
Comprehensive, Multiple Level Assessment and Multiple Criteria Ranking of Transportation Projects

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Abstract:

Purpose: The transportation projects are evaluated comprehensively, using different perspectives and aspects of assessment. The purpose of the paper is to present the assessment methodology

Design/Methodology/Approach: The evaluation has been formulated as a multiple level, multiple criteria ranking problem with a hierarchical, 3-level structure. At each level of the analysis the transportation projects are assessed by a set of criteria, including transportation project operational characteristics, transportation policy – based, tactical criteria and a high-level, long-term impact, strategic measures. Separate rankings of the considered projects have been generated for all levels of the hierarchy. Their original aggregation procedure, based on the transportation projects' utilities has been proposed and resulted in the ranking of all projects.

Findings: The developed methodology, called Hierarchical – Multiple Level, Multiple Criteria Evaluation (HMLMCE) of TP-s has its significance both from a theoretical and practical point of view. It has been applied in a large city of Poznan, Poland as an important decision-making tool for municipal authorities considering the implementation of concrete transportation projects in the city/ metropolitan area.

Practical Implications: Solution's application showed the ability to analyze the impact of transportation projects on basic traffic characteristics of the city, their influence on tactical aspects associated with the implementation of sustainable transportation policy in the city as well as their role in the fulfillment of the city strategy. The proposed method can be applied in any urban transportation system and after slight modifications in other transportation and logistics systems.

Originality/Value: The paper presents an original and universal approach to assessing and ranking transportation projects – TP-s featured by the extension and improvement of an urban transportation system.

Keywords: Transportation projects, hierarchical evaluation, multiple criteria analysis.

JEL Classification: M2, L9.

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1. Introduction

Urban transportation system is a set of components, including: transportation infrastructure (roads, tramways, bus and tram stops, parking lots, hubs) fleet of vehicles (cars, and buses, light trains, trams, subway), human resources and governing rules (traffic regulations, service standards, management rules) that ensure a coordinated and efficient transfer/ movement of people (passengers) and/or goods from their origins to destinations in a certain metropolitan area (Perez, Carrillo, and Montoya-Torres, 2015; Kornec 2018). Usually, urban transportation system has its public component, called mass transit system and its private component. The former is focused on the transfer of passengers while the latter includes both the movement of people and goods.

Municipal authorities, governing the metropolitan areas are interested, among other responsibilities, in the proper management and control of urban transportation systems. Through the efficiency, flexibility, and reliability of transportation systems the governing bodies want to offer dwellers / local communities a certain level of transportation services within metropolitan areas, including, among others: comfort of traveling, safety and security of transportation solutions, accessibility to transportation systems, timeliness of travels, environmental friendliness of transportation.

Due to budget limitations the authorities must rationalize funds spent on transportation services in the metropolitan area and push operators on implementing solutions ensuring appropriate coordination of the movement of people (and goods), sufficient utilization of the transportation infrastructure and fleet, high, competitive cost-effectiveness of the transfer of passengers (and freight) (Perez, Carrillo, and Montoya-Torres, 2015; Kornec 2018).

Due to the above-mentioned requirements constant monitoring and adjustment of urban transportation systems is required. In certain cases, the existing urban transportation systems need improved coordination, further substantial conceptual extension and reshape, infrastructural and technological development and many other actions to satisfy the required standards of transportation services within metropolitan areas. Different categories of transportation projects can be applied to satisfy these needs.

In general, transportation projects are specific goal-oriented undertakings carried out by transportation planners, transportation operators and/or municipal authorities that are focused on the implementation of certain transportation solutions, infrastructural and technological components, transportation policies and management rules and others to enhance and improve transportation operations and provide a better transportation service for the transportation of passengers and goods (Perez, Carrillo, and Montoya-Torres, 2015; Kornec, 2018). Usually, these projects carried out in the urban environment tend to restructure the urban transportation system, redesign its certain segments, and enhance the transportation service offered by the system.

The urban transportation projects may range from street / road resurfacing, implementing bus/ tram/ subway route changes, building a new road segment, changes in timetables and better coordination of schedules combined with fleet reassignment, upgrading a

roundabout and/or overpass, developing a new tramway depot, replacing the fleet of buses/ trams, building a new P&R parking lot and many others.

In many cases the implementation of transportation projects in urban transportation system is required to adapt the system to the new changing environment. In that case the projects are focused on technological, organizational, and social – oriented changes. Their introduction is necessary to improve its standard and performance and enhance the passengers' satisfaction from using it. In any case transportation projects require substantial effort to be implemented. They are associated with substantial financial, environmental, and social expenditures (Garrett, 2014; Plane, 1995; Žak and Thiel, 2001).

In most cases transportation projects (TP-s) in the urban transportation systems are carried out as investment processes and require substantial funds from the municipal budget. In budgetary dispute transportation projects compete with others and a construction of a balanced, rational portfolio of activities is required. The allocation of the funds is the responsibility of the municipal authorities, such as: City Councils and City Boards.

Thus, a comprehensive and reliable evaluation of the projects is required to properly rank them and select the best candidates to be financed from the public funding. Municipal authorities perceive transportation projects as tools that can satisfy certain major municipal goals defined in the city policies and strategies, such as the city's transportation policy and the city's development strategy. As indicated in this paper the considered goals can be shaped in the form of a hierarchical tree composed of three main levels, i.e., strategic level, tactical level, and operational level. The authors of this paper claim that evaluation of transportation projects should cover many aspects and should satisfy the interests, requirements and expectations of different stakeholders, characteristic for the above-mentioned levels of analysis.

It is also important to indicate that in the real-life analysis of the projects certain interactions between them exist. In the evaluation process different profiles and specific features of the projects must be considered. It is natural that projects associated with city logistics and/or transportation or education may compete with projects focused on health care and/or technological, informational innovation. On the other hand, concrete projects in one area (e.g., culture – organization of a cultural event) may be complementary with some projects in other areas (e.g., infrastructural development – site and access roads construction). These interactions should be considered in the analysis and ranking of the projects.

All the circumstances, limitations and interactions described above should be considered in the evaluation of transportation projects and a comprehensive and consistent methodology is required to satisfy all of them. Evaluation of transportation projects has been discussed in many reports (Saaty, 1995; Zak, 2017; Zak and Kruszynski, 2015; Macharis, DeWitte, and Ampe, 2009; Zak, 2011) and different methodologies of evaluating transportation projects have been developed, including cost-benefit analysis (CBA) (Boardman, Greenber, Vinning, and Weimer, 2013; Annema, Mouter, and

Razaei, 2015), cost-effectiveness analysis (CEA), regional economic impact study (REIS), environmental impact assessment (EIA) and Multiple Criteria Analysis (MCA) (Satty, 1995; Zak, 2011; De Brucker *et al.*, 2011). In our opinion two of them are most popular for transportation applications and most frequently used for the evaluation of transportation projects. These are Cost – Benefit Analysis and Multiple Criteria Analysis, often called Multiple Criteria Decision Making /Aiding.

Cost–Benefit Analysis (CBA) (Boardman, Greenber, Vinning, and Weimer, 2013; Annema, Mouter, and Razaei, 2015) is a universal methodology of assessing socio – economic benefits of a certain solution, project and/or undertaking and commonly used for the evaluation of transportation projects. The principal rule of the CBA is to investigate whether a certain transportation concept generates overall benefits and balances the costs associated with its implementation. The major principle of CBA is the maximization of the global social welfare of the society. In most US reports the CBA methods are mainly used for the evaluation of transportation projects (Lee, 2000).

The evaluation criteria applied in the CBA for transportation projects' assessment are as follows (Lee, 2000), internal and external costs, travel time, safety, consumer surplus, environmental aspects, comfort of travel, security, convenience, and reliability.

According to CBA methodology all these aspects/ criteria are defined as positive (benefit-oriented) and negative (cost-oriented) effects of a transportation project and expressed in financial terms (monetary units). Finally, they are aggregated, discounted over time and the final cost-benefit outcomes of different transportation projects are compared. Usually, in the CBA three measures are computed to assess the overall profitability / utility of the considered transportation projects (investments), including: Economic Net Present Value (ENPV), Economic Internal Rate of Return (EIRR) and Benefit-Cost Ratio (BCR) (Boardman, Greenber, Vinning, and Weimer, 2013, Annema, Mouter, and Razaei, 2015).

Multiple Criteria Analysis (MCA), often called Multiple Criteria Decision Making/ Aiding (MCDM/A) (Vincke, 1992; Macharis, DeWitte, and Ampe, 2009; Figueira, Greco, and Ehrgott, 2005; Ehrgott, Figueria, and Greco, 2010) is a methodology that can assist the Decision Maker (DM) in analyzing and evaluating transportation projects, from several different perspectives, often of a contradictory character. It is the methodology that helps to analyze trade-offs associated with transportation projects and balance conflicting interests of various stakeholders interested in the implementation of concrete transportation projects.

