Group-Oriented, Hierarchical and Multiple Criteria Evaluation of Urban Transportation Projects

Mirosław Kruszyński[1], Jacek Żak[2]

Abstract:

Purpose: Different approaches have been proposed to assess various transportation projects, processes, and systems. Two major streams of transportation projects assessment include Multiple Criteria Analysis (MCA) and Cost-Benefit Analysis (CBA). In many cases the decision process concerning the selection of a concrete transportation project for implementation has a participatory character and involves group – oriented analysis. In this paper, based on the combined methodologies of MCA and GDM (Group Decision Making), we propose a generic paradigm of the assessment of urban transportation projects considered for implementation in a certain metropolitan area.

Design/Methodology/Approach: Our approach allows to evaluate transportation projects using different criteria formulated at different levels of the hierarchical analysis - operational, tactical, and strategic. The important component of our approach is the team-based decision-making process that helps to categorize and rank the projects. This process involves interaction between many entities (bodies) and requires searching for combined preferences generated through compromise-oriented exchange of viewpoints.

Findings: The proposed methodology is designed to assist the group decision maker (Gr-DM) in planning and developing the transportation infrastructure, enhancing the transportation services, and improving the operations of a transportation system. The proposed approach is tested in Poznan, Poland as a real-world case study.

Practical implications: Methodology can be applied by municipal authorities (councils, commissions) while defining annual financial budget and the portfolio of the municipal investments.

Originality/Value: New paradigm is presented and discussed

Keywords: Multiple Criteria Decision Making/Aiding, AHP and Electre III/IV Methods, Group Decision-Making (GDM), Methodology Multiple Level, Multiple Criteria and Group-Oriented Evaluation of Transportation Projects.

JEL classification: M2, M51.

Paper Type: Research article.

---

[1]*Poznan University of Technology, Faculty of Engineering Management, Poznan, Poland; Corresponding author, e-mail: miroslaw.kruszynski@put.poznan.pl;*
[2]*The same as in 1, jacek.zak@put.poznan.pl;*

1. Introduction

The management of urban transportation in metropolitan areas requires different activities, including, among others: recognition of major traffic flows (development and up-date of the OD matrix), design and development of a transportation network, integration of private and public transportation in this network, ensuring the appropriate standard of transportation (quality of travel, accessibility of the transportation system, rational travel time) resulting in the appropriate modal split, selection and coordination of transportation modes used in the public transportation sub-system, definition of transportation routes/ tasks for each mode in this sub-system, allocation of vehicles and crews to the defined routes for each mode, definition of timetables for different modes of the public transportation sub-system, capacity management of the road and rail infrastructure leading to the reduction of congestion and travel delays.

Many of these activities require constant monitoring of the current condition of the urban transportation system, carrying out satisfaction surveys among system's users and introducing appropriate adjustments and improvements in its operations, organizational structure, and infrastructural components. Very often the introduced changes in the urban transportation system are performed in the form of concrete transportation projects.

Urban transportation projects (TP-s) are the investment processes carried out in the transportation systems focused on development and enhancement of the urban transportation system. They include such undertakings as: building a new municipal ring or road segment, upgrading a roundabout and/or overpass, developing a new tramway depot, extending the subway line, constructing a new or refurbishing an existing passengers' bus terminal, replacing the fleet of buses, or building a new P&R parking lot (Lee, 2000; Gercek, Karpak, and Kilincaslon, 1998; Morisugi, 2000; Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013; Zak, 2005). They are usually associated with substantial capital investment and organizational effort and may range from mega, multi-million dollars projects affecting the whole metropolitan area to small local improvements in the specific section of the city.

The evaluation and selection of urban transportation projects (TP-s) for real life implementation is a complex and very challenging task. It involves the assessment of many aspects the considered projects are associated with and the analysis of several areas they may affect. The ranking of transportation projects (TP-s) may also involve the consideration of interests of various stakeholders whose expectations and aspirations should be taken into consideration while selecting the projects. As presented in the work of Żak, Fierek, Kruszyński and Zmuda-Trzebiatowski (2013) the evaluation and selection of TP-s in the urban environment is usually associated with the definition of the annual, municipal budget in which certain public funds are allocated for the investment in transportation infrastructure. In budgetary dispute transportation projects compete with others and a construction of a balanced, rational portfolio of activities is required.

In this process, while developing the draft of the budget, municipal authorities (City Council, City Board) must consider several critical constraints (financial, infrastructural) and the above-mentioned interests of different stakeholders. The proposed urban TP-s

should satisfy the expectations of such bodies as: local communities – residents, transportation system users (passengers, drivers), transportation system operators (carriers) and representatives of many organizational units of municipal authorities (Urban Planning Office, Urban Transportation Board, Road and Railway Board). In many cases the interests of these bodies may have a contradictory character and a balanced, compromise solution must be found to satisfy them. Due to the complexity of the considered undertakings and their noticeable influence on multiple dimensions of life many parameters and characteristics should be considered while evaluating and ranking the projects.

They should refer to such aspects as, economic, technical, social, safety-oriented, environmental and many others, project – specific ones. Since in many cases the implementation of transportation projects is offered to concrete service providers and/ or their consortia (builders and developers, software houses, maintenance contractors, designers) these entities must compete for their contracts in the open tender procedures. In such circumstances the projects are assessed in these processes by several criteria, such as, costs, duration, timeliness of completion, environmental friendliness, quality standards, nuisance/harmfulness, and others.

In the process of urban TP-s' evaluation and ranking municipal authorities (e.g., City Council, City Board) usually act as the Decision Maker (DM) and one of the major stakeholders. They are actively involved in the decision process associated with their selection and implementation. Municipal authorities often consider urban TP-s as a tool to satisfy major goals/ objectives of the city's transportation policy and the city's development strategy. As a result, the impact of the projects on the fulfilment of the objectives of various levels of city management should be considered. These objectives may be constructed in the form of a hierarchical tree of goals composed of three main levels, i.e., strategic level, tactical level, and operational level. The requirements and expectations resulting from each of these levels should be included in the evaluation of transportation projects.

In addition, the decision process concerning urban TP-s' assessment and selection involves many actors and various interactions between them. Members of the City Board must exchange ideas between themselves and consult them with the collective body of the City Council. In the dynamic and participatory process many consultations with residents are performed and the generated opinions are considered. In many instances experts, analysts and consultants support the decision makers in their analysis. They provide their professional knowledge and expertise to thoroughly analyze the considered transportation projects and produce their comprehensive, objective, and reliable assessment. As described above the decision process has a group-oriented character and many individuals belonging to various distinctive groups participate in this process.

The above presented description of the process of assessing and selecting the urban TP-s leads to the following methodological conclusions:

- The evaluation requires that multiple criteria are used, and their trade-offs are considered. As a result, different aspects characterizing transportation projects should

take into account and a compromise solution should be generated while ranking the projects. To satisfy these conditions the methodology of Multiple Criteria Decision Making/ Aiding (MCDM/A) (Roy, 1990; Vincke, 1992) should be applied to assess urban transportation projects in a coherent and comprehensive manner.

- The evaluation of urban transportation projects should take into consideration their impact on the satisfaction of various municipal objectives, constituting the hierarchy of metropolitan goals. Thus, the projects must be assessed at operational, tactical and strategic levels and these assessments ought to be aggregated to generate final and overall, objective ranking of the considered projects.
- The decision process associated with the ranking and selection of urban transportation projects has a group-oriented character. Many individuals representing different social and professional groups participate in this process. Thus, the rules and principles of Group Decision Making (GDM) (Kilgour and Eden, 2010; Saaty and Paniwati, 2008) should be applied to properly model the decision situation and generate rational and reliable outcomes of the urban transportation projects' assessment.

Thus, the major research objective of this paper is to extend the previously proposed, universal methodology of evaluating and selecting urban transportation projects (TP-s) (Zak and Kruszynski, 2021; Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013) by their group-oriented assessment. The above cited exiting approach satisfied the two first indications, while the third one contributes to its extension and modification. Thus, the authors develop a modified approach to urban TP-s' evaluation, called group-oriented, hierarchical - multiple level and multiple criteria assessments of the projects. In this approach the authors combine the methodologies of MCDM/A (Roy, 1990; Vincke, 1992) and GDM (Jelassi, Kersten, and Zionts, 1990) and apply them in an aggregated form at different levels of evaluation, operational, tactical and strategic. As a result, they generate the overall rankings of urban transportation projects (TP-s) based on their coherent, comprehensive evaluation that includes the analysis of their impacts on satisfaction of metropolitan goals/ objectives defined in the documents characterizing the projects (operational goals), Transportation Policy of the City (tactical goals), Strategy of the City/Metropolitan Area, often denominated by City/Metropolitan Area Development Strategy (strategic goals).

To the best of the authors' knowledge the proposed approach has an original and unique character. As described in section 2 the group-oriented, hierarchical - multiple level and multiple criteria evaluations of urban transportation projects (TP-s) have not been reported in the literature, yet. The novelty of the proposed methodology is, the combined application of MCDM/A and GDM at different levels of project assessment and the analysis of transportation projects' impacts on the satisfaction of various municipal goals. Formulating the decision problem as a hierarchical - multiple level, multiple criteria, and group – oriented ranking problem the authors consider the real-life case study in a medium-sized metropolitan area (Poznan city in Poland).

The research problem is associated with the analysis of 18 urban TP-s of a different character and scope, including, private – individual TP-s (7 items), public TP-s (4 proposals), non-motorized (pedestrians and bikers-oriented TP-s (4 investments) and

projects focused on integration of the transportation system (3 items). All the projects are evaluated from different perspectives at 3 levels of analysis: operational, tactical, and strategic. To model the group-oriented decision process they simulate two alternative ways of reaching the compromise solution: the "Ex-ante Analysis" and "Ex-post Analysis". The former is focused on the development of an aggregated model of preferences, common for different stakeholders, prior to the performance of computational experiments (Zak *et al.,* 2010).

The latter refers to performing in the first place a series of computational experiments resulting in the generation of different rankings of the projects based on alternative models of preferences, representing the interests of various groups of stakeholders. As its name suggests in this approach the final compromise is reached through the analysis of results performed after the completion of computational experiments. In the computational phase two alternative multiple criteria ranking methods: ELECTRE III/IV and AHP are used. To generate the final ranking of the projects the aggregation procedure is proposed.

