Application of AHP method for multi-criteria evaluation of variants of the integration of urban public transport

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Abstract

This article presents the idea of travel demand management and basic concepts of urban public transport integration. The process of striving for integration of urban transport requires detailed analysis of tools to assess the activities. The cities often offer different variants of the integration, but it is difficult to determine which option is the best. This choice can be easier by making an assessment of variants of the integrated system of urban public transport (ISUPT) by using multi-criteria decision aid methods (MCDA). The aim of the article is to present the main elements of the methodology of MCDA, and then the possibility of applying it to assess variants of ISUPT. To assess variants of ISUPT, one of the MCDA methods – the AHP ranking method was used. Special attention was paid to the complexity of the considered problem, where it is necessary to take into account many aspects of it, such as: economic, technical, environmental and social. In order to show the practical application of the proposed methodology, the example of Cracow was used.

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Keywords: travel demand management; public transport; variants of integration; multi-criteria decision aid; traffic simulation;

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1. Introduction

Car traffic in cities causes a decrease in travel speed, irregularity of public transport operation and, as a consequence for travellers, significant time losses, including productive and resting time. Because of congestion the accessibility to the destination points, especially those that are located in the city centre, is threatened. Other difficulties concern: road safety, increasing air pollution, traffic noise and global warming (Banister, 2005). Construction of new roads and transport facilities requires large financial resources, covers large areas and results in the reductions in space which could be allocated to other purposes (parks, playgrounds, etc.). Parked vehicles are often obstacles for pedestrians, cyclists and the disabled. Transport also contributes to urban sprawl and to the decentralization of cities. Concerning these problems, cities have realized that the key issue for the reduction of problems is to cause a change in people’s mobility behaviours, towards lower car usage and to encourage them to travel using public means of transportation, use more bikes and walk (Nosal&Starowicz, 2010). This approach does not aim to completely eliminate car journeys, but, to a more rational use of individual transport modes e.g. car travels in case of a lack of opportunity to choose other mobility means. Another possibility is the shared usage of one vehicle by a number of people, meaning carpooling or car-sharing systems (Correia&Viegas, 2010). We can shape travellers’ attitudes and behaviours using the concept of travel demand management. Travel demand management is an approach to the passenger transport, oriented on the promotion of sustainable mobility modes and on the management of a demand for car usage. City residents can make a choice related to sustainable mobility means, however at the same time some car restrictions and good conditions for pro-ecological transport need to be implemented. These solutions and their strong promotion can make public and bike transport, as well as walking trips, more competitive than cars.

Travel demand management includes many instruments, strategies and solutions which have different influences. Many of them are related to offering new transportation options, while others provide incentives to decrease the number of travels to change the mobility mode, trip destination, route or time. Some of them can limit the need for physical movement thanks to substitutes, like telecommunication technology or more efficient land use planning. Land use planning can be related e.g. to traffic calming, which includes various strategies to reduce traffic speeds and volumes on specific routes and make them more pedestrian and bicycle friendly. Also with techniques, such as the increased residential and employment densities, mixed land use, and office and home-office balance, we are able to reduce a total number of vehicle travels as a result of the localization of common destinations, such as: stores, services, jobs (Litman, 1999). Whereas infrastructural instruments, which are related to the development of public transport, walks and bicycle-friendly solutions can concern improvements in organization and quality of services, organization of Park&Ride and Bike&Ride systems, city bike rental schemes etc. Especially in Polish conditions the key issue of mobility management process is to provide the residents with a high-quality public transport service, dense, cohesive and safe bike path networks but also well signed, safe pedestrian routes (Starowicz, 2000). The next type of travel demand management instruments are financial instruments that usually aim to make car travels more expensive and difficult, and thus, less attractive for the drivers. Cordon pricing (area pricing) is the most commonly applied financial instrument (Banister, 2005). Some pricing schemes are time-based and take into account both, the transit through the area and the parking effects. Travel demand management concept consists also of a range of “soft” instruments corresponded to individual clients’ needs that can be flexibly adapted to various conditions and expectations of target groups (Nosal, 2011). Examples of “soft” instruments are information and consulting, related to providing the travelers’ with information on sustainable mobility modes, analysis of present transport situation, search of solutions, evaluation of the alternative options and the recommendation of the best solution. This kind of instruments also concerns the organization and coordination of new ways of travelling (e.g. carpooling system) or additional public transport services (e.g. organization of shuttle service between selected area and an exchange point). “Soft” instruments could also be related to educational and promotional activities, meaning all measures focusing on users’ travel awareness raising. The most popular educational and promotional event is “European Mobility Week”. Finally, one of the instruments which allows shaping mobility patterns is an integration of urban transport system, that can occur at different levels and may involve many activities described above. Implementation of the integration of urban transport systems helps to improve in travel conditions and leads to increasing the public transport usage.
This article consists of four sections. The introduction presents the background of the work and explains the idea of travel demand management. The second section describes the concept of urban public transport integration as one of instruments of travel demand management. In the next one the main elements of the methodology of multi-criteria decision aid (MCDA) is characterized and then the possibility of applying it to assess variants of the integrated system of urban public transport is shown. Section four is a summing up chapter.