MCA defines the evaluation of transportation projects as a certain multiple criteria decision problems with two major components: variants/candidates (transportation projects – TP-s) and evaluation criteria (characteristic measures, interests). As indicated by different authors (Saaty, 1995; Rudnicki, 1999; Cascetta, 2009; Zak and Thiel, 2011; Zak, 2011), these criteria used for the evaluation of transportation projects may include investment costs/profitability, safety and security, environmental friendliness, reliability (timeliness, schedule fulfillment), travel/delivery time, accessibility, and others.

According to the MCA the evaluation measures/criteria should constitute together a consistent family of criteria, characterized by the following features (Vincke, 1992; Figueira, Greco, and Ehrgott, 2005), to guarantee a complete evaluation of variants, to be not redundant, to adequately indicate the global preferences and expectations of the DM. As opposed to CBA in MCA these criteria do not have to be transformed to the monetary units and aggregated.

The MCA/MCDM/A methodology (Vincke, 1992; Figueira, Greco, and Ehrgott, 2005) clearly identifies major participants of the decision making/aiding process, such as, the decision maker (DM), the analyst and the interveners (stakeholders) and describes their roles in this process. The recognition of the interests of different bodies is the critical component of the MCA. Usually, two major aspects are considered while defining the preferences of major stakeholders: the importance (weight) of criteria and sensitivity of the DM's and stakeholders in assessing / differentiating the variants.

As opposed to CBA and classical OR techniques MCA/ MCDM/A methods do not yield optimal solutions, because the solutions that would simultaneously optimize several, contradictory criteria do not exist. Instead of that the methodology of MCA/ MCDM/A searches for the compromise solution that satisfies the interests of the above-mentioned parties, analyzes the trade-offs between the considered criteria and takes into account specific preferences and expectations of the DMs and stakeholders. As a final output the MCA generates, either: a ranking of variants – ranking problem, a set of the most desired solution (optimal in a multiple objective sense) – choice problem or the classification of variants – classification problem (Zak, 2005). Different MCA methods can be applied to this end, including: Electre I, II, III/IV and AHP methods (ranking); LBS and TOPSIS (choice), Electre TRI (classification).

De Brucker, Macharis, and Verbeke (2011) proposed a modified MCA method, i.e., the Multi-Actor Multi-Criteria Analysis (MAMCA), which can be considered as an institutional approach to transportation projects' evaluation. The idea of this approach is based on a development of different MCA modules for each stakeholder within the overall model of the decision process. Therefore, each of the involved stakeholders (e.g., transportation system users, local community, municipal authorities, and manufacturers) may define their own sets of criteria and specific parameters.

The authors of this paper claim that none of the research publications has reported the evaluation of transportation projects based on the hierarchical structure of the evaluation criteria and indicated their impact on operational, tactical, and strategic goals of the city/municipal area. Thus, in this paper the multidimensional and multiple level evaluation of transportation projects has been carried out. The authors propose an original methodology of evaluating and ranking transportation projects based on their 3-level hierarchical assessment.

The transportation projects evaluation is defined as multiple criteria ranking problem and thus, the proposed approach is based on the application of one of the Multiple Criteria Ranking methods, i.e., the Analytic Hierarchy Process method (Saaty, 1980; Saaty, 1995; Saaty, 2005). The selection of the AHP method for the multiple level, multiple criteria

assessments of transportation projects is based on two rationalities, the AHP method itself is focused on the hierarchical structure of the decision problem and it generates ranking of variants based on their utilities which is exploited in the proposed procedure of the aggregation of rankings. As presented in the paper the multiple level application of the AHP method results in the generation of the overall priority ranking of all considered transportation projects and thus indicating the most rational sequence of implementing specific transportation projects in the city.

The paper presents a case study in which the proposed procedure has been applied to the evaluation of 18 transportation projects considered for implementation in the metropolitan area of Poznan city in Poland. The following categories of projects have been considered in this case study, projects focused on integration of the transportation system, non-motorized transportation projects that encompass, private (individual) transportation projects, public transportation projects.

The paper is composed of 5 sections. The introduction provides the background for the analysis and defines the objectives of the research. Section 2 is focused on the definition of the decision problem. Section 3 contains the description of the proposed original research methodology and a novel paradigm of HMLMCE of TP-s. A comprehensive section 4 presents the results and analysis of computational experiments carried out with the application of the proposed methodology. Final, concluding remarks are stated in section 5. The paper is supplemented by a list of references.

2. Definition of the Decision Problem

The considered decision problem is handled by the City Hall in the above-mentioned 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 different categories of projects, including TP-s 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, passengers traveling by public transportation, road users and local community.

The considered decision problem has been defined as a hierarchical – multiple level, multiple criteria ranking problem (HMLMCRP). 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. They can be categorized into four major groups, including (Zak, Fierek, Kruszyński, and Zmuda-Trzebiatowski, 2013):

- Group I – 3 projects focused on integration of the transportation system, marked in the abbreviated form by IT-1, IT-2, IT-3,
- Group II – non-motorized transportation projects that encompass 4 new developments called variants NM-1, NM-2, NM-3, NM-4,
- Group III – private (individual) transportation projects – 7 proposals denominated by variants PrT-1, PrT-2, PrT-3, PrT-4, PrT-5, PrT-6, PrT-7,
- Group IV – public transportation projects – 4 investments labelled PuT-1, PuT-2, PuT-3, PuT-4.

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

Table 1. Basic characteristics of TP-s (variants) divided into four – major groups (Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013)

Variant	Category of Investment	Description	Function	Location
1	2	3	4	5
Group I – Integration of the TP-s				
IT-1	4-level, underground parking lot.	Area: 8 000 m ² . Capacity: 300 cars.	P&G parking lot.	City centre.
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.
Group II – Non-motorized TP-s				
NM-1	7 parking lots for bikes.	Capacity: between 5 and 50 bikes.	Promotion of biking	City centre near key transferring nodes.
NM-2	1 parking lot for bikes.	Capacity: 25 bikes.	Promotion of biking	Northern part of the city near bus terminal
NM-3	New bicycle path.	Length: 5km.	Promotion of biking	Through the city centre.
NM-4	New pedestrian underpass.	Underpass under the roundabout.	Improvement of the pedestrian infrastructure	Western part of the city.
Group III – Private TP-s				
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-2	Upgrade of the road segment.	Principal arterial way with 2 roads and 3 lanes in each direction. Length: 5 km.	Part of the inner ring road.	Northern part of the city.
PrT-3	Upgrade of the road segment.	Principal arterial way with 2 roads and 3 lanes in each direction. Length: 2,5 km.	Part of the inner ring road.	Northern 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.
PrT-5	New overpass.	Overpass with 2 roads and 3 lanes in each direction constructed over the major N-S railway track.	Part of the inner ring road	Southern part of the city.
PrT-6	Upgrade of the road segment.	The arterial way with 2 roads and 3 lanes in each direction. Length: 3,5 km.	S-W connection between the city	Northern part of the city.

			centre and the local highway.	
PrT-7	Upgrade of the roundabout.	Multiple level, multiple lane roundabout with underpasses.	Key transportation node in the city centre.	City centre.
Group IV – Public TP-s				
PuT-1	New tramway depot (shed).	Area: 17 ha. Capacity: 150 streetcars. Length of the railroads within depot: 13 km with 109 switches.	Garage & backup facilities for the fleet of the streetcars.	Eastern part of the city.
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-3	Upgrade of the tramway railroad.	Replacement of the switches on a 10 km long railroad	Modernization of the network	Diagonal line / route through the whole city.
PuT-4	Fleet replacement.	Replacement of 40 streetcars for the new low-floor vehicles.	Modernization of the fleet. Improvement of the travelling standards.	The whole public transportation system

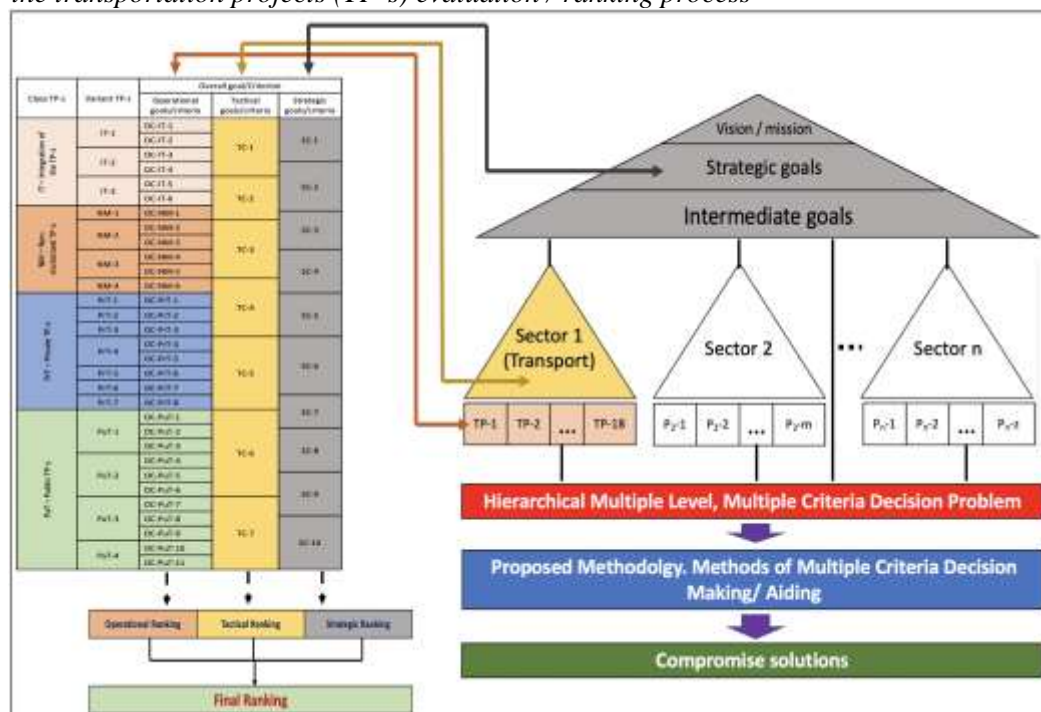
Source: Own study.

