	Talgo, Spain	MVM, Russia
3	Track machines	Plasser, Switzerland	Mathisa, Switzerland	Kaluga, Russia	Caterpillar, US	Mitsubishi, Japan
4	Railway tracks	Azovstal, Ukraine	Trinec, Czech Republic	Voest Alpina, Austria	Hutta, Poland	Nizhntagilsk, Russia
5	Concrete support	Azovstal, Ukraine	Thissen-Krupp, Germany	Voest Alpina, Austria	Nikšić, Montenegro	Nizhntagilsk, Russia
6	Steel profiles	Azovstal, Ukraine	Thissen-Krupp, Germany	Voest Alpina, Austria	Resita, Romania	Nizhntagilsk, Russia
7	Armature iron	Azovstal, Ukraine	Nikšić, Montenegro	Veost Alpina, Austria	Resita, Romania	Nizhnjagilsk, Russia
8	Monoblock wheels	Valdunes France	Dnepropetrovsk, Ukraine	Bohumin, Czech Republic	Bals, Romania	Viksa, Russia
9	Technical oil	Total, France	Shell, US	Mobil, US	FAM, Serbia	Lukoil, Russia
10	Wagon axle box bearings	Thinken, US	SKF, Sweden	FAG, Germany	ZKL, Slovakia	GPZ, Russia
11	Locomotive series GM 661 spare parts	General Motors, US	General Motors, US	General Motors, US	General Motors, US	General Motors, US

Table 8. Decision table – supplier choice, based on the procurement contract criteria

No	Supplier	Criteria					
		K1 – quality		K2 – procurement risk			
		Sub-criteria		Sub-criteria			
		K1.1	K1.2	K2.1	K2.2	K2.3	K2.4
		Price (rank)	Design (rank)	Advance rate (rank)	Payment term (rank)	Compensation payment (rank)	Delivery term (rank)
A1	Siemens, Germany	6	9	5	5	3	7
A2	Alsthom, France	6	9	6	6	6	8
A3	Bombardier, Canada	7	9	5	4	1	5
A4	Talgo, Spain	8	7	8	7	3	6
A5	MVM, Russia	9	6	9	9	9	9
Intensity of significance	Criteria type: +/–	–	+	–	+	+	–
	W_j	7		3			
	W_{jk}	7	3	9	3	7	9

In decision tables, two different supplier selection criteria groups have been applied: (1) procurement contract criteria (Table 8) and (2) loan contract criteria (Table 9). Ranking (intensity) importance of each observed attribute of a supplier (W_j and W_{jk}) is conducted from the aspect of the established strategic goals, but also according to the preferences of procurement portfolio management. The importance of sub-criteria is limited by the importance of criteria, so the multiplier of these two criteria is the indicator of preferences of procurement portfolio management. The Table 8 reads K1.1 = 49, K1.2 = 21, K2.1 = 27, K2.2 = 9, K2.3 = 21 and K2.4 = 27. This shows that procurement portfolio management approaches the supplier choice from the aspect of securing the company liquidity, so the preferred supplier is the one offering the lowest price (32% importance), as it directly correlates to lowering financial resources needed for DMU procurement project.

Figure 3 showcases a simple portfolio formation schematic in a practical PPM model. The figure provides a schematic representation of suppliers, a selection model through which a procurement project portfolio is defined, when it comes to the realization of 11 modernization projects for Serbian Railways. This process is performed by running a linear programing mathematical model (AHP), which is provided within the "Expert Choice" software package.

Table 9. Decision table – supplier choice, based on the financing contract criteria

No	Supplier	Criteria					
		K1 – price		K2 – financing risk			
		Sub-criteria		Sub-criteria			
		K1.1	K1.2	K2.1	K2.2	K2.3	K2.4
		Project value [mln EUR]	Advance rate [%]	ROI terms [year]	Annuity rate [mln EUR]	Interest rate [%]	Annual income [mln EUR]
A1	Siemens, Germany	72.180	20	20.1	6.691	3	3.600
A2	Alsthom, France	69.550	30	19.3	5.915	4	3.600
A3	Bombardier, Canada	64.300	40	17.9	4.470	3	3.600
A4	Talgo, Spain	62.990	25	17.5	6.013	5	3.600
A5	MVM, Russia	59.050	20	16.4	5.760	4	3.600
Intensity of significance	Criteria type: +/–	–	–	–	–	–	+
	W_j	7		3			
	W_{jk}	8	2	9	3	3	9