The paper is composed of 5 sections and supplemented by a list of references. In section 1 introductory remarks and the background of the topic considered are presented. Section 2 is focused on the theoretical background of research. It includes the principles of MCDM/A, GDM, their combined form and their application to urban transportation projects' (TP-s') assessment. The applied MCDM/A methods are also described in this section. The concept of multiple level, multiple criteria and group-oriented assessment of urban TP-s is characterized in section 3. This section includes the novel approach to TP-s' evaluation. Section 4 presents practical application of the proposed approach, including the results of computational experiments and their analysis. It is followed by conclusions / final remarks and references.

2. Theoretical Background of the Research

2.1 General Introduction to Urban Transportation Projects' (TP-s) Evaluation

Several methodologies of evaluating transportation projects (TP-s), processes and systems have been reported in the literature (Ehrgott, Figueira, and Greco, 2010; Lee, 2000). In general, they can be divided into two major groups, including, general purpose methodologies, such as, Expert Panel – EP and Multiple Criteria Analysis – MCA / Multiple Criteria Decision Making/Aiding – MCDM/A and detailed methodologies, i.e., Benchmarking – B, Cost Benefit Analysis – CBA, Cost Effectiveness Analysis – CEA, Cost Utility Analysis – CUA, Economic Impact Analysis – EIA and Social Return on Investment Analysis – SRoIA (Commision, 2008; Ehrgott, Figueira, and Greco, 2010; Lee, 2000; Vickerman, 2000).

Based on the comprehensive literature review one may conclude that Cost Benefit Analysis (CBA) and Multiple Criteria Decision Making/Aiding (MCDM/A) may be considered as the most frequently used methodologies of transportation projects' (TP-s) evaluation (Commision, 2008; Lee, 2000; Morisugi, 2000; Ehrgott, Figueira, and Greco, 2010). CBA is a technique which is used by decision-makers (mostly governmental

bodies) to appraise the efficiency of a policy, it's theoretically unambiguous and it's seen as valuable input for decision making on governmental spending. MCDM/A refers to a class of decision-making methods based on which several alternatives are evaluated with respect to several criteria. Benefits and costs are expressed in monetary terms and are adjusted for the time value of money.

The latter involves a comprehensive, multiple – dimensional analysis of transportation projects. It allows for considering many evaluation aspects (criteria) and satisfying subjective, frequently contradictory interests and expectations of different stakeholders. The objective of MCDM/A – based evaluation of transportation solutions / projects is to balance the existing trade-offs and generate a compromise output. In MCDM/A analysis the following parameters and characteristics are used to evaluate the considered transportation solutions (Caliskan, 2006; Zak and Thiel, 2001), comfort of travel, accessibility, travel time and travel costs, noise and pollution levels, investment costs and profitability, safety, etc.

Annema, Mouter, and Razaei, (2015) compare in their article these two approaches and discuss their usefulness for TP-s assessment from a politicians' perspective. They refer in their analysis to an important question in the context of the presented research: how a useful transportation policy appraisal tool might look like? They find out that politicians use CBA for TP-s assessment but in a non-decisive manner and they consider its aggregate outcome (the composite result of CBA) pretentious. At the same time, they seem especially interested in the TP-s appraisal tools which would show clearly to them the important political trade-offs resulting from any transportation policy. Thus, the authors of the above-mentioned paper claim that politicians appreciate the principles of MCDM/A but they do not apply them in a proper manner.

Many papers report that MCDM/A methodology allows for considering both financially oriented measures, i.e., such characteristics that can be expressed in financial terms (including the aspect of the value of money in time), and those that require non-financial interpretation e.g., of social, environmental, or technical character. These features constitute major assets of this methodology (Figueira, Greco, and Ehrgott, 2005; Caliskan, 2006; Cascajo, 2005).

Therefore, in many reports' authors present practical applications of MCDM/A methodology for analysis, evaluation and ranking of specific transportation-related investments. For example, Ren and Lützen (2015) present in their article the application of MCDM/A methodology to the evaluation and selection of the most appropriate (desirable) technology for emissions reduction from shipping. The authors investigate several alternative technologies and rank them from the best to the worst. The analysis has been carried under uncertainty and incomplete information.

Thus, non-deterministic methods have been applied to develop a consistent methodology for selecting technology focused on transport emissions reduction under these specific conditions. The proposed approach consists in combining Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and VIKOR methods. Fuzzy AHP method has been used to determine the weights of the evaluation criteria and the relative performance of the

alternatives with respect to each evaluation criterion, and VIKOR method has been applied to prioritize the alternative technologies.

2.2 The Methodology of Multiple Criteria Decision Making/Aiding (MCDM/A)

2.2.1 Basic notions and general features of MCDM/A

Multiple Criteria Decision Making/Aiding (MCDM/A) is a field of study that originates in Operations Research - OR (Hillier and Lieberman, 2001) and focuses its efforts on solving multiple criteria decision problems, that is such complex decision situations in which several, often contradictory, points of view must be taken into account (Vincke, 1992). The multiple criteria decision problem may refer to three alternative situations that consist in (Roy, 1990; Vincke 1992):

- choosing the best/ most desirable variant from all feasible variants/ solutions (choice problematic),
- sorting the variants, i.e., assigning them into predefined classes (sorting problematic),
- ranking the variants, i.e., ordering them from the best to the worst (ranking problematic).

In all three situations the major components of the multiple criteria decision problem are: a set of actions/ variants/ solutions A and a consistent family of criteria F. The set of A can be defined directly in the form of a complete list or indirectly in the form of certain rules and formulas that determine feasible actions/ variants/ solutions, e.g., in the form of constraints (Zak, 1999). The consistent family of criteria F should guarantee the following features of evaluation (Roy, 1990):

- completeness, which means it should provide a comprehensive and complete evaluation of the set A,
- consistency with the DM's global preferences, which means that each criterion in F having a specific direction of preferences (minimized or maximized) should contribute to satisfactory expression of the DM's expectations and interests,
- non-redundancy, which means that each criterion should not be co-related with other criteria in F and its domain should be disjoint with the domains of other criteria.

The MCDM/A methodology clearly identifies the major participants of the decision making/ aiding process, such as: the decision maker (DM), the analyst and the interveners (stakeholders). DM defines the objectives of the decision process, expresses preferences, and finally evaluates the solutions obtained. The analyst is responsible for the decision support process. He/she constructs a model of decision-making, selects the methods and tools to assist in solving the decision problem, explains the consequences of such decisions. The interveners/ stakeholders are the active participants of the decision process. They express subjective opinions and expectations and define their preferences. The process of solving a multiple objective decision problem is based on the application of computerized tools and methods. Those methods can be classified in different ways.

For this research, they are categorized based on two classification criteria, i.e., the purpose of the decision process, which results in their split into (Figueira *et al.,* 2005):

- Multiple criteria choice/ optimization methods.
- Multiple criteria sorting methods.
- Multiple criteria ranking methods.

2.2.2 The Applied Multiple Criteria Ranking Methods

In this paper two most representative multiple criteria ranking methods of the European and American school of MCDM/A, i.e., ELECTRE III/IV and AHP are applied to evaluation of TP-s. Their description is presented below.

ELECTRE III method (Skalka, 1986; Vincke, 1992) allows to rank a finite set of variants evaluated by a family of criteria, and based on the preferential information submitted by the DM. The preferential information is defined in the form of criteria weights - w and the indifference - q, preference - p and veto – v thresholds (Skalka, 1986). The outranking relation in the Electre III method is built on the basis of the so-called concordance and discordance tests. In the concordance test, concordance indicators $C(a, b)$ are computed, while in a discordance test discordance index $D_j(a,b)$ for each criterion j is calculated. These indexes are aggregated into an outranking relation S for each pair of alternatives (a,b). The outranking relation indicates the extent to which "a outranks b" overall. This relation is expressed by the degree of credibility $d(a,b)$, which is equivalent to the global concordance indicator $C(a, b)$ weakened by the discordance indexes $D_j(a,b)$.

The values of $d(a,b)$ are from the interval [0,1]. Credibility $d(a,b)=1$ if and only if the assertion a S b ("a outranks b") is well founded, $d(a,b)= 0$ if there is no argument in favor of a S b (not a S b – "a does not outranks b"). Based on the values of $d(a,b)$ the method establishes two preliminary rankings - complete descending and ascending preorders. In the descending distillation the ranking process starts from the selection of the best variant, which is placed at the top of the ranking while in the ascending distillation the variants are ranked in the inverse order.

The results can be presented either in the form of the ranking matrix or in the form of the outranking graph. They are the results of the intersection of the above mentioned complete preorders. The ranking matrix and the outranking graph define the pairwise relationships between variants. The following situations can be distinguished there: indifference (I), preference (P), lack of preference (P~) and incomparability (R).

The AHP (Analytic Hierarchy Process) method (Saaty, 1980) allows to rank a finite set of variants A based on the hierarchical analysis of the decision problem. Through the definition of the overall objective, evaluation criteria, sub-criteria and variants the method constructs the hierarchy of the decision problem. On each level of the hierarchy, based on the pair-wise comparisons of criteria, sub-criteria and variants, the DM's preferential information is defined in the form of relative weights w_r (Saaty, 1980). Each weight represents relative strength of the compared element against another, and it is expressed as a number from 1 to 9. All weights have a compensatory character, i.e., the

value characterizing the less important element (1/2, 1/5, 1/9) is the inverse of the value characterizing the more important element in the compared pair (2, 5, 9).

The algorithm of the AHP method focuses on finding a solution for a, so-called, eigenvalue problem (Saaty, 1980) on each level of the hierarchy. As a result, a set of vectors containing normalized, absolute values of weights w_a for criteria, sub-criteria and variants is generated. The sum of the elements of the vector is 1 (100%). The absolute weights w_a are aggregated by an additive utility function. The utility of each variant i – U_i is calculated as a sum of products of absolute weights w_a on the path in the hierarchy tree (from the overall goal, through criteria and sub-criteria) the variant is associated with. The utility U_i represents the contribution of variant i in reaching an overall goal and constitutes its aggregated evaluation that defines its position in the final ranking.

2.3 The Concept of Group Decision Making (GDM)

Group decision making (also known as collaborative decision making) (Kilgour and Eden, 2010; Saaty and Paniwati, 2008) is a decision process and an associated methodology of making a compromise / consensus decision in a situation when individuals collectively make a choice from the available alternatives or select a commonly acceptable course of action. In GDM the final decision is no longer attributable to any single individual who is a member of the group but to the group. It is assumed that in the GDM all individuals participating in the decision-making process contribute to the final outcome. Groups simultaneously also have a greater wealth of knowledge available to them than do individuals. For example, a corporate investment committee may contain individuals with business, investment, legal, or accounting experience. Clearly, it is difficult for individuals to compete with the informational resources of groups. Moreover, through discussion, groups can do a better job of processing the available information - for instance, they may more readily identify bad decisions or faulty logic.

