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EVALUATION OF ALTERNATIVES TO INTEGRATE SPECIAL TRANSPORTATION SERVICES FOR PEOPLE WITH MOVEMENT DISORDERS

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Integrating the most appropriate special transportation service for people with movement disorders model may result in great economy efficiency and social benefit balance. However, most existing researches are based on improving the accessibility of public transport services or development of routing and scheduling under stochastic input data. The aim of this paper is to project the evaluation algorithm for the purpose of assessing the appropriate model of integration which would enable the employment of existing resources and filling the gap in assurance the mobility needs of people with mobility impairments. This paper identifies the evaluation indicators which are selected from international publications. Firstly the performance indicators of special transportation services were selected, further the sustainable development of public transport services evaluation indicators were selected, classified and adjusted to the goal of this paper. As a final result of indicators selection, a set of indicators classified into two groups – cost and benefit - was carried out. The decision making is based on Fuzzy Analytic Hierarchy Process and Fuzzy Technique for Order Preference by Similarity to Ideal Solution methods. A case study is provided to demonstrate the application of proposed evaluation algorithm.

Keywords: sustainable development, urban public transport, people with movement disorders, special transportation services, indicator, analytic hierarchy process, fuzzy technique

1. Introduction

This paper is focused on the problem of the public transport accessibility to people with reduced mobility. In the context of the sustainable development approach threatening numbers of people with some kind of movement disorders and growing percentage of elderly people in the society refers to the necessity to optimize the integration of special transportation services. Observing the cases starting from total integration and ending with pure urban public transport accessibility and absence of special transportation services, it is contended that the integration decision should be taken after comprehensive analysis of the existing resources, environmental factors and the demand.

This paper will address the main criteria to be estimated while taking the decision which integration model of special transportation services for people with reduced mobility should be applied in existing urban public transport system through combination of regular public transport services and complementary flexible transport schemes and shared-use transport.

2. Literature Review

This research is the continuation of previous studies of the authors (Bazaras *et al.,* 2013; Palsaitis and Verseckiene, 2014). It is important to mention that three models for special transportation services to people with movement disorders were formed. First model includes only door-to-door service to the narrow target group. Such services are usually called demand responsive transit (DRT). The most significance of this model is the highest flexibility and adaptation to special mobility needs, however operational costs of such service is quite high, while the narrow target group limits the possibility to reach maximum efficiency of the service. The alternative special transportation service (STS) for people with movement disorders (PMD) model includes door-to-door services also working as a public transport (PT) feeder. This option enables the possibility to attract a wider range of consumers still keeping the adaptation of the service to special needs. The negative side of this option lies in reduces flexibility, increased travel time to people with movement disorders and complicated process of the service provision. The third option is of the highest integration level. It represents the idea of the concept of "Mobility-as-a-service". The combination of all resources available, including funding, operators, authorities, etc., maximum efficiency of the whole system can be reached. On the other hand, comparing with the first alternative lowest dedication of the service to the target group is considered.

Further, in order to establish the research gap and select the evaluation indicators, a systematic review of the articles published in English speaking journals was conducted (papers were selected from databases: SienceDirect, Springer, Scopus, Research Gate). The review is presented below.

2.1. Performance criteria of the special transportation services for people with movement disorders

Foreign practice shows that the most important goal of planning the mobility of PMD is to improve the public transport accessibility. Further the necessity to provide door-to-door services is acknowledged trying to minimize the scope of it as possible. Special transportation services to people with movement disorders varies depending on the flexibility. Door-to-door services, dedicated to PMD, vary in different countries. Some types can be excluded: paratransit, demand responsive transport, taxi services, shared taxi services, car-sharing, community car-sharing, etc. It is recognized that the operating costs of DRT services are very high so performance indicators of STS should be rated and the balance between PT accessibility and additional services should be reached. Integration alternatives should be considered to select the most appropriate to the exact system.

The criteria of flexible transportation services are complicated to evaluate because of its heterogeneity. Some of them are stochastic, others – deterministic, on the other hand, part of the indicators are of the quantitative nature, others – of qualitative nature. In case of the evaluation of the alternatives to implement additional service to assure the mobility of PMD, those measures should be assessed applying multi-criteria approach.

