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Katarzyna SOLECKA
Cracow University of Technology, Department of Transportation Systems
Warszawska 24, 31155 Cracow, Poland
Corresponding author. E-mail: ksolecka@pk.edu.pl

ELECTRE III METHOD IN ASSESSMENT OF VARIANTS OF INTEGRATED URBAN PUBLIC TRANSPORT SYSTEM IN CRACOW

Summary. There is a lot of methods which are currently used for assessment of urban public transport system development and operation e.g. economic analysis, mostly Cost-Benefit Analysis – CBA, Cost-Effectiveness Analysis - CEA, hybrid methods, measurement methods (survey e.g. among passengers and measurement of traffic volume, vehicles capacity etc.), and multicriteria decision aiding methods (multicriteria analysis). The main aim of multicriteria analysis is the choice of the most desirable solution from among alternative variants according to different criteria which are difficult to compare against one another. There are several multicriteria methods for assessment of urban public transport system development and operation, e.g. AHP, ANP, Electre, Promethee, Oreste. The paper presents an application of one of the most popular variant ranking methods – Electre III method. The algorithm of Electre III method usage is presented in detail and then its application for assessment of variants of urban public transport system integration in Cracow is shown. The final ranking of eight variants of integration of urban public transport system in Cracow (from the best to the worst variant) was drawn up with the application of the Electre III method. For assessment purposes 10 criteria were adopted: economical, technical, environmental, and social; they form a consistent criteria family. The problem was analyzed with taking into account different points of view: city authorities, public transport operators, city units responsible for transport management, passengers and others users. Separate models of preferences for all stakeholders were created.

METODA ELECTRE III W OCENIE WARIANTÓW ZINTEGROWANEGO SYSTEMU MIEJSKIEGO TRANSPORTU PUBLICZNEGO W KRAKOWIE

Streszczenie. Obecnie do oceny rozwoju i funkcjonowania systemu miejskiego transportu publicznego stosuje się wiele metod m.in. analiz ekonomicznych – w tym w szczególności analizę kosztów i korzyści (ang. Cost-Benefit Analysis – CBA), CEA, Analizę Efektywności Kosztowej, metody hybrydowe, metody pomiarowe (badania ankietowe np. wśród pasażerów oraz pomiary np. natężeń ruchu, napełnień pojazdów itp.), a także metody wielokryterialnego wspomagania decyzji (analizy wielokryterialnej). Celem ostatniej grupy – analiz wielokryterialnych – jest wybór rozwiązania najbardziej pożądanego z wariantowych rozwiązań według różnych kryteriów trudno porównywanych ze sobą. Istnieje wiele metod wielokryterialnych służących ocenie rozwoju i funkcjonowania systemu miejskiego transportu publicznego, np. AHP, ANP, Electre, Promethee, Oreste. W artykule przedstawiono zastosowanie jednej z popularnych metod szeregowania wariantów – metodę Electre III. Szczegółowo przedstawiono algorytm postępowania metody Electre III, a następnie jej zastosowanie do oceny wariantów zintegrowanego systemu miejskiego transportu publicznego (ZSMTP) w Krakowie. Za pomocą metody Electre III dokonano uszeregowania końcowego 8 wariantów ZSMTP od najlepszego do najgorszego. Do oceny przyjęto zestaw 10 kryteriów o charakterze ekonomicznym, technicznym, środowiskowym oraz społecznym, tworzących spójną rodzinę kryteriów. Problem rozpatrywano, uwzględniając różne punkty widzenia, tj. władz miasta, operatorów miejskiego transportu publicznego, zarządów transportu publicznego, pasażerów oraz innych uczestników ruchu. Dla wszystkich zainteresownych podmiotów stworzono oddzielne modele preferencji.

1. INTRODUCTION

Based on a review of Polish and foreign literature, it is possible to conclude that in urban public transport system assessment the following methods are most frequently used: [7, 9, 13 - 17, 26, 27], economic analyses – in particular the Cost-Benefit Analysis (CBA), Cost Effectiveness Analysis (CEA), as well as multicriteria decision aiding methods (multicriteria analysis). The third group of analyses aims at selection of the most desired solution from variant solutions according to diverse and difficult to compare criteria. The multi-criteria analysis is aimed to facilitate taking into account in the frames of assessment of urban transport operation these goals of the decision-maker which sometimes cannot be included within the financial and economic analysis, e.g. such as a social aspect [23]. Approaching the economic assessment of investments into transport by conducting an analysis of social costs and benefits frequently proves to be ineffective since the evaluation of the costs and benefits (e.g. related to improvement of the environment quality) is difficult and ambiguous. In a situation where the social costs are higher than social benefits, in keeping with the CBA methodology, given transport investment plans should be abandoned. However, in face of the need for specific standards to be met (e.g. legal standards concerning environmental protection), such plans must be carried through. In such a case, conducting the cost/benefit analysis has little sense, it is only important to select from among the existing investment completion possibilities the one guaranteeing that a specific effect will be achieved at the lowest costs possible. It must be emphasised that the CBA analysis does not extend to effects, which are not capitalised. The assessment of public transport systems frequently takes into account both social and ecological consequences, which at times are difficult to translate into a monetary form. Multicriteria analysis permits for the assessment utilising quantitative and qualitative criteria, not necessarily in the monetary form. The criteria measurement method may be subjective [7]. Taking into account the considerations above, the multicriteria analysis appears the most appropriate method for the assessment of transport investments. The literature of the subject [1, 5, 6] provides also other methods used in construction and assessment of public transport systems, e.g. hybrid methods, that is a combination of several methods (e.g. application of macroscopic and mesoscopic traffic simulation methods in variant construction) or the urban public transport system assessment method in the form of measurements (polls and surveys, e.g. among passengers and measurements of traffic volume, vehicle capacity, passenger exchange time, etc.).