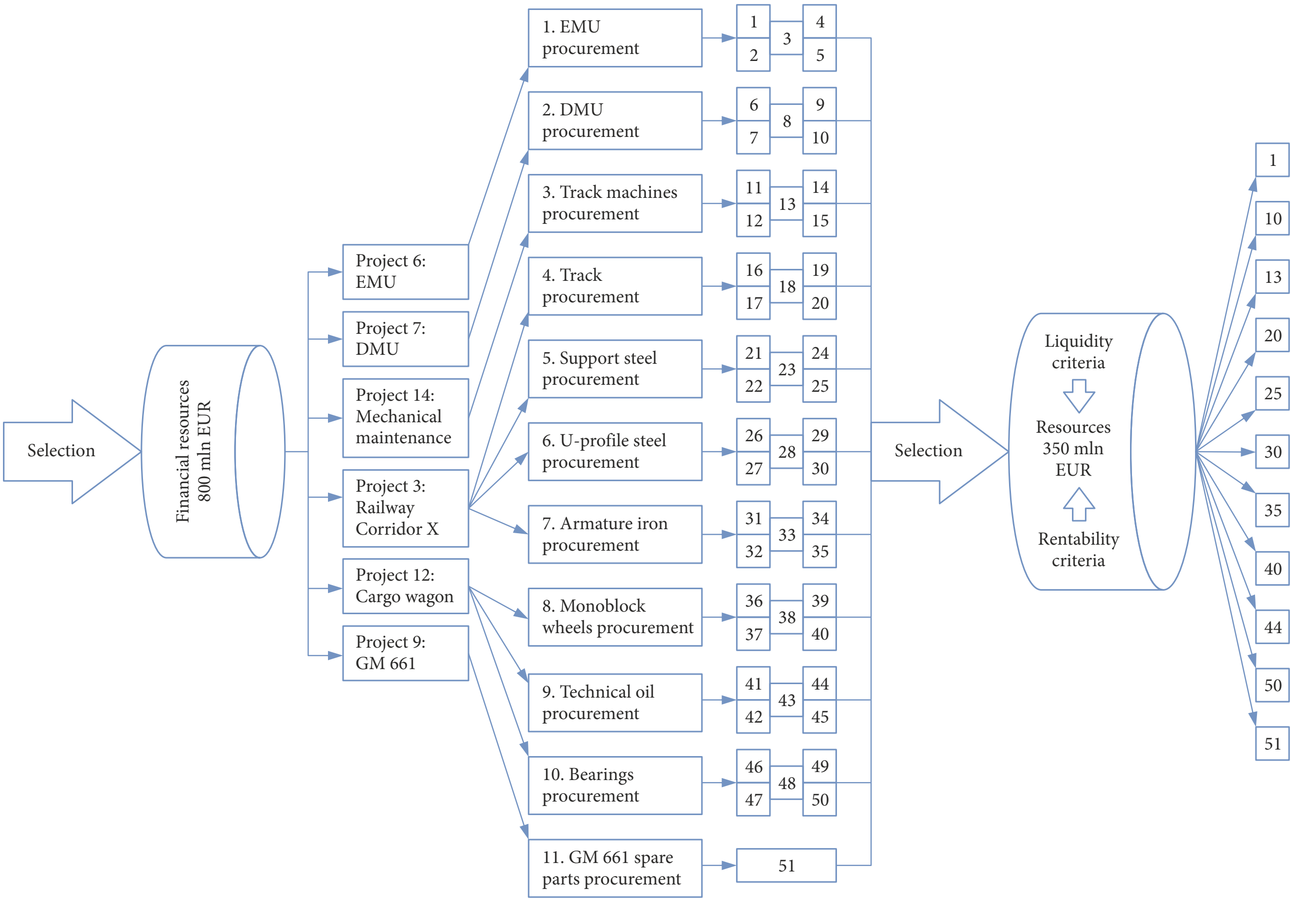

Figure 3. Railway modernization project (phase II) – procurement projects supplier choice model (created by authors)

Figure 4 showcases a simple two-step project selection model algorithm, according to the explained process of portfolio formation in the practical PPM model (JSC "Serbian Railways" modernization). For the portfolio, the 11 suppliers from the Table 5 have been selected (A5, A10, A1, A20, A25, A30, A40, A44, A50, A51).

From the shown algorithms (Figures 3 and 4), it can be seen that, in the 1st phase of the selection, 6 projects that enable strategic goals have been selected (from the initial 15 modernization projects). In the 2nd phase, the portfolio consisting of 6 modernization projects has been segmented into 11 procurement projects (Table 3). 51 suppliers of railway material and equipment (Table 7) applied for the selection, with 11 being selected, based on available strategic resources and the established criteria, and sub-criteria related to liquidity and profitability.