In the process of the criteria system formation the authors have been focused on six groups of criteria: intermodal connectivity, intermodal integration, occupancy rate, quality of service, functional diversity and service accessibility, as listed in Table 1. First group includes measures that are important to consider ensuring the connectivity between fixed and flexible transportation services. Usually insufficient funding leads to disagreements between stakeholders therefore the gaps in the public transport "supply chain" occurs. The smoother travel planning leads to the bigger possibility to attract passengers (IPCD, 2013; Duarte and Rojas, 2012; OECD, 2015). Second group includes measures, improvement of which leads to successful public transport integration (SPUTNIC, 2009). Public transport integration is claimed to be a significant factor for the increased demand of public transport services. Whereas this paper includes the evaluation of the services of different integration level, these measures are rather relevant. The third group includes vehicles occupancy rate. Nevertheless, public transport is a social service, it should be self-sustaining. Passenger load factor is an important indicator for the evaluation of the performance of any transport service. The only one way to cover costs is by selling tickets, therefore the higher the load factor is, the lower dependence on the subsidies occurs. This factor could be calculated as a ratio of passenger-kilometres travelled to seat-kilometres available. Public transport quality could be measured by numerous indicators (European Union, 2002; Pticina and Yatskiv, 2015; etc.). However, quality of special transportation services to people with movement disorders gets different meaning. According to their additional needs, the definition of quality takes on a broader meaning. The fourth group includes the measures of quality of STS to PMD (CIVITAS, 2010). The fifth group includes measures of functional diversity. This criterion is significant for evaluation because STS for PMD is also should be adapted to different situations. For example, in some cases a need for the vehicle with bedding could arise, while the biggest demand is for vehicles with wheelchair's fixation. Also the choice for different services' demand can arise. The last group includes service accessibility measures. Supplementing basic PT accessibility measures such as service coverage, waiting time, travel cost, etc., adaptation of the infrastructure, accessibility planning, user involvement, integrated accessibility planning, meeting users' needs, accessibility maintenance, fare policy, seamless travel, setting a target passenger should be evaluated as STS to PMD accessibility measures.

Table 1. Criteria for special transportation services to people with movement disorders evaluation

Criteria	Measures
Intermodal connectivity	Two or more local modes are connected, intercity and local transport modes are connected (including bicycle roads, pedestrian paths, parking lots, accessibility to people with disability).
Intermodal integration	Arrangements between operators, independent authority, network, schedules, transfers, information, fares tickets, access to facilities, stations designs, control.
Occupancy rate	Number of trips, the distance of one trip, number of passengers per trip, seats available.
Quality of service	Availability, convenience, frequency, operating hours, additional equipment, assistance, safe conditions, adequate price, the ease of using the service, information accessibility, safety and security training.
Functional diversity	Various equipment, supply of services: door-to-door services, public transport feeder services, car-sharing services, etc.
Service accessibility	Basic PT accessibility measures, adaptation of the infrastructure, accessibility planning, user involvement, integrated accessibility planning, meeting users' needs, accessibility maintenance, fare policy, seamless travel, setting a target passenger.

2.2. Sustainable public transport development

Despite the fact that there is a huge number of indicators for sustainable mobility measurement, there is no indicators' system for special transportation services for people with movement disorders evaluation.

The evaluation of sustainable mobility attaches importance to three dimensions: economic, environment and society. Sustainability indicators reflect the reality that the three different segments are very tightly interconnected, as shown in the Figure 1.

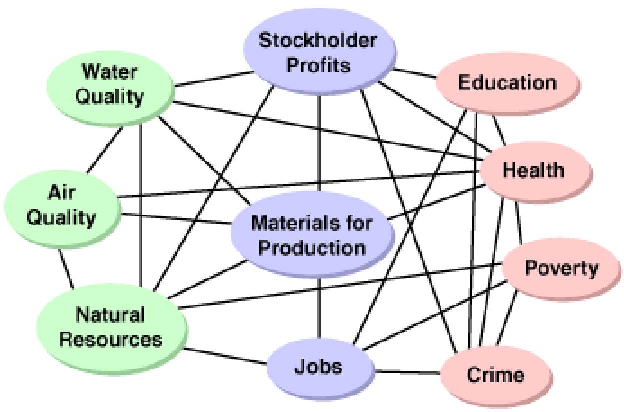

Figure 1. Web of interactions between the community and environmental dimensions (SM, 2017)

After a systematic literature review 69 indicators were identified with 27, 21 and 21 to economic, social and environmental dimensions respectively, as shown in Table 2 (Jain and Tiwari, 2017; Tafidis *et al*., 2017; VTPI, 2008, 2016; WBCSD, 2015; Nicolas *et al.*, 2003). Economic development refers to a community's progress toward economic objectives such as increased income, wealth, employment, productivity and social welfare. Economic public transport sustainability is directly connected to community dependence to private cars. Better developed walking, cycling and public transport system brings greater value to economic productivity. Sustainable transportation indicators should reflect both cost and benefit criteria considering that increased net benefits to society leads to greater accessibility and productivity. Social public transport sustainability meets the requirements, listed below:

- Meeting the diverse needs of people now and in the future;
- Promoting personal well-being;
- Promoting social cohesion and inclusion;
- Creating equal opportunities for all;
- Promoting good governance;
- Engaging people's creativity, energy and diversity.

Sustainable public transport indicators should measure individuals' characteristics (age, special needs, etc.), incomes, origin/destination points, safety using the service, motorization level, inclusive service planning. The negative effects of PT (and transport in general) on the environment are as follows:

the effect of vehicle carbon dioxide, CO2, emissions on climate change and the effect of other vehicle emissions that cause air pollution leading to negative health effects (Alonso *et al.*, 2015). Environmental public transport sustainability indicators should be considered to decrease negative impact to the environment promoting public transport service and trying to attract all possible customers.