2. Integration of urban transport system as one of instruments of travel demand management

Integration is a consolidation, combining, creation of a whole from parts or merger (Polish Language Dictionary, 2002), (Tokarski, 1980). Integration can occur at different levels and may involve many aspects and activities. M. Janic and A. Reggiani (2001) claim that there is no general accepted definition of integration of urban public transport and it is differently understood by many authors. For example the measures of Propolis project (2004) were concentrated on integration of spatial development and transport policy in metropolitan areas. The authors offered alternative solutions for integration of transport systems for different cities. Interesting insights on integration were also presented by A. Maya (1993), who defined the design rules for effective integrated public transport systems as well as discussed different types of transport integration. Many definitions of urban public transport integration can be found in literature (Dydkowski, 2005; Hine, 2000; Hull, 2005; Ibrahim, 2003; ISOTOPE, 1997; Janic&Reggiani, 2001; May, 1993; NEA, OGM and TSU , 2003; Potter & Skinner, 2000; Preston, 2010; Propolis, 2004, QUATTRO, 1997) but the most popular are formulated by:

- the authors of NEA, OGM and TSU projects (2003), who define the integration as the organizational process, in which the elements of public transport system (network and infrastructure, fares and ticketing, information and marketing, etc.) served by different operators, who use different transport modes, interact more efficiently and closely. This results in general improvement in travel conditions and quality of service.
- the authors of QUATTRO (1997) and ISOTOPE (1997) projects, who define integration as the way in which the individual elements of public transport are embedded in the chain of movement.

Commonly, in the urban public transport services, the word ‘integration’ is used for solutions that guarantee a continuity of a “door to door” journey (Janic&Reggiani, 2001). Urban transport is to provide attractive chain of services in the relationship “door to door” through the integration of:

- different means of public transport,
- public and individual transport,
- transport policy with other policies concerning the spatial planning or investments in infrastructure.

The integration of urban public transport may take place at different levels (Solecka, 2013):

- **Infrastructure integration** consists of a defined (arranged) combination of elements that make up integrity of a transport network. This relates to, first and foremost, all such elements as: location of bus stops, stations, and interchange junctions for easy/convenient changing of a means of transport (Wesolowski, 2008). Hence integration will also be affected by: a common tram - bus track, common stops for different means of public transport, stairs, elevators, walkways, underpasses and crossings.
- **Organizational integration** includes all levels of the transport network serving urban, agglomeration or regional traffic. It involves the integration of means of transport, through the organization of transport, which helps to ensure the continuity of a journey in the shortest time possible. The most commonly used tool for the organizational integration is the coordination of timetables, which involves their adjustment one to another in such a way that minimizes time losses related to the necessity to change the means of transport.
- **Economic and financial integration**, just like organizational integration covers all levels of transport network that serve urban, agglomeration or regional traffic. It consists in organization of journeys via different means of transport, to assure the passengers the best economic and financial conditions of the journey when changing the
means of transport (regardless of the carrier). Tariff integration is one of the most commonly used tools of economic and financial integration.

- **Informational integration** also covers all levels of transport network that serves urban, agglomeration or regional traffic. It consists in providing passengers with stress-free journeys throughout the transport system. An integrated passenger information system means that passenger information is shared across the network, regardless of a carrier or a mode of transport. We can distinguish different sources of information on the public transport for end users: information provided at customer service points, via telephone, Internet (computers, mobile devices) and at bus stops and stations. Information in real time is an additional convenience for passengers, because this allows passengers bigger flexibility of journeys to better respond to delays and/or disruptions in the network.

- **Spatial integration** involves specific spatial development of urban forms with the existing transport network. Appropriate land use and the development of transport infrastructure are to ensure the alignment of planning and land management with transport planning.