The TP-s considered in this analysis are evaluated by a set of hierarchical criteria, constituting a multiple level of goals (Figure 1):

- The overall goal of the analysis placed at the top of the hierarchical table (right-hand side of the figure) can be formulated as a selection and sequencing of TP-s for a certain metropolitan area. This overall goal is associated with the mission and vision of the city and its intermediate goals. It is further divided into city strategic goals, tactical goals for different sectors (areas), including transportation and different operational criteria characteristic for specific projects in various sectors.
- As presented in Figure 1 strategic goals correspond to ten overall measures of city development, denominated by strategic criteria, SC-1 – SC-10. At the tactical level sector – oriented criteria correspond to the sectorial policies in different areas, such as: culture, education, health care, transportation, etc. As far as transportation is concerned 7 tactical criteria, TC-1 – TC-7 are used to evaluate different activities in this sector.
- At the operational level all the analysed projects are divided into classes and evaluated by a family of criteria characteristic for a certain class of projects. As previously indicated all 18 TP-s are split into 4 groups, including, Public TP-s, Private TP-s, Non-motorized TP-s and Integration oriented TP-s (see column: “Class of TP-s”).
- For each of these groups separate families of operational criteria (OC) are proposed to evaluate all TP-s that belong to a specific group. Eleven criteria, denominated by OC-PuT-1 – OC-PuT-11, assess public TP-s. Eight criteria marked by the symbols OC-PrT-1 – OC-PrT-8 are used to evaluate private TP-s. In each of the two remaining groups six criteria are applied to evaluate non-motorized (NM) and integration – oriented (IT) TP-s. These criteria are labelled OC-NM-1 – OC-NM-6 and OC-IT-1 – OC-IT-6, respectively. Their definitions are presented in Table 3.
- The considered TP-s are placed in column – “Variants – TP-s”. As the chart indicates they are evaluated by all 3 categories of strategic, tactical, and operational criteria,

which results in strategic, tactical, and operational rankings, respectively (see bottom part of Figure 1). These rankings, properly aggregated allow to generate the final ranking of TP-s.

Figure 1. Hierarchy of objectives and the allocation of the corresponding criteria for the transportation projects (TP-s) evaluation / ranking process



Source: Own study.

Table 2 presents the denomination of all criteria and their assignment to each level of hierarchy and each group of projects. As indicated in Table 2 some criteria have been given the same names, but their meaning and scope may be different. The concrete definitions of all criteria are presented in Table 3.

Table 2. The sets of criteria on each level of hierarchy (Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013)

Level of hierarchy	Criterion	Transportation Projects (TP-s)			
		Integration of Transportation	Non-motorized Transportation	Private Transportation	Public Transportation
Operational criteria	Investment costs	OC-IT-1	OC-NM-1	OC-PrT-1	OC-PuT-1
	Investment profitability	OC-IT-2	OC-NM-2	OC-PrT-2	OC-PuT-2
	Nuisance of the investment process	OC-IT-3	OC-NM-3	OC-PrT-3	OC-PuT-3
	Safety	-	OC-NM-4	OC-PrT-4	OC-PuT-4
	Quality of transportation infrastructure	-	OC-NM-5	OC-PrT-5	OC-PuT-5
	Environmental friendliness	OC-IT-4	-	OC-PrT-6	OC-PuT-6

	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-IT-5	-	-	OC-PuT-11
	Integration ratio of the urban transportation system	OC-IT-6	OC-NM-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.

Table 3. Definition of criteria (Zak, Fierek, Kruszyński, and Zmuda-Trzebiatowski, 2013)

Operational criteria
<p>Investment costs (OC-PrT-1; OC-PuT-1, OC-NM-1, OC-IT-1) [mln PLN] – minimized. This criterion of financial character is very important for local municipal authorities. It is defined as a total amount of money required to carry out a specific TP, including: labor costs, material costs, costs of equipment and machinery.</p>
<p>Investment profitability (OC-PrT-2, OC-PuT-2, OC-NM-2, OC-IT-2) [%] – maximized. This criterion is a financial – economic parameter that evaluates financial performance (efficiency) of particular TP-s. It is defined as an internal rate of return (IRR) or in other words the interest rate at which the discounted investment costs and incomes generated by the urban transportation system balance in a certain time horizon (20 years).</p>
<p>Nuisance of the investment process (OC-PuT-3, OC-PrT-3, OC-NM-3, OC-IT-3) [pts] – minimized. This criterion measures all the temporal and / or permanent inconvenience for local community (in particular inhabitants of the area located in the neighbourhood of the TP-s being under fulfilment), resulting from the investment process associated with the implementation of particular TP-s. The criterion is defined as a number of points, assigned by experts, measuring the level of negative impact of the TP-s. In the definition of this criterion such issues as: investment duration period, demolition of the buildings, relocations of inhabitants, traffic and everyday life impediments have been taken into account.</p>
<p>Safety (OC-PrT-4, OC-PuT-4, OC-NM-4) [pts] – maximized. This criterion evaluates the impact of particular TP-s on the overall level of road safety within the area associated with the project. It is defined as a number of points assigned by experts for different components that eliminate threats of traffic accidents (flyovers, ring roads, elimination of rail – road intersection), crosswalks, underpasses).</p>
<p>Quality of transportation infrastructure (OC-PuT-5, OC-PrT-5, OC-NM-5) [pts] – maximized. This criterion measures the relative improvement of the transportation infrastructure resulting from the implementation of particular TP-s. It is defined as a number of points assigned by experts that characterize</p>

the impact of a specific project on the overall quality of transportation infrastructure within the zone associated with the TP-s.

Environmental friendliness (OC-PuT-6, OC-PrT-6, OC-IT-4) [pts] – maximized. This criterion characterizes the level of environmental friendliness of the considered TP-s. It is defined as a number of points, assigned by experts, that corresponds to the evaluation of the positive and negative impact of particular TP-s (investments) on environment both in the neighbourhood of the TP-s as well as in the whole metropolitan area. The definition of this criterion takes into account such elements as: direct interference of the TP-s in the environment (e.g., forest clearing), changes in the levels of noise and air pollution, enhancement or degradation of the environmental standards.

Average travel time (OC-PrT-7) [minutes] – minimized. This criterion represents an important component of the travellers' comfort of travel. It is defined as arithmetic average of times required to cover a distance of an average travel in an urban transportation system by private transportation means.

Utilization of road infrastructure (OC-PrT-8) [%] – maximized. This criterion measures the impact of particular TP-s on balancing traffic demand and supply (transportation infrastructure). It is computed as a ratio of an average traffic volume and overall capacity of the road network in a certain area associated with particular TP.

Average speed of the public transportation means (OC-PuT-7) [km/h] – maximized. This criterion represents an important component of the passenger's comfort of travel. It is defined as weighted average of operational speed of all transportation modes (bus and tram) operating in a considered public transportation system (PuTS). In the computation of this criterion the applied weights correspond to the modal split (percentage – wise) in the PuTS, i.e.: they represent the shares of travels carried out by particular transportation modes in this system. This criterion has a clear impact on passengers' riding times and thus, it is a social-, passenger – oriented parameter.

Standard of travel (OC-PuT-8) [pts] – maximized. This criterion contributes to the overall passengers' comfort of travel. It is defined as percentage share of rides carried out in good conditions by public transportation means (uncrowded and clean vehicles, seats available, good ventilation, appropriate driver's behavior and appearance) in the total number of rides in the public transportation system.

Directness of connections (OC-PuT-9) [%] – maximized. This criterion is defined as a percentage share of travels/journeys carried out in a public transportation system (PuTS) without any transfers, i.e.: as direct connections by public transportation means between origins and destinations, in the total number of travels performed in the public transportation system.

