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Indicators as a Tool for Assessing the Level of Sustainable Urban Freight Logistics

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ABSTRACT

Urban transport system planning has been moving towards sustainability in recent years, and the concept of urban freight logistics is an integral part of this planning. Urban freight logistics involves many stakeholders that participate in its operation and should be considered in the system planning process. The paper presents one of the approaches to the methodology for the selection of key indicators suitable for the evaluation and monitoring of a sustainable system of urban freight logistics in such a way that it reflects as much as possible the needs of all involved stakeholders. This is done by applying the selected method of multi-criteria analysis with the involvement of various urban freight logistics stakeholders. Based on the proposed methodology, the paper defines significant indicators that can be considered for further evaluation of the level of a sustainable urban freight logistics system. In addition to the possibilities of further development of this methodology, the application of determined significant indicators for calculating the proposed index of sustainable urban freight logistics is discussed. The proposed procedure can be implemented in the preparatory steps in the framework of the creation of sustainable urban logistics plans (SULPs).

KEYWORDS

urban transport planning; sustainable urban freight logistics; urban freight transport; sustainable development indicators.

1. INTRODUCTION

Sustainable urban development is usually related to three basic pillars: environment, society and economy. These areas are interlinked, and transport plays an important role in all aspects of sustainable development. From this perspective, it is a priority at the level of research teams and individual researchers, governments and international cooperation to find a solution in the field of sustainability in cities and regions that would also lead to the improvement of the environment and lives of people or to effective use of transport systems and natural resources. However, this approach is very demanding due to the complexity and interconnection of individual systems and sub-systems. If targeting only such measures that would reduce the impact of transport on the environment, it is necessary also to consider other effects in other areas of sustainable development, i.e. how limiting these measures are for inhabitants and whether the measures are cost-effective.

The simplification of the complex issue of sustainability is a way to manage indicators effectively in order to achieve the goals set at the beginning of creating sustainable development strategies. The use of a set of indicators is proposed, e.g., by Litmann, who argues that one indicator cannot be as effective as a complex system of indicators, which enables a better evaluation of goals [1]. As can be seen, there is no consensus in terms of the definition of sustainable urban transport; therefore, there are various approaches to collecting and defining indicators that enable its effective assessment. Nevertheless, there is an increasing demand for new and more efficient tools for assessment, which could help in decision-making processes and would be able to respond to new challenges concerning climate change and thus also sustainable urban development.

It is similar in the case of evaluating the sustainability of urban freight logistics, which is an integral part of the urban transport system. Urban freight logistics involve not only the movement of goods, but also other operations generated by freight activity in urban areas. The fact is that freight logistics impact multiple stakeholders, and they are mostly not taken into consideration when planners and decision makers look into potential solutions to the issues generated by freight operations.

Studies and projects by many authors in the given area have over the years presented their own approaches to the compilation of sets of key indicators for monitoring and assessing the sustainability level of urban freight logistics. The aim of this paper was to create a new approach to the methodology for the selection of suitable key performance indicators for the evaluation and monitoring of a sustainable system of urban freight logistics in such a way that it reflects the needs of all involved stakeholders as much as possible. This means, in particular, entities in the area of freight transport planning in the city, authorities with decision-making powers, stakeholders directly involved in urban logistics etc. At the same time, key indicators were consulted with selected experts so that the above general pillars of sustainable development are also taken into consideration.

The paper is structured as follows: Section 2 presents a review on the main frameworks and approaches to develop sets of sustainable indicators in the area of urban freight logistics. Section 3 presents the proposed methodology and the development of key performance indicators that are evaluated based on the AHP methodology, which is applied in Section 4. Finally, the discussion about the possibilities of using the proposed methodology and the outputs can be found in Section 5, and the conclusions are summarised in Section 6.

2. SUSTAINABLE URBAN FREIGHT LOGISTICS INDICATORS APPROACHES

To be able to monitor the progress in transport sustainability, it is necessary to determine the vision, goals and target groups for cities, as well as to create a tool based on sustainability assessment that would provide feedback [2]. Evaluation is most commonly performed through indicators. Indicators are predefined data (usually of quantitative nature), which are used to monitor the progress in achieving a specific goal or a target value.

In this respect, there have been many studies and results of research projects have been published, dealing with the process of the evaluation of sustainable urban development in general, mainly on the basis of various assessment methods of the so-called sustainable mobility indicators. These indicators should help in decision-making processes when planning urban transport towards sustainability and also partially include indicators for urban freight logistics [3–5].

2.1 Measuring the sustainability of urban freight logistics and mobility development

Sustainable transport indicators have become common elements in planning transport and decision-making in the area of strategies and transport policies, mainly in the EU [4]. Within the EU research project entitled "ASSESS", indicators for EU transport policy assessment were proposed for the period 2010–2020 [5]. These indicators form a solid basis for the assessment of sustainable urban mobility and freight logistics. Their great advantage is that they are well-measurable (data can be obtained mainly from statistical databases).

Within the EU project "SUMMA" (SUstainable Mobility, policy Measures and Assessment), a set of indicators was created for transport policy creators [6]. This approach was built on the integral description of the policy system and has contributed to understanding how a transport system can respond to policy and external factors changes.

The following *Table 1* provides an overview of some research resources, projects and strategies describing indicators for the assessment of the impact of sustainable urban transport and urban freight logistics or dealing with the methodology on how to use these indicators for assessment of sustainability measures connected with urban freight logistics system planning. In the analysed material, a total of 716 assessment indicators have been identified, with some of them being repeatedly or similarly mentioned in various other resources.

It shall be noted that the table concerns indicators in the field of urban transport in general. Various authors have been dealing with selected areas of transport within sustainable mobility, e.g. promotion of walking and cycling in cities [10], or only the indicators related to sustainable freight development in cities [12]. Other

Table 1 – Overview of selected resources concerning proposed indicators of sustainable urban transport and urban freight logistics

Resource	Authors	Number of indicators
Indicators to Assess the Sustainability of Transport Activities	Dobranskyte-Niskota et al., 2007 [7]	36
How to Monitor Sustainable Mobility in Cities? Literature Review in the Frame of Creating a Set of Sustainable Mobility Indicators	Gillis et al., 2016 [8]	20
Strategies and Measures for Sustainable Urban Transport Systems	Persia et al., 2016 [9]	53
SUMMA (SUstainable Mobility, policy Measures and Assessment)	RAND Europe et al., 2004 [6]	62
Measuring sustainability of transport in the city - development of an indicator-set	Toth-Szabo et al., 2011 [3]	83
Some use – Little influence? On the roles of indicators in European sustainable transport policy	Gudmundsson a Sorensen, 2013 [4]	20
Well Measured Developing Indicators for Comprehensive and Sustainable Transport Planning	Litmann, 2019 [1]	40
Creating Walkable and Bikeable Communities: A User Guide to Developing Pedestrian and Bicycle Master Plans	Roughton et al., 2012 [10]	29
New Approaches to Strategic Urban Transport Assessment	Hale, 2011 [11]	58
An indicator approach to sustainable urban freight transport	Rai et al., 2018 [12]	45
Sustainable urban mobility indicators: Policy versus practice in the case of Greek cities	Tafidis et al., 2017 [13]	75
The application of urban sustainability indicators - A comparison between various practices	Shen et al., 2011 [14]	115
Indicators and data collection methods on urban freight distribution: non-binding guidance documents on urban logistics: final report	Bossche et.al, 2017 [17]	80

authors analysed their proposed indicators from the perspective of sustainable urban development in relation to the impact of transport in general [7, 8, 13].