Table 2. Sustainable mobility indicators

Dimensions	Indicators
Economical	Productivity; Affordability; Mobility; Finance equity; Resilience; User satisfaction; Commute time; Employment accessibility; Transport diversity; Mode share; Congestion delay; Cost efficiency; Crash costs; Planning quality; Mobility management; Ridership on fixed routes transit buses; Percentage of people choosing transit over car; Miles of fixed-route bus service; Transit revenues per transit-rider trip; Cost per transit-rider trip; Public expenditure on public transit; Transport resource cost savings; Transport operators revenues; Investment financing costs; Total net benefits (sum of costs/ benefits by type); Costs of employee parking; Subsidies to employees (company cars)
Social	Traffic crashes; User rating; Safety; Fitness; Community liveability; Cultural preservation; Non-drivers; Affordability; Disabilities; Non-motorized transport; Children's travel; Inclusive planning; Equity; Total time spent in traffic; Level of service of PT and slow modes; Vitality of city centre; Accessibility to the centre; Accessibility to the services; Proportion of households owning 0,1 or more cars; Distance travelled; Expenditures for urban mobility: amounts for private/public transport, for fixed/variable cost of car-share of the average income of households
Environmental	Climate change emissions; Other air pollution; Air pollution; Noise pollution; Water pollution; Land use impacts; Habitat protection; Habitat fragmentation; Resource efficiency, Energy use intensity; Air quality and GHG emissions; Surface water quality – rivers, lakes; Impaired waters; Ground water; Exposure to pollutants from major roadways; Proximity to contaminated sites; Children's lead exposure; Asthma prevalence; Diabetes rate

After the adjustments, that have been made to exclude the indicators to evaluate sustainable mobility of STS to PMD (classification of the indicators to separate dimensions, the selection of the repetitive indicators, assigning of the indicators to the different dimensions in the scope of research, etc.) and combination of the indicators mentioned with STS to PMD evaluation indicators, the final list of indicators was carried out, as shown in Table 3. Moreover, grouping the indicators to cost and benefit categories is accomplished for future assessment. Cost category includes factors that influence the resources that are used to implement the solution proposed. Benefit category includes factors that influence the increased welfare due to the solution considered.

Table 3. Selected indicators for evaluation of special transportation services to people with movement disorders

Dimension	Indicators	Definition	Cate-gory
Economic (D_1)	I_1: Productivity	Project goals fulfilment	B
	I_2: Investment costs	Vehicles purchase costs, etc.	C
	I_3: Vehicle reimbursement	Reducing the social benefits for cars' acquirement	C
	I_4: Fare rebates	Fare rebates for people with disabilities, elderlies, etc.	C
	I_5: Operational costs	Expenditures by operators providing the service	C
	I_6: Travel costs	Transport related user charges	C
Social (D_2)	I_7: PT accessibility to PMD	Service matching special needs	B
	I_8: Amount of PMD	Sufficient demand	B
	I_9: Affordability	Affordability by lower income classes	C
	I_{10}: Inclusive planning	Forming PT policy parallel to STS to PMD	B
	I_{11}: Safety	Additional safety to PMD, provided by STS	B
	I_{12}: Automobilization index	Utilization of passenger vehicles	C
STS performance (D_3)	I_{13}: Intermodal connectivity	Synchronized parameters of the services (frequency, etc.)	B
	I_{14}: Intermodal integration	Planning the whole trip at once	B
	I_{15}: Occupancy	Ratio of passenger-kilometres travelled to seat-kilometres available	B
	I_{16}: Quality of service	Service of the level required	B
	I_{17}: Functional diversity	Possibility to choose service type and operator	B
	I_{18}: Service accessibility	Seamless travel	B
Environmental (D_4)	I_{19}: Climate change emission	Emission of all types affecting climate change	C
	I_{20}: Other air pollution	Air pollutants from road transport	C
	I_{21}: Resource efficiency	Using the Earth's limited resources in a sustainable manner while minimizing impacts on the environment	C
	I_{22}: Usage of fossil fuels	Percentage of alternative fuel vehicles in the fleet	C
	I_{23}: Land usage	Space used for stations and parking	C
	I_{24}: Energy consumption	Energy and fossil fuels consumed	C

2.3. Multiple-criteria decision making in public transport

Public transport system evaluation requires a wide range of indicators. As was mentioned before, they are of different nature so hardly assessable. Moreover public transport planning process involves various interest groups, participants and stakeholders. Public transport projects could be evaluated by single-criteria cost/benefit analysis (CBA) properly enough, however, it is not the best choice for assessing qualitative contexts such as social or political view, since the financial equivalence measures may not necessarily represent such opinion adequately (Shang *et al.*, 2004). The need to take into account the indicators assigned not only to system performance measurement but also to economic, environmental and social dimensions, public transport projects are characterized as well suited to multiple-criteria decision making (MCDM).