Headway (OC-PuT-10) [minutes] – minimized. This criterion is another indirect component of passengers' comfort of travel in the PuTS due to the fact that it is correlated with such characteristics as: passenger's waiting times, degree of crowdedness in the vehicles and/or transferring frequency. It measures how the implementation of particular TP-s influences on the reduction or increase of the average headway in the PuTS which can be interpreted as the enhancement or degradation of the comfort of travel. The criterion is defined as the distance in time (or the time interval) that separates two vehicles travelling the same route in the same direction. It is computed as arithmetic average of the headways on all routes (trams or buses) in the PuTS.

Accessibility of the public transportation system (OC-PuT-11, OC-IT-5) [minutes] – minimized. This criterion measures the travellers' convenience in reaching and leaving the public transportation network (bus, tram). It is interpreted in different manners for public and integration-oriented TP-s. In the first case it is defined as travellers' walking time between origins and destinations of the travels and the public transportation system entry and exit points, respectively. In the second case the criterion is expressed as travellers' walking time between the P&R parking lot and the closest entry/exit point to/from the public transportation system.

Integration ratio of the urban transportation system (OC-IT-6, OC-MN-6) [pts] – maximized. This criterion defines the level of intermodal integration of an urban transportation system that is strictly linked with the provision of smooth and efficient “door – to – door” transportation within the metropolitan area. It is defined as a number of points, assigned by experts, evaluating such integrating solutions as: number and capacity of Park & Ride parking lots, bicycle lockers and bicycle rental points located near key transferring nodes, number of integrated stops/platforms (for buses, trams) and number of transportation modes and routes available in major transferring nodes.

Tactical criteria, based on the transportation policy

Transportation costs savings (TC-1) [PLN] – maximized. This criterion measures the impact of particular TP-s on the overall transportation costs generated in the urban transportation system. It is defined as the daily economic savings (expressed in monetary units) resulting from the implementation

of the particular TP-s in the urban transportation system. The criterion takes into account time and cost savings generated both by public and private transportation.

Accessibility of the transportation system (TC-2) [%] – maximized. This criterion measures the travellers' convenience in reaching and leaving the whole transportation network (roads, public transportation routes). It is defined as a share of the length of new road segments and new public transportation routes in the total length of the urban transportation network.

Average travel time (TC-3) [minutes] – minimized. This criterion represents an important component of the passenger's comfort of travel. It is defined as weighted average of times required to cover a distance of an average travel in an urban transportation system by private as well as public transportation means. In the computation of this criterion the applied weights correspond to the modal split (percentage – wise) in the urban transportation system, i.e.: they represent the shares of travels carried out by private and public transportation modes in this system. This criterion is minimized.

Safety and security (TC-4) [pts] – maximized. This criterion evaluates the impact of particular TP-s on the overall level of safety and security in the urban transportation system. It is defined as a number of points assigned by experts for different components that eliminate threats of traffic accidents (flyovers, ring roads, elimination of rail – road intersections, crosswalks, underpasses) as well as risk of vandalism and violence (monitoring, lighting).

Share of public transportation in the modal split (TC-5) [%] – maximized. This criterion corresponds to the city's tactical goal defined in the transportation policy and focused on the promotion of public transportation means in the metropolitan area. It is defined as a percentage share of travels carried out by public transportation means in the total number of travels in the whole metropolitan area.

Integration of the transportation system (TC-6) [pts] – maximization. This criterion defines the level of intermodal integration of an urban transportation system that is strictly linked with the provision of smooth and efficient “door – to – door” transportation within the metropolitan area. It is defined as a number of points, assigned by experts, evaluating such integrating solutions as: number and capacity of Park & Ride parking lots, bicycle lockers and bicycle rental points located near key transferring nodes, number of integrated stops/platforms (for buses, tram, light rail) and number of transportation modes and routes available in major transferring nodes, coordination of timetables, number of users of common ticket for all public transportation means.

Availability of parking areas (TC-7) [%] – maximized. This criterion measures the parking policy of the city which assumes that the number of cars parked along the roads and on the sidewalks should be reduced. It is defined as a ratio of the overall capacity of the designated parking areas in the city centre and the total parking capacity of the central zone.

Strategic criteria, corresponding to the City Development Strategy

Investment productivity (SC-1) [mln PLN] – maximized. This criterion evaluates the level of additional city's incomes resulting from economic activities induced by the implementation of particular TP-s and taxes associated with these activities.

Impact on the labour market (SC-2) – maximized. This criterion measures the impact of TP-s on the unemployment rate. It is defined by the number of new jobs generated as a result of the projects implementation in the metropolitan area.

Investment competitiveness (SC-3) [pts] – maximized. This criterion measures the city's attractiveness for a potential local and international investor and the impact of particular TP-s on the city's chances to generate external sources of financial funds. It is defined by the number of points, assigned by experts, based on the estimation of such features as: market potential, taxation policy, existence of special economic zones.

Academic potential (SC-4) [pts] – maximized. This criterion measures the city research and technological potential. It evaluates the impact of specific TP-s on the city Research & Development activities, international academic position, technological innovation, and development of academic institutions. The criterion is defined by the number of points, assigned by experts, based on the evaluation of certain parameters measuring the academic life of the city, including: the number of students per 1000 inhabitants, percentage share of foreign students, number of international scientific conferences and meetings organized in the city, the position of local academic institutions in the international rankings.

Social attractiveness (SC-5) [pts] – maximized. This criterion assesses the impact of particular TP-s on social and cultural position of the city. It is defined by the number of points, assigned by experts, based

on the number of social, cultural, sport and trade events, fairs and promotional meetings organized in the city.

Comfort of life (SC-6) [pts] – maximized. This criterion is an overall measure of satisfaction of the local community associated with living in the considered metropolitan area. It is defined by the number of points, assigned by experts, based on the assessment of such parameters as: average salary, unemployment rate, GDP per capita.

Spatial harmony (SC-7) [%] – maximized. This criterion measures the impact of particular TP-s on the general land – use plan of the metropolitan area and the consistency of the proposed TP-s with this plan. It is defined as a percentage share of the area of specific TP-s which is concordant with the area allocated for this TP-s in a local land use plan.

Image of the city (SC-8) [pts] – maximized. This criterion evaluates national and international reputation of the city, its popularity and competitive position. It measures the impact of TP-s on the promotional image of the metropolitan area. The criterion is defined by the number of points assigned by experts based on the estimation of such characteristics as: percentage share of inhabitants with a university degree, position of the city in different rankings and competitions, presence in media, tourist catalogues and guidebooks, participation in international events (fair), recognition by international institutions, etc.

Economical balance of the metropolitan area (SC-9) – maximized. This criterion evaluates the economic fairness of different regions and zones within the metropolitan area. It is defined as the ratio of the GDP per capita for an average inhabitant of the metropolitan area (except the central zone) and the GDP per capita for an average inhabitant of the core city (central zone).

Level of metropolitan integration (SC-10) [pts] – maximized. This criterion evaluates organizational, social and infrastructural integration of the metropolitan area and the impact of TP-s on these characteristics. It is defined by the number of points, assigned by experts, based on the evaluation of such elements as: number of common metropolitan initiatives, number of administrative districts participating in the metropolitan union, total budget generated by different administrative districts for various metropolitan activities, number of administrative districts supporting common organization of the public metropolitan transportation.

Source: Own study.

3. Research Methodology

The methodological pillars of the presented research are such fields as, Operations Research (Hillier and Lieberman, 2001) and Multiple Criteria Decision Making/Aiding (Figueira *et al.*, 2005; Zak, 2011). Both theories have been combined and appropriately customized to solve the considered decision problem and construct the original methodology of HMLMCE of TP-s.

Operations Research (Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013) can be classified as an interdisciplinary field of knowledge located at the boundaries of such areas as: mathematics, probability theory and statistics, computer science, economics and management, engineering and physical sciences, behavioural sciences. It is the area that conducts comprehensive “research on operations” and provides a variety of quantitative tools and methods that help the Decision Maker (DM) to make rational decisions.

Operations Research techniques have been applied extensively by researchers, managers, analysts, and engineers to solve complex decision problems that arise in different organizations, business units and systems. Operations Research, as a field of knowledge, focuses its efforts on conducting a comprehensive analysis of a certain decision situation, constructing its mathematical description (mathematical model) and finally finding an optimal solution to the decision problem faced, using appropriate computer-based, quantitative, analytical methods and tools.

The classical, state-of-the-art Operations Research methods include, linear and non-linear programming procedures, transportation and assignment algorithms, network optimization methods, integer and dynamic programming techniques, metaheuristic algorithms, game theory and decision analysis tools, simulation, and Markov Chains methods, queuing and inventory theory - based procedures. All these techniques are applied in such situations in which planning, control, and coordination of various operations (activities) is required.