In many GDM processes individuals who are co-responsible for making a final decision may represent different decision makers (DM-s) and interveners (stakeholders). Due to natural differences between people their interests often remain in conflict (Leyva-Lopez and Fernandez-Gonzalez, 2003) which is a result of different value systems, distinct ethical and ideological views, subjective evaluations of the issue considered, different roles played by DM-s and interveners in the society (Roy, 1990). Thus, getting this decision requires that the persons involved in the decision-making process look for a compromise/ consensus in relation to their individual expectations.

Zhang, Kuwano, Lee, and Fujiwara (2009) present in their paper an interesting application of GDM in transportation. Specifically, they develop a new household discrete choice model to represent heterogeneous group decision-making mechanisms in travel choice behaviour. The authors integrate different types of household choice models based on latent class modelling approach under the principle of random utility maximization. In their approach a latent class corresponds to a particular group decision-making mechanism and the household utility function is defined to theoretically reflect its members' preferences and intra-household interaction. The proposed model can deal

with not only the choice situations where multiple household members involved in joint decision are known a priori, but also the situations where the involved members are unknown. As a case study, the authors investigate three types of household utility functions: multi-linear, maximum, and minimum types, in the context of couples' car ownership behaviours.

2.4. Hybrid Methods Based on MCDM/A and GDM

2.4.1 The idea of combining MCDM/A and GDM: The description of selected methods and approaches

GDM is often discussed in a context of MCDM/A (Jelassi, 1990). It has been proven by some reports that the combination of MCDM/A and GDM (supported by group negotiations) can be an effective tool in overcoming interpersonal conflicts and giving the actors a chance to reach a compromise. A good example of a joint application of MCDM/A and GDM methodologies is presented in the article of Jarke and others (Jarke, Jelassi, and Shakun, 1987) in which a computer-based system MEDIATOR is described.

The computer tool is based on an evolutionary design system, which supports the negotiations by seeking a compromise based on the exchange of information between the participants of the negotiations. The latter are the role players who can form coalitions to reach a common goal (consensus). The search for consensus is based on the joint action of negotiating. As a tool supporting the group negotiations a well-known MCDM/A method, called UTA, is applied. The decision problem solved by UTA method is presented in the MEDIATOR system in a graphical form, as an area consisting of three parts: area of control, area of utility, area of objective. The area of utility is constructed through the application of the marginal utility function. Individual marginal utility functions, representing the interests and aspirations of group members are created based on the application of UTA method. Negotiations end when the participants reach the same individual marginal utility functions.

Another example of a successful application of combined methodologies of MCDM/A and GDM is a computer tool, called CO-OP system, proposed by Bui and Jarke (1986). It's designed specifically to assist policy makers in reaching the consensus in the negotiation-based processes. The system solves a various decision problem from different areas that are formulated as multi-criteria decision-making problems. The solution procedure of this decision problem is composed of the following six stages: I – definition of the decision problem and initial construction of variants and criteria, II – definition of the norms of behavior for a group of decision makers, III – definition of the weights of the criteria, IV – individual verification of the set of the variants by each group member, V – group-oriented evaluation of the set of variants, VI – generation of the final ranking of variants and negotiation-based search for a group compromise.

The proposed mechanism leads to reaching a final consensus between the participants of negotiations (policymakers) and prioritization of the considered variants. The authors propose selected MCDM/A methods to generate the ranking of the considered alternatives.

The next contribution by Rao, Goh, Zhao, and Zheng (2015) refers to the application of a fuzzy multi-attribute group decision making (FMAGDM) technique to the selection of the City Logistics Centre (CLC) location. The proposed method is a complex computer system that allows for the evaluation of alternative CLC locations from a sustainability perspective. The evaluations of selected locations are provided by experts in a linguistic form. The proposed approach is based on the application of a linguistic 2-tuple, which is used to evaluate potential alternative CLC locations. The 2-tuple collects the linguistic evaluation values of all the locations according to all considered evaluation criteria. A new 2-tuple hybrid ordered weighted averaging (THOWA) operator is proposed to aggregate the overall evaluation values of all experts into a collective evaluation value for each alternative, which is then used to rank and select the considered CLC locations.

A real-life application is demonstrated to validate the proposed approach and to highlight the practicality and effectiveness of its implementation. To reach this end the authors compare their approach with a well-known multiple criteria TOPSIS method (fuzzy Technique for Order of Preference by Similarity to Ideal Solution).

Another interesting approach to support the solution process of multiple criteria and group decision-making problems presented by Lewandowski (1989). The author develops a computer system, called SCDAS (Selection Committee Decision Analysis and Support) to assist the policy makers in choosing the best option from a finite set of alternatives, based on a certain level of satisfaction of decision makers. In this approach, policymakers collectively define two levels for specific purposes. The first of them is the level of aspiration, which is interpreted as a satisfactory value for each objective. The second is the level of reserves, determined by the lowest, acceptable by the decisions makers value for each objective. Then the steps of decision-making process are defined.

With the help of computer tools various indicators are calculated. They support the realization of the decision process and evaluating of variants'/options' non-compliance with folded levels: aspirations and reserves. In the next stage of the procedure individual evaluations of options/alternatives (with respect to each criterion) are provide. On this basis, the rankings are created. To create a global ranking of alternatives, evaluation of individual variants is averaged.

2.4.2 The application of combined MCDM/A and GDM approach in the evaluation of transportation projects

The literature survey presented in this subchapter proves that the evaluation of TP-s requires the analysis of interests of different stakeholders. It has been revealed in many publications (De Brucker, Macharis, and Verbeke, 2011; Munda, 2004) that many actors play a critical role in the decision-making processes concerning TP-s. At the same time the analysis of TP-s requires that many aspects, including, technical, economic, social, environmental, and safety-oriented are taken into consideration. Thus, the application of combined of MCDM/A and GDM approaches sounds quite rational.

Macharis and Bernardini (2015) describe in their article different MCDM/A methods applied for the assessment of transportation projects (TP-s) and claim that their multiple criteria evaluation should be combined with group–oriented decision making processes

concerning their assessment and selection. They prove that the stakeholders' involvement in the decision-making processes concerning TP-s' selection is an important issue. Thus, they demonstrate that a multi-actor approach incorporated in the multiple criteria assessments of TP-s has clear advantages against the "pure" MCDM/A methodology. In the authors' opinion the operational efficiency or robustness of an MCDM/A method is partly dependent on the possibility to involve more stakeholders, instead of one individual decision maker (DM), into the decision-making process. They further demonstrate that adding group-based decision making renders the whole process more robust. Based on their analysis they demonstrate that the involvement of different groups of stakeholders in the multiple criteria assessments of TP-s enriches the content and scope of the analysis and makes the evaluation of TP-s more comprehensive, realistic, and valuable. The authors indicate that the multiple criteria, multi-actor approach for TP-s assessment is an interesting track for further research.

The above-mentioned statements have been further supported by De Brucker, Macharis, and Verbeke (2011) who proposed a modified version of the MCDM/A methodology, called Multi-Actor Multi-Criteria Analysis - MAMCA, which can be treated, as an institutional approach to assess transportation projects (TP-s). The authors confirm that the involvement of different actors in the decision process concerning TP-s enriches its evaluation and provides valuable insights. Thus, in their concept they rely on the opinions, expectations, and requirements of such groups of stakeholders as: experts, citizens, and politicians. As a result, they propose MAMCA as an enriched methodology of Multiple Criteria evaluations of TP-s. The overall idea of this approach is based on the development of different modules of MCDM/A methodology for each entity involved in the decision-making process. The MAMCA allows evaluating different alternatives (policy measures, scenarios, technologies) according to different objectives of various stakeholders participating in the assessment process.

Unlike a conventional MCDM/A methodology where alternatives are evaluated on several criteria, the MAMCA explicitly includes the points of view of different stakeholders. The methodology consists of 7 steps. The first step is the definition of the problem and the identification of the alternatives. Next, the relevant stakeholders are identified. Thirdly, the key objectives of the stakeholders are identified and given a relative importance or priority (weights). Fourthly, for each criterion, one or more indicators are constructed. The fifth step is the construction of the evaluation matrix. The different scenarios are scored on the objectives of each stakeholder group. For each stakeholder group a traditional multiple criteria evaluations are performed. The different points of view of stakeholders are brought together into a multi-actor perspective. This, in the sixth step, yields a ranking of the various alternatives and reveals their strengths and weaknesses. The last, seventh stage of the methodology includes the actual implementation of the selected solution.

Based on the insights of the analysis, an implementation can be developed, taking the wishes of the different actors into account. The MAMCA methodology has already proven its usefulness in several transport related decision problems. It was used to cope with an intermodal terminal location decision problem, for a study on the choice between waste transport alternatives, for the location choices of a new high speed train terminal,

in the development of the master plan of the Port or for the evaluation of DHL's hub strategy at Brussels airport.

Another example of the integrated approach encompassing MCDM/A and GDM methodologies for TP-s evaluation, called Social Multi-Criteria Evaluation – SMCE, is proposed by Munda (2004). SMCA is based on the combined application of the techniques of MCDM/A methodology and group participation of various stakeholders and citizens in the process of generating the consensus-based decisions while carrying out a multiple criteria evaluation of considered options. SMCA is developed to facilitate decision making in the situations when it is necessary to take into account the conflicting interests of different groups and various criteria of a contradictory character. This "participatory nature" of SMCA methodology assumes that the groups of parties choose the criteria and then the analyst presents information about their impact on achieving objectives of the stakeholders. As a results groups of decision makers compare the obtained results with its own holistic judgment.

Concluding, the evaluation of TP-s is a widely discussed topic in academic publications and research reports. As presented above the popularity of application of combined MCDM/A and GDM methodologies for TP-s evaluation is growing. At the same time the authors of this paper dare claim that this methodological combination has never been applied for the evaluation of urban TP-s at different levels of the hierarchical goals, including, strategic, tactical, and operational ones. The implementation of the combined MCDM/A and GDM - based approach to the multiple level evaluation of TP-s sounds like a very interesting and challenging research task.