Multi-criteria analysis (MCA) or multi-criteria decision making (MCDM) is a type of tool that allows decision makers to go beyond single-criterion approaches that often fall short in environmental and urban planning challenges and to include a wide range of criteria. Over 70 techniques were developed, while the most popular use in the transport sector, the methods with multi-attributes, such as (AHP, MAUT, MAVT, SMART, SMARTER, VISA) and methods of classification (PROMETHEE, ELECTRE, TOPSIS) (Boujelbene and Derbel, 2015; Macharis *et al*., 2009; Friedrich *et al*., 2016). Whereas public transport projects' goals are usually not strictly defined (for example, in this case the main goal of the research is to find the appropriate STS to PMD integration model which would ensure mobility needs herewith distributing the resources in most efficient way), thus they can be named as fuzzy. Moreover, the special transportation service integration problem could be assigned to mobility management, public transport policy and public transport fields, therefore interests coordination is of essential importance. In the scope of this paper the main goal is to rank the indicators selected and combine it with finding the most efficient alternative of integration the special transportation service to people with movement disorders. According to all circumstances and constraints listed below, the combination of two approaches was selected – fuzzy Fuzzy Analytic Hierarchy Process (F-AHP) and and Fuzzy Technique for Order Preference by Similarity to Ideal Solution (F-TOPSIS). The combination of two approaches mentioned was successfully applied in previous studies (Sun, 2010; Bhutia and Phipon, 2012; Berdie *et al*., 2017; Aktan and Tosun, 2013). AHP is a structured technique for organizing and analyzing complex decisions. Different from classical set theory, fuzzy set theory permits the gradual assessment of the membership of elements in relation to a set (described using a membership function) (Kubler *et al*., 2016). To deal with uncertainty and vagueness in decision making process, the comparison ratios as triangular fuzzy number can be expressed (Qu *et al*., 2017). In the second phase of evaluation F-TOPSIS technique is applied. TOPSIS technique is used to choose the best alternative proposed, which is the one that is closest to the positive ideal solution (solution that maximizes the benefit criteria and minimizes cost criteria) and farthest to negative ideal solution (wise versa). The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers (Kabir and Hasin, 2012). As a result, ranking of the options is obtained. The alternative with highest closeness coefficient represents the best alternative (Sodhi and Prabhakar, 2012).

3. Methodology

3.1. Research framework

The objective of this research is to select the most appropriate special transportation service to people with movement disorders integration model in the context of existing urban public transport system. According to previous studies where integration models were formed, further research is based on two steps. Firstly, the international publications on special transportation services to people with movement disorders and sustainable public transport development were considered in order to select the evaluation indicators (mentioned in previous chapter). Secondly, the experts were invited to make a pair-wise comparison of selected indicators and further the pair-wise comparison matrix was constructed. Fuzzy weight of each indicator can be set. Then the experts were asked to compare each indicator against each alternative. The best option for the special transportation service to people with movement disorders integration is chosen as a result. The detailed research framework is submitted in Figure 2.

The following sections present the detailed explanation of techniques applied.