Operations Research attempts to allocate scarce resources (labor, cash, machines and equipment, facilities, ground, and space, etc.) to competing operations / activities in an optimal manner. Thus, it searches for certain solutions that optimize a single objective function. The area of application of Operations Research is widespread and includes manufacturing, transportation and logistics, construction, telecommunication, financial planning and banking, health care and public services, the military, and utilities, to mention just a few.

Multiple Criteria Decision Making/Aiding (MCDM/A) (Żak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013) is a field of study that originates in Operations Research (Hillier and Liebermann, 2001) and thus its nature is like the profile and overall approach applied in Operations Research. Similarly, to OR, MCDM/A attempts to equip the DM in a set of tools and methods that help him or her to solve complex decision problems. At the same time, MCDM/A, as opposed to OR, 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 considered (Vincke, 1992).

The major components of the multiple criteria decision problem, i.e., 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 (Żak, 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 – min or maximized – max) 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.

MCDM/A is a field, which aims at giving the DM different tools, methods and algorithms that enable him/her to advance in solving the above defined multiple criteria decision problems. 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). Decision-maker defines the objectives, expresses preferences, and finally evaluates the solution obtained.

The analyst is responsible for the decision support process. 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 process of solving a multiple objective decision problem is based on the application of computerized tools and methods. Those methods are usually classified as follows (Figueira *et al.*, 2005):

- methods of the American inspiration, based on the utility function e.g., AHP, UTA,
- methods originated in Europe, based on the outranking relation (e.g., Electre III/IV methods, Promethee I and II, Oreste,
- interactive methods e.g., GDF, SWT, Steuer, STEM, VIG.

Based on the principles of OR and MCDM/A, in this paper the following steps / phases, constituting the traditional stages of solving a decision problem have been carried out (Zak, Fierek, Kruszynski, and Zmuda-Trzebiatowski, 2013):

1. Identification and verbal description of the decision problem;
2. Construction of the specific mathematical decision model (data, variants/ solutions, consistent family of criteria, constraints, critical conditions at each level of the hierarchy; construction of evaluation matrices, building the DM's preference model);
3. Application of the AHP method as the most appropriate tool to solve the considered decision problem; computational experiments carried out at each level of the hierarchy resulting in the generation of the intermediate rankings;
4. Aggregation of four intermediate rankings associated with four major groups of TP-s into the one joint ranking at the bottom level;
5. Aggregation of rankings from different levels into the one final ranking;
6. Selection of the most desired, compromise solution;
7. Sensitivity analysis.

4. Computational Experiments

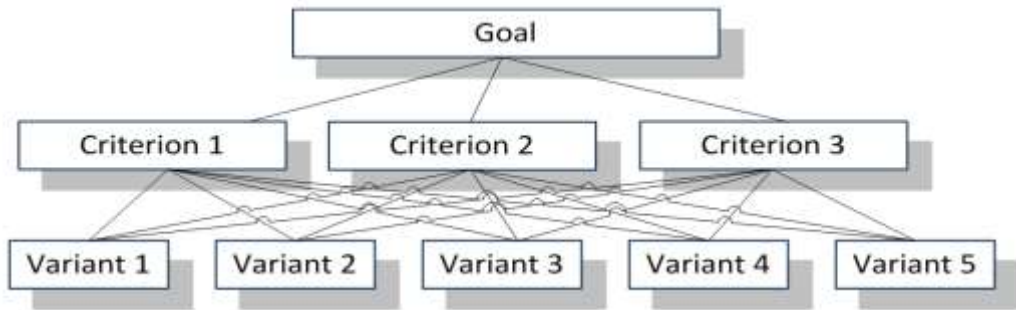
4.1 The Applied Computational Method

The AHP (Analytic Hierarchy Process) method constitutes the computational tool and the basis for the proposed "HMLMCE of TP-s" paradigm. It is a multiple objective ranking procedure, proposed by Saaty (1980), focused on the hierarchical analysis of the decision problem. Due to the fact that the Authors proposed in this paper, the hierarchical structure of goals (described in a previous section), they define the hierarchy of the decision problem as a sub-hierarchy (Figure 2).

The method is based on the multi-attribute utility theory (Keeney, Raiffa, and Mayer, 1993) and allows to rank a finite set of variants A . Through the definition of the overall objective, evaluation criteria, sub-criteria and variants the method constructs the sub-hierarchy of the decision problem. On each level of the sub-hierarchy, based on the pairwise 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).

Figure 2. Sub-hierarchy of the decision problem



Source: Own study.

The algorithm of the AHP method focuses on finding a solution for a, so-called, eigenvalue problem (Saaty, 1980) on each level of the sub-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 sub-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.

The important element of the AHP algorithm is the investigation of the consistency level of matrices of relative weights w_r on each level of sub-hierarchy. Through the calculation of a, so-called, consistency index CI one can measure how consistent is the preferential information given by the DM. If the value of CI is close to 0 the preferential information given by the DM is almost perfect. The acceptable level of CI is below 0,1.

4.2 Computational Tests: Case Study Analysis

Computational tests have been performed along the principles described in section 3. Seven staged have been applied as a solution procedure of the considered decision problem. 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 (see section 2“). This phase has also involved the construction of the evaluation matrix – presented in Table 4. The matrix includes numerical evaluations of all variants (TP-s) on all criteria (operational, tactical, strategic).

Table 4. Evaluation matrix for the compared variants – TP-s at each level of hierarchy

Transportation project	Operational Criteria								Tactical Criteria							Strategic Criteria													
	OC-PrT-1 [min PLU]	OC-PrT-2 [%]	OC-PrT-3 [%]	OC-PrT-4 [min]	OC-PrT-5 [jobs]	OC-PrT-6 [%]	OC-PrT-7 [jobs]	OC-PrT-8 [jobs]	TC-1 [PLU]	TC-2 [%]	TC-3 [min]	TC-4 [jobs]	TC-5 [%]	TC-6 [jobs]	TC-7 [%]	SC-1 [min PLU]	SC-2 [number of new employment]	SC-3 [jobs]	SC-4 [jobs]	SC-5 [jobs]	SC-6 [jobs]	SC-7 [%]	SC-8 [jobs]	SC-9	SC-10 [jobs]				
PrT-1	55,2	6	14	9,1	7	32,0	3	6	51900	15	9,1	6	31,5	7	32	7,0	5	5	0,0	3,0	2,6	0	0	2,20	1,1				
PrT-2	942,0	5	3	2,5	7	31,0	6	4	101900	8	2,5	4	29,7	3	32	500,0	256	4	0,0	2,1	2,3	50	0	2,11	2,1				
PrT-3	583,0	8	4	3,4	7	33,0	7	3	139400	5	3,4	3	30,7	5	32	50,0	14	4	0,0	2,4	2,0	100	0	2,19	3,4				
PrT-4	1910,0	12	35	10,3	3	45,0	7	7	226900	22	10,3	7	26,3	5	32	2024,0	1458	7	0,0	3,8	7,8	80	0	2,13	8,2				
PrT-5	302,0	6	1	8,4	3	36,0	8	9	101900	3	8,4	9	29,0	5	32	29,0	35	4	0,0	2,7	3,9	100	0	2,12	6,3				
PrT-6	70,0	4	2	2,4	1	36,5	6	3	51900	1	1,3	3	28,8	2	32	8,0	3	3	0,0	1,5	3,0	0	0	2,18	2,4				
PrT-7	200,0	5	1	4,5	4	37,9	9	7	76900	0	3,5	7	29,8	9	32	120,0	150	5	0,0	3,5	7,4	100	0	2,12	4,3				
Transportation project	OC-PuT-1 [jobs PLU]	OC-PuT-2 [%]	OC-PuT-3 [min]	OC-PuT-4 [%]	OC-PuT-5 [jobs]	OC-PuT-6 [min/h]	OC-PuT-7 [min]	OC-PuT-8 [jobs]	OC-PuT-9 [jobs]	OC-PuT-10 [jobs]	OC-PuT-11 [jobs]																		
PuT-1	250,0	1	7,2	58	3	23,0	14,5	3	3	3	2	51900	0	0,0	3	30,8	7	32	15,0	112	5	0,0	1,3	4,3	100	0	2,11	0,0	
PuT-2	110,0	5	6,9	59	3	24,0	14	4	6	2	6	51900	5	8,9	2	39,6	3	32	8,0	63	1	0,0	3,7	5,5	0	0	2,11	3,4	
PuT-3	34,0	-2	7,1	58	3	23,5	14,2	6	7	1	5	51900	0	1,4	1	31,4	9	32	20,0	8	0	0,0	1,5	2,5	30	0	2,14	1,5	
PuT-4	250,0	11	7,0	60	5	24,0	13,8	6	7	5	7	51900	15	9,2	5	39,2	9	32	10,0	200	3	0,0	2,8	5,0	70	0	2,10	5,8	
Transportation project	OC-MN-1 [min PLU]	OC-MN-2 [%]	OC-MN-3 [jobs]	OC-MN-4 [min]	OC-MN-5 [jobs]	OC-MN-6 [jobs]	OC-MN-7 [jobs]																						
MN-1	2,6	-5	6	72	2	5							0	0	1,3	6	34,3	3	32	0,9	0	1	0,3	0,0	1,0	0	0	2,13	2,3
MN-2	0,4	-5	5	30	1	7							0	0	1,3	10	34,3	3	32	0,1	0	1	0,2	0,0	1,2	0	0	2,16	2,3
MN-3	2,1	-5	7	99	8	4							0	0	1	7	34,3	8	32	2,3	2	0	0,0	0,0	1,0	0	0	2,14	2,1
MN-4	2,8	-5	8	28	4	8							0	0	0,3	8	34,3	8	32	2,1	3	1	0,0	0,0	1,0	0	0	2,17	3,5
Transportation project	OC-IT-1 [min PLU]	OC-IT-2 [%]	OC-IT-3 [jobs]	OC-IT-4 [jobs]	OC-IT-5 [jobs]	OC-IT-6 [min]																							
IT-1	14,0	5	3	3	4	3							0	0	0,3	2	34,9	6	45	9,0	16	0	0,0	5,2	1,0	0	0	2,18	5,5
IT-2	14,0	3	2	7	2	1							25000	0	7,1	3	39,5	9	32	8,6	164	0	0,5	5,6	2,5	100	0	2,18	10,0
IT-3	10,0	3	3	2	6	5							0	0	0,3	2	34,5	7	51	1,3	55	0	0,2	5,1	1,0	100	0	2,11	5,5