3. The New Approach to Transportation Projects' Evaluation: The Concept of Group-Oriented, Hierarchical-Multiple and Multiple Criteria Assessment

As a result of conclusions drawn in section 2 a universal methodology of group-oriented, hierarchical-multiple level, multiple criteria and group-oriented evaluation of urban transportation projects has been proposed. This methodology is an extension of an original approach/paradigm focused on the multiple level and multiple criteria evaluations of transportation projects, proposed by, Zak and Kruszyński (2021) and Zak *et al.* (2013). The major alteration of the extended version of the proposed approach consists in the introduction of a group-decision making (GDM) component at each level of the TP-s evaluation and its integration with the MCDM/A methodology. The new approach is composed, again, of five levels of decision hierarchy, presented in Figure 1.

At each level of the paradigm multiple criteria and group-oriented decision problems are solved. In the process of solving the decision problems at each level of the hierarchy an important role of 4 groups of stakeholders, including: Municipal Authorities (MA), Public Transport Operator (PTO), Passengers / Road Users (P) and Local Community/ Residents (LC), is envisaged. At level I specific multiple criteria and group-oriented, urban transportation decision problems are solved. These problems refer, for example, to such issues as: definition of the best (most desirable) location of P&R parking lots, ranking and selection of the most useful (characterized by the highest utility) public transportation vehicles (trams or buses), design and evaluation of alternative solutions

for a road segment / inner municipal ring. Each of these problems has a multiple criteria and group – oriented character and is formulated as a multiple criteria (ranking, choice, or classification) decision problem. While solving these problems different aspects and interests of the above-mentioned groups of stakeholders are considered and the interaction between them is involved.

Figure 1. A universal paradigm of hierarchical - multiple level, multiple criteria, and group-oriented evaluation of urban transportation projects.
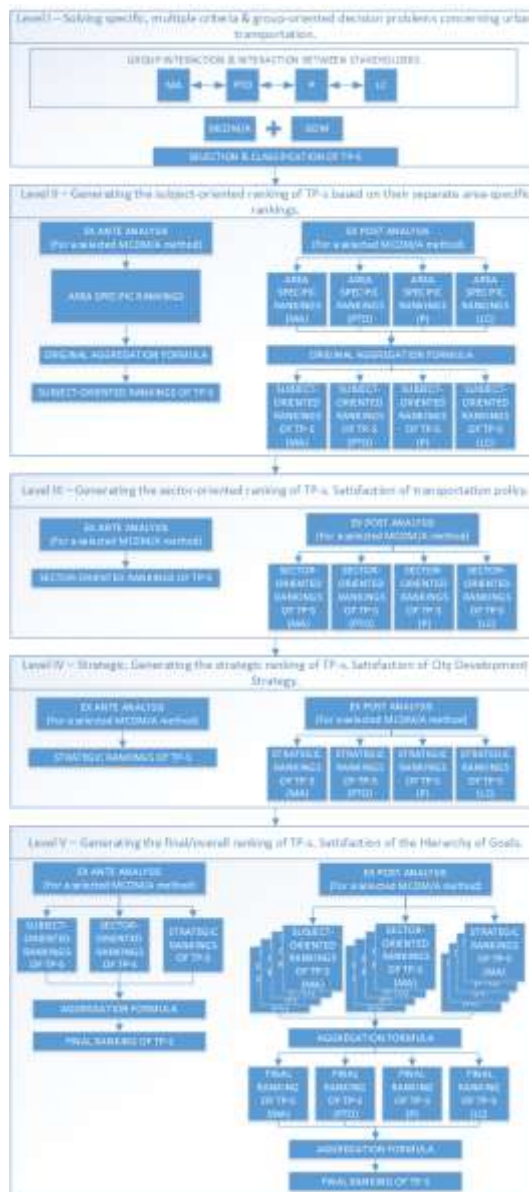
Thus, at level one the combined MCDM/A and GDM methodologies are applied to solve the considered problems. The solutions to these problems constitute the examples of the urban transportation projects – TP-s being under consideration. Thus, selected P&R parking lots, chosen trams or defined solution for the inner municipal ring / road are the units inserted to the overall list of TP-s being evaluated. The result of level I is the selection and classification of TP-s. At levels II to IV the evaluation of TP-s from different perspectives is performed. The decisions problems at these levels are formulated as multiple criteria ranking problems. At level II the TP-s are evaluated based on operational (project – specific) aspects. Specific criteria are used to assess different categories of projects, including, private transportation (PrT) TP-s, public transportation (PuT) TP-s, integration (IT) – oriented TP-s and non-motorized (NM) TP-s.

As a result, their separate rankings are generated and certain aggregation formulas are applied to produce subject-oriented ranking (Kruszynski and Zak, 2014). This generic subject-oriented (transportation – specific) ranking is the outcome of this analysis / evaluation at level II. At level III tactical assessment of TP-s is carried out and the urban transportation projects are evaluated based on several objectives / goals (criteria) defined in the transportation policy of the city. As a result, sector-oriented (transportation policy based) ranking of TP-s is generated. At level IV a similar approach is used to evaluate the TP-s from a strategic perspective. At this level it is investigated how the TP-s satisfy the overall, strategic objectives of the municipal area. The outcome of the level IV analysis is the strategic ranking of TP-s. Level V is focused on the integration/ aggregation of results generated at levels II to IV (Kruszynski and Zak, 2015). Using an aggregation formula, the subject-oriented, sector-oriented, and strategic rankings of TP-s are combined. As a result, the final ranking of TP-s is generated (Zak and Kruszynski, 2015).

It is worth mentioning that at each level of the analysis the interaction between individuals (constituting one group of stakeholders) and the interaction between separate groups (MA, PTO, P, LC) take place. These interactions refer to concrete issues associated with the multiple criteria evaluations of TP-s, such as, elaboration of criteria, definition of the DM's and stakeholders' preference models, final evaluation of generated solutions. At levels II to V the group decision process is performed in two alternative ways, called: "Ex-Ante Analysis" and "Ex-Post Analysis". In the "Ex-Ante Analysis" the group interaction is performed prior to the phase of computational experiments and allows for the elaboration of an aggregated, common model of preferences for all 4 groups of stakeholders (Zak *et al.,* 2010). As a result, 1 computational experiment is performed and 1 ranking of TP-s is generated, according to 1, common model of preferences. In the "Ex-Post Analysis" all computational experiments are performed according to specific, separate models of preferences, characteristic for each group of stakeholders (MA, PTO, P, LC). As a result, several rankings of TP-s are generated, and a consensus must be found after the experiments to aggregate results and generate the final ranking of all projects.

The two above-described concepts of Group Decision Making (GDM), i.e., "Ex-Ante Analysis" and "Ex-Post Analysis" is the novelty of the proposed approach. The authors insert these two concepts into the generic algorithm of multiple level, multiple criteria

evaluations of TP-s and investigate their role in the assessment process, including their strengths and weaknesses.

In the authors' opinion the new paradigm better reflects the decision situation and allows for performing a more realistic decision game / process involving appropriate interactions between major actors (MA, PTO, P, LC) of the decision process. At level I specific urban transportation decision problems are solved whereas at levels II to IV multiple criteria decision sub-problems, isolated from the multiple level, multiple criteria ranking problem, are analyzed. Final solution to multiple level, multiple criteria decision problem (including comprehensive, global evaluation of TP-s of various characters) is achieved at the last stage (V) (Kruszynski, 2014).

4. Practical Application of the Proposed Approach

4.1 Definition of the Decision Problem

As presented in section 1 the considered decision problem consists in evaluating and ranking a set of urban transportation projects (TP-s). It is handled by the City Hall (City Board) in a medium - sized metropolitan area of Poznan city in Poland. The decision maker (DM) – City Board is responsible for designing the city budget, which must be accepted in the final voting by the City Council. The DM must prioritize the projects and make decision regarding their inclusion in or rejection from the annual budget. It is expected that the final ranking of transportation projects (TP-s) generated by their computed utility (for the city) should result in constructing the sequence of introducing and implementing the projects under constrained budgetary funds.

While making the final decision, the DM should consider the interests and expectations of major stakeholders (interveners) interested in the implementation of TP-s in the metropolitan area. In the analysed decision situation, the major stakeholders are, municipal authorities (MA), public transportation operator (PTO), passengers traveling by public transportation combined with road users (P) and local community /residents – LC. The considered decision problem has been defined as a multiple level, multiple criteria ranking problem with its group-oriented component (MLMCRP with GOC). It consists in evaluating and ordering (from the best to the worst) 18 TP-s, representing the variants of the considered decision problem. The analysed set of TP-s covers a variety of investments and undertakings focused on enhancement of transportation infrastructure, replacement of transportation fleet and development of advanced / modern transportation solutions.

Major features of the considered TP-s – variants:
The proposed TP-s can be categorized into four major groups, including:

- Group I – private (individual) transportation projects – 7 proposals denominated by variants PrT-1, PrT-2, PrT-3, PrT-4, PrT-5, PrT-6, PrT-7;
- Group II – public transportation projects – 4 investments labelled PuT-1, PuT-2, PuT-3, PuT-4;

- Group III – non-motorized transportation projects that encompass 4 new developments called variants NM-1, NM-2, NM-3, NM-4;
- Group IV – 3 projects focused on integration of the transportation system, marked in the abbreviated form by IT-1, IT-2, IT-3.

All the projects included in Group I concentrate on the extension and development of the road transportation infrastructure while their counterparts in Group II improve the condition of the public transportation system (infrastructure and fleet). TP-s assigned to Group III provide different transportation solutions for pedestrians and bikers. The Group IV projects facilitate the integration of the urban transportation system. Short characteristics of examples categories of TP-s (variants) are presented in Table 1. The definition of all variants is presented in the article by Zak and Kruszynski (2021) and Zak *et al.* (2013).

Table 1. *Basic characteristics of selected examples of TP-s (variants) divided into four major classes*

Group I – Private TP-s				
Variant	Category of Investment	Description	Function	Location
1	2	3	4	5
PrT-1	New road segment.	Principal arterial way with 2 roads and 3 lanes in each direction. Length: 2 km.	Part of the inner ring road.	Southern part of the city.
PrT-4	New road segment.	Principal arterial way with 2 roads and 3 lanes in each direction. Length: 8 km.	Part of the inner ring road	Western part of the city.
Group II – Public TP-s				
PuT-2	New tramway railroad.	Separated railroad. Part of the railroad in the tunnel. Total length of the railroad: 1,6 km. Length of the tunnel: 1,1 km.	Connection between tramway depot, residential area, shopping and city centre.	Eastern part of the city.
PuT-4	Fleet replacement.	Replacement of 40 streetcars for the new low-floor vehicles.		
Group III – Non-motorized TP-s				
NM-1	7 parking lots for bikes.	Capacity: between 5 and 50 bikes.		City centre near key transferring nodes.
NM-2	1 parking lot for bikes.	Capacity: 25 bikes.		Northern part of the city near bus terminal
Group IV – Integration of the TP-s				
IT-2	3-level parking lot.	Area: 10 000 m^2. Capacity: 500 cars.	P&R parking lot.	Western boundary of the city, near the key transferring node.
IT-3	5-level parking lot.	Area: 10 000 m^2. Capacity: 450 cars.	P&G parking lot.	City centre.