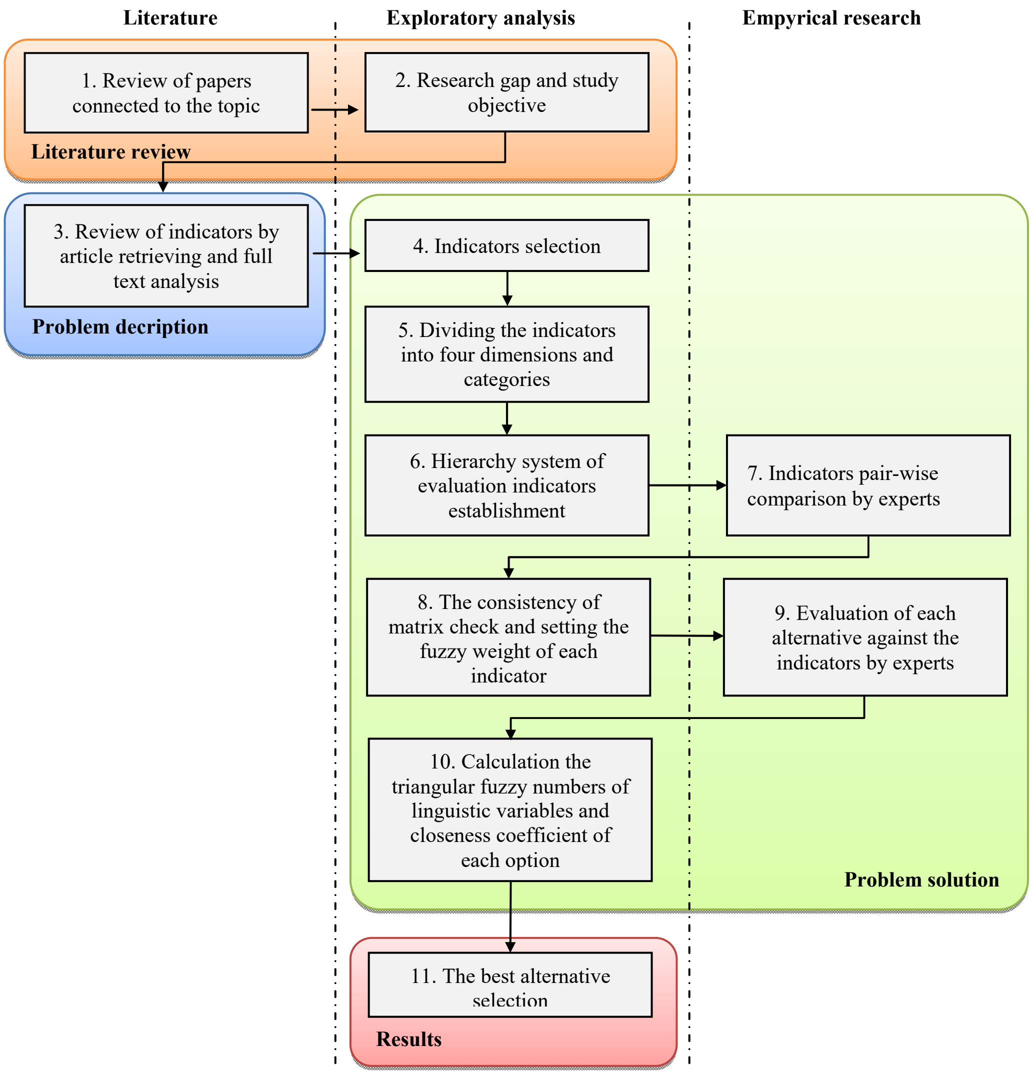

Figure 2. Proposed framework for evaluation of the alternatives of the special transportation services for people with movement disorders

3.2. Fundamental knowledge

F-AHP. Fuzzy set is a class of objects with a continuum of grades of membership ranging between zero and one (Zadeh, 1975). A triangular fuzzy number (TriFN) is represented as a triplet $\widetilde{M} = (m_1, m_2, m_3)$ (Qu). The membership function of TriFN $\widetilde{M}$ is given by:

$$(x) = \begin{cases} 0, x < m_1 \\ (x - m_1)/(m_2 - m_1), m_1 \le x \le m_2 \\ (m_3 - x)/(m_3 - m_2) \quad m_2 \le x \le m_3 \\ 0, x > m_3 \end{cases}. \quad (1)$$

The basic arithmetic operations can be made on TriFN are as follows:

(1) Addition of two TriFN:

$$\tilde{m} \oplus \tilde{n} = (m_1 + n_1, m_2 + n_2, m_3 + n_3), m_1 \ge 0, n_1 \ge 0.$$

(2) Subtraction of two TriFN:

$$\tilde{m}(-)\tilde{n} = (m_1 - n_1, m_2 - n_2, m_3 - n_3), m_1 \ge 0, n_1 \ge 0.$$

(3) Multiplication of two TriFN:

$\tilde{m} \otimes \tilde{n} = (m_1 \times n_1, m_2 \times n_2, m_3 \times n_3), m_1 \geq 0, n_1 \geq 0.$

(4) Division of two TriFN:

$\tilde{m}(/)\tilde{n} = (m_1 / n_1, m_2 / n_2, m_3 / n_3), m_1 \geq 0, n_1 \geq 0.$

(5) Inverse of a TriFN:

$\tilde{m}^{(-1)} = (1/m_3, 1/m_2, 1/m_1).$

The distance between two TriFN can be calculated as follows:

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2]}\,. \quad (2)$$

Linguistic variables applied in the evaluation are used to express the importance of one indicator against the other doing pair-wise comparison and rating specific option against each indicator. Linguistic variables are adapted from Abdulah and Najib (2014) and presented in Tables 4 and 5.

Table 4. Fuzzy number preference scale

Fuzzy number	Linguistic variable	TriFN
$\tilde{9}$	Absolutely important	(7,9,9)
$\tilde{7}$	Rather important	(5,7,9)
$\tilde{5}$	Essentially important	(3,5,7)
$\tilde{3}$	Weakly important	(1,3,5)
$\tilde{1}$	Equally important	(1,1,3)
$\tilde{1}^{-1}$	Equally less important	(1/3,1,1)
$\tilde{3}^{-1}$	Weakly less important	(1/5,1/3,1)
$\tilde{5}^{-1}$	Essentially less important	(1/7,1/5,1/3)
$\tilde{7}^{-1}$	Rather less important	(1/9,1/7,1/5)
$\tilde{9}^{-1}$	Absolutely less important	(1/9,1/9,1/7)
$\tilde{2}, \tilde{4}, \tilde{6}, \tilde{8}, \tilde{2}^{-1}, \tilde{4}^{-1}, \tilde{6}^{-1}, \tilde{8}^{-1}$	Medium value of two adjacent triangular fuzzy numbers	

Table 5. Linguistic variables for option ratings

Linguistic variable	Membership function
Very poor (VP)	(1, 1, 3)
Poor (P)	(1, 3, 5)
Fair (F)	(3, 5, 7)
Good (G)	(5, 7, 9)
Very good (G)	(7, 9, 9)

Further steps of application F-AHP to aggregate the weight of each criteria:

Step 1: Establishing the hierarchy system of evaluation indicators.