Sustainability in transport needs to be perceived as a complex issue reflecting nearly all areas and factors influencing the transport system. In particular, it is not necessary to approach the implementation of measures to increase sustainability in transport in general but also from the perspective of the individual participants in the transport system, whether it is carriers, customers, municipalities creating policy and strategies or a group of carriers. Touratier-Muller and Jaussaud [15] created a set of indicators for freight transport operators to assess the degree of sustainability of their urban freight logistics activities. This approach is interesting because it enables individual actors in city logistics to take a responsible approach to increasing the sustainability rate in cities on this basis (unlike the central approach of a methodology for city transport planners).

2.2 Frameworks for assessing the level of sustainable urban freight logistics

When creating frameworks for analysing the level of urban freight logistics sustainability, there is a need for indicators exclusive to urban freight logistics activities (Wolpert and Reuter, 2012) [16]. Within the studies and analyses dealing with sets of indicators for urban freight logistics, it has been observed that the methods for collecting data are not systematic, and different data sets therefore often cannot be compared with each other. Data describing urban freight logistics are often incompatible, which makes it difficult to compare observations between cities and activities at different times. One reason could be that different cities and countries do not collect data on urban freight logistics on a regular basis (van den Bossche et al., 2017) [17]. There is therefore a need to establish a set of common key performance indicators and bring a unique methodology on how to implement these KPIs in the process of sustainable urban freight logistics system planning.

Research by van den Bossche et. al [17] determines the common indicators needed in an urban freight transport context and data collection methods to collect these indicators. It also finds that stakeholders are often unaware of the usefulness of the urban freight transport indicators they commonly use. Thus, there is a need to collect and analyse data in a more focused way, and then use results to affect policy and decision-making.

Foltynski designed a methodical managerial tool for urban freight logistics management that includes working with indicators [18]. The author's processes extend and complement the sustainable urban logistics plan (SULP) as a strategic document. The sustainable urban logistics plan (SULP) is a tool to support policy focused on a large number of small and medium-sized cities in Europe that may not have the resources for major policy assessment and modelling of sustainable urban logistics [19].

Another useful tool is a directly supporting online tool for cities to be able to assess the impacts of their activities in the field of urban freight logistics on sustainable urban development. The above-mentioned tool is an output of the European project NOVELOG [20]. An overview of the possibilities and evaluation of this tool is addressed, for example, by Matusiewicz [21].

The paper presents a methodology for selecting important indicators of sustainable development in urban freight logistics which can be used for assessing the level of urban freight logistics system sustainability. For this purpose, AHP tools are used. A similar approach can be seen in the works of other authors, e.g. Nathanail et al., who use the AHP method and set criteria to determine the effective location of a consolidation centre in a specific urban area [22].

3. METHODOLOGY

There are diverse versions of potential indicators and their metrics for describing sustainable transport strategies or subsystems. An important criterion for these indicators is that they should clearly and concisely define all links to sustainable development goals. There can be different types of indicators:

- Quantitative and qualitative data;
- Individual indicators (e.g. individual views in questionnaire surveys);
- Ratios;
- Relative indicators.

Based on the research of publications concerning the relevance of the identified indicators to the possibility of effective assessment of the development of a given urban freight logistics system, assessment indicators are proposed. Specifically, these are indicators that can be quantified so that they can be used for further research. In designing indicators, the authors considered the pillars of sustainable development. For this purpose, they built an expert panel of assessors who were consulted on the suitability of the proposed indicators. The expert team tried to integrate as many indicators as possible that could be used in decision-making processes within the framework of sustainable development to the maximum possible extent.

For the subsequent hierarchical process, it is necessary to assign the proposed indicators to individual scenarios (strategies) that best reflect the goals of city management leading to sustainable development. In this context, the authors have proposed the following strategies that should be considered by city management in decision-making processes in various areas (e.g. transport planning):

1) *Reduction of environmental impact* – Strategies including the processes of transport and urban planning in order to improve the environment in cities.
2) *Effective urban and spatial planning* – Strategies of effective urban and spatial planning include the processes aimed at reducing the impacts of freight transport on the quality of life of inhabitants and to increase the effectiveness of the city logistics system functioning.
3) *Enhancing safety* – Strategies including the processes of transport and spatial planning aimed at enhancing safety of vulnerable participants in the urban freight logistics.
4) *Prosperity of region* – Social-economic strategies aimed at increasing the prosperity of a given region including the processes related to the development of individual economic sectors of the region.
5) *Economic sustainability* – Support of an economically sustainable system of urban freight logistics by cities and creation of city logistics infrastructure with regard to the effectiveness of incurred costs.

The definition and structure of the set of strategies was developed on the basis of the well-known goals of sustainable development. Indicators were assigned to the strategies proposed in this way, which correlate with the results of other authors dealing with this issue. *Table 2* contains a list of these indicators with their description and the sources, in which the indicator is similarly considered for the evaluation of a given or similar sustainable development strategy. The last column of the table represents the influence of the indicator on sustainable development: (+) if an increase in the value of the indicator enhances positive development or (-) if the decrease in the value of the indicator enhances negative development. The influence of the indicators was

Table 2 – Indicators by individual strategies for the purposes of determining weights