Speaking of the problem of the integration of public transport, we cannot forget about the issue of intermodality. It is understood as the passengers’ use of different modes of transport in one journey. Passenger transport intermodality requires the integration of routes and information, as well as coordination and service in communication points and coordinating schedules and ticket unification. Continuous journeys require appropriate land use and urban planning. Improvement of intermodality in passenger transport is a key element in the development of an efficient and integrated transport system.

Many EU projects (MIMIC, GUIDE, PIRATE, EU - SPIRIT) highlight the high importance of urban public transport integration and focus on providing solutions ensuring the trip flow. The MIMIC project (1999) shows the need to ensure continuity of passenger travel from door to door, because an additional change and its consequences such as time losses (related to change of transport mode and bus stop, waiting for a vehicle, buying an extra ticket, etc.), together with the lack of provision of favourable change conditions, can be the reason for giving up with public transport and choosing private transport. Planning, organization, functionality and availability of changes as a part of the public transport integration was also emphasized by the authors of GUIDE project (1999). They analysed the impact of the spatial development on the location of interchange points. The PIRATE project (1999) paid special attention to the promotion of intermodal travel in public transport to encourage passengers to use public transport modes and the same provide higher fluidity of public transport journey. The EU - SPIRIT project (2001) highlighted the importance of providing information about transport modes such as long-distance trains, regional and local trains as well as subway, bus and tram system. The figure below shows examples of integration.

![Integration Examples](image)

**Fig.1.** (a) Common tram - bus track in Cracow; (b) Common stops for buses and trams in Nantes; c) Interchange point in Nantes; d) Promotion of integrated tariff in Cracow. Own sources.

### 3. Multi-criteria decision aid methods in the assessment of an integrated urban public transport in Cracow

Currently in the cities various variants of the integration of urban public transport are often created, however it is difficult to determine which option is the best, which variant brings the greatest benefits for passengers and other stakeholders. The evaluation of the variants of integrated system of urban public transport (ISUPT) will help to make the best decision, using the multi-criteria decision aid methods (MCDA). The aim of the article is to present
the main elements of the methodology of multi-criteria decision aid (MCDA), and then the possibility of applying it to assess variants of ISUPT.

Multi-criteria decision aid is a branch of knowledge deriving from operational research that provides the decision-makers with the tools and methods that help to solve complex multi-criteria decision problems. During the analysis of these problems it is crucial to consider a number of, often, opposing points of view. A multi-criteria decision problem may involve (Ehrgott, 2005), (Roy, 1990), (Vincke, 1992):

- the problem of choice (optimization) – the decision-maker determines a subset of decisions (action, options) considered the best ones in terms of the considered family of criteria,
- the problem of classification (sorting) – the decision-maker decision maker splits a set of decisions (activities, and action variants) into subsets (classes, categories), in accordance with the accepted standards,
- the problem of ranking – the decision-maker aims to put the variants in order from the best to the worst one.

To select the best ISUPT solution, we suggest the use of a complex methodology, consisting of the 5 following stages (Solecka, 2013):

- stage 1: Diagnosis and assessment of the current status of the public transport system.
- stage 2: Formulation of the concept of ISUPT evaluation as a multi-criteria problem of ranking of given variants.
- stage 3. Review and evaluation of methods for multi-criteria ranking of given options.
- stage 4. Conducting computational experiments using selected methods of options ranking.
- stage 5. Summary of computational experiments.

This present paper considers selected aspects of stage 2 and 4. Stage 2 of the methodology is composed of the following steps:

- formulating a decisive problem,
- creating variants,
- creating a consistent family of criteria,
- defining preferences of the decision-maker and of interveners.

The decisive problem was formulated as a multi-criteria problem of ISUPT variant classification. The methodology precisely identifies the main stakeholders in the decision-making process, interested in a given solution aiming at solving the decisive problem. In the case of the integration of urban public transport, they are:

- a decision-maker – city authorities,
- interveners – board of urban transport, operator of the urban public transport, passengers of the urban public transport and other traffic users,
- analyst – transport expert, a person experienced in IT.

Designing variants constitutes a heuristic assisted construction supported by traffic simulation. Integration in created variants may refer to the existing system of urban public transport or an integration which allows the development of the public transport system.