Step 2: Construct pairwise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system. Decision makers should assign linguistic variables to pair-wise comparisons by determining the one stronger compared to another.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix}, \quad (3)$$

where

$$\tilde{a}_{ij} = \begin{cases} \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}, when\ i\ is\ more\ important\ than\ j \\ 1, when\ i = j \\ \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, when\ i\ is\ less\ important\ than\ j \end{cases}.$$

Step 3: Computing consistency index (CI) and consistency ratio (CR).

To ensure the consistency of the constructed matrix, we should first convert a fuzzy number $\tilde{M}$ (*l, m, n*) to a crisp one by:

$$M_{-crisp} = (l + 4m + n)/6 \quad (4)$$

Then, consistency should be checked by CI and CR by:

$$CI = (\lambda_{max} - n)/(n - 1) \quad (5)$$

$$CR = CI/RI \quad (6)$$

where RI stands for random index and can be obtained from Table 6 (Qu *et al.,* 2017).

When CR ≤ 0.1, the matrix is right with acceptable consistency. Otherwise, when CR > 0.1, it should be reassessed.

Table 6. Random index *RI (n)*

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Step 4: Use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by Hsieh *et al.* (2004) as follows:

$$\tilde{r}_i = \sqrt[n]{(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \cdots \otimes \tilde{a}_{ij})}, \quad (7)$$

$$\tilde{\omega}_i = \tilde{r}_i \otimes (\tilde{r}_1 \oplus \tilde{r}_2 \oplus \cdots \oplus \tilde{r}_n)^{-1}.$$

Here $\tilde{a}_{ij}$ refers to fuzzy comparison value of indicator i to j, $\tilde{r}_i$ stands for the geometric mean of fuzzy comparison value of indicator *i* to each indicator *j*, (*j* = 1, 2, …, *n*); $\tilde{\omega}_i$ is the fuzzy weight of the *i*th indicator, being indicated by a TriFN, $\tilde{\omega}_i = (\omega_{i1}, \omega_{i2}, \omega_{i3})$, with ω_{i1}, ω_{i2}, ω_{i3} representing its lower, medium, and upper values.

The final fuzzy weight (FFW_i) of indicator I_i is obtained according to formula:

$$FFW_i = \tilde{\omega}_i \times \omega_{D_i} \quad (8)$$

where FFW_i ir ω_{D_i} represent the final fuzzy weight of indicator I_i and weight of dimension D_i to which the indicator belongs.

F-TOPSIS. In this phase we propose to evaluate the options against each criterion weighted. The basic idea of TOPSIS is: suppose there is a positive ideal solution (PIS) and a negative ideal solution (NIS) and we have to find the alternative that should have the shortest distance from the PIS and the longest distance from the NIS. The merit of using a fuzzy approach is to assign the relative importance of attributes using fuzzy numbers instead of precise numbers for suiting the real world in fuzzy environment (Sun, 2010).

Step 1: Construct and normalize the fuzzy decision matrix. The fuzzy decision matrix for the options and the indicators can be established as follows:

$$\widetilde{D} = \begin{array}{c} \\ I_1 \\ I_2 \\ \vdots \\ I_u \end{array} \begin{array}{c} \begin{array}{cccc} O_1 & O_2 & \cdots & O_v \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \tilde{x}_{uv} & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (9)$$

$$\tilde{x}_{uv} = \frac{1}{K} \sum_{k=1}^{K} \tilde{x}_{uv}^{k} \quad (10)$$

where $\tilde{x}_{uv}$ refers to the performance rating of option O_v with respect to indicator I_u, given by decision maker *k* and $\tilde{x}_{uv}^{k} = (a_{uv}^{k}, b_{uv}^{k}, c_{uv}^{k})$.

Step 2: Normalize the fuzzy decision matrix.

The normalized fuzzy decision matrix is given by:

$$\tilde{R} = [\tilde{r}_{uv}]_{m \times n}, u = 1, 2, \cdots, m; v = 1, 2, \cdots, n \quad (11)$$

where

$$\tilde{r}_{uv} = \left(\frac{a_{uv}}{c_v^*}, \frac{b_{uv}}{c_v^*}, \frac{c_{uv}}{c_v^*} \right), c_v^* = \max_u c_{uv} \text{ (benefit criterion)}$$

$\tilde{r}_{uv} = \left(\frac{a_v^-}{c_{uv}}, \frac{a_v^-}{b_{uv}}, \frac{a_v^-}{a_{uv}}\right), a_v^- = \min_u a_{uv}$ (cost criterion)

Step 3: Calculate the weighted normalized matrix.

$$\tilde{Q} = [\tilde{q}_{uv}]_{m\times n}, u = 1,2,\cdots,m;\ v = 1,2,\cdots,n;\ \tilde{q}_{uv} = \tilde{r}_{uv} \otimes \tilde{\omega}_u \quad (12)$$

Step 4: Calculate the fuzzy positive ideal solution (FPIS) and fuzzy negative ideal solution (FNIS).