ID	Indicator	Description	Sources	Unit	Influence
Reduction of Environmental Impact					
1C1	Energy consumption in logistic facilities	The share of energy consumption in warehouses and other logistic facilities per m² of their area	[6], [14]	kWh/m²	-
1C2	Arable land take rate for logistic projects	The area of arable land intended for logistic projects in the region in a given year	[6], [14]	km²/year	-
1C3	Logistic entities with the ISO 14001 certificate of environmental management	The share of logistic entities with the ISO 14001 certificate of environmental management in the overall number of logistic entities in the region	[15]	%	+
1C4	Share of alternative fuels in the overall fuel consumption of low-emission and zero-emission vehicles	The share of alternative fuels in the overall fuel consumption of low-emission and zero-emission vehicles within urban freight logistics of a given territory	[3], [4], [6], [7], [12], [14], [17], [20]	%	+
1C5	Driving performance of low-emission and zero-emission vehicles	The share of driving performance of low-emission and zero-emission vehicles in the overall driving performance of vehicles within urban freight logistics	[6], [9], [12], [13], [18], [20]	%	+
1C6	Share of vehicles with conventional combustion engines meeting the strictest EURO standards	The share of vehicles with conventional combustion engines meeting the strictest EURO standards in the overall number of trucks belonging to logistic entities in a given region	[3], [4], [6], [7], [12], [14], [17], [20]	%	+
1C7	Volume of greenhouse gases produced by trucks	The share of average volume of greenhouse gases released in the air by individual categories of trucks per km travelled within their driving performance	[3], [4], [6], [7], [12], [14], [17], [20]	gCO_2/km	-
1C8	Emissions generated by logistic entities	The share of emissions generated by logistic entities within a given territory or their share in the overall logistic outputs	[18], [21]	gCO_2/year	-
1C9	Share of low-emission and zero-emission vehicles in the overall number of vehicles	The share of low-emission and zero-emission vehicles in the overall number of vehicles participating in urban freight logistics in a given region	[6], [7], [9], [12], [13], [14] [17], [20]	%	+
Effective Urban and Spatial Planning					
2C1	Noise level generated by the operation of logistic facilities	Noise level generated by the operation of logistic facilities in an industrial area adjacent to residential areas of cities	[18]	dB	-
2C2	Share of freight transport in the overall intensity of transport in urban road network	The share of intra-city and transit freight transport on backbone roads in the overall intensity of transport.	[3], [4], [6], [7], [12], [13], [14], [17], [18], [20]	%	-
2C3	Number of places for picking up shipments	The number of automatic and manual dispensing points within parcel shipping services in the city centre or in a given territory. Again, it is suitable to consider rather a ratio indicator.	[9], [14], [18]	number/km²	+
2C4	Area of industrial premises	Area of industrial premises in the cadastral area of a city in km² or the share of area of industrial premises in the overall area of the city.	[6], [14]	%	-
2C5	Number of parking places for supply within city centres	The number of parking places for supply within city centres (ramp, emergency lane, parking place etc.) or it is recommendable to introduce some ratio indicator (e.g. the ratio of the number of parking places for supply to the number of shops for supply).	[3], [6], [12], [18]	Number of parking places	neutral
2C6	Number of distribution and logistics centres	The number of distribution and logistics centres in a given area, or it is suitable to consider a more relevant ratio indicator.	[9], [18]	Number	-
2C7	Average distance of the logistic centre and delivery points in city centres	The average distance of logistic/storage/distribution centres and delivery points in city centres.	[17], [18], [21]	km	-
2C8	Illegal parking of supply vehicles	The share of illegal parking of supply vehicles in the total number of parking places for trucks within a monitored area.	[9]	%	-
2C9	Average number of tonnes of goods transported over a distance of 1 km	Average number of tonnes of goods transported over a distance of 1 km within the urban freight logistics system.	[17], [20]	tkm	+
Enhancing Safety					
3C1	Number of speed indicators on the road network	Number of speed indicators on the main roads in a given area or on the whole road network in a given territory	[4], [7], [9], [13], [17]	number	+
3C2	Monitoring of vehicle speed	The share of the length of the transport network with a vehicle speed monitoring device in km in the overall length of the road network (%).	[4], [7], [9], [12] [13], [17]	%	+
3C3	Number of truck drivers tested positively for alcohol and other drugs	Number of truck drivers tested positively for alcohol and other drugs in the overall number of drivers participating in city logistics.	[15]	%	-
3C4	Number of accidents caused by truck drivers	Number of accidents caused by truck drivers within urban freight logistics concerning a given territory	[7], [13], [15]	number/year	-
3C5	Number of km in transport network intended for freight transport with noise level exceeding 55 dB	Number of km in transport network intended for freight transport in residential areas with noise level exceeding 55 dB (can be determined separately for day and night).	[3], [4], [6], [7], [9], [12], [17]	km	+
3C6	Hazardous materials transported within regular urban freight logistics	The volume of hazardous materials transported within urban freight logistics of a given territory in the monitored period.	[15], [20], [21]	t/year	-
3C7	Number of serious accidents caused by truck drivers	Share of serious accidents with injuries or death caused by truck drivers in the region in the total number of accidents.	[15], [18]	%	-
3C8	Number of dead or injured employees of logistic entities	Number of employees of logistic entities injured or killed during the performance of their job within a monitored period	[12], [15]	number/year	-
Prosperity of Region					
4C1	Number of job positions in urban freight logistics	The share of job positions urban freight logistics in the region in the absolute employment rate in the region.	[6], [7], [9], [12]	%	+
4C2	Level of strategic planning at the level of municipalities	The level of strategic planning and data collection from individual logistics entities by municipality management.	[9], [17]	0-5 point scale	+
4C3	Number of registered entities participating in urban freight logistics	Number of registered entities participating in the processes of urban freight logistics in the region. Ratio indicators can be considered.	[9], [17]	number	neutral
4C4	Average monthly wages in the logistics sector	Average monthly wage in the logistics sector in a given region and year.	[6], [12], [20]	CZK	+
4C5	Annual change in the number of job positions in the logistics sector	Increase in the number of job positions in the logistics sector in a given year within the city	[6], [20]	number of job positions / year	+
4C6	Customer satisfaction with services	Customer satisfaction with services provided within urban freight logistics determined, e.g. based on survey and expressed in percentage.	[12], [15]	%	+
4C7	Share of logistic services in total city income	Share of income from logistic services in total city income (in the relevant currency) in the monitored period.	[6], [9], [20]	%	+
4C8	Difference of total average wage and average wage in the logistics sector	Difference of the total average wage in the region and average wage in the logistics sector in the region in the monitored period.	[6], [9], [20]	CZK	-
Economic Sustainability					
5C1	Average fuel consumption of trucks with conventional engines	Average fuel consumption of trucks with conventional engines operated within urban freight logistics.	[3], [4], [6], [7], [9], [12], [15]	l/100km	-
5C2	Financing the construction of the infrastructure of sustainable urban freight logistics	The volume of funds spent by the public sector on the construction of infrastructure for sustainable urban freight logistics in the region within a monitored period or a percentage share in the total GDP of the region.	[6], [17], [20]	CZK/year or %	+
5C3	Warehouse capacity	The capacity of all warehouses intended for urban freight logistics located in the city in the monitored period.	[14], [15], [17]	t/year	+
5C4	Transport performance in intermodal transport	Transport performance within intermodal transport, which is a part of urban freight logistics in the monitored region and given year	[6], [9], [20]	tkm/year	+
5C5	Reimbursements/subsidies within urban freight logistics	The amount of funds provided by the public sector to improve the infrastructure and system of urban freight logistics in a given year and region.	[12], [14], [17]	CZK/year or %	+
5C6	Average space utilisation in storage and distribution centres	Average space utilisation in storage and distribution centres of city logistics in the region.	[15], [17]	%	+
5C7	Freight transport performance	Freight transport performance within city logistics in the region within the monitored period.	[7], [8], [12], [15], [20]	tkm/year	neutral
5C8	Density of transport network intended for urban freight logistics	The share of the length of transport network intended for routes within urban freight logistics and the total city area.	[6], [9], [12], [20]	km/km²	neutral
5C9	Delivery time slots	The total delivery time slots in a day/week.	[12], [15], [17]	hours	+

compared with similar indicators mentioned in the studies by domestic and foreign authors who determined this influence in the same way.