Multicriteria Decision Aiding (MCDA) is a field of science originating from operations research, interchangeably referred to as the multicriteria analysis or multicriteria decision making [24, 27, 28]. In the study by R. Słowiński [21] and M. Zeleny [28], the multicriteria decision aiding is defined as making decisions in the presence of multiple criteria/objectives, whereas in the work of P. Vincke [27] as solving of complex decision problems which must take into account multiple, frequently contradictory points of view. MCDA as a scientific discipline has undergone a dynamic development in recent years [11, 12, 29]. It is aimed at equipping the decision-maker with tools able to facilitate solving complex decision problems which must take into account multiple, frequently contradictory points of view. The MCDA methodology precisely identifies the main participants of the decision-making process [4, 11, 12, 18, 19], i.e. the decision-maker, the analyst, and other entities interested in solving a given decision-making problem. In relation to urban public transport, the decision-makers are, for example, local authorities which must take into account interests of multiple entities (interveners); the analyst maybe a transport system specialist/expert and a person equipped with IT know-how whereas interveners are passengers, i.e. clients making use of urban public transport services, public transport operators responsible for the provision of services, urban public transport management board responsible for appropriate administration and organisation of the public transport system, other traffic participants (people/residents who are not passengers of the public transport system, e.g. cyclists).

The most frequently applied classification of multicriteria decision-making (MCDM) problems is the one taking into account their division into [8, 10, 18, 19, 25, 27]:

- Problems of choice (optimisation) where the decision-maker determines a subset of decisions (actions, variants) considered optimal in relation to the criteria family under consideration.
- Problems of ranking (ranking, ordering) where the decision-maker strives to rank variants from the most optimal to the least optimal.
- Problems of classification (sorting) where the decision-maker divides the set of decisions (actions, variant operation) into subsets (classes, categories) in compliance with the adopted norms.

The available literature of the subject holds numerous classifications of MCDA methods. The most popular of these include the one presented by P. Vincke [27] who divided the MCDA methods into three groups: multi attribute utility theory methods, outranking methods, and interactive methods.

The article makes use of one of the variant ranking methods - the Electre III method, belonging to the outranking methods group.

2. ELECTRE III METHOD

The Electre method family consists of: Electre I, Electre IV, Electre Is, Electre TRI, Electre III, and Electre IV. The first three methods are used in aiding multicriteria choice issues, Electre TRI is used for the issues of classification, whereas the last two methods, Electre III and Electre IV, are used in solving multiple-criteria ranking problems.

The Electre III method, created by B. Roy [19], originates from the co-called European school based on the outranking relationship. The Electre III algorithm consists of three stages [29]:

- Constructing assessment matrix and defining decision maker's preferences.
- Building the outranking relation S.
- Utilising outranking relations leading to the generation of the final variant ranking.

Stage I. Constructing assessment matrix and defining the decision-maker's preference model

Stage I commences with defining a consistent criteria family G assessing the variant set A. For all the variants, the values of specific criteria functions are determined. Next, the decision-maker's preference model is built by determining indifference q_i, preference p_i, and veto v_i thresholds as well as criteria weight indexes w_i. Those thresholds determine the preferences range between variants according to individual criterion: equivalent (below q), weak preferences (q and p), strong preference (between p and v) and incomparability (above v). Variants a and b are classified as equivalent if the difference between their assessments $g_i(a)$ and $g_i(b)$ for a particular criterion is so small (less then q), that difference between both variants is impossible to be distinguish by a decision maker. The variant a is less preferred than to variant b if difference between their assessments $g_i(a)$ and $g_i(b)$ for individual criterion (between q and p) is visible for a decision maker, but the decision maker hesitates to recognizes a better variant. Variant a is preferred strongly than variant b if the difference between assessments $g_i(a)$ and $g_i(b)$ for particular criterion is so important that decision maker is convinced about preference one variant over the other. Variants a and b are incomparable if the different between their assessments $g_i(a)$ and $g_i(b)$ so high (higher then v), that the objects cannot be compared according to individual criteria. This feature is typical for Electre III method.

Stage II. Building the outranking relation

In Stage II, for each ordered pair (a,b) the following is computed: concordance index C(a,b) and discordance index D_i(a,b). The outranking relation evaluates a credibility degree, that *a* is least as good as *b* and it is expressioned by the concordance index C(a,b). In turn, measure of the denial of the relationship S(a,b) is discordance index D_i (a,b).