Source: *Own study.*

4.2 Definition of Consistent Families of Criteria for Different Levels of Analysis

Each of the variants has been successively evaluated using three groups of criteria - subject-specific, sectorial, and strategic ones. The first group of criteria – subject-specific, adapted to the characteristics of the projects considered considers their industry specific features. Subject-specific criteria are divided into four groups corresponding to the four classes of urban transportation projects described above. The sectorial criteria reflect the objectives of the Poznan City Transportation Policy. Strategic criteria are based on three strategic objectives defined in the development strategies of most medium-sized cities, the development of innovative economy and improvement of the investment attractiveness of the city, increase of the importance of the city, improvement of the quality of life and the attractiveness of spatial and architectural arrangement of the city.

Table 2 presents the assignment of particular criteria to each level of the multiple level hierarchy (presented in Figure 1) and to each group of projects. Despite the fact that some criteria have been given the same names, their meaning and scope may be different. The definition of all criteria is presented in the article by Zak and Kruszynaki (2021) and Zak et al. (2013).

Table 2. *The sets of criteria on each level of the multiple level hierarchy*

Level of hierarchy	Criterion	Transportation Projects (TP-s)			
		Private Transportation	Public Transportation	Non-motorized Transportation	Integration of Transportation
Operational criteria	Investment costs	OC-PrT-1	OC-PuT-1	OC-MN-1	OC-IT-1
	Investment profitability	OC-PrT-2	OC-PuT-2	OC-MN-2	OC-IT-2
	Nuisance of the investment process	OC-PrT-3	OC-PuT-3	OC-MN-3	OC-IT-3
	Safety	OC-PrT-4	OC-PuT-4	OC-MN-4	-
	Quality of transportation infrastructure	OC-PrT-5	OC-PuT-5	OC-MN-5	-
	Environmental friendliness	OC-PrT-6	OC-PuT-6	-	OC-IT-4
	Travel time	OC-PrT-7	-	-	-
	Utilization of road infrastructure	OC-PrT-8	-	-	-
	Average speed of the public transportation means	-	OC-PuT-7	-	-
	Standard of travel	-	OC-PuT-8	-	-
	Directness of connections	-	OC-PuT-9	-	-
	Headway	-	OC-PuT-10	-	-
	Accessibility of the public transportation system	-	OC-PuT-11	-	OC-IT-5
	Integration ratio of the urban transportation system	-	-	OC-MN-6	OC-IT-6
Tactical criteria	Unit transportation costs	TC-1			
	Accessibility of the transportation system	TC-2			
	Travel time	TC-3			
	Safety	TC-4			

	Share of public transportation in the modal split	TC-5
	Integration of transportation system	TC-6
	Availability of parking areas	TC-7
Strategic criteria	Investment productivity	SC-1
	Impact on the labor market	SC-2
	Investment competitiveness	SC-3
	Academic potential	SC-4
	Social attractiveness	SC-5
	Comfort of life	SC-6
	Spatial harmony	SC-7
	Image of the city	SC-8
	Economical balance of the metropolitan area	SC-9
	Level of metropolitan integration	**SC-10**

Source: *Own study.*

4.3 Multiple Criteria and Group Oriented Evaluation of Urban Transportation Projects: Computational Experiments

All the computational experiments refer to levels II to V of the presented multiple level paradigm (Figure 1). They have been performed with the application of two multiple criteria ranking methods – ELECTRE III/IV and AHP, representing two major schools of the MCDM/A methodology (see section 2). These methods are universal in nature and can be applied to a wide range of multiple level, multiple criteria ranking problems; their computational efficiency is very satisfactory; ELECTRE III and AHP methods are reliable and users' friendly MCDM/A methods; both the applied MCDM/A method are able to generate intermediate and final rankings of TP-s. They have been applied both in the "Ex-ante Analysis" and in the "Ex-post Analysis". The application of two alternative methods allowed to demonstrate the universality of the presented approach.

In the first phase of the computational procedure the decision problem has been recognized which resulted in the identification of the hierarchy of goals and the associated consistent families of criteria. This phase has also involved the construction of the evaluation matrix. The matrix includes numerical evaluations of all variants (TP-s) on all criteria (operational, tactical, strategic).

In the second phase the model of preferences for the DM (MA) and the stakeholders (PTO, P and LC) has been elaborated. In the „Ex-ante Analysis" the group-oriented modeling of preferences resulted in the aggregation of separate preferential models defined for each group of interveners (MA, PTO, P and LC) into one overall model of preferences prior to the performance of computational experiments at each level of the hierarchy.

In the „Ex-post Analysis" separate rankings have been generated based on different models of preferences for the DM (MA) and stakeholders (PTO, P and LC). In this case the group-oriented aggregation of results (rankings) has been carried out after the completion of computational experiments (see figure 1). In this phase a discussion and brainstorming with DM and stakeholders have been organized to find a consensus and a common standpoint concerning preferences and final ranking.

In the computational experiments performed with the application of ELECTRE III/IV method in both "Ex-ante Analysis" and "Ex-post Analysis", the importance of criteria has been expressed in the form of absolute weights. The sensitivity to changes of the criteria values has been defined by the three thresholds of indifference – q, preference – p and veto – v for each criterion. Table 3 presents an example of preferences defined for the PTO in the experiment based on the application of the ELECTRE III/IV method at level II in the "Ex-post Analysis".

In the computational experiment with the application of the AHP method the model of the DM's and stakeholders' preferences is based on the relative weights representing the strengths of elements in the pairwise comparison of criteria and variants. As described in section 2, the relative weights are defined as numbers from 1 to 9 and their inverses. In the analysed case this comparison is carried out for criteria and variants at each level of hierarchy (operational, tactical, and strategic). Due to the complex structure of the analysed decision situation (number of stakeholders, variants, criteria, and applied approaches of group interaction) the number of performed pairwise comparisons has been substantial, including: 2005, 5460 and 7875 on operational, tactical, and strategic levels, respectively.

Table 3. *Preferences of the PTO defined in the experiment performed with the application of ELECTRE III/IV method in the "Ex-post Analysis" at level II. The values of weights and thresholds for operating criteria*

Preferential information – PTO – Ex-post Analysis-Level II. ELECTRE III/IV

Criteria	Preference direction	Weight	Indifference threshold (q)	Preference threshold (p)	Veto threshold (v)
OC-PrT-1 [mln zł]	Decreasing (Cost)	3,000	10	100	2000
OC-PrT-2 [%]	Increasing (Gain)	2,000	2	3	20
OC-PrT-3 [points]	Decreasing (Cost)	2,000	2	3	10
OC-PrT-4 [points]	Increasing (Gain)	9,000	2	3	8
OC-PrT-5 [%]	Increasing (Gain)	5,000	1	10	50
OC-PrT-6 [points]	Increasing (Gain)	4,000	2	3	8
OC-PrT-7 [mins]	Increasing (Gain)	9,000	2	3	15
OC-PrT-6 [%]	Increasing (Gain)	4,000	10	20	50

Source: Own study.

The next step of the computational experiments is the aggregation of intermediate rankings at subsequent levels of the hierarchical paradigm. As presented in table 4, different forms of aggregation are performed at levels II to V of the proposed algorithm. Due to axiomatic differences of the applied MCDM/A methods the aggregation formulas are method – dependent and differ for ELECTRE III/IV and AHP algorithmic procedures, respectively. In all cases the aggregation is required to combine all intermediate rankings into one resulting ranking.

At level II, the aggregation is required to aggregate partial, class-oriented rankings into one subject-specific ranking. It concerns the intermediate rankings of private transportation projects (PrT class); public transportation projects (PuT class); non-motorized transportation projects (NM class) and projects focused on integration of the transportation system (IT class) and results in the generation of the subject-specific ranking. This aggregation is performed for both "Ex-ante Analysis" and "Ex-post Analysis", regardless of the applied MCDM/A method (ELECTRE III/IV, AHP). It is worth mentioning that in the "Ex-post Analysis" the aggregation at level II concerns 4 groups of entities, including: the DM (MA) and stakeholders (PTO, P, LC).

As a result, 10 aggregations have been performed at level II, which led to the generation of 10 rankings for all 18 TP-s. As an example of the above-described analysis 4 partial (class-oriented) rankings generated with the application of AHP method in the "Ex-post Analysis", based on the preferences of the PTO are demonstrated in figure 2a, b, c, d. Figure 2e presents an aggregated subject-specific ranking of all 18 TP-s.

Both in "Ex-ante" and in "Ex-post" Analyses the aggregation is performed according to formula (1) in table 4 for the computational experiments based on the application of AHP method. When the ELECTRE III/IV method is used for computational experiments another two-step procedure of aggregation is applied. In the first phase the scoring of all TP-s is performed based on their positions in the respective rankings. Each TP is awarded 2, 1 and 0.5 points for any preference (P), indifference (I) and incomparability (R) relations against other projects, respectively. This validation of projects is carried out with the application of formula (4a) in Table 4.

Afterwards the obtained results are normalized with the use of one of normalization methods, e.g., vector normalization. As a result, utility of each individual TP is computed. This utility value, resulting from the position of TP in the ELECTRE III/IV – based ranking can be compared with each project original utility calculated by the AHP method. The second phase of aggregation consists in applying formula (4) in table 4 to integrate partial (class-oriented) rankings in one subject-specific ranking.