The list of indicators created in this way is a proposal based on a literature review, i.e. it contains indicators that are used by other authors in similar way in their works (*Table 1* shows the relationship of the given indicator to the works of other authors). This proposal of the indicators forms the basis for their prioritisation and determination of key indicators for the needs of urban freight transport system planning and monitoring, which is further implemented with the help of the selected AHP method.

The authors performed the analysis of mathematical methods of multicriteria decision analysis related to determining the weights of the indicators [23]. Based on this analysis, it was decided that for the purposes of the identification of the key indicators for assessing the sustainability of freight logistics development in cities and their immediate surroundings, the method of quantitative pairwise comparison of indicators will be applied – the so-called Saaty method. By applying this method, the importance of the individual indicators of sustainable urban freight logistics contained in the given strategies can be determined according to their respective weight value. The initial step is to define the relationship between each pair of factors where the level of significance is determined in the range of 1–9 according to set rules [23]: if the *i*-th and *j*-th factors are equal, s_{ij}=1; if the *i*-th criterion is weakly preferred over the *j*-th, s_{ij}=3; if the *i*-th criterion is preferred strongly over the *j*-th, s_{ij}=5; with a very strong preference of the *i*-th criterion, s_{ij}=7; with the absolute preference of the *i*-th criterion, s_{ij}=9. If the *j*-th criterion is preferred over the *i*-th, inverse values are entered in the Saaty matrix (s_{ij}=1/3 for weak preference, s_{ij}=1/5 for strong preference etc.).

This indicates the basic characteristics of the Saaty matrix. Specifically, it is a square matrix $n \times n$ and reciprocal matrix, which means that $s_{ij}=1/s_{ij}$. The elements in the matrix represent the estimated shares of weights of the *i*-th and *j*-th criteria. The diagonal of the Saaty matrix always shows the value of 1 (each criterion is equivalent to itself).

Saaty [23] proposed several numerically very simple methods to estimate the weights. The vector of its values is marked as $\boldsymbol{v} = (v_1, v_2, \ldots, v_k)$. The most commonly used method of weight quantification is the normalised geometric mean of a row in the Saaty matrix. Therefore, this method is sometimes referred to as the "logarithmic least squares method".

A "priority vector", i.e. the normalised weight is calculated for each criterion using the geometric means of each row in the matrix divided by the sum of the geometric means of all criteria [24].

The geometric means of each row in the matrix *S* [21] is calculated as follows:

$$g_i = \sqrt[k]{\prod_{j=1}^{k} s_{ij}};\ ij=1,2,...,k \tag{1}$$

where:

g_i – geometric means;
s_{ij} – elements of the Saaty matrix;
$\prod$ – the product of the values of the elements in the Saaty matrix.

Normalised geometric means [23]:

$$v_i = \frac{g_i}{\sum_{i=1}^{k} g_i};\ i=1,2,...,k \tag{2}$$

where:

v_i – normalised geometric means;
g_i – geometric means;
$\sum$ – sum of the values of geometric means.

One of the conditions for determining the weights of the criteria using the Saaty method is sufficient quality of the Saaty matrix expressed by the consistency of the matrix. The elements in the Saaty matrix are usually not perfectly consistent, i.e. $s_{hj}=s_{hi} \times s_{ij}$, is not valid for all $h_{i,j}$ = 1, 2, …, *n*. Perfect consistency would be achieved only in the case of a matrix whose elements would represent the actual shares of criteria weights. The degree of consistency can be determined using the consistency index (CI), which is defined as follows [24]:

$$CI = \frac{l_{\max} - n}{n - 1} \tag{3}$$

where l_{max} is the highest eigenvalue of the Saaty matrix and n is the number of criteria. The matrix can be considered sufficiently consistent if CI ≤ 0.1.

The first step of the Saaty method is to determine the relationship between each pair of indicators when the level of significance (preference) is determined in a spot range of 1–9 [24]. This is determined as follows:

- to ensure the greatest possible objectivity when determining the weights of the individual indicators, 15 experts operating in the area of transport planning, urban freight transport and sustainable urban development were asked to determine preferences between individual indicators. Each of the experts set a level of significance for each pair of indicator;
- for each element of the matrix, a product of the sub-matrices of all experts was established and then the average was calculated.

By applying the Saaty method, the order of strategies was achieved based on their importance. Similarly, based on the preferences of the experts, the importance of the individual indicators of sustainable urban freight logistics contained in each strategy was determined. The results are discussed in the next section.

4. EVALUATION OF SIGNIFICANCE OF PROPOSED INDICATORS

Based on literary research and discussion with the expert panel members, the authors proposed 43 indicators of sustainable urban freight logistics. These indicators are suitable for monitoring the desired results of the application of specific urban freight logistics strategies over time [25]. At the same time, these indicators can be implemented in the models of system dynamics and monitor the dynamics of their development.

The application of the Saaty method enabled determining the order of strategies according to their significance. Similarly, based on the assessors' preferences, the significance of individual sustainable urban logistics indicators included in given strategies was determined. The Saaty matrices show a high degree of consistency. The resulting hierarchy of individual sustainable urban freight logistics strategies and the hierarchy of individual indicators within each strategy evaluated on the basis of their significance using the assignment of weights are represented by means of graphs (*Figures 1–6*).

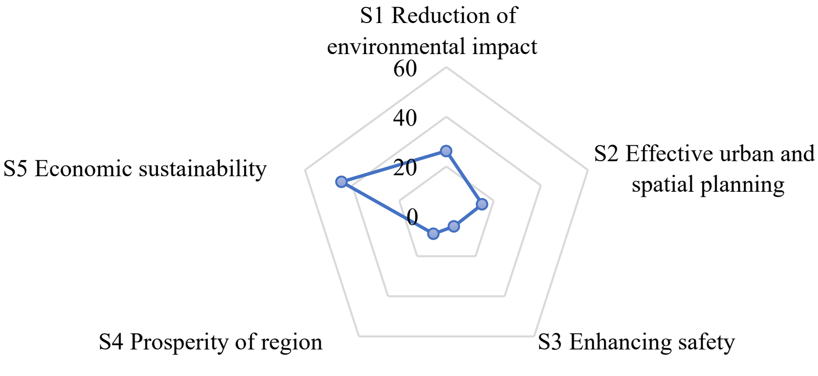

Figure 1 – Weights of individual strategies assessed on the basis of Saaty method

Within the evaluation of the strategies, the application of the MCA method shows that the assessors assign the greatest weight to the economic sustainability strategy (S5 – 0.445), i.e. the focus on supporting economically sustainable systems of urban freight logistics from the side of the cities and creating the infrastructure of the urban freight logistics with regard to the effectiveness of the incurred costs. Another significant strategy within logistics planning is, according to the assessors, the strategy including the processes of transport and spatial planning aimed at improving the environment in cities (S1 – 0.262).