The concordance and discordance indexes are computed as follows [29]:

$$C(a,b) = \frac{1}{W}\sum_{i=1}^{n} w_i \cdot c_i(a,b), where\ W = \sum_{i=1}^{n} w_i \tag{1}$$

where:

w_i – i^{th} criterion weight index,

$c_i(a,b)$ – Concordance index from the point of view of the i^{th} criterion,

In the formula (1), it is assumed that:

$$C(a,b) = \begin{cases} 1\ if\ g_i(a) + q_i(g_i(a)) \geq g_i(b) \\ 0\ if\ g_i(a) + p_i(g_i(a)) \leq g_i(b) \\ a\ linear\ function\ with\ the\ value\ between\ 0\ and\ 1; \end{cases} \tag{2}$$

and

$$D_i(a,b) = \begin{cases} 0\ if g_i(a) + p_i(g_i(a)) \geq g_i(b) \\ 1\ if\ (a) + \mathcal{V}_i(g_i(a)) \leq g_i(b) \\ a\ linear\ function\ with\ the\ value\ between\ 0\ and\ 1 \end{cases} \tag{3}$$

Partial concordance index:

- if g_i(a) is better than g_i(b) or worse, but not by more than indifference threshold q_i, than g_i fully supports the hypothesis that *a* is at least as good as *b*, C(a,b)=1,
- if g_i(a) is worse than g_i(b) by at least preference threshold p_i, than g_i does not confirm hypothesis, that *a* is at least as good as *b* (because *a* is definitely worst than *b*), C(a,b)=0,
- if g_i(a) is worst than g_i(b) by more than indifference threshold q_i, but less than preference threshold p_i, there is not full concordance and fully discordance with the statement, that *a* is at least good as *b* (because *b* is week prefer over *a*), C(a,b)$\in$(0;1),
- if threshold are linear and when is needed to appeal to the thresholds (it means *a* is worse than *b* and we don't know what will be coefficient value), then count it by worse assessment that g_i(a).

Discordance test verifies that there are no criterion on whom a is critically worse than b. Partial discordance index:

- if g_i(a) is worse than g_i(b) about at least as veto threshold v_i, than g_i in full confirm discordance according hypothesis that *a* is at least as good as *b*, D_i(a,b)=1,
- if g_i(a) is better than g_i(b) or worse, but not by more than preference threshold p_i it means to lack of discordance D_i(a,b)=0,
- if g_i(a) is worse than g_i(b) by more than preference threshold p_i, but less than veto threshold v_i, it means that the discordance is a partial, D_i(a,b)$\in$(0;1).

The manner of definition of indexes: concordance ci(a,b) and discordance Di (a, b) in the ELECTRE III method is presented in Figure 1.

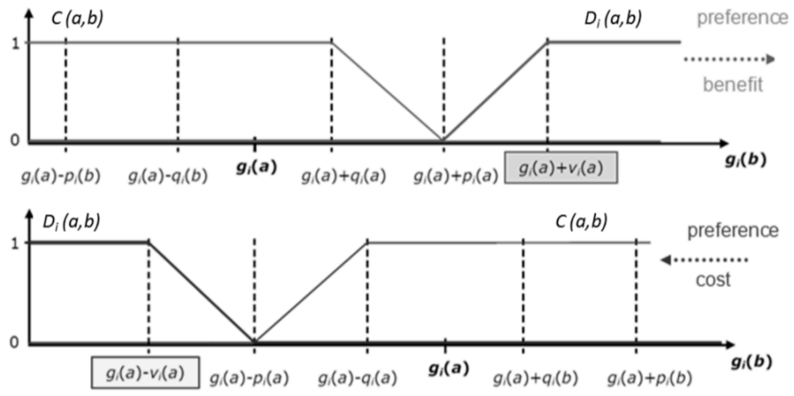


Fig. 1. The manner of defining of indexes: concordance C(a, b) and discordance D_i(a, b) in the ELECTRE III [20] method on the cost/ benefit example

Rys. 1. Sposób definiowania współczynników: zgodności C(a, b) i niezgodności D_i(a, b) w metodzie ELECTRE III [20] na przykładzie kosztu i zysku

The outranking relation defined by the outranking degree S(a,b).

$$S(a,b) = \begin{cases} C(a,b) \; if \; \forall_i \;\; D_i(a,b) \leq C(a,b), \\ C(a,b) \prod_{i \in I(a,b)} \dfrac{1 - D_i(a,b)}{1 - C(a,b)} \end{cases} \tag{4}$$

where: I (a,b) is a set of criteria for which D_i(a,b)>C(a,b). S(a,b) means degree „credibility degree hypothesis, that *a* is higher than *b*".