$$S^* = (\tilde{q}_1^*, \tilde{q}_2^*, \cdots, \tilde{q}_v^*), \tilde{q}_v^* = max_u\{q_{uv}\}, u = 1,2,\cdots,m;\ v = 1,2,\cdots n \quad (13)$$

$$S^- = (\tilde{q}_1^-, \tilde{q}_2^-, \cdots, \tilde{q}_v^-), \tilde{q}_v^- = min_u\{q_{uv}\}, u = 1,2,\cdots,m;\ v = 1,2,\cdots n \quad (14)$$

Step 5: Calculate the distance of each option to FPIS (d_v^*) and FNIS (d_v^-).

$$d_v^* = \sum_{u=1}^{m} d_q(\tilde{q}_{uv}, \tilde{q}_v^*), v = 1,2,\cdots,n \quad (15)$$

$$d_v^- = \sum_{u=1}^{m} d_q(\tilde{q}_{uv}, \tilde{q}_v^-), v = 1,2,\cdots,n \quad (16)$$

$$d_q(a,b) = \sqrt{\frac{1}{3}\sum_{u=1}^{m}(a_u - b_u)^2} \quad (17)$$

Step 6: Compute the closeness coefficient CC_V for each option.

$$CC_v = \frac{d_v^-}{d_v^- + d_v^*}, v = 1,2,\cdots,n \quad (18)$$

Step 7: Rank the options.
Different options are ranked according to CC_V in decreasing order.

4. Case Study

Background information

The PT network in Vilnius is operated only by municipal carrier exploiting buses and trolleybuses. The situation should change significantly after the entrance of private carriers at the beginning of the next year. The management model of Vilnius PT could be assigned to typical with municipality responsible for strategic decisions, Transport Authority responsible for operational planning and the operator which acts only as a carrier.

A study of the assessment of the urban PT accessibility for people with movement disorders in Vilnius was conducted in the preview researches of the authors. The research was implemented in two steps: general urban PT accessibility assessment and the assessment of special decisions required to meet the needs of PMD. The final assessment was carried-out in accordance with Methodology for Describing the Accessibility of Transport in Europe (MEDIATE).

PT accessibility assessment according to Public Transport Accessibility Level (PTAL) methodology revealed that the best developed public transport network is in the centre of Vilnius. It is natural because the biggest concentration of households, work places and other centres of attraction are in the centre. Other large area wards are of uneven distribution in regards to people density, therefore the total PTAL level is lower than it is in the separate areas in the same ward. Traditional public transport cannot function effectively in low density areas, therefore, alternative services should be created. Those households do not have private cars and live in poor accessible areas, are socially isolated and face discomfort to plan their trips.

The information about public transport adaptation to the needs of PMD was collected from Vilnius Transport Authority database and experts. It can clearly be seen that major needs are unsatisfied. Accordingly, it could hardly be stated that Vilnius is partly accessible for people with disability.

The results of evaluation made on the basis of MEDIATE public transport accessibility measurement methodology lead to the following conclusions - the PT policy in the best case is systematic, but isolated to specific population groups, or selected travel chain elements, modes or parts of the transport system.

Weights determination by means of F-AHP

According to AHP methodology, the maximum number of indicators to compare is 15, therefore, the decision to divide them was made as shown in Figure 3.

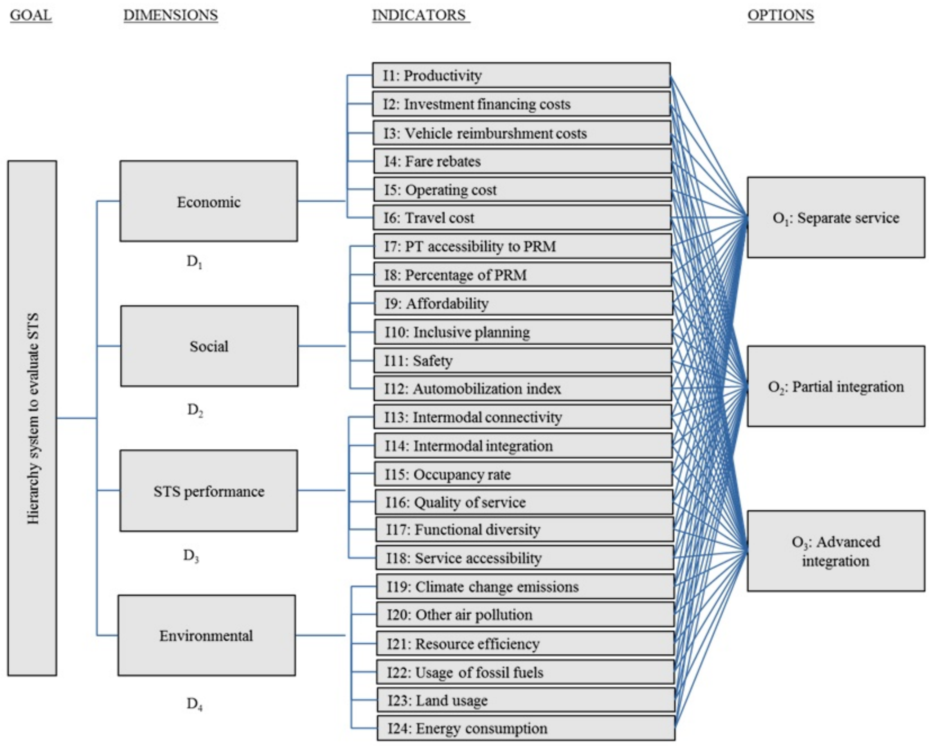

Figure 3. Hierarchy system to evaluate special transportation services to people with movement disorders