The construction of variants is done according to the principles of shaping transport systems (Bauer & Szalkowski, 2011), (Bauer, 2012). It involves, e.g. the introduction of new means of public transport, new routes, lines, in order to facilitate the integration of urban public transport, the introduction of tools that integrate urban public transport, etc. The constructed variants are then encoded in the VISUM traffic macro simulation program. As a result of the traffic simulation, we obtain a number of parameters that characterize ISUPT. The results are necessary to calculate the value of evaluation criteria. Below, there is an example of variants of the integrated system of urban public transport designed for Cracow:

- W0 – existing state showing the current level of integration of urban public transport in Cracow.
W1 – bus-rail. Integration of fast suburban railway network (Polish abbreviation: szybka kolej aglomeracyjna: SKA) with bus transport.

W2 – rail-tram-bus. Integration of SKA with tram and bus transport.

W3 – subway. Integration of subway with SKA and tram and bus transport.

W4 – tram-rail. Integration of SKA with tram transport.

W5 – tram. Integration of tram transport (in particular of a fast tram ST) with bus transport.

W5A – tram-sub variant of variant W5. Integration of tram transport (in particular of a fast tram, ST).

W6 – dual-system tram. Integration of a two-system tram with tram transport.

The above-mentioned variants were differentiated primarily in terms of the presence of tools that integrate urban public transport. Moreover, we controlled circulation frequencies; we changed line routes of the means of transport. Figure 2 shows a graphical representation of variant W5; meaning the sequence of new tram lines and lines where we changed routes, interchange junctions and the newly introduced tram-bus tracks.

In order to assess ISUPT, we suggest using a set of 10 criteria contemplating technical, economic, social and environmental aspects. Table 1 shows the suggested evaluation criteria along with their allocation to the areas of interest of the major interest groups trying to solve the problem of urban traffic integration.
Table 1. Evaluation criteria.

<table>
<thead>
<tr>
<th>No.</th>
<th>Name of the criterion</th>
<th>Decision maker</th>
<th>Interveners</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Travel time*</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>2</td>
<td>Journey standard*</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>3</td>
<td>Rolling stock use index**</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>4</td>
<td>Environmentally friendly****</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>5</td>
<td>Level of integration of public urban transport system*</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>6</td>
<td>Reliability of urban public transport system**</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>7</td>
<td>Safety of journeys (situations and traffic)*</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>8</td>
<td>The profitability of the urban public transport system***</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>9</td>
<td>Availability of the urban public transport system*</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>10</td>
<td>Investment costs***</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

Legend: *social criteria, ** technical criteria, *** economic criteria, **** environmental criteria

Detailed definitions along with their calculation method were presented in the paper of K. Solecka (Solecka, 2013). In the process of modelling the preferences of a decision-maker and of the interveners, the following main preference aspects should be contemplated:

- validity criteria mean the significance of a particular criterion for individual entities. By weight, they express their subjective feeling of the significance of criteria. The importance of criteria can be expressed in absolute scale (e.g., Electre Method), as well as relative significance coefficients defining the importance of each criterion on the basis of their pairwise comparisons (e.g. AHP method).
- susceptibility to changes in the values of criteria, meaning at how significant criteria values, the decision-maker or interveners begin to distinguish between variants. The sensitivity of the decision-maker and the interveners to the changes in the criteria is defined by preference thresholds: q - equivalence, p-preference, v-veto for each criterion. For instance, by means of the Electre method or by using relative validity coefficients for variants, compared in pairs, with respect to each criterion, e.g. AHP method.

The criteria validity values and the values of susceptibility to changes of the criteria values is determined on the basis of surveys conducted among problem stakeholders, or among transport experts who evaluate these two aspects from the perspective of all stakeholders interested in the integration of urban public transport. Figure 3 shows the survey results carried out in Cracow among stakeholders (a comparison of the results for three groups: passenger, operator, city authorities). Survey questionnaires focused on determining the importance of evaluation criteria of ISUPT. Of note, not all the criteria are equally important for the analysed entities, rolling stock use index is important for the transport operator and passengers, while not very significant for the city authorities.
To assess the multi-criteria evaluation of ISUPT, we could use both, European school methods (e.g. Electre, Promethee) and the U.S. school (e.g. AHP, ANP). However, this article presents the possibility of applying the AHP evaluation method to assess ISUPT in Cracow. The AHP method consists in aggregating different criteria into one optimized additive utility function. It assumes that all variants are comparable; meaning that in each pair of variants, the decision-maker will always choose a preference or will considers them equivalent. Preference modelling is done by comparing pairs of variants, criteria or sub-criteria. Computational experiments are performed for three approaches:

- separate rankings are aerated for all interested stakeholders and a decision-maker – selection of the best,
- one common ranking for all stakeholders is created and a separate ranking for the decision-maker.