Source: Own study.

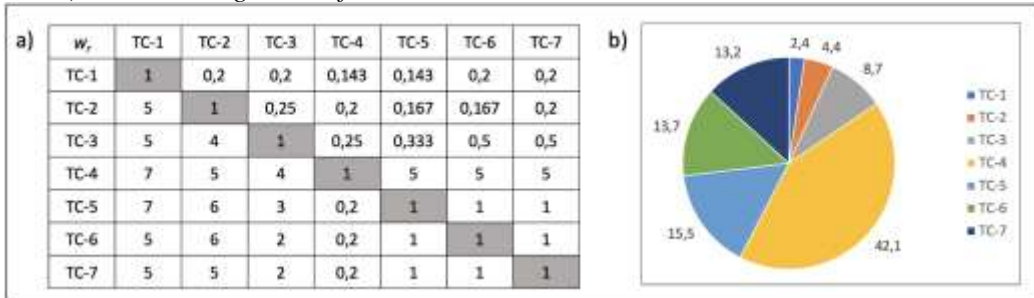
In the second phase, based on the questioner survey and interviews the preferences of the DM and stakeholders have been recognized and then transformed into the model of preference characteristic for the AHP method. The model of the DM's preferences is based on the relative weights w_r representing the strengths of elements in the pairwise comparison of criteria and variants. As described in the previous section, the relative weights w_r are defined as numbers from 1 to 9 and their inverses. In the analysed case this comparison is carried out on each level of sub-hierarchy (criteria, variants) and hierarchy (operational, tactical, and strategic levels). The example of pairwise comparison of tactical criteria is presented in figure 3a. Due to the complex structure of the analysed decision situation, the number of pairwise comparisons was substantial, including:

- 401 pairwise comparisons (113 comparisons of criteria and 288 comparisons of variants), on the operational level,
- 1092 pairwise comparisons (21 comparisons of criteria and 1071 comparisons of variants), on the tactical level,
- 1575 pairwise comparisons (45 comparisons of criteria and 1530 comparisons of variants) on the strategic level.

In the next phase the consistency of the preferential information provided by the DM has been checked. The consistency indexes CI for each level of sub-hierarchy and hierarchy

have been calculated. The values of *CI* have ranged from 0 to 0,09, which means that the preferential information had been accurately defined.

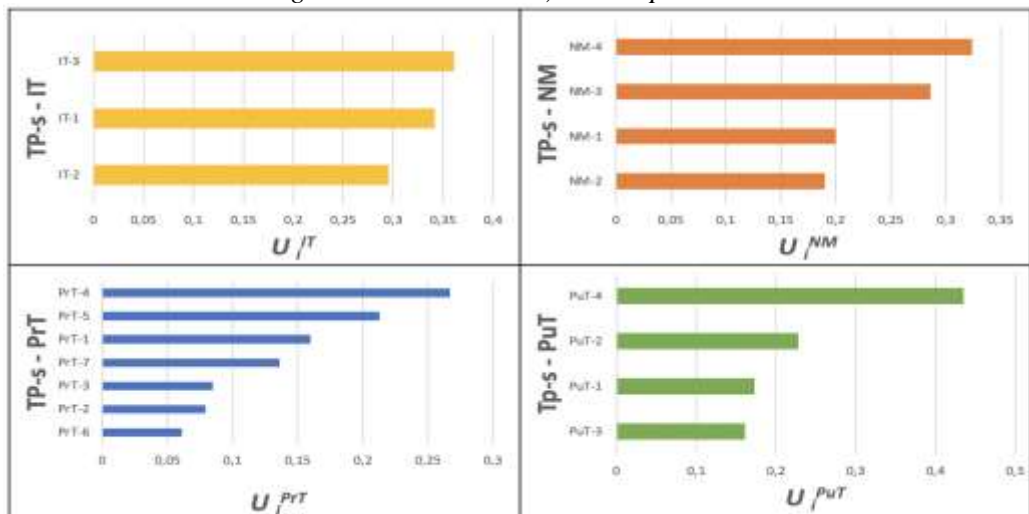
Figure 3. Results of pairwise comparison of tactical criteria – a) relative weights w_r and b) absolute weights w_a of the tactical criteria



Source: Own study.

In the next phase of the computational experiment a set of vectors containing normalized, absolute values of weights w_a for criteria and variants have been generated. The exemplary results of these computations i.e., the ranking of tactical criteria for TP-s from all classes in the form of above-mentioned vectors (pie chart), is presented on figure 3b. The sum of the elements of the vector is 1 (100%). The strength of each element is represented by the value of its absolute weight w_a . The most important criteria (the largest values of absolute weights w_a) in the considered set are TC-4 (safety and security) – with its $w_a=42,1\%$ and TC-5 (share of public transportation in the modal split) – featured by $w_a=15,5\%$. The least important criteria (the lowest value of absolute weights) are TC-1 (transportation costs savings) – with its $w_a=2,4\%$ and TC-2 (accessibility of the transportation system) featured by $w_a=4,4\%$.

Figure 4. The rankings of each group of TP-s (Private TP-s, Public TP-s, Non – Motorized TP-s and Integration oriented TP-s) at the operational level

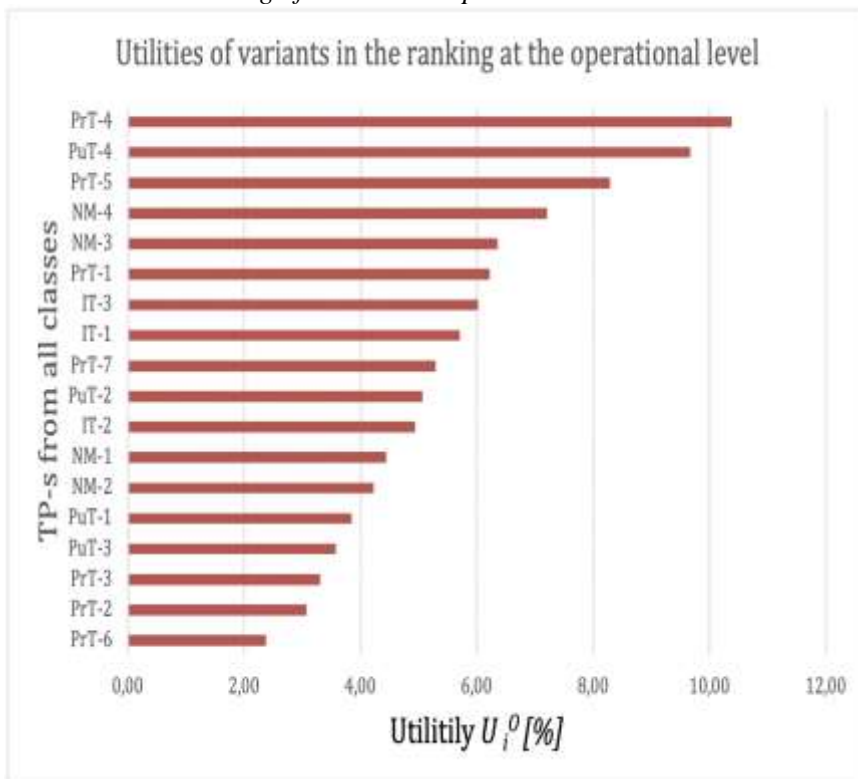


Source: Own study.