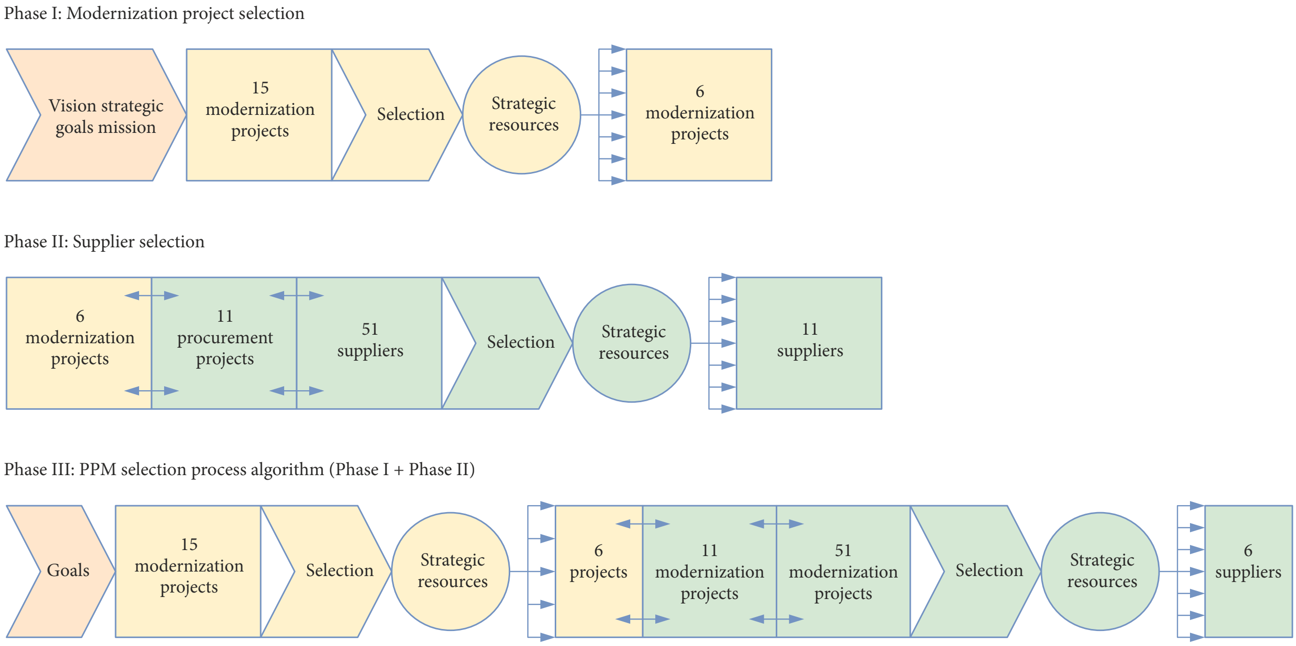

Figure 4. PPM selection process algorithm (created by authors)

All 51 suppliers that applied were subjected to the same selection criteria. This entire process of selection leads to the procurement project portfolio that includes 11 favourable suppliers of railway material and equipment necessary for the realization of railway modernization project (Figure 4).

2.3. Discussion and choice results presentation

From the overview shown above (Section 2.2) it is clear that, during the 1st selection phase, a selection is made from the suggested Project inventory of those modernization projects that contribute the most to the realization of the entire modernization program, which has been established by the state transportation development strategy. In the 1st selection phase, the criteria used are the ones of project value and contribution relative to the success of the modernization program. The result of the 1st selection phase is the choice of 6 (out of 15) modernization projects (projects number 3, 6, 7, 9, 12 and 14) (Table 2). The value of these projects (385240000 EUR) is compatible with the available sum of the financial resources (800 mln EUR), and by realizing them, Serbian Railways could become the leading company on the trans-European corridor Northwest–Southeast (Railway Corridor X) and thereby improve its long-term competitive position, increase the business income and drastically reduce the state subventions.

The result of the 2nd selection phase is the choice of the most suitable suppliers, which can realize the 6 selected modernization projects. These selected modernization projects 1st need to be segmented into material and equipment procurement projects, that are necessary for their realization. Through this process, the 6 modernization projects selected during the 1st phase are transformed into 11 procurement projects (Section 2.2.3). In the presented model, 5 suppliers have applied for each of the 11 procurement projects. All the suppliers are well-known manufacturers of railway material and equipment, with General Motors being the unique producer of locomotives series GM 661. In this way, a portfolio consisting of 11 procurement projects is actually presented as a portfolio consisting of 51 suppliers. Through the process of selection, and based on the criteria of profitability and rentability, this portfolio is narrowed down to a portfolio of 11 most suitable suppliers (Table 7, Figure 3). The goal of the 2nd selection phase is to simultaneously use the project portfolio for the selection of the most suitable supplier and therefore efficiently decide on the realization of each project in the conditions of secure financing. In the 2nd selection phase, the criteria and sub-criteria used evaluate the internal profitability of each project, as well as their contribution to the realization of liquidity as the strategic business goal. The result of the 2nd selection phase is a significant decrease of procurement costs in the condition of limited financial resources. This can be seen as a paradigm for more efficient resource management in the current business of railways companies.