To computational experiments conducted by AHP method, EXPERT CHOICE program was used. Table 2 shows obtained results, where value 1 means the best option. Summing up the results obtained by AHP method, we can indicate that the best solutions are variant W5A and variant W6. However, the least recommendable variant, in turn, proved to be variant W0.
Table 2. A summary of the final results obtained as a result of computational experiments using AHP method

<table>
<thead>
<tr>
<th>Operator</th>
<th>Urban transport board</th>
<th>Passenger</th>
<th>Other participants</th>
<th>City authorities (decision maker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W5A</td>
<td>1,000</td>
<td>W5A</td>
<td>1,000</td>
<td>W5A</td>
</tr>
<tr>
<td>W6</td>
<td>.888</td>
<td>W5</td>
<td>.918</td>
<td>W6</td>
</tr>
<tr>
<td>W5</td>
<td>.714</td>
<td>W6</td>
<td>.912</td>
<td>W2</td>
</tr>
<tr>
<td>W3</td>
<td>.569</td>
<td>W1</td>
<td>.907</td>
<td>W4</td>
</tr>
<tr>
<td>W4</td>
<td>.540</td>
<td>W4</td>
<td>.864</td>
<td>W5</td>
</tr>
<tr>
<td>W1</td>
<td>.507</td>
<td>W2</td>
<td>.848</td>
<td>W3</td>
</tr>
<tr>
<td>W2</td>
<td>.505</td>
<td>W0</td>
<td>.789</td>
<td>W1</td>
</tr>
<tr>
<td>W0</td>
<td>.501</td>
<td>W3</td>
<td>.648</td>
<td>W0</td>
</tr>
</tbody>
</table>

As a result of the above computational experiments conducted by AHP method, we can present the final ranking: W5A, W6, W5, W2, W4, W3, W1, W0, (where W5A means the best option and W0 the worst option).

<table>
<thead>
<tr>
<th>Interveners</th>
<th>City authorities (decision-maker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W6</td>
<td>W5A</td>
</tr>
<tr>
<td>W5A</td>
<td>W6</td>
</tr>
<tr>
<td>W5</td>
<td>W5</td>
</tr>
<tr>
<td>W3</td>
<td>W2</td>
</tr>
<tr>
<td>W2</td>
<td>W3</td>
</tr>
<tr>
<td>W4</td>
<td>W4</td>
</tr>
<tr>
<td>W1</td>
<td>W1</td>
</tr>
<tr>
<td>W0</td>
<td>W0</td>
</tr>
</tbody>
</table>

In the second approach, the final ranking looks as follows: W5A, W6, W5, W2, W3, W1, and W0. (where W5A means the best option and W0 the worst option). In this case, the difference between variant W5A and W6 is insignificant.

<table>
<thead>
<tr>
<th>Interveners and decision-makers</th>
</tr>
</thead>
<tbody>
<tr>
<td>W5A</td>
</tr>
<tr>
<td>W6</td>
</tr>
<tr>
<td>W5</td>
</tr>
<tr>
<td>W3</td>
</tr>
<tr>
<td>W2</td>
</tr>
<tr>
<td>W4</td>
</tr>
<tr>
<td>W1</td>
</tr>
<tr>
<td>W0</td>
</tr>
</tbody>
</table>

In the third approach, W5A and W6 proved to be the best variants. The difference between these two options is insignificant.

4. Conclusions

In modern cities, individual transport leads to serious problems related to, among others: congestion on roads and environmental pollution. Therefore it is extremely important to strive to change people’s travel behaviours towards the use of more sustainable means of transport: public transport, bicycle, walks, car sharing and carpooling. This can be achieved by using the concept of the transport demand management. In order to encourage city residents to use public means of transport and to improve its conditions, a range of instruments of transport demand management are being implemented. One of the solutions is to increase the role of urban public transport by ensuring consistency of transport systems and the integration done within the framework of the public transport and public transport to correlate with the individual transport. Public transport integration is of great importance, both at the local and at the regional level. In order to choose the best solutions implemented for the purpose of the integration of public transport, among others, methods of multi-criteria decision aid are used. The article contains examples of the use of AHP method to assess ISUTP variants that were suggested for the City of Cracow. The end result of the used methodology is the ranking of integration options from best to the worst one, based on the considered criteria. The obtained results should be regarded as an aid in making the final decision, an indication of a certain direction that will satisfy all involved stakeholders. The presented methodology can be used by the city authorities and the board.
of public transport when making decisions related to choosing the best variant of the operation of ISUTP. This methodology can be used for both, cities and larger areas such as agglomerations.

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