Stage III. Application of outranking relations

At this stage, two complete pre-orders are obtained, referred to as the ascending (bottom-up) or descending (top-down). This stage is based on the variant ranking algorithm based on the obtained outranking degrees S(a,b). The algorithm is based on the determination of value λ = max, b∈A S(a,b) and the cut-off threshold s(λ). Based thereon, only these variant dyads (a, b) are analysed for which S (a,b) are sufficiently close to λ. This proximity is determined by means of the result λ - s(λ). The qualification coefficient k_w is determined for objects which satisfy this relation, which is the difference between the number of variants, that a individual variant a is higher, and the number of variants by which is surpassed determined of variant. The variant with the highest qualification index value is located at the top in the top-down pre-order. In further order, from among the remaining variants the best one is selected again and it is placed on the subsequent rank in the classification. The procedure is repeated until the variant set is exhausted. The bottom-up ranking is built analogically, but the procedure commences with the worst solution which is placed at the end of the ranking. Further procedure is similar to the one employed in the top-down ranking, whereby in the subsequent iterations always the worst variant is selected from among those remaining to be considered and placed on the subsequent bottom-up ranking positions. The final ranking constitutes the final solution and results from the intersection, i.e. a logical quotient, of both pre-orders. Their intersection produces the final ranking. Variant *a* is classified higher than variant *b* (aPb) if it is better than variant *b* in the top-down pre-order (or in the bottom-up pre-order) and not worse than variant b in the bottom-up pre-order (or in the top-down pre-order). Variant *a* is indifferent from variant *b* (aIb) if variant *a* is indifferent from variant *b* both in the top-down and bottom-up pre-order. Variant *a* is incomparable with variant *b* (aRb) if variant *a* is better than variant *b* in the top-down pre-order (or in the bottom-up pre-order) and worse than variant *b* in the bottom-up pre-order (or in the top-down pre-order). The final pre-order is obtained according to the following principle: the variant which is best by none other (one that is preceded by none other in any of the pre-orders) obtains ranking 1. Ranking 2 is obtained by those variants which are best by ranking 1 variants. As a result, the final variant ranking is created where the following relations may occur between the variants: equivalence (I), outranking (P), reverse outranking (P*) and incomparability (R). The result may be presented in the form of the ranking matrix and/or outranking graph.

3. APPLICATION OF THE ELECTRE III METHOD IN ASSESSMENT OF VARIANTS OF INTEGRATED URBAN PUBLIC TRANSPORT IN CRACOW

3.1. Variants

Seven integrated urban public transport system (IUPTS) variants were created for Cracow to be subsequently submitted to a traffic simulation in the Visum macro-simulation software application. Variants were created on the basis of heuristic (expert) methods and with the use of traffic simulation tools. In the variant construction process, the public transport network principles were adhered to [2, 3]. The variants were constructed on the basis of the new routes, lines of various means of transportation, and by appropriate modelling of tools integrating urban public transport in the traffic macrosimulation software (transfer nodes, shared stops, shared bus-tram lanes, shared tickets, common information, schedule coordination). The proposed integrated urban public transport systems created for Cracow are presented below:

W0 – existing state presenting the current level of public transport integration in Cracow;
W1 – bus and rail. Integration of Light Express City Train (LECT) with bus transport;
W2 – Rail-tram-bus. Integration of the LECT with tram and bus transport;
W3 – Underground railway. Integration of underground railway with the LECT and tram and bus transport;
W4 – Tram and rail. Integration of the LECT with tram transport;
W5 – Tram. Tram transport integration (particularly fast trams [FT]) with bus transport;
W5A – Tram – a W5 variant sub-variant. Integration of tram transport (particularly the fast tram [FT]);
W6 – Two-system tram. Integration of the two-system tram with tram transport.

The above-given variants were in first order distinguished in terms of incidence of tools for integration of urban public transport, introduction of new modes of transport, furthermore, service frequencies were manipulated and transport mode routes were altered. Detailed variant characteristics were presented in K. Solecka's work [22].

As a result of the traffic simulations performed, a number of parameters characterising particular variants was obtained. Variants W0 – W1 are bus-transport oriented variants whereas variants W5, W5A, and W6 are characteristic for a significant advantage of the rail-and-tram transport. According to the parameters obtained from traffic simulation in the Visum software, in terms of the parameters analysed, variant W3 proved to be the best. The average passenger travel speed in the network is the highest while the passengers spend the least time in the network, considering the transport activity in passenger-hours. Also variant W4 obtained very positive results taking into analysis such indicators as: average travel time, average time on public transport vehicles, average time of waiting for a transfer, average initial stop waiting time. The final assessment of the variant selection will be performed based on the consistent criteria family consisting of multiple other assessment parameters which take into account all possible aspects of assessment. Only some of the parameters obtained as a result of traffic simulation will be used in the assessment, therefore all the obtained results may differ significantly.

3.2. IUPTS variant assessment criteria

On the basis of a review of literature on the criteria used in urban public transport assessment and principles to be met by a consistent assessment criteria family, a set of ten criteria was proposed which took into account the interests of the main groups interested in the solution (passengers, operator, public transport management, other traffic participants, authorities of the city which in the problem being considered appear in the role of the decision-maker). These criteria include:

– **Travel time (TT) [min**] – minimised criterion. It secures social requirements of urban public transport passengers, i.e. aimed at reducing the travel time between the starting point and the destination. The criterion takes into account: average time required to reach a stop on foot, average waiting time at the stop, average time spent on public transport vehicles, average transfer time, and average time required to reach destination from the stop on foot.
– **Standard of travel (ST) [-]** – maximised criterion. It takes into account social requirements of urban public transport passengers by guaranteeing the passengers the optimum travel conditions by urban public transport. It determines the percentage share of the travel performed in good and very good conditions during an entire urban public transport travel. This criterion takes into account two, in the opinion of the paper's author, most crucial elements describing the standard of travel, i.e.: share of direct travel (not transfer), share of seated travel, i.e. the number of passengers able to occupy seats on the urban public transport vehicles.
– **Rolling stock utilisation index (RSU) [%]** – maximised criterion. It is a technical criterion allowing to assess rolling stock utilisation effectiveness. It was defined as a quotient of traffic activity performed by passenger-kilometres to maximum traffic activity possible to be realised by urban public transport vehicles in the area subject to analysis.
– **Environmental friendliness (EF) [-]** – maximised criterion. It takes into account requirements related to minimisation of harmful environmental impacts. It determines the level of variability of nitric oxide emissions, sulphur dioxide, carbon oxides, and noise.
– **Urban public transport system integration level (TI) [%]** – maximised criterion. It secures social requirements of urban public transport passengers by guaranteeing them the most convenient travel conditions with taking into account the continuity, time, cost, and comfort of travel. It determines the urban public transport integration level by taking into account a number of relevant tools for integrating urban public transport: integrated transfer nodes, shared stops, availability of uniform, common information for passengers (common information for passengers such as: transport network maps covering all modes of transportation in operation within the area subject to analysis, changing content displays on stops with the common timetable-related information covering all modes of transportation in operation within the area subject to analysis, transfer-related information displayed on stops and on-board), common tariff, coordinated timetables, shared intermodal road sections (e.g. bus-and-tram lanes).
– **Reliability of the urban public transport system (RT) [%]** – maximised criterion. The core of the criterion is to guarantee the lowest unreliability and the highest punctuality being in the interest of the operator, public transport management, and passengers. This criterion was defined as a sum of shares of timely rounds (realised in compliance with timetable) whose value is dependent on the fallibility of public transport vehicles and share of timely rounds dependent on the level of individual vehicle traffic congestion. It is assumed that if any vehicle defect occurs, the round is not taken into account.
– **Safety of Travel (ST) [-]** – maximised criterion. This criterion was expressed by means of the number of points awarded by experts characterising the road and situational safety level in the urban public transport system. The criterion takes into account five travel-safety related elements: the share of vehicles equipped in CCTV systems, share of stops/transfer nodes equipped with CCTV systems, share of length of sections of roads and streets with the public transport traffic separated from the remaining traffic (including tunnel travel time, separate lanes), share of junctions with grade-separated passes for public transport vehicles, share of illuminated stops
– **Urban public transport system profitability (P) [%]** – maximised criterion. The criterion reflecting the synthetic economic-financial effectiveness of the urban public transport system,

taking into account the interrelation between revenues (proceeds from ticket sales) and its costs generated by the IUPTS
- **Urban public transport system accessibility (AT) [-]** – maximised criterion. It determines the average density of the urban public transport network within the area subject to analysis. It is assumed that the higher total value of IUPTS routes per area unit, the more accessible urban public transport system is to passengers
- **Investment costs (IC) [PLN]** – minimised criterion. The criterion is related to the costs of realisation of urban public transport nodal and linear infrastructure. The criterion takes into account the costs of construction of new sections of roads (streets, trackways) for urban public transport, new stop construction costs, new transfer nodes construction costs, rolling stock acquisition costs, costs related to equipping stops/vehicles with information, costs related to equipping vehicles/stops with CCTV.

Detailed definitions were presented in a study by K. Solecka [22]. Individual criteria to a different degree allow to take into consideration interests of specific groups with vested interests in the issue of the urban public transport system integration (decision-maker – city authorities, interveners: public transport management board, operator, passenger, other participants). Table 1 presents criteria values obtained.

3.3. Modelling Decision-Maker's Preferences

In the decision-maker and interveners preference modelling process, two main preferential aspects were taken into consideration:

- Criteria weight, relevance of particular criterion for individual entities. Through weights they express their own subjective judgement regarding to the relevance of criteria. Criteria weight may be expressed in an absolute scale (e.g. Electre, Promthee methods) as well as in the form of relative weight coefficients determining the weight of individual criteria on the grounds of their comparison in dyads (e.g. AHP method).
- Decision-maker and interveners' sensitivity to changes in criteria value. The sensitivity to the changes in criteria values means the significant criteria value making it possible for the decision-maker and interveners to distinguish between the variants. The decision-maker and interveners' sensitivity to changes in criteria values are defined by means of preference thresholds: q - equivalence, p - preferences, v - veto for each criterion [19] e.g. such methods as Electre, Promethee or using relative weight coefficients for the variants compared in dyads in relation to each criterion, e.g. AHP method.