Whereat the hierarchy system of evaluation indicators is established, assignment of linguistic variables and AHP matrixes construction follows. Then pair-wise comparison matrix is constructed and the matrix must pass consistency check by calculating consistency index and consistency ratio. According to methodology proposed by Qu *et al.* (2017) and with the aid of R open source programming language and software environment, fuzzy weight of each indicator is obtained as a result (Table 7).

Table 7. Fuzzy weights of indicators I_1-I_{24}

Dimensions (weight)	Indicator	Fuzzy Weight	Final Fuzzy Weight
Economic (0.3)	I_1	(0.080; 0.189; 0.462)	(0.024; 0.057; 0.139)
	I_2	(0.055; 0.146; 0.327)	(0.017; 0.044; 0.098)
	I_3	(0.016; 0.033; 0.070)	(0.005; 0.010; 0.021)
	I_4	(0.022; 0.044; 0.113)	(0.007; 0.013; 0.034)
	I_5	(0.141; 0.333; 0.728)	(0.042; 0.100; 0.218)
	I_6	(0.115; 0.255; 0.635)	(0.034; 0.076; 0.190)
Environmental (0.1)	I_7	(0.189; 0.402; 0.851)	(0.057; 0.121; 0.255)
	I_8	(0.037; 0.089; 0.235)	(0.011; 0.027; 0.071)
	I_9	(0.079; 0.193; 0.452)	(0.024; 0.058; 0.135)
	I_{10}	(0.096; 0.238; 0.538)	(0.029; 0.071; 0.161)
	I_{11}	(0.025; 0.049; 0.128)	(0.008; 0.015; 0.038)
	I_{12}	(0.015; 0.029; 0.063)	(0.005; 0.009; 0.019)
STS for PMD performance (0.3)	I_{13}	(0.019; 0.032; 0.077)	(0.006; 0.010; 0.023)
	I_{14}	(0.015; 0.029; 0.056)	(0.005; 0.009; 0.017)
	I_{15}	(0.092; 0.194; 0.487)	(0.028; 0.058; 0.146)
	I_{16}	(0.183; 0.409; 0.822)	(0.055; 0.123; 0.247)
	I_{17}	(0.053; 0.116; 0.281)	(0.016; 0.035; 0.084)
	I_{18}	(0.093; 0.220; 0.479)	(0.028; 0.066; 0.144)
Social (0.3)	I_{19}	(0.040; 0.086; 0.245)	(0.004; 0.009; 0.025)
	I_{20}	(0.028; 0.071; 0.163)	(0.003; 0.007; 0.016)
	I_{21}	(0.170; 0.407; 0.898)	(0.017; 0.041; 0.090)
	I_{22}	(0.062; 0.148; 0.410)	(0.006; 0.015; 0.041)
	I_{23}	(0.015; 0.029; 0.072)	(0.002; 0.003; 0.007)
	I_{24}	(0.101; 0.258; 0.621)	(0.010; 0.026; 0.062)

Comparison of different options using F-TOPSIS

At this stage different options have to be compared using selected indicators and F-TOPSIS. Firstly, it is necessary to evaluate different options against each other. Secondly, linguistic variables are transformed to TriFNs (Triangular fuzzy number). Thirdly, F-TOPSIS is applied to calculate the closeness coefficient (CC_V) of each option (see Table 8). The one with the highest CC_V is chosen as the best special transportation service to people with movement disorders solution.

Table 8. CCV of the five options

	O_1	O_2	O_3
CCv	0.302	0.4002	0.446

Different options are ranked according to their CC_V in decreasing order (O_3>O_2>O_1). Therefore, O_3: advanced integration is the best STS for PMD option, while O_1: separate service is the worst one.

5. Conclusions

White Paper on Transport Policy of 2011 make statement that modern transport system should be sustainable from an economic, social as well as environmental point of view. Despite the existence of a huge number of indicators for sustainable mobility measurement, there is no indicators' system for special transportation services (STS) for people with movement disorders (PMD) evaluation.

In research the indicators of special transportation services are set based on wide literature review and proposed framework for evaluation of the alternatives of the STS for PMD. In the second step the decision makers were asked to complete the pair-wise comparison in each of four dimensions that were separated during the process of indicators selection. The weight for each indicator was settled by means of F-AHP. In third step decision makers were asked to compare indicators according to their impact to the different models performance indicators (on the basis F-TOPSIS).

A case study of Vilnius is provided to demonstrate the application of proposed evaluation algorithm. The case study revealed that advanced integration would be the best solution of special transportation service for people with reduced mobility integration task.

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