Table 4. *Aggregation formulas at different levels (II to V) of a hierarchical - multiple-level, multiple-criteria and group-oriented evaluation of urban transportation projects for the application of both AHP and ELECTRE III/ IV methods*

Level	AHP	The number of formula	ELECTRE III	The number of formula
1	2	3	4	5
II	$U_i^m = \dfrac{U_{i_k}^k \cdot l^k}{l}$ where $l = \sum\limits_{k=1}^{n} l^k$	**(1)**	$U_i^m = \dfrac{U_{i_k}^k \cdot l^k}{l}$ $l = \sum\limits_{k=1}^{n} l^k,$	**(4)**
				(4a)

$$U_{i_k}^k = \frac{a \cdot P_{i_k}^k + bI_{i_k}^k + cR_{i_k}^k}{\sum_{i_k=1}^{l^k} a \cdot P_{i_k=1}^k + \sum_{i_k=1}^{l^k} b \cdot I_{i_k}^k + \sum_{i_k=1}^{l^k} c \cdot R^j} \cdot 100\%$$

III U_i^o (2) $$U_i^o = \frac{a \cdot P_i^o + b \cdot I_i^o + c \cdot R_i^o}{\sum_{i=1}^{l} a \cdot P_i^o + \sum_{i=1}^{l} b \cdot I_i^o + \sum_{i=1}^{l} c \cdot R_i^o} \cdot 100\%$$ (5)

IV U_i^s (3) $$U_i^s = \frac{a \cdot P_i^s + b \cdot I_i^s + c \cdot R_i^s}{\sum_{i=1}^{l} a \cdot P_i^s + \sum_{i=1}^{l} b \cdot I_i^s + \sum_{i=1}^{l} c \cdot R_i^s} \cdot 100\%$$ (6)

**V** $$U_i = \frac{U_i^m \cdot w_m + U_i^o \cdot w_o + U_i^s \cdot w_s}{w_m + w_o + w_s}$$ (7)
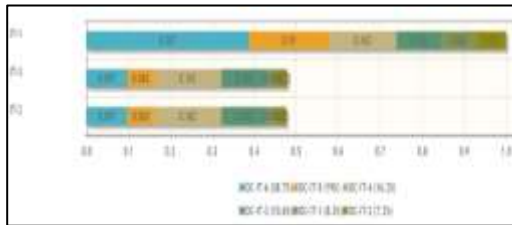
Source: Own study.

Where:

U_i^m – utility of variant/project i in the subject-specific ranking,

$U_{i_k}^k$ – utility of variant/project i_k in ranking of projects with class k,

l^k – number of evaluated variants/projects of urban transportation with class k, where k = 1,2, …, n,

n – number of classes, where n = 1, 2, … 4,

i_k – variant/project i within class k, where i_k = 1, 2, …, l^k,

i – the index of variant/project, where i = 1, 2, …, l,

l – number of evaluated variants/projects of urban transportation,

a,b,c – point indexes, where a = 2, b = 1, c = 0.5,

$P_{i_k}^k$ – number of relations of preference (P) in the ranking of projects i_k within class k,

$I_{i_k}^k$ – number of relations of indifference (I) in the ranking of projects i_k within class k,

$R_{i_k}^k$ – number of relations of incomparability (R) in the ranking of projects i_k within class k,

P_i^o – number of relations of preference (P) of project i in the sectorial ranking,

I_i^o – number of relations of indifference (I) of project i in the sectorial ranking,

R_i^o – number of relations of incomparability (R) of project i in the sectorial ranking,

P_i^s – number of relations of preference (P) of project i in the strategic ranking,

I_i^s – number of relations of indifference (I) of project i in the strategic ranking,

R_i^s – number of relations of incomparability (R) of project i in the strategic ranking,

U_i^o – utility of variant/project i in the sectorial ranking,

U_i^o – utility of variant/project i in the strategic ranking,

U_i – utility of variant/project i in the final ranking,

w_m – weight (importance) of the subject-specific ranking,

w_o – weight (importance) of the sectorial ranking,

w_s – weight (importance) of the strategic ranking.

Figure 2. *Rankings of TP-s obtained in "Ex-post Analysis" using the preferences of the PTO, generated at: level II (a, b, c, d, e), with the application of AHP method, a) Intermediate ranking of projects in PrT class, b) Intermediate ranking of projects in PuT class, c) Intermediate ranking of projects in IT class, d) Intermediate ranking of projects in NM class, e) an aggregated subject-specific ranking of all 18 TP-s*
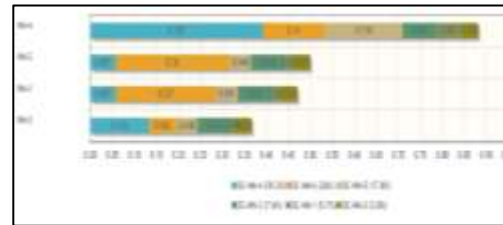

a)

b)

c)

d)

e)
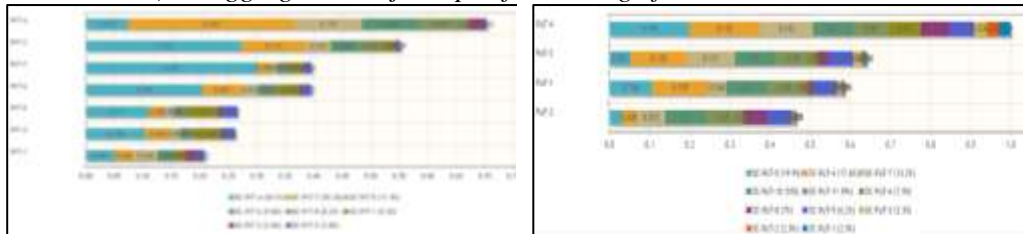
At level III, all computational experiments both in "Ex-ante Analysis" and "Ex-post Analysis" have been focused on generating the sectorial ranking of 18 TP-s. At this level all projects belonging to different classes have been uniformly assessed using a single, common set of criteria (one family of criteria). The aggregation of rankings is not required at level III. In all the computational experiments based on the application of AHP method the utilities of TP-s are computed automatically within the computational procedure. In the experiment in which the ELECTRE III/IV method is used the scoring and normalization procedures, equivalent to those used in level II, are applied. This computation is performed according to formula (5) in Table 4.

At level IV, all computational experiments both in "Ex-ante Analysis" and "Ex-post Analysis" are performed according to the same rules as those applied at level III. The final output of the TP-s evaluation at level IV is the strategic ranking of all 18 TP-s. Similarly, to level III the aggregation of rankings is not required at level IV. The same

rules concerning computational utilities scoring and normalization apply. The scoring and normalization procedures in the experiment perform with the application of ELECTRE III/IV method are carried out according to formula (6) in Table 4.

Figure 3. *Rankings of TP-s obtained in "Ex-post Analysis" using the preferences of the PTO, generated at: with the application of AHP method, a) subject-specific ranking (level II) b) sectorial ranking (level III), c) strategic ranking (level IV), d) final ranking*


a)

b)

c)

d)
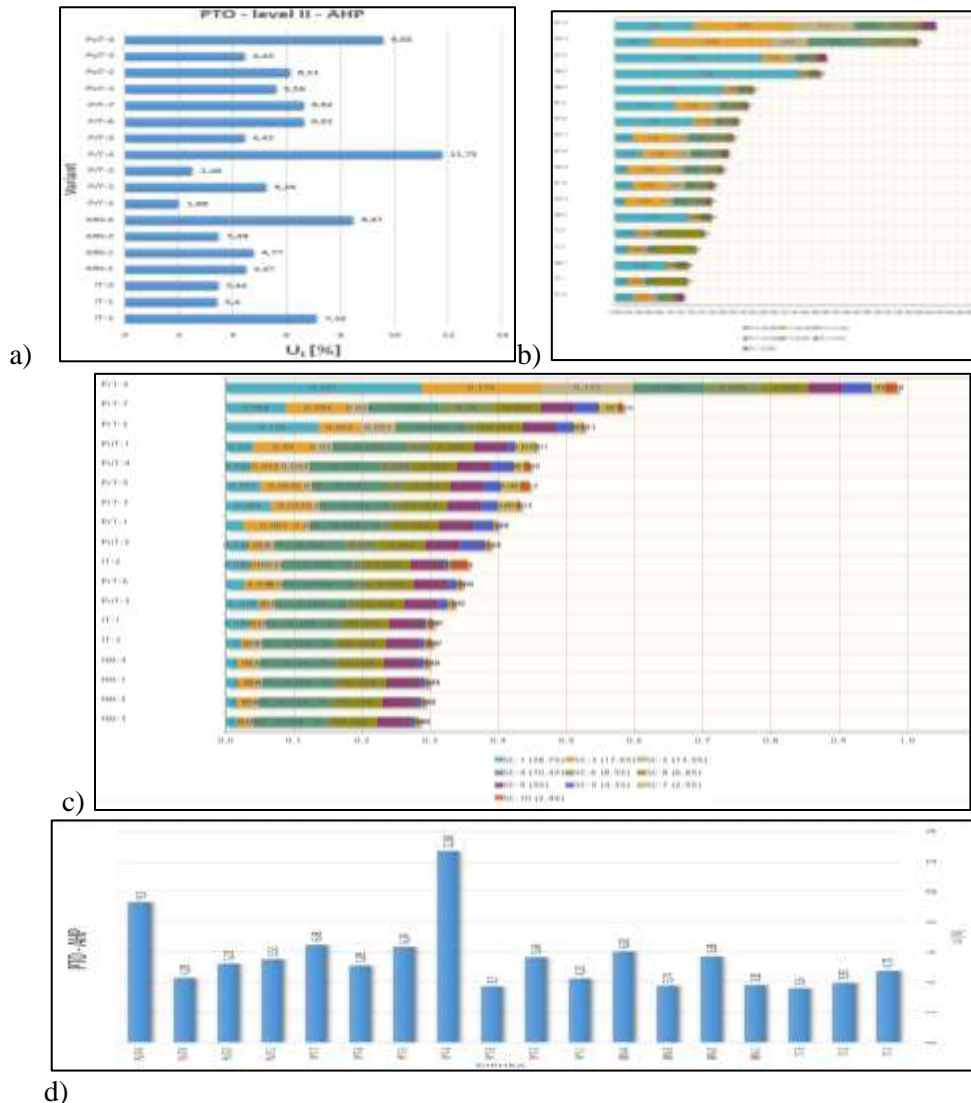
Source: Own study.

The computational experiments at level V are focused on aggregating 3 previously generated rankings at levels II, III and IV. Thus, the final ranking is the resultant of subject-specific ranking, sectorial ranking, and strategic ranking. The aggregation of the above-mentioned rankings is performed according to formula (7) in Table 4. The

computation at the level V resulted in the generation of 10 final rankings, including: 2 rankings in the "Ex-ante Analysis" and 8 rankings in the "Ex-post Analysis". In the "Ex-ante Analysis" each ranking was generated by the application of one of the MCDM/A methods (AHP or ELECTRE III/IV). In the "Ex-post Analysis" each MCDM/A method was applied for four groups of stakeholders (MA, PTO, P, LC). An example of this analysis is presented in Figure 3. It shows the respective rankings generated in the "Ex-post Analysis" according to the preferences of PTO at level II – subject-specific ranking (Figure 3a), level III – sectorial ranking (Figure 3b), level IV – strategic ranking (Figure 3c). These rankings are aggregated into overall final ranking of TP-s (Figure 3d).