The both presented project selection phases (through which the modernization projects are selected into procurement projects, and these are then transformed into the portfolio of the most suitable suppliers) show the importance of the implementation of PPM when it comes to efficient management of railway companies.

Presented below are the selected supplier choice results, with the criteria being rentability. The results are visualized through 3 graphs made by the software package "Expert Choice", which is based on the AHP method. An example of the selection of diesel motor engines (DMU) is given. This is the position number 2 from the Supplier overview (Table 7). It can be seen that 5 eminent European manufacturers have competed for the project. The identification table for the Position 2 (Table 10 – DMU supplier ranking results) gives the ranking of DMU suppliers achieved through software processing of the suppliers' performances compared to the established selection criteria (software package "Expert Choice"). Based on the offered price and financing conditions, it can be seen that the most favourable supplier is A5, and the least favourable is A3. The final ranking is A5 > A4 > A2 > A1 > A3.

Figures 5–7 give the 3 ways of graphical representation of the selection results, based on the established criteria. These 3 types of graphs, supported by the software package "Expert Choice" are: (1) weighted coefficients comparison in relation to the goal node; (2) performance sensitivity analysis; (3) 2D plot.

The comparison of weighted coefficients in relation to the goal node (Figure 5) enables simultaneous graphical and numerical representation of the supplier ranking. The analytical value of this representation is special in that it allows for transparent tracking and control of input preferences related to portfolio management during the compilation of an optimal procurement project portfolio. This enables appropriate correction of weighted coefficients at any moment, which influences the selection results. Figure 5 shows the supplier ranking results based on two factors, which have a significant impact on project profitability: the offered price (80% importance weight) and financing risk (20% importance weight). A higher level of decision-making precision has been achieved through further segmentation of these criteria onto sub-criteria (overall offering value, advance amount, ROI time, interest rate, annuity level, expected yearly DMU exploitation income). Weighted coefficients for criteria and sub-criteria have been established through subjective preferences of the project team (financial and commercial management) in relation the project profitability.

The performance sensitivity analysis (Figure 6) is included in the selection results representation as it produces a simple graphical showcase of the supplier ranking. This analysis showcases the supplier ranking by considering all criteria. The supplier ranking can be can sorted in relation to any and all criteria, such as the main criteria (price and risk), as well as the sub-criteria. The performance sensitivity analysis graph has a dynamic character, because it allows real-time adjustment of the criteria importance by interfacing with the software.

2D plot is an auxiliary illustration, which enables graphical comparison between suppliers, based on two criteria (Figure 7). Based on the selected criteria (*X*- and *Y*-axis), the best ranked suppliers are placed in the upper right quadrant. The more a supplier is closer to the upper right edge of the quadrant, the better its rank is, based on the selected criteria.

These methods of results presentation are suitable because they enable clear and unambiguous information and quick decision-making. Graphical representation of the selection results enables an efficient decision-making when it comes to project portfolio selection.

Table 10. DMU supplier ranking results based on profitability criteria

Procurement portfolio name:	JSC "Serbian Railways" modernization
Procurement project number:	2
Procurement project name:	diesel trains (DMU) procurement
Subject:	selection of a supplier into the procurement project portfolio
Supplier rank:	A5 > A4 > A2 > A1 > A3