The authors also introduced a set of indicators related to spatial planning and urbanistic aspects in cities. This was based on the literary research specified above, where various authors stated that effective spatial planning enables urban traffic flow optimisation, including freight transport flows. The assessors evaluated the strategy of effective urbanistic and spatial planning including the processes aimed at reducing the impact of freight transport on the quality of life of urban populations and increasing the effectiveness of the urban freight logistics system functioning as equally important (S2 – 0.152). A lower significance was assigned to strategies including the processes of transport and spatial planning aimed at the safety of vulnerable participants in urban freight transport (S3 – 0.052) and social-economic strategies aimed at increasing the prosperity of the region including the processes related to the development of individual economic sectors of the region (S4 – 0.089).

As for the two strategies evaluated as significant, significant indicators are those with a weight exceeding 10 % of the whole set of indicators (*Figure 1*). Within the strategy "Economic Sustainability" (S5), these are mainly the indicator monitoring the volume of funds spent by the public sector on the construction of the infrastructure for sustainable urban freight logistics in the region for a monitored period or percentage share in the total GDP of the region (5C2 – 0.187), indicator for monitoring the average fuel consumption of trucks with conventional engines (5C1 – 0.176), indicator for monitoring the transport performance in intermodal transport in the city (5C4 – 0.166), average utilisation of space in storage and distribution centres (5C6 – 0.111) or the indicator of warehouse capacity (5C3 – 0.102).

Within the strategy "Reduction of Environmental Impact" (S1), significant indicators include the share of low-emission vehicles in the total number of registered vehicles in city logistics (1C9 – 0.258), the share of vehicles with conventional combustion engines meeting the strictest EU standards (1C6 – 0.138) – here, the question is which EU standards can be considered relevant; furthermore, indicators concerning the share of alternative fuels in the total fuel consumption of low-emission and zero-emission vehicles used within city logistics (1C4 – 0.127), the volume of greenhouse gases produced by the feel of trucks ensuring logistics in a given city (1C7 – 0.122) or the arable land take rate for transport and logistic projects within the cadastre of a given city in a given year (1C2 – 0.106). The weights of all indicators in a given set are shown in *Figure 2*.

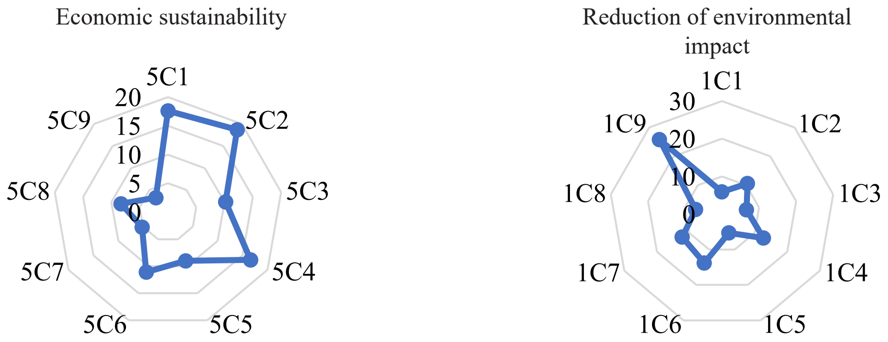

Figure 2 – Weights of individual indicators assessed in strategy S5 (on the right) and S1 (on the left) according to the Saaty method

The third significant strategy, i.e. "Effective Urban and Spatial Planning" (S2) includes indicators related to the processes aimed at improving urban and spatial planning in order to improve transport and logistics in each city towards sustainability. Based on AHP, the significant indicators primarily include determining the rate of illegal parking of supply vehicles (2C8 – 0.220), which is related to the effectiveness of creating parking places and supply system planning in city centres; furthermore, it is also the average distance between the logistics hub on city outskirts and delivery points in city centres (2C7 – 0.179), average tonnes of goods transported within 1 km distance within city logistics (2C9 – 0.145), share of industrial zones in the total area of a given city (2C4 – 0.126), and the number of distribution and logistics hubs in a monitored territory (2C6 – 0.117). The weights of all indicators in a given set are presented in *Figure 3*.

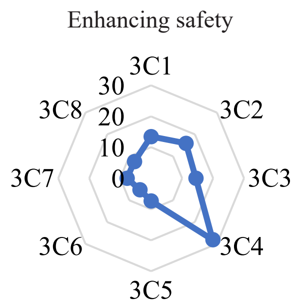

Figure 3 – Weights of individual indicators assessed within strategy S2 according to the Saaty method

The two remaining strategies were evaluated by the assessors as less significant in terms of sustainability in urban freight logistics, specifically, "Enhancing the Prosperity of Region" (S4), where greater weight in terms of influencing sustainable development was assigned to the indicators included in the strategy "Economic Sustainability". Within the S4 strategy, indicators such as the average monthly wage in the logistics sector in a given region (4C4 – 0.208), annual change in the number of job positions in the logistics sector (4C5 – 0.182), the number of job positions in city logistics (4C1 – 0.177), and the share of logistics services in total city income (4C7 – 0.140) were evaluated as significant. The weights of all indicators in the given set are presented in the graphs in *Figure 4*, which also indicates that, for instance, the indicator expressing the difference between the total average wage and the average wage in the logistics sector in the given region (4C8) was assigned the weight of 0.097.

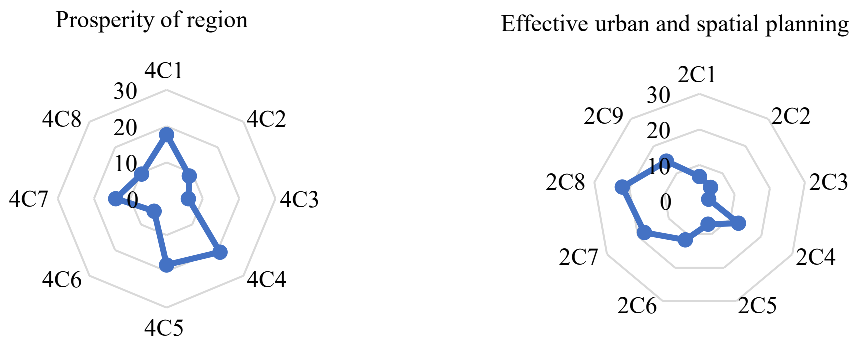

Figure 4 – Weights of individual indicators assessed in the S4 (on the left) and S3 (on the right) according to the Saaty method

As for the strategy concerning enhancing safety in general (S3), the most significant indicators in terms of urban freight logistics and its sustainability were the number of accidents caused by truck drivers in a given territory (3C4 – 0.281), the degree of truck speed monitoring on the urban road network (3C2 – 0.159), the number of truck drivers tested positively for alcohol and other drugs (3C3 – 0.144) and the number of speed indicators on the urban road network (3C1 – 0.135).