The examples of the computational results generated by the application of ELECTRE III/IV and AHP methods, at levels II - V in the "Ex-ante Analysis" are summarized in the numerical and graphical forms in table 5 and Figure 4, respectively. Their equivalents based on the preferences of passengers/road users (P) for "Ex-post Analysis" are presented in Table 6 and Figure 5, respectively.

Figure 4. *Selected results of computational experiments. Rankings of PT-s based on the computation of their utilities Ui, in the "Ex-ante Analysis" a) with the application of AHP method, b) with the application of ELECTRE III/IV method*

a)   b)
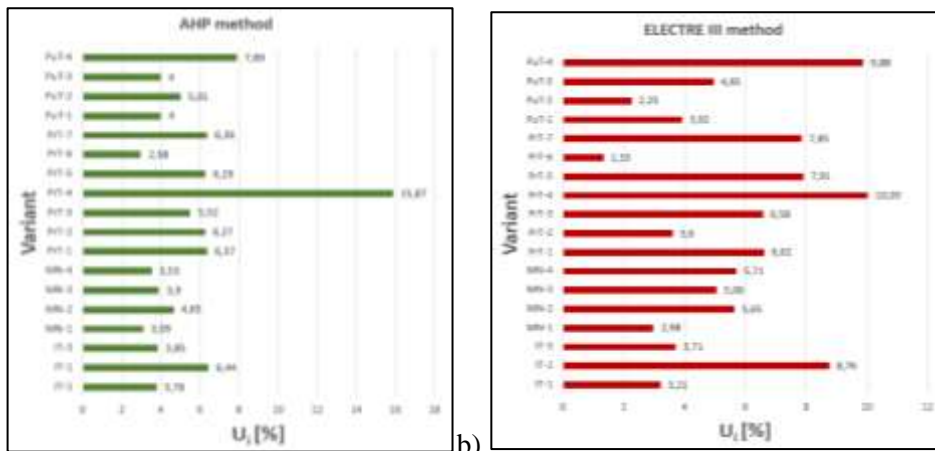
Source: *Own study.*

Table 5. *Selected results of computational experiments. Rankings of PT-s based on the computation of their utilities Ui, in the"Ex-ante Analysis" for both applied methods (AHP and ELECTRE III/IV)*

Final ranking ex ante analysis

Variant	AHP method Levels					ELECTRE III method Levels				
	II	III	IV	V	Position in the ranking	II	III	IV	V	Position in the ranking
	U_i^m [%]	U_i^o [%]	U_i^s [%]	U_i 33/33/33 [%]		U_i^m [%]	U_i^o [%]	U_i^s [%]	U_i [%] 33/33/33	
IT-1	5.32	2.41	3.62	**3.78**	**15**	5.56	1.78	2.31	**3.21**	15
IT-1	7.11	5.46	6.76	**6.44**	**3**	11.11	4.63	10.54	**8.76**	3
IT-3	4.22	3.01	4.33	**3.85**	**14**	0.00	3.38	7.74	**3.71**	13

|				**3.09**	**17**	5.56	1.07	2.31	**2.98**	16
MN-1	4.18	2.28	2.90	**3.09**	**17**	5.56	1.07	2.31	**2.98**	16
MN-2	7.25	3.86	2.83	**4.65**	**10**	5.56	9.07	2.31	**5.65**	8
MN-3	6.07	3.16	2.48	**3.90**	**13**	5.56	7.30	2.31	**5.06**	10
MN-4	4.69	3.41	2.50	**3.53**	**16**	5.56	9.25	2.31	**5.71**	9
PrT-1	7.87	7.34	3.89	**6.37**	**4**	11.67	5.87	2.31	**6.62**	6
PrT-2	3.11	5.66	10.04	**6.27**	**7**	0.97	3.74	6.10	**3.60**	14
PrT-3	4.97	7.28	4.62	**5.52**	**8**	8.26	3.74	7.74	**6.58**	7
PrT-4	11.56	18.20	17.85	**15.87**	**1**	6.80	12.09	11.19	**10.03**	1
PrT-5	4.81	8.35	5.71	**6.29**	**6**	6.32	8.19	9.22	**7.91**	4
PrT-6	3.04	2.28	3.61	**2.98**	**18**	0.97	0.71	2.31	**1.33**	18
PrT-7	3.49	6.09	9.51	**6.36**	**5**	3.89	9.79	9.88	**7.85**	5
PuT-1	4.22	2.59	5.19	**4.00**	**11**	0.00	5.51	6.26	**3.92**	12
PuT-2	4.76	5.83	4.43	**5.01**	**9**	4.44	0.00	2.31	**2.25**	17
PuT-3	5.06	3.65	3.30	**4.00**	**11**	4.44	4.63	5.77	**4.95**	11
PuT-4	8.27	9.24	6.15	**7.89**	**2**	13.33	9.25	7.08	**9.88**	2
Total	100.0	100.0	100.0	**100.0**		100.0	100.0	100.0	**100.0**	

***Source:** Own study.*

Table 6. *Selected results of computational experiments. Rankings of PT-s based on the computation of their utilities U_i, in the "Ex-post Analysis" for both applied methods (AHP and ELECTRE III/IV)*

	MA				PTO				P				LC			
Rankings	**AHP**		**ELECTRE**		**AHP**		**ELECTRE**		**AHP**		**ELECTRE**		**AHP**		**ELECTRE**	
	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position	U_i [%]	Position
IT-1	4,21	14	2,60	17	4,73	11	3,25	17	3,25	18	4,53	13	4,73	12	3,96	16
IT-2	5,18	9	5,88	9	3,93	14	4,42	13	6,79	3	5,66	8	7,17	3	4,96	11
IT-3	3,34	17	3,02	15	3,60	18	4,65	10	3,93	14	5,29	9	5,04	11	5,95	6(7)
MN-1	4,82	10	4,14	10	3,81	15	4,10	15	4,66	12	4,13	14	5,27	10	4,69	13
MN-2	7,13	4	5,96	8	5,68	6	5,18	8	6,11	5	3,52	15	6,65	5	4,73	12
MN-3	4,63	11	3,65	13	3,74	16	4,54	12	5,19	9	4,96	10(11)	5,70	9	5,95	6(7)
MN-4	5,47	8	3,79	11	6,02	5	4,59	11	5,96	6	4,59	12	6,16	7	4,40	14
PrT-1	6,08	7	10,29	2	4,23	13	9,14	2	6,21	4	8,24	2	6,26	6	8,67	1
PrT-2	6,38	6	7,07	5	5,64	7	5,41	6	5,15	10	4,96	10(11)	4,57	14	6,55	5
PrT-3	4,55	13	6,18	7	3,70	17	6,50	5	3,71	15	7,23	6	4,21	15	5,72	9
PrT-4	11,91	1	9,86	3	12,68	1	9,13	3	13,27	1	7,85	4	8,28	1	7,92	4
PrT-5	7,31	3	10,75	1	6,34	4	8,80	4	5,65	7	8,01	3	6,77	4	8,18	2

PrT-6	2,77	**18**	1,37	**18**	5,09	**10**	1,86	**18**	3,36	**17**	2,66	**18**	3,83	**16**	2,26	**18**
PrT-7	6,42	**5**	8,26	**4**	6,48	**3**	9,67	**1**	5,37	**8**	8,35	**1**	5,77	**8**	8,03	**3**
PuT-1	3,95	**15**	3,54	**14**	5,51	**8**	5,34	**7**	4,24	**13**	7,60	**5**	3,80	**17**	5,83	**8**
PuT-2	4,60	**12**	3,71	**12**	5,23	**9**	3,91	**16**	5,09	**11**	3,36	**16**	4,59	**13**	2,75	**17**
PuT-3	3,87	**16**	2,98	**16**	4,28	**12**	4,36	**14**	3,66	**16**	3,34	**17**	3,62	**18**	4,08	**15**
PuT-4	7,38	**2**	6,95	**6**	9,30	**2**	5,15	**9**	8,40	**2**	5,72	**7**	7,58	**2**	5,37	**10**
Total	100,00		100,00		100,00		100,00		100,00		100,00		100,00		100,00	

Source: Own study.

Figure 5. *Selected results of computational experiments. Rankings of PT-s based on the computation of their utilities Ui, in the "Ex-post Analysis" for a group P a) with the application of AHP method, b) with the application of ELECTRE III/IV method.*

a)   b)
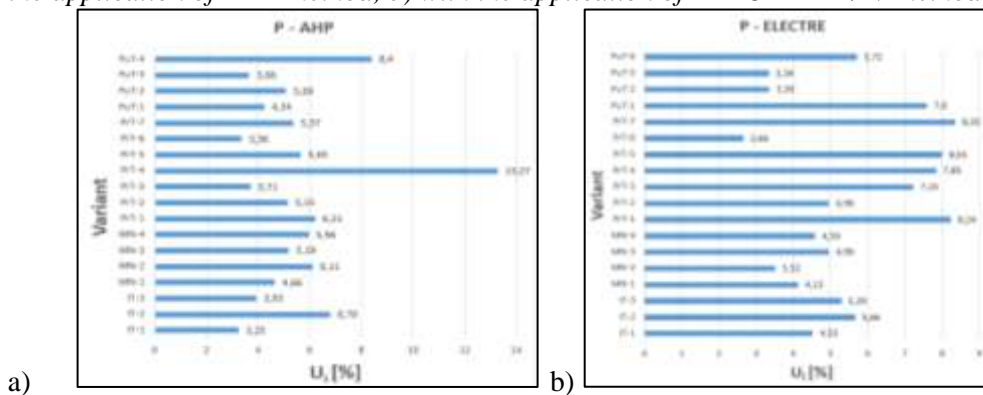
Source: Own study.

5. Conclusions

The paper presents an original methodology of urban transportation projects' (TP-s) evaluation that involves their multiple criteria assessment and group decision making processes at different levels of the hierarchical paradigm. The proposed approach, called group oriented, hierarchical – multiple level and multiple criteria evaluation (GOHIMULEMCE) of TP-s is composed of 5 levels. The performed evaluation of TP-s allows for the analysis of their impact on the satisfaction of operational, tactical and strategic objectives/ goals of the city/ municipal area. In the proposed approach the authors combine the concepts of MCDM/A and GDM and apply them in an aggregated form at different levels of evaluation of TP-s.