In the next phase of the AHP method computational procedure the absolute weights w_a are aggregated by an additive utility function and the utility of each variant $i - U_i$ is calculated. The utility U_i defines the position of each variant in the final ranking. Based on the computation of the utilities of TP-s the intermediate rankings of projects (variants) at each level of the hierarchy have been generated. Four rankings, corresponding to the evaluation of TP-s in respective classes have been constructed at the operational level (Figure 4) and then aggregated into one operational ranking (Figure 5).

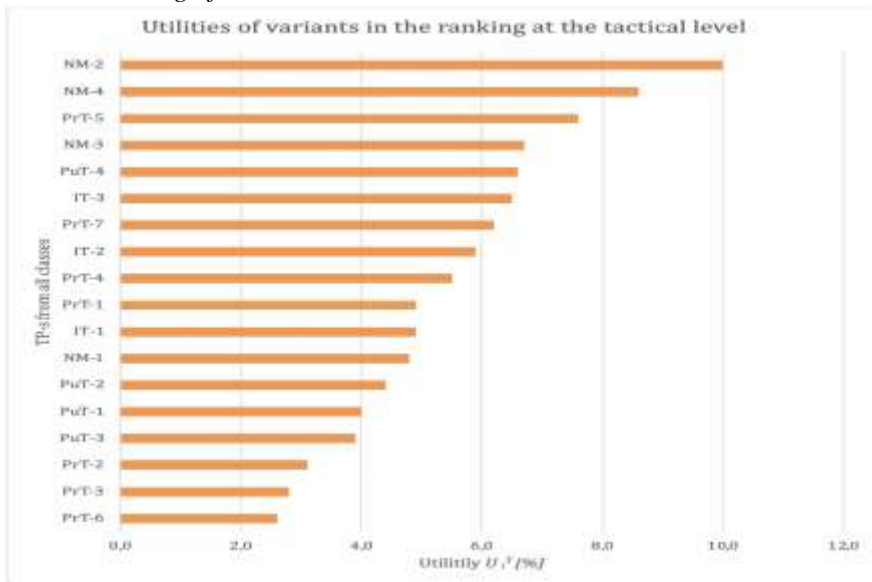
Due to the fact, that at the operational level, the number of considered variants in each ranking differs, it was necessary to aggregate all the rankings of this level into one common graph (Figure 5). The aggregation of the rankings was based on the normalization of utilities of each TP-s (Private TP-s – U_i^{PrT} , Public TP-s – U_i^{PuT} , Non-motorized TP-s – U_i^{NM} , Integration oriented TP-s – U_i^{IT}). The details of this aggregation can be found in the works of Kruszyński and Żak (2015), Zak and Kruszynski, (2015), Kruszynski, (2020). Similar rankings of all TP-s for tactical (Figure 6) and strategic levels (Figure 7) have been also produced.

Figure 5. The overall ranking of TP-s at the operational level



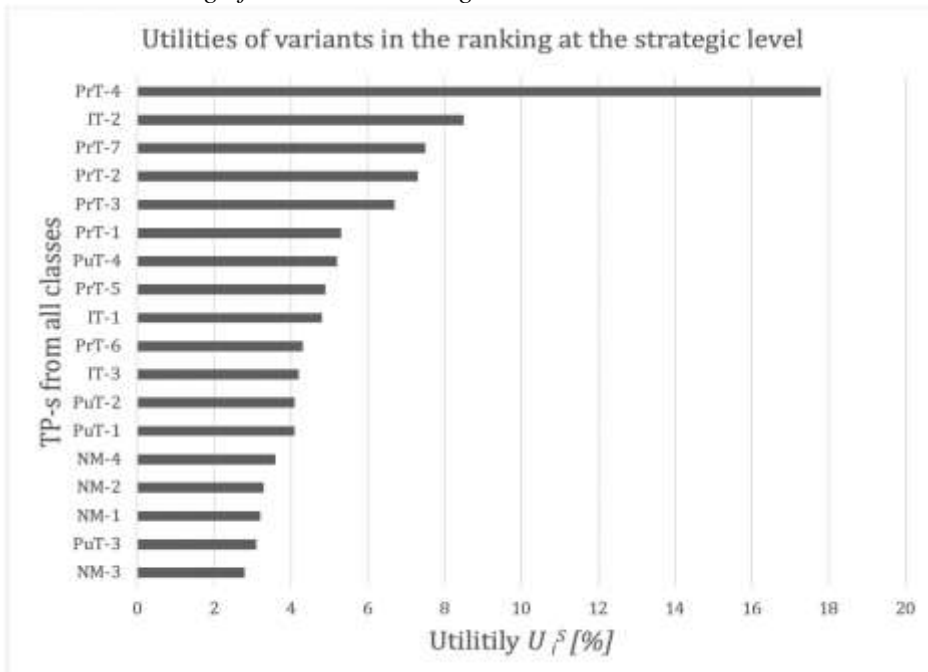
Source: Own study.

Figure 6. The ranking of TP-s at the tactical level



Source: Own study.

Figure 7. The ranking of TP-s at the strategic level



Source: Own study.

In the next step all 3 rankings generated at the operational, tactical, and strategic levels have been combined by the aggregation procedure proposed in formula 1.

$$U_i = \frac{U_i^O \cdot w_a^O + U_i^T \cdot w_a^T + U_i^S \cdot w_a^S}{w_a^O + w_a^T + w_a^S} \quad (1)$$

where:

w_a^O, w_a^T, w_a^S – absolute weights w_a of the operational (O), tactical (T) and strategic (S) levels of hierarchy, obtained with the application of the AHP method based on the relative weights w_r expressed by the DM (pair-wise comparisons of the importance of the considered levels).

U_i^O, U_i^T, U_i^S – utilities of the TP-s corresponding to their overall evaluations at the operational, tactical, and strategic levels, respectively.

The last stage of the computational experiment, i.e., the sensitivity analysis was performed using a scenario approach. Three scenarios were proposed in which different weights of rankings were adopted using the expert method (Delphi) and the fourth scenario, in which the weights of the operational, tactical, and strategic criteria were calculated using the AHP method (Table 5 and Table 6).

Table 5. Weights of rankings (O – operational, T – tactical and S – strategic) for the four scenarios

Scenarios	Weights of rankings:		
	w_a^O	w_a^T	w_a^S
Scenario I	0,33	0,33	0,33
Scenario II	0,20	0,30	0,50
Scenario III	0,50	0,30	0,20
Scenario IV	0,122	0,6483	0,2297

Source: Own study.

Based on this aggregation the final ranking of all TP-s for all four scenarios has been generated. This ranking in the graphical form with the computed utilities of all variants is presented in Figure 8.

The final ranking of 18 TP-s from the best to the worst, with four alternative scenarios is the overall output of the proposed approach. It clearly indicates the most desirable sequence of TP-s to be carried out in a certain metropolitan area to satisfy the city’s transportation policy and strategy. It also indicates how the final ranking changes with the alternation of the preferences of the DM, corresponding to the weights of the intermediate rankings (operational, tactical, and strategic).

As one can see the position of the TP-s somehow depends on the considered scenarios. However, the absolute leader and winner of the classification is project PrT-4, regardless the applied scenario. Variant PrT-4 substantially outranks all other variants with its utility between $U_i = 9\%$ and $U_i = 13\%$, depending on the scenario. This means that TP – PrT-4 – representing the construction of a new arterial road, being a part of an inner ring in the highly congested area has a critical meaning for the city (metropolitan area).

Table 6. The final output of the computational tests – the utilities – U_i of all 18 TP-s for different scenarios

TP-s	U_i^0 [%]	U_i^T [%]	U_i^S [%]	U_i [%]			
				Scenario I	Scenario II	Scenario III	Scenario IV
IT-1	5,7	4,9	4,8	5,1	5,0	5,3	5,0
IT-2	4,9	5,9	8,5	6,4	7,0	5,9	6,4
IT-3	6,0	6,5	4,2	5,5	5,3	5,8	5,9
NM-1	4,4	4,8	3,2	4,1	3,9	4,3	4,4
NM-2	4,2	10,0	3,3	5,8	5,5	5,8	7,8
NM-3	6,4	6,7	2,8	5,2	4,7	5,8	5,8
NM-4	7,2	8,6	3,6	6,4	5,8	6,9	7,3
PrT-1	6,2	4,9	5,3	5,4	5,4	5,6	5,2
PrT-2	3,1	3,1	7,3	4,4	5,2	3,9	4,1
PrT-3	3,3	2,8	6,7	4,2	4,9	3,8	3,8
PrT-4	10,4	5,5	17,8	11,1	12,6	10,4	8,9
PrT-5	8,3	7,6	4,9	6,9	6,4	7,4	7,1
PrT-6	2,4	2,6	4,3	3,1	3,4	2,8	3,0
PrT-7	5,3	6,2	7,5	6,3	6,7	6,0	6,4
PuT-1	3,8	4,0	4,1	3,9	4,0	3,9	4,0
PuT-2	5,1	4,4	4,1	4,5	4,4	4,7	4,4
PuT-3	3,6	3,9	3,1	3,5	3,4	3,6	3,7
PuT-4	9,7	6,6	5,2	7,1	6,5	7,9	6,7

Source: Own study.