5. DISCUSSION

By using the Saaty method of pairwise comparison of weights, it was possible to determine the significance of individual strategies and indicators of sustainable urban freight logistics. This approach can in general help in deciding which strategy of sustainable urban freight logistics to prefer and implement considering the expected impact. An indisputable advantage of this method is the fact that it can be used for the evaluation of the impacts that cannot be adequately monetised and thus be evaluated using, for instance, the traditional "cost-benefit analysis".

The weights of individual sustainable urban freight logistics strategies were found without predetermined values of individual indicators. Each indicator was assigned a weight that determines its significance in relation to other indicators. In the final report of the PROPOLIS project, Lautso et al. [26] proposed a general formula for expressing the degree of sustainability in general for urban transport (entitled sustainability index) considering a certain number of sustainable development indicators, weights of indicators with determined values and the function of the values of these indicators, which standardise the value of indicators on a scale from zero to one.

In terms of expressing the level of sustainability for a specific city, a similar, yet partly modified approach can be applied to the results of the multicriteria analysis performed by the authors of the paper. The aim is to obtain a unique value by aggregating all the proposed indicators and their weights determined based on the hierarchical structure of strategies and indicators. As an aggregation method, the method of weighted linear combination [26] can be applied, which is used, for example, in the area of GIS creation where the criteria (indicators) are standardised to a common numerical range and then combined using weighted averages.

The aggregation of weights with standardised values of individual indicators and weights of individual strategies enables expressing a certain degree of sustainable freight logistics development of a given city, or more specifically, the "Sustainable Urban Freight Logistics Index".

$$\textit{Sustainable urban freight logistics index} = \sum_{i=1}^{m} v_s \left(\sum_{i=1}^{n_s} a_i v_i h_i \right) \quad (4)$$

where:

m – number of strategies of sustainable urban freight logistics;
v_s – weight of strategy s;
n_s – number of indicators in strategy s;
a_i – value 1 or -1 (depending on the effect of indicator i on sustainable development);
v_i – weight of indicator i;
h_i – standardised value of indicator i for a specific city/territory.

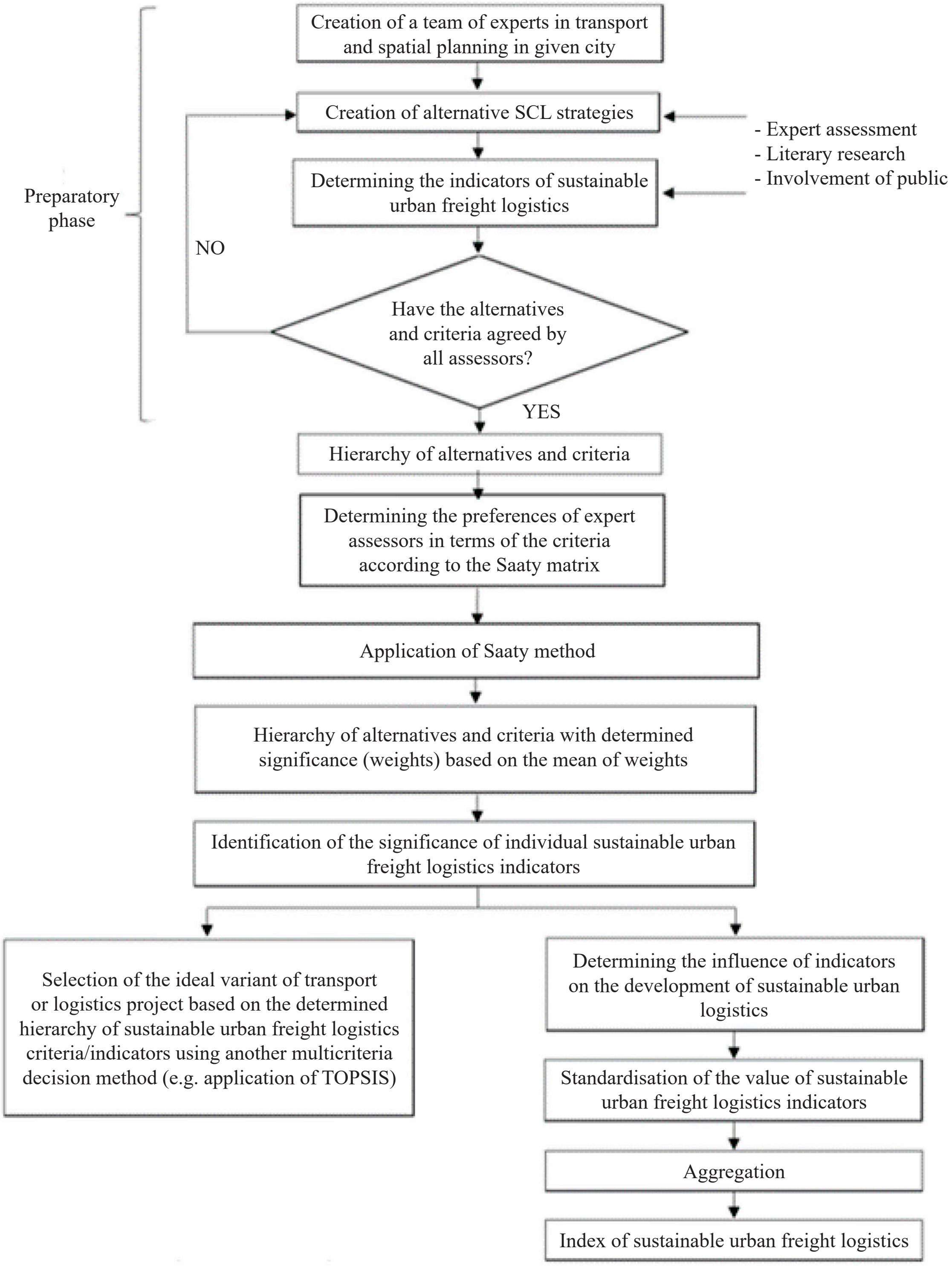

Figure 5 – Diagram of the proposed calculation of sustainable urban freight logistics index

Table 3 – Selected key indicators for determining the Sustainable Urban Logistics Index