The new and original approach to TP's evaluation is an extension of the procedure labeled a multiple level, multiple criteria evaluation (MULEMCE) of TP-s, developed by Zak and Kruszynski (2015) and (2021). The novelty of this new approach is the introduction of a group-decision making (GDM) component at each level of the TP-s

evaluation and its integration with the MCDM/A methodology. In the process of evaluating TP-s an important role of 4 groups of stakeholders, including: Municipal Authorities (MA), Public Transport Operator (PTO), Passengers / Road Users (P) and Local Community/ Residents (LC), is envisaged. The authors propose two alternative ways of modeling group interaction between those groups the "Ex-ante Analysis" and "Ex-post Analysis". In the "Ex-Ante Analysis" the group interaction is performed prior to the phase of computational experiments and allows for the elaboration of an aggregated, common model of preferences for all 4 groups of stakeholders.

As a result, 1 computational experiment is performed and 1 ranking of TP-s is generated, according to 1, common model of preferences. In the "Ex-Post Analysis" all computational experiments are performed according to specific, separate models of preferences, characteristic for each group of stakeholders (MA, PTO, P, LC). As a result, several rankings of TP-s are generated, and a consensus must be found after the experiments to aggregate results and generate the final ranking of all projects.

In the computational phase the authors apply two alternative multiple criteria ranking methods: AHP and ELECTRE III/IV and accommodate their axiomatic characteristics to the specific features of the considered decision problem. They propose various aggregation formulas to generate at different levels of hierarchy combined rankings from their intermediate counterparts. The original aggregation formulas, different for AHP and ELECTRE III/IV methods allow for generating the final/overall ranking of all considered urban transportation projects (TP-s). The aggregation mechanism is based on computing the utilities of all projects.

It is worth mentioning that the defined decision problem is characterized by high complexity and specific internal structure. For these reasons solving the problem was an intriguing and challenging task. 18 TP-s has been evaluated by 3 different sets of criteria, including: 6-11 criteria at the operational level, 7 criteria at the tactical level and 10 criteria at the strategic level. In addition, two alternative ways ("Ex ante Analysis" and "Ex-post Analysis") of modeling the preferences of major stakeholders have been introduced. Considering 4 groups of stakeholders this resulted in the generation of 10 models of preferences.

The following elements constitute an original output of this research:

- Formulation of the multiple level, multiple criteria, and group-oriented decision problem. Definition of several sets of criteria evaluating TP-s at different levels of the hierarchy. Considering different aspects of evaluation and interests of different stakeholders. Modeling of the DM's and stakeholders' preferences based on two original approaches – "Ex-ante Analysis" and "Ex-post Analysis".
- Developing an original solution procedure of the multiple level, multiple criteria and group-oriented decision problem based on the application and customization of the AHP and ELECTRE III/IV methods combined with the utilization of the rankings' aggregation formulas.

- Utilization of the concept of utility for TP-s evaluation and ranking. Aggregating different criteria values into final utilities of TP-s. Aggregating intermediate rankings into one final graph based on the computation of TP-s' utilities.

The presented approach has a universal character and can be applied as an efficient tool of evaluating and ranking various TP-s considered for implementation in any urban transportation system. The designed procedure can serve as a decision support methodology for developing a rational annual budget focused on investment in different activities concerning urban transportation. After slight modification (redefinition of criteria, restructuring of hierarchy) it can be also used for evaluating and ranking different projects and undertakings in other transportation and logistics systems and analysing their impact on operational, tactical, and strategic goals of the considered objects (entities).

It has a universal character and can be applied as an efficient tool in evaluating and ranking various TP-s considered for implementation in the urban transportation system. The performed evaluation of TP-s allows for the analysis of their impact on the satisfaction of operational, tactical, and strategic objectives/ goals of the city/ municipal area. The designed procedure can serve as a decision support methodology for developing a rational annual budget focused on investment in different activities concerning urban transportation.

Further research will be conducted in the following directions:

- The application of different MCDM/A methods to the evaluation of TP-s, including PROMETHEE, ANP, TOPSIS, MAMCA, ORESTE, MAPPAC and comparing the generated results. Development of different method-dependent formulas of aggregating intermediate results and generating final rankings of TP-s.
- Development and examination of alternative ways of handling the group interaction in the analyzed decision situation. Comparison the newly introduced approaches with the "Ex-ante Analysis" and "Ex-post Analysis".

The application of the cost – benefit analysis (CBA) to the evaluation and ranking of the TP-s and its comparison with the MCDM/A methodology. The analysis of the suitability of both methodologies to handling the multiple level and group-oriented evaluation of TP-s.

References:

Annema, J., Mouter, N., Razaei, J. 2015. Cost-benefit Analysis (CBA), or Multi-Criteria Decision-Making (MCDM) or Both: Politicians' Perspective in Transport Policy Appraisal. Transportation Research Procedia, Volume 10, 788-797.

Bui, T., Jarke, M. 1986. Communications Design for Co-oP: A Group Decision Support System. ACM Transactions on Office Information Systems, Vol. 4, No. 2, 81-103.

Davies, G., Burgess, J., Eames, M., Mayer, S., Staley, K., Stirling, A., Williamson, S. 2003. Deliberative mapping: appraising options for addressing "the kidney gap". Final Report to the Wellcome Trust, London.

De Brucker, K., Macharis, C., Verbeke, A. 2011. Multi-criteria analysis in transport project evaluation: an institutional approach. European Transport, Nr 47, 3-23.

Ehrgott, M., Figueria, J, Greco, S. 2010. Trends in Multiple Criteria Decision Analysis. Springer, New York, Dordrecht, Heidelberg, London.

Figueira, J., Greco, S., Ehrgott, M. (eds). 2005. Multiple criteria analysis: State of the art. Surveys. International Series in Operations Research & Management Science. Springer Science + Bussines Media, Boston.

Gercek, H., Karpak, B., Kilincaslon, T. 1998. A Multiple Criteria Approach for the Evaluation of the Rail Transit Networks in Istanbul. Presentation of the 8th World Conference on Transport Research. Antwerp, July 12-17.

Jarke, M., Jelassi, T., Shakun, M. 1987. Mediator: Toward a Negotiation Support System. European Journal of Operational Research, Vol. 31, No. 3, 314-334.

Jelassi, T., Kersten, G., Zionts, S. 1990. An Introduction to Group Decision and Negotiation Support. W.C.A. Bana e Costa, Reading in Multiple Criteria Decision Aid. Springer Verlag Berlin-Heidelberg.

Khraibani, R., de Palma, A., Picard, N., Kaysi, I. 2016, A new evaluation and decision-making framework investigating the elimination-by-aspects model in the context of transportation projects' investment choices. Transport Policy, Volume 48, 67-81.

Kilgour, M., Eden, C. (Eds.). 2010. Handbook of Group Decision and Negotiation. Springer.

Kruszyński, M. 2014. Multiple-Criteria Decision Aiding Methodology in Urban Transportation Management. PhD thesis.

Kruszyński, M., Żak, J. 2015. The Aggregation of Rankings in Multiple Level, Multiple Criteria Evaluation Urban Transportation Projects. Logistyka, 2/2015.

Lee, D.B.Jr. 2000. Methods for evaluation of transportation projects in the USA. Transport Policy, No. 7, 41-50.

Lewandowski, A. 1989. SCDAS – Decision Support System for Group Decision Making: Decision Theoretic Framework. Decision Support Systems, Vol. 5, 403-423.

Macharis, C., Bernardini, A. 2015. Reviewing the use of Multi-Criteria Decision Analysis for the evaluation of transport projects: Time for a multi-actor approach. Transport Policy, Volume 37, 177-186.

McAndrews, C., Marcus, J. 2015, The politics of collective public participation in transportation decision-making. Transportation Research Part A: Policy and Practice, Volume 78, 537-550.

Morisugi, H. 2000. Evaluation methodologies of transportation projects in Japan. Transport Policy, No. 7, 35-40.

Munda, G. 2004. Social multi-criteria evaluation: Methodological foundations and operational consequences. European Journal of Operational Research, Vol. 158, Nr 3, 662-677.

Rao, C., Goh, M., Zhao, Y., Zheng, J. 2015. Location selection of city logistics centers under sustainability. Transportation Research Part D: Transport and Environment, Volume 36, 29-44.

Ren, J., Lützen, M. 2015. Fuzzy multi-criteria decision-making method for technology selection for emissions reduction from shipping under uncertainties. Transportation Research Part D: Transport and Environment, Volume 40, 43-60.

Renn, O., Webler, T., Dienel, P., Jonson, B. 1993. Public participation in decision making: A three-stage procedure. Policy Sciences, Nr 26, 189-214.

Saaty, T., Peniwati, K. 2008. Group Decision Making. RWS Publications, Pittsburgh.

Vincke, P. 1992, Multicriteria Decision-Aid. John Wiley & Sons, Chichester.

Wismans, L., Brands, T., Van Berkum, E., Bliemer, M. 2014. Pruning and ranking the Pareto optimal set, application for the dynamic multi-objective network design problem. Journal of Advanced Transportation, 48, 88-607.

Zhang, J., Kuwano, M., Lee, B., Fujiwara, A. 2009. Modeling household discrete choice behavior incorporating heterogeneous group decision-making mechanisms. Transportation Research Part B: Methodological, Volume 43, 230-250.

Żak, J. 2005. Multiple-Criteria Decision Aiding Methodology in Road Transportation. Poznan: Poznan University of Technology.

Żak, J., Bieńczak, M., Fierek, S., Kruszyński, M., Ratajczak, J., Sawicka, H., Zmuda-Trzebiatowski, P. 2010. Application of the multi-criteria decision support (WWD) methodology to solve selected decision problems related to city management, (manuscript).

Żak, J., Fierek, S., Zmuda-Trzebiatowski, P., Kruszyński, M. 2013. Multiple Level, Multiple Criteria Ranking of Transportation Projects. Conference Presentation of the 13th World Conference on Transport Research, Rio de Janeiro, 15-18 July, (manuscript).

Żak, J., Kruszynski, M. 2015. Application of AHP and ELECTRE III/IV Methods to Multiple Level, Multiple Criteria Evaluation of Urban Transportation Projects. Transportation Research Procedia, 820-830.

Żak, J., Kruszynski, M. 2021. Comprehensive, Multiple Criteria Assessment and Multiple Level Ranking of Transportation Projects. In: Celebration of 10th anniversary of Faculty of Engineering Management.