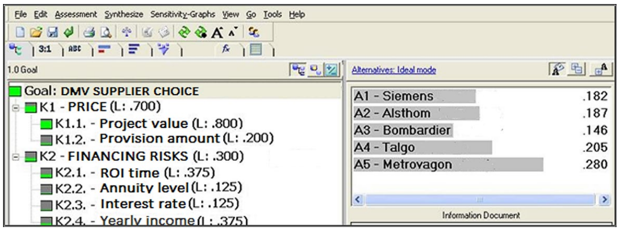

Figure 5. Weighted coefficient supplier ranking

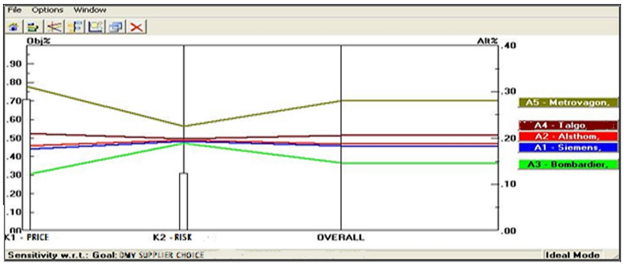

Figure 6. Performance sensibility analysis

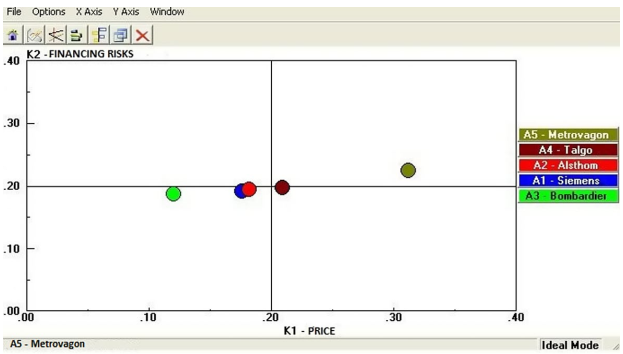

Figure 7. 2D plot

Conclusions

Proposed procurement project portfolio selection model, which utilizes the AHP method of MCDM enables higher efficiency and competency in managing limited business resources, which is especially important for otherwise unprofitable railway systems.

The AHP based approach that was applied in this paper enables project comparison through direct comparison of suppliers in relation to quality of offered commercial conditions and the level of project risk, especially the risk, which comes with project financing. The result of the selection process is a supplier rank according to established criteria, which enables easy decision-making and a simultaneous formation of the procurement project portfolio.

The application of the AHP method in project selection can significantly influence the reduction of resources needed for project financing (10%, or more than 36 mln EUR in the shown example). The two-step project selection model enables a simultaneous supplier selection, which additionally lowers the costs and time of the selection process, when compared to the traditional and extensive decision-making process. In the model, the achieved procurement cost reduction is directly reflected in the growth of project profitability and indirectly positively influences the company liquidity. Modelling liquidity and profitability as strategic goals influences the structural change direction of the engaged resources in benefit of resources obtained from owned sources, and also lowers donations to railways from the state budget. AHP selection process enables a ration usage of available resources in relation to task goals. The positive effect of AHP application in a PPM model management are greater in large business systems, as the project efforts are multiplied. The PPM model application, as a business resource of sorts, can significantly contribute to performance increase when it comes to operations of large transport systems, such as railways.

The shown segmentation of investment projects onto procurement projects enables centralization of procurement on the level of project portfolio, which leads to added benefits from the economy of scale, better negotiation position, and wider flexibility in terms of disposition and management of financial resources. In large business systems, the positive effects of the PPM model application are multiplied if the procurement function is integrated. If an integrated procurement were to be organized as a singular business entity in a railway business system, the synergy of the unique PPM model application and centralized procurement would come to a greater effect. Procurement could become a significant generator of new financing sources for the railway sector.

The application of the AHP method as a decision-making technique in PPM does not lead only to cost reduction, transparency and other managerial benefits. Multiple different benefits are also present in practical and theoretical aspect, as all key success factors are included in the decision-making process, without being limited to technical performance of a project, an approach dominant in the traditional railway business practices. AHP method application also influences the reduction of subjective business decisions in the area of public procurement. All these benefits contribute to a systematic and transparent management and control, which is a practice largely underdeveloped from the state-owned railway systems.

The two-step procurement and supplier selection model of this paper includes only the projects related to procurement of investment material and equipment. The showcased segmentation of investment projects into procurement projects, however, does not solve the financing issues of the infrastructural project as a whole, as that includes planning, projecting, contracting, technical supervision and other specialized processes. Forming a methodological process, which would include the financing of large infrastructural project in their wholes represents a challenge for future research of multi-criteria selection in the area of efficient PPM.

This model can also be applied to decision-making in outsourcing projects. Outsourcing processes are common in railway company reforms, considering their conglomerate-like nature that largely accumulates business losses. If the procurement function were to be outsourced from a railway company, the synergy of PPM application, project financing and economy of scale would be emphasized. In these conditions, an integrated approach to procurement could become a significant generator of new financing sources in railway companies.

PPM model, which includes AHP MCDM is also recommended in implementation of public–private partnership project, which are based on external financing. The application of project financing in the realization of public infrastructural projects requires project oversight during its entirety, including.

These notes could be useful as guidelines for further research of challenges presented by project selection in the area of modernization of large infrastructural systems, like railways.

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