Criteria weight values and values of sensitivity to criteria weight changes were determined on the basis of surveys performed among entities interested in the issue and among transport experts who assess these two aspects from the point of view of all the entities with interest in urban public transport integration. The obtained results are presented in tables 2 and 3 below. Tables 2 and 3 show that the most important criterions are K7 – safety of travel and K5 – level of urban public transport integration. Analyzing weight of criteria range it should be emphasized, that in spite of assumed range from 1 to 7 (where 1 means less important criteria, and 7 means very important), the lowest average weight for intervenient and decision maker is on the level 3,19. It means that all analyzed criteria are important for taking into bodies. For each criterion it was determined value veto threshold by respondents. It means the strong divergence between some variants. Little differences between equivalence thresholds – *q* and preference thresholds – *p*, e.g. criterion K9, show about definite stand on respondent to this criterion. The similar values of equivalence thresholds – *q* and preferences - *p* to result in limited range weak preference relationship between variants, which is interpreted as an uncertainty area. It can be concluded that for the small differences between variants, respondent discerns a strong preference one variant to the other.

Table 1

Values of criteria for particular variants [22]

Variant symbol	Symbol	K1	K2	K3	K4	K5	K5	K6	K7	K7	K8	K9	K10
	Name of Criterion	Travel Time	Standard of Travel	Rolling Stock Utilisation Index	Environmentally-friendly	Urban Public Transport System Integration Level	Criterion K5 Standardised Value	Reliability of Urban Public Transport System	Safety of Travel	Criterion K7 Standardised Value	Profitability of Urban Public Transport System	Accessibility of Urban Public Transport System	Costs of Investment
	Unit	**[min]**	**[-]**	**[%]**	**[%]**	**[%]**	**[%]**	**[-]**	**[-]**	**[%]**	**[%]**	**[-]**	**[PLN]**
	Preference direction	Min	Max	Max	Max	Max	Max	Max	Max	Max	Max	Max	Min
W0		53.32	0.456	50.14	0	25.90	0.00	92.8	0.19	0	-26	1.61	0.00
W1		51.65	0.495	48.77	49	37.69	42.57	93.4	0.39	48	-24	1.69	432,892,800
W2		51.02	0.550	38.84	59	45.88	72.15	93.5	0.40	53	-34	1.75	955,630,600
W3		50.84	0.506	43.01	78	31.20	19.15	93.6	0.57	93	-31	1.69	9,685,460,000
W4		49.45	0.519	47.34	57	32.73	24.64	93.5	0.53	82	-33	1.71	1,459,193,100
W5		50.93	0.487	47.23	81	50.68	89.45	93.4	0.59	97	-30	1.67	1,958,287,800
W5A		50.11	0.582	41.8	100	44.22	66.14	94.1	0.57	93	-48	1.53	2,678,189,200
W6		50.22	0.501	46.68	64	53.60	100.00	92.8	0.60	100	-34	1.69	2,128,785,200

Table 2

Relevance of criteria for decision-maker and interveners [22]

No.	Criterion	Decision-maker	Interveners					
		City Authorities	**Public Transport Management Board**	**Operator**	**Passenger**	**Other participants**	**Median for interveners**	**Median for interveners and decision-maker**
1	Travel Time	3	5.3	5.17	6.44	2.40	4.83	4.46
2	Standard of Travel	7	4.77	4.74	5.44	2.29	4.31	4.85
3	Rolling Stock Utilisation Index	1	5.29	5.27	2.93	1.45	3.73	3.19
4	Environmentally-friendly	6	5.29	4.87	3.97	5.16	4.82	5.06
5	Urban Public Trasnport System Integration Level	7	5.74	5.73	6.17	3.00	5.16	5.53
6	Reliability of Urban Public Transport System	7	6.32	6.19	6.33	2.68	5.38	5.7
7	Safety of Travel (situational and traffic-related)	7	5.62	6.07	6.00	4.58	5.57	5.86
8	Profitability of Urban Public Transport System	5	6.53	5.72	1.83	1.56	3.91	4.13
9	Accessibility of Urban Public Transport System	4	5.45	4.40	6.13	3.05	4.76	4.61
10	Costs of Investment	3	6.69	2.08	2.03	2.96	3.44	3.35

Table 3

Preference Model in Electre Method [22]

Criterion	City Authorities (Decision-Maker)				Transport Management Board				Operator				Passenger			
	q	p	v	w	q	p	v	w	q	p	v	w	q	p	v	w
K1	3	3.8	4	3	1	2	3	5.3	1.5	3	4	5.17	0.05	0.9	1.8	6.44
K2	0.005	0.03	0.08	7	0.05	0.1	0.2	4.77	0.05	0.1	0.2	4.74	0.008	0.05	0.1	5.44
K3	4.5	13	15	1	1	2	5	5.29	1.5	2.5	5	5.27	3	8	15	2.93
K4	2	3	10	6	3	5	20	5.29	10	15	30	4.87	15	25	50	3.97
K5	2	3	5	7	5	10	15	5.74	5	10	15	5.73	3	5	10	6.17
K6	0.009	0.01	0.12	7	0.02	0.03	0.1	6.32	0.04	0.05	0.15	6.19	0.02	0.03	0.1	6.33
K7	0.01	0.03	0.09	7	0.1	0.15	0.2	5.62	0.03	0.05	0.1	6.07	0.05	0.08	0.15	6.00
K8	6	13	18	5	2	5	10	6.53	5	10	15	5.72	15	18	20	1.83
K9	0.16	0.19	0.21	4	0.05	0.1	0.15	5.45	0.15	0.18	0.2	4.40	0.03	0.05	0.1	6.13
K10	1.7	4	6	3	1	1.5	3	6.69	3	7	9	2.08	3	7	9	2.03