ID	Key indicator	Weight [%]	Influence
S1	*Reduction of environmental impact (81% of all indicators in the set)*		
1C9	Share of low-emission and zero-emission vehicles in the total number of vehicles	25.8	+
1C6	Share of vehicles with conventional combustion engines meeting the strictest EURO standards	13.8	+
1C4	Share of alternative fuels in the total fuel consumption of low-emission and zero-emission vehicles	12.7	+
1C7	Volume of greenhouse gases produced by trucks	12.2	-
1C2	Arable land take rate for logistic projects	10.6	-
1C1	Energy consumption in logistic facilities	5.9	-
S2	*Effective urban and spatial planning (81.3% of all indicators in the set)*		
2C8	Illegal parking of supply vehicles	22	-
2C7	Average distance between logistic hub and delivery points in city centres	17.9	-
2C9	Average number of tonnes of goods transported within a 1-km distance	14.5	+
2C4	Area of industrial zones	12.6	-
2C6	Number of distribution and logistics centres	11.7	-
2C3	Number of places of picking up shipments	2.6	+
S3	*Enhancing safety (79.7% of all indicators in the set)*		
3C4	Number of accidents caused by truck drivers	28.1	-
3C2	Monitoring of vehicle speed	15.9	+
3C3	Number of truck drivers positively tested for alcohol and other drugs	14.4	-
3C1	Number of speed indicators on the road network	13.5	+
3C7	Number of serious accidents caused by truck drivers	7.8	-
S4	*Prosperity of region (80.4% of all indicators in the set)*		
4C4	Average monthly wage in the logistics sector	20.8	+
4C5	Annual change in the number of job positions in the logistics sector	18.2	+
4C1	Number of job positions in city logistics	17.7	+
4C7	Share of city income from logistics services in the total income	14	+
4C8	Difference between the total average wage and average wage in the logistics sector	9.7	-
S5	*Economic development (83.2% of all indicators in the set)*		
5C2	Financing of the construction of sustainable city logistics infrastructure	18.7	+
5C1	Average fuel consumption of trucks with conventional engines	17.6	-
5C4	Transport performance in intermodal transport	16.6	+
5C6	Average utilisation of storage and distribution facilities	11.1	+
5C3	Capacity of warehouses	10.2	+
5C5	The amounts of reimbursements/subsidies within city logistics	9	+

The value a_i expresses the polarity of the indicator i, or the nature of the influence of the indicator on the sustainable development of the city. The value is $a_i = 1$, if the increase in the value of the indicator strengthens the positive development, or $a_i = -1$, if the degree in the value of the indicator strengthens the negative development. The polarity of individual indicators (their impact on sustainable development) is presented in *Tables 2 and 3*.

For the purpose of determining the sustainable urban freight logistics index (when being applied specifically to a given city), it is first necessary to standardise the values of sustainable urban freight logistics indicators to a common numerical range. Voogd (1983) presents an overview of various standardisation procedures. Typically, the minimum and maximum values are used for creating a scale. An example of this is the linear scale [27]:

$$h_i = \frac{(R_i - R_{min})}{(R_{max} - R_{min})} \cdot standardised\ range \tag{5}$$

where:

h_i – standardised value of indicator i;
R_i – initial value of the indicator i intended for standardisation;
R_{min} – minimum value in the set of indicators;
R_{max} – maximum value in the set of indicators;
Standardised scale – determined range from 0 to 100.

Another possibility to use the determined weights and indicators (criteria) is, e.g., the application of the TOPSIS method for selecting a suitable transport project in compliance with the principles of sustainable urban development. TOPSIS is another method of multicriteria analysis, which uses determined weights based on the calculation of the least distance from the ideal variant or the greatest distance from the base variant. For the application of the TOPSIS method, or to express the overall score of the variants of transport projects, it is also necessary to quantify the individual selected indicators associated with the given transport projects.

The proposed process of determining the significance of individual indicators and their further application is presented in the following diagram. The calculation of the sustainable urban freight logistics index for a given city or individual city areas consists of the following steps presented in *Figure 5*.

For the purposes of determining the sustainable urban logistics index for a given city, it is possible to use only the most relevant indicators, or to use some other method to select suitable indicators [28]. Significant indicators that could be further used can be selected on the basis of the Pareto principle, according to which 80 % of information can represent a whole. In this case, the Pareto principle would be used to select the key indicators, which could be further used, e.g. for determining the sustainable urban freight logistics index. The selected key indicators with the determined impact on the sustainable development of a city so that they represent 80 % of the weight in each assessed strategy are presented in *Table 3*.

The theoretical approach to calculating the sustainable urban freight logistics index described above can be applied in the case of a city as such where the individual values of the indicators are aggregated into one global index. However, it is also possible to use this method for calculating the sustainable urban logistics index for individual areas of cities. Therefore, the division of the areas of a given city with the regard to the diversity of the functional areas is important, as each functional city area has its diverse features, mainly in relation to planning transport, resources and goals, residents' journeys etc.

6. CONCLUSION

The paper discusses the possible use of the evaluation of transport projects in the field of urban freight logistics based on suitable indicators of sustainable urban freight logistics, and the possibilities of further use and development of the procedure for the selection of these indicators.

Based on the literature review, the authors proposed set of 43 general indicators within the framework of sustainable urban freight logistics. The authors assigned the proposed indicators to individual strategies based on the visions and goals of sustainable urban development. By applying the methods of multicriteria analysis, the identification of the hierarchy of important indicators significance was achieved. The very proposal of identifying appropriate indicators in a given area is an innovation in the initial stages of transport-decision-making processes at the level of management of individual cities, when it is possible to consider this method when developing plans for sustainable urban freight logistics. The authors relied on the recommendations given in the documents relating to the developing a plan for sustainable urban logistics, which directly state the necessity of choosing a suitable method for determining and then evaluating the indicators by which it is possible to monitor the implementation of the plan for sustainable freight logistics or to achieve specific goals. At the same time, it is desirable to apply the method of determining indicators already in the preparatory and analytical phases of creating a plan for sustainable freight logistics in cities.

The proposed indicators integrate the basic aspects of sustainable development in the context of transport freight and can further serve in the next stages of implementing sustainable urban logistics plans in practice in the sense of monitoring and evaluating the impact of individual decisions in the field of transport projects on the overall city transport system. These indicators, with their determined significances (weights) and their values, can be further used in the area of traffic modelling in the city territory based on the selection of an indicator related to a specific modelling variable, taking into account the significance of the sustainable urban logistics strategy. It was found that indicators of sustainable urban freight logistics are also applicable for simulating the development of their values, e.g. using a system dynamics simulation tool. Such a tool can be helpful for city decision planning processes, because simulation models conceived in this way can show the development trend based on the integration of other influences (variables). The determination of indicators of sustainable urban freight logistics can continue with the use of various other methods, especially in a microscopic concept. In particular, further research should focus on quantifying the actual influence of these indicators on the sustainable city development.

In the chapter devoted to the possibility of applying these indicators, the calculation of the sustainable urban freight logistics index is proposed. For the purposes of determining the sustainable urban freight logistics index, the authors modified the method of weighted linear aggregation so that it was possible to directly follow on from the previous step – determining the significance of indicators of sustainable urban logistics. The project relevant to this topic is in an early step, so it was not possible to include a case study in the paper, to which the calculation of the index of sustainable urban freight logistics would be applied. In the next phases of the project, a proposed methodology for the identification of significant indicators and the calculation of the index of sustainable urban freight logistics will be applied to a specific city in the form of a case study. The results so far presented in this paper indicate that the proposed procedure can find a real reflection in practice. In the next phases of the project, the authors plan to implement these results into geoinformation system tools for a specific city, which in the case of the Czech Republic is a new approach in the field of combining informatics and sustainability in transport.

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REFERENCES

[1] Litmann T. *Well measured: Developing indicators for comprehensive and sustainable transport planning*. Victoria Transport Policy Institute; 2019. https://www.vtpi.org/wellmeas.pdf [Accessed 10th Dec. 2019].