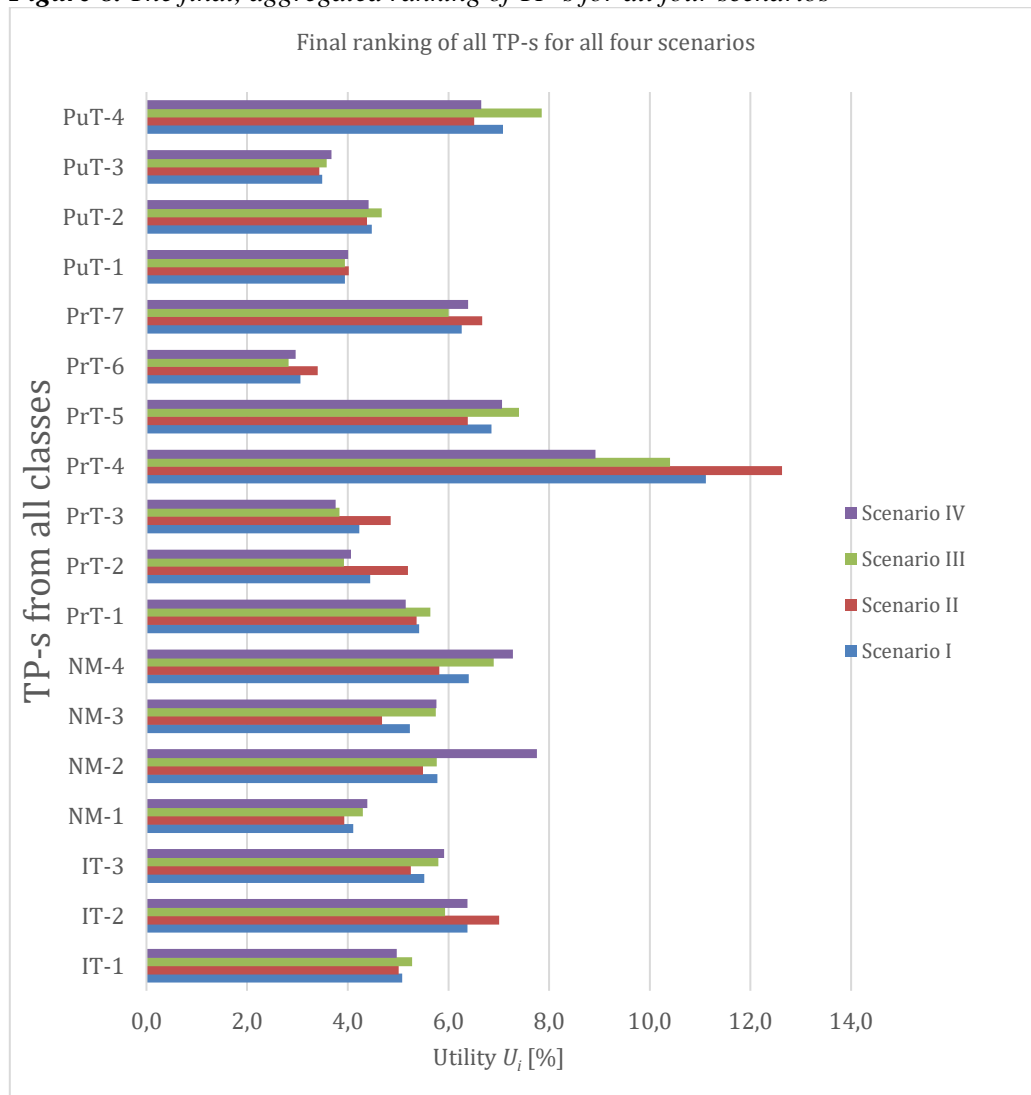
As indicated by the final ranking PrT-4 has the largest impact on the fulfilment of the city goals and, thus, should be included in the annual municipal budget with the highest priority and implemented in the first place in the considered metropolitan area.

In addition to project PrT-4 the leaders of the final ranking are the following candidates: project PuT-4 – fleet replacement in the public transportation system (scenario I and III), project IT-2 – construction of a new P&R parking lot (scenario II) and projects NM-2 - and NM-4 – construction of a new parking lot for 25 bikes and development of a new pedestrian underpass (scenario IV).

Project PuT-4 with its utility values between $U_i = 6\%$ and $U_i = 8\%$ is placed high in the rankings of two scenarios: I and III. This project focused on the replacement of 40 new, low-floor trams, and backup equipment for them has a great importance for the public transportation system and the standard of the passenger's service. As a result, it has a great impact on the fulfilment of transportation policy and city goals (high standard of life; comfortable mobility). A similar role plays project IT-2 that ensures the integration of different transportation modes in the urban transportation system. Its utility between $U_i = 6\%$ and $U_i = 7\%$ indicates its importance for the metropolitan area. This project focused on the development of a new P&R parking lot should substantially enhance the

integration of private and public transportation and the enhancement of sustainable transportation. These principles belong to the major goals of the city.

Figure 8. The final, aggregated ranking of TP-s for all four scenarios



Source: Own study.

Two remaining projects NM-2 and NM-4, belonging to the projects improving non-motorized mobility are featured by utilities between $U_i = 6\%$ and $U_i = 8\%$, depending on the scenario. These projects are focused on the development of transportation infrastructure for bikers and pedestrians. Both projects tend to change the behaviour of travellers and their way of moving in the city. Thus, they are also important to satisfy the city goals and critical transportation policy objectives.

It is worth mentioning that the values of utilities of variants PuT-4, IT-2, NM-2 and NM-4 fall in a similar range (6%- 8%). This means that their importance for the city is similar. All these projects satisfy the city goals in approximately same degree. Thus, they should be considered as equally important, alternative candidates for inclusion in the annual municipal budget and be implemented in the metropolitan area with the same, high priority.

Three variants located at the bottom of the ranking (Pr-T-6, PuT-3, PuT-1) are featured by low utilities U_i between 2% and 4%. They are focused on implementing different solutions for public and private urban transportation system, including. the upgrade of the tramway railroad (PuT-3), development of a new tramway depot (shed) – PuT-1 and construction of a new arterial road – PrT-6. Low utilities of these variants mean that these projects have the lowest impact on the city's objectives. Consequently, the DM may consider these TP-s as the candidates for being excluded from the budget.

5. Conclusions

The paper presents an original methodology of evaluating and ranking various transportation projects (TP-s) considered for implementation in the urban transportation system. The projects are evaluated with the application of Multiple Criteria Decision Making / Aiding methodology. The authors construct the hierarchical, multiple level structure of goals and investigate how the considered TP-s satisfy these goals. They measure the impact of particular TP-s on the operational, tactical and strategic objectives of the city (metropolitan area). As a result, different categories of TP-s are ranked based on their evaluation with the application of TP-s oriented criteria, transportation policy tactical goals and metropolitan area strategic goals.

In the computational phase the authors apply the AHP method and accommodate its hierarchical structure to specific features of the considered decision problem. It is proved that the proposed procedure, labeled a hierarchical – multiple level, multiple criteria evaluation (HMULEMCE) method of TP-s can support efficient development of the municipal budget of a certain city. It can assist the DM – City Board in evaluating the overall utility of particular TP-s for the city and selecting the most desirable variants for their inclusion in the city's annual budget.

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 the computational phase 54 matrices of relative weights w_r have been constructed and computational handled which resulted in the construction of 54 vectors of absolute weights w_a . At this level more than 3000 pair-wise comparisons were required to carry out the experiment. In addition, 54 values of consistency indexes have been computed and 7 intermediate rankings of TP-s have been generated to construct 1 final graph.

The following elements constitute an original output of this research:

- Formulation of the multiple level, multiple criteria 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.
- Developing an original solution procedure of the hierarchical - multiple level, multiple criteria decision problem based on the application and customization of the AHP method combined with the utilization of the rankings' aggregation method.
- 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 in any urban transportation system for assessment of transportation projects. 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).

Further research will be conducted in the following directions:

- The application of different MCDM/A methods to the evaluation of TP-s, especially those based on the outranking relation (e.g., Electre method) and comparing the generated results. Another formula of aggregating intermediate results may be required to use the outranking methods to be solving a multiple level, multiple criteria decision problem.
- Further research on the definition of criteria correlated with various divisions and specific character of the considered TP-s. Possible redefinitions of criteria and their scopes. This stream of research may be particularly important if the number of TP-s will increase.
- The application of the cost – benefit analysis (CBA) to the evaluation and ranking of the TP-s. In the author's opinion the comparison of CBA and MCA methodologies should prove certain advantages of the latter.

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