	Other participants				Interveners				Interveners + Decision-Maker			
	q	p	v	w	q	p	v	w	q	p	v	w
K1	2.5	3.5	5	2.40	2	3.5	4	4.83	2.5	3.8	4	4.46
K2	0.1	0.12	0.2	2.29	0.08	0.11	0.2	4.31	0.01	0.08	0.15	4.85
K3	4	10	15	1.45	2	5	10	3.73	2.5	7	10	3.19
K4	5	10	25	5.16	10	15	30	4.82	5	10	25	5.06
K5	15	20	25	3.00	10	15	20	5.16	8	13	18	5.53
K6	0.1	0.15	0.2	2.68	0.05	0.1	0.15	5.38	0.05	0.08	0.11	5.7
K7	0.25	0.3	0.4	4.58	0.1	0.15	0.3	5.57	0.1	0.15	0.25	5.86
K8	18	20	22	1.56	10	15	18	3.91	8	13	15	4.13
K9	0.18	0.2	0.22	3.05	0.1	0.15	0.18	4.76	0.13	0.16	0.19	4.61
K10	2	5	7	2.96	1.5	3	5	3.44	1.6	3.5	5.5	3.35

3.4. Computational Experiments

Computational experiments with the application of the Electre III method were performed with the use of the Electre III/IV programme. The results obtained for all three approaches are presented below.

Approach I
- Urban Public Transport Passenger Preference Model

On the basis of the above-given preference information (table 3), computational experiments were conducted. Following the performed computational experiments, results were obtained and subsequently presented in the form of a matrix: Concordance Matrix, Credibility Matrix, and Ranking Matrix. The results were presented in the form of a table and as a graph. Analysing the table presented in Figure 2a, one may state that the value obtained at the intersection of verse W0 and column W6 is C (W0,W6) = 0.14. This means that the degree of concordance that variant W0 is at least as good as variant W6 is low. This situation may be interpreted as preference of variant W6 towards variant W0, which confirms the value of the concordance index C (W6,W0) equalling 0.99. In the case of the credibility matrix (Figure 2b), values in the interval from 0 to 1 were obtained. Interpretation thereof can be presented in the following manner: the value obtained at the intersection of verse W0 and column W6 is 0. This means that the degree of credibility, that variant W0 is at least as good as variant W6 and equals zero. In the situation where the matrix value is close to or equal one signifies a high degree of credibility that a given variant is at least as good as the one being compared against it. The final ranking matrix (Figure 2c) takes into consideration the following relations: equivalence– I, outranking – P, reverse outranking – P* and incomparability – R. This matrix demonstrates advantages of one variant over the other one and incomparability of variants. It corresponds with the final ranking presented in the form of a final graph and as a table. (Figure 2d, e)

In the final ranking generated with the use of the Electre III method, from the passenger's point of view, variant W5 turned out to be the best solution whereas variant W0 obtained the lowest score.

Similar computational experiments were performed for the remaining entities whereas their results are presented in table 4.

a)

Concordance Matrix

	W0	W1	W2	W3	W4	W5	W5A	W6
W0	1	0.23	0.14	0.27	0.27	0.14	0.27	0.14
W1	1	1	0.62	0.4	0.57	0.57	0.4	0.52
W2	0.95	0.96	1	0.65	0.7	0.65	0.4	0.71
W3	0.93	0.94	0.59	1	0.65	0.82	0.41	0.69
W4	1	1	0.7	0.92	1	0.76	0.63	0.82
W5	1	0.95	0.76	0.6	0.65	1	0.53	0.7
W5A	0.77	0.8	0.85	0.84	0.7	0.82	1	0.84
W6	0.99	1	0.76	0.78	0.7	0.92	0.53	1

b)

Credibility Matrix

	W0	W1	W2	W3	W4	W5	W5A	W6
W0	1	0	0	0	0	0	0	0
W1	1	1	0.62	0	0	0	0	0
W2	0.95	0.96	1	0	0	0	0	0
W3	0	0	0.065	1	0	0	0	0
W4	1	1	0.7	0	1	0	0	0
W5	1	0.95	0.76	0.6	0	1	0	0.7
W5A	0.77	0	0	0	0	0	1	0
W6	0.99	1	0.76	0.78	0.6	0	0	1

c)

Ranking Matrix

	W0	W1	W2	W3	W4	W5	W5A	W6
W0	I	P^-	P^-	P^-	P^-	P^-	P^-	P^-
W1	P	I	P^-	R	P^-	P^-	R	P^-
W2	P	P	I	R	P^-	P^-	R	P^-
W3	P	R	R	I	P^-	P^-	P^-	P^-
W4	P	P	P	P	I	P^-	R	P^-
W5	P	P	P	P	P	I	P	P
W5A	P	R	R	P	R	P^-	I	R
W6	P	P	P	P	P	P^-	R	I

d)

Rank	Alternative
1	W5
2	W5A W6
3	W4
4	W2 W3
5	W1
6	W0

e)