[2] Munier N. *Introduction to sustainability – Road to a better future*. Dordrecht: Springer; 2005.

[3] Toth-Szabo Z, Várhelyi A, Koglin T, Angjelevska B. *Measuring sustainability of transport in the city – development of an indicator*. Lund University, Bulletin 261 - Traffic & Roads; 2011.

[4] Gudmundsson H, Sorensen CH. Some use – Little influence? On the roles of indicators in European sustainable transport policy. *Ecological Indicators*. 2013;35:43-51.

[5] De Ceuster G, et al. *ASSESS Final report*. Brussels: DG TREN, European Commission; 2005. http://www.tmleuven.be/project/assess/ [Accessed 14th Sep. 2019].

[6] RAND Europe, et al. *SUMMA (Sustainable Mobility, policy Measures and Assessment): Deliverable 3 of Workpackage 2: Operationalising sustainable transport and mobility*. 2004. http://www.summa-eu.org/control/reports [Accessed 7th May 2009].

[7] Dobranskyte-Niskota A, Perujo A, Pregl M. *Indicators to assess sustainability of transport activities Part 1: Review of the existing transport sustainability indicators initiatives and development of an indicator set to assess transport sustainability performance*. European Commission, Joint Research Centre; 2007.

[8] Gillis D, Semanjski I, Lauwers D. How to monitor sustainable mobility in cities? Literature review in the frame of creating a set of sustainable mobility indicators. *Sustainability.* 2016;8(1);29. DOI: 10.3390/su8010029.

[9] Persia L, Cipriani E, Sgarra V, Meta E. Strategies and measures for sustainable urban transport systems. *Transportation Research Procedia*. 2016;14:955-964. DOI: 10.1016/j.trpro.2016.05.075.

[10] Roughton C, et al. *Creating walkable and bikeable communities: A user guide to developing pedestrian and bicycle master plans.* Center for Transportation Studies at Portland State University; 2012.

[11] Hale CA. New approaches to strategic urban transport assessment. *Australian Planner*. 2011;48(3):173-182. DOI: 10.1080/07293682.2011.592505.

[12] Rai HB, Lier TV, Meers D, Macharis C. An indicator approach to sustainable urban freight transport. *Journal of Urbanism: International Research on Placemaking and Urban Sustainability*. 2018;11:102-81.

[13] Tafidis P, Sdoukopoulos A, Pitsiava-Latinopoulou M. Sustainable urban mobility indicators: Policy versus practice in the case of Greek cities. *Transp. Res. Procedia*. 2017;24:304-312. DOI: 10.1016/j.trpro.2017.05.122.

[14] Shen L-Y, Ochoa JJ, Shah MN, Zhang X. The application of urban sustainability indicators – A comparison between various practices. *Habitat International*. 2011;35:17-29. DOI: 10.1016/j.habitatint.2010.03.006.

[15] Touratier-Muller N, Jaussaud J. Development of road freight transport indicators focused on sustainability to assist shippers: An analysis conducted in France through the FRET 21 programme. *Sustainability*. 2021;13; 9641. DOI: 10.3390/su13179641.

[16] Wolpert S, Reuter C. Status quo of city logistics in scientific literature: A systematic literature review. *Transportation Research Record Journal of the Transportation Research Board*. 2012;2269.

[17] Van den Bossche M, et al. *Indicators and data collection methods on urban freight distribution. Nonbinding guidance documents on urban logistics N° 6/6*. European Commission. Final report. Dec. 2020.

[18] Foltyński M. Management tool for streamlining city logistics. *Transportation Research Procedia*. 2016;16:89-103. DOI: 10.1016/j.trpro.2016.11.010.

[19] Ambrosino G, Liberato A, Pettinelli I. *Sustainable Urban Logistics Plans (SULP) Guidelines*. Ljubljana: Civitas Forum; 2015.

[20] NOVELOG. *NOVELOG Project Website*. 2016. http://novelog.eu [Accessed 1st May 2019].

[21] Matusiewicz M. SULP (Sustainable Urban Logistics Plan) as a tool for shaping sustainable urban logistics: Review of European Projects supporting the creation of SULP. *Transport Economics and Logistics*. 2019;84:71-78. DOI: 10.26881/etil.2019.84.06.

[22] Nathanail E, Adamos G, Gogas M. A novel framework for assessing sustainable city logistics. *Transp. Res. Proc.* 2017;25:1036-1045. DOI: 10.1016/j.trpro.2017.05.477.

[23] Sénquiz-Díaz C. Effect size of logistics: Evidence from selected countries. *LOGI – Scientific Journal on Transport and Logistics*. 2021;12(1):123-134. DOI: 10.2478/logi-2021-0012.

[24] Saaty THL, Vargas LG, Wendell RE. Assessing attribute weights by ratios. *Omega, The International Journal of Management Science*. 1983;2(1):9-13.

[25] Skrúcaný T, et al. Assessing the energy intensity and greenhouse gas emissions of the traffic services in a selected region. *LOGI – Scientific Journal on Transport and Logistics*. 2021;12(1):25-35. DOI: 10.2478/logi-2021-0003.

[26] Lautso K, et al. *PROPOLIS – The final text to the project*. Finland; 2004.

[27] Voogd H. *Multicriteria evaluation for urban and regional planning*. London: Pion; 1983.

[28] Dudziak A, Caban J. The urban transport strategy on the example of the city bike system in the city of Lublin in relation to the Covid-19 pandemic. *LOGI – Scientific Journal on Transport and Logistics*. 2022;13(1):1-12. DOI: 10.2478/logi-2022-0001.

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Indikátory jako nástroj pro hodnocení úrovně udržitelné městské

Abstrakt

Plánování systému městské dopravy se v posledních letech posouvá k udržitelnosti a koncept městské logistiky je nedílnou součástí tohoto plánování. Městská logistika zahrnuje mnoho zúčastněných stran, které se podílejí na jejím provozu a jejichž potřeby by měly být zohledněny v procesu plánování celého systému. Příspěvek představuje jeden z přístupů k metodice výběru klíčových indikátorů vhodných pro hodnocení a sledování udržitelného systému městské logistiky tak, aby co nejvíce reflektoval potřeby všech zainteresovaných subjektů. Toto je provedeno aplikací vybrané metody multikriteriální analýzy se zapojením různých aktérů městské logistiky. Na základě navržené metodiky jsou v příspěvku definovány významné indikátory, které lze uvažovat pro další hodnocení úrovně udržitelného systému městské logistiky. Kromě možností dalšího rozvoje této metodiky je diskutována i aplikace stanovených významných indikátorů pro výpočet navrženého indexu udržitelné městské logistiky. Navrženou metodiku je možné implementovat v přípravných krocích v rámci tvorby plánů udržitelné městské logistiky (PUML).

Klíčová slova
plánování městské dopravy; udržitelná městská logistika; městská nákladní doprava; indikátory udržitelného rozvoje.