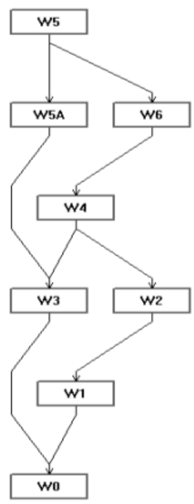


Fig. 2. Concordance Matrix (a), Credibility Matrix (b), Ranking Matrix (c), Final Ranking as a table (d), Final Ranking as a graph (e)

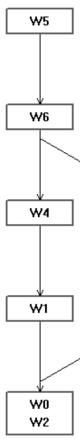
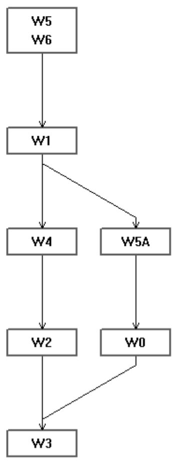
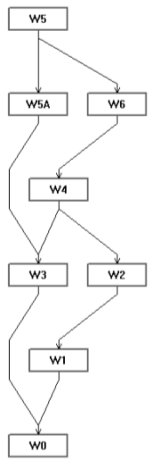
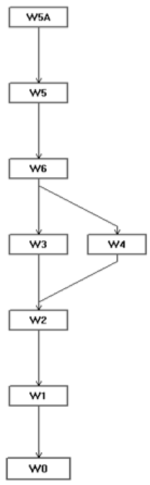
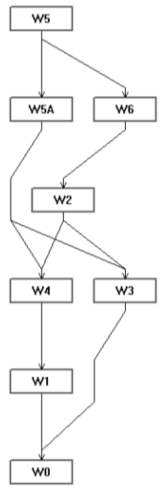
Rys. 2. Macierz zgodności (a), macierz wiarygodności (b), macierz uszeregowania końcowego (c), uszeregowanie końcowe w formie tabelarycznej (d), uszeregowanie końcowe w formie graficznej (e)

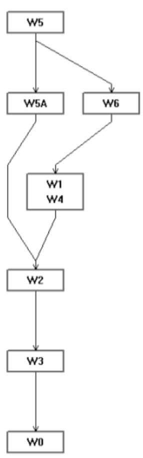
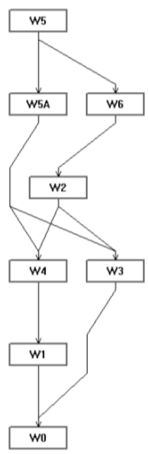
4. CONCLUDING REMARKS

The paper in a detailed manner presents one of the MCDA methods, namely the Electre III method – a variant ranking method. By completing all steps in the Electre III methodology, the final ranking of IUPTS variants was obtained on the basis of which it is easy to indicate a solution optimal in terms of the considered points of view with taking into account a variety of assessment criteria. As a result of the computational experiments performed for three approaches, very close final results were obtained. Variant W5, the tram variant is the recommended variant, however variants W6, based in a two-system tram, and W5A tramways subvariant of variant W5 also deserve consideration. These variants are oriented towards development of rail transport, especially trams, and they are characteristic for a very extensive fast tram network. The Electre III method presented proves extremely useful in solving transport problems whereas the obtained final results indicate the desired directions of operation.

Table 4

Summary of results of computational experiments of the IUPTS variant assessment preformed using the Electre III method

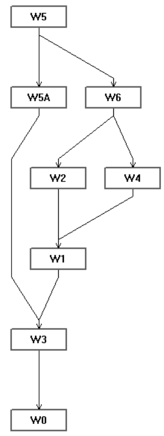
Approach I				
Operator	**Transport Management**	**Passenger**	**Other participants**	**City authorities (Decision-Maker)**
Rank / Alternative 1 W5 2 W6 3 W4 W5A 4 W1 W3 5 W0 W2	Rank / Alternative 1 W5 W6 2 W1 3 W4 W5A 4 W0 W2 5 W3	Rank / Alternative 1 W5 2 W5A W6 3 W4 4 W2 W3 5 W1 6 W0	Rank / Alternative 1 W5A 2 W5 3 W6 4 W3 W4 5 W2 6 W1 7 W0	Rank / Alternative 1 W5 2 W5A W6 3 W2 4 W3 W4 5 W1 6 W0
				
As a result of the computational experiments performed using the Electre III method it is possible to determine the final ranking taking into consideration Approach I: W5, W6, W5A, W4, W3, W2, W1,W0, (where W5 signifies the best variant, whereas W0 the worst variant).				

Approach II				
Interveners			**City Authorities**	
Rank / Alternative 1 W5 2 W5A W6 3 W1 W4 4 W2 5 W3 6 W0			Rank / Alternative 1 W5 2 W5A W6 3 W2 4 W3 W4 5 W1 6 W0	
In Approach II, the final ranking is as follows: W5, W5A, W6, W4, W2, W1, W3, W0 (where W5 signifies the best variant, whereas W0 the worst variant).				

Approach III

Interveners and Decision-Maker

Rank	Alternative
1	W5
2	W5A W6
3	W2 W4
4	W1
5	W3
6	W0



In Approach III variant W5 turned out to be the best one, whereas variant W0 the worst one.

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