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Assessment of Sustainable Mobility by MCDM Methods in the Science and Technology Parks of Vilnius, Lithuania

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Abstract: The development of science and technology parks (STPs) has become a trendy tool for promoting the economy, innovation, and technology for more than 30 years worldwide. However, STPs poses challenges for urban planners seeking a vision of sustainable urban development. These places become an object of attraction for many highly skilled workers who create daily traffic flows. The proper accessibility and provision of transport infrastructure and services become the challenge for the development of such places because the availability of services influences the choice of travel mode and the possible employees' travel behaviour. The authors of the research aim to assess the level of development of infrastructure and transport services conducive to the sustainable mobility of science and technology park staff in Vilnius city. Changing mobility behaviour into a more sustainable way is of interest to many scientists and practitioners, so the authors think that STP staff can represent a group of educated, working-age stakeholders within the city population, who has an interest in sustainable mobility travel options and can set an example of sustainable travel. Besides, recommendations for the planning and sustainable development from the sustainable urban mobility point of view of science and technology parks and similar institutions are provided. To achieve this goal, the authors use scientific empirical and theoretical research as well as multi-criteria decision-making (MCDM) methods. The results show the link between the distance from the developed STP site to the city centre and the more sustainable mobility of workers. Therefore, it is suggested to develop STPs closer to the urban centre as it often does not require large-scale development, nor do they engage in the polluting industry. Moreover, the authors suggest the key criteria that should be considered for STP development.

Keywords: science and technology parks; sustainable mobility; MCDM; urban planning

1. Introduction

The development of science and technology parks makes a significant contribution to economic development, employment growth, and the development of technology and innovation technologies that create high added value nationwide. According to the STP development practice in Lithuania, small to medium and less often large business entities are locating in these places. Along with businesses, they also attract large numbers of highly qualified employees. Being an important strategic place, the development of STPs poses challenges for urban planners seeking a vision of sustainable urban development. One of the challenges for the development of such places is the proper accessibility and provision of transport infrastructure because STP staff create daily traffic flows. Providing a necessary infrastructure and service can be one of the tools, that helps to change travelling behaviour and encourage STPs' employees to travel more sustainably (e.g., by bicycle, scooter, public transport, or just walking) rather than using a private car. In this way, STP staff should set an example of sustainable travel across the city and add up to the sustainable city vision.

One of the most widely recognized definitions of sustainable development term has been used since 1987 as Brundtland Commission (formerly known as World Commission on Environment and Development) has released the report 'Our Common Future', commonly called the Brundtland Report. By this report, sustainable development seeks to meet the needs and aspirations of the present without compromising the ability to meet those of the future [1]. Since then, much progress has been made in shaping this policy, developing and refining sustainable development goals and strategies. In 1992, the Rio Declaration and Agenda 21 by the United Nations (UN) [2] set out the principles of sustainable development and adopted a global action plan. In the European context, the European Union (EU) Sustainable Development Strategy was adopted in 2001, setting out EU action to implement sustainable development policies among the Member States [3]. The 17 universal, global and interlinked sustainable development goals (SDGs), which cut across a wide range of policies and are intended to be implemented by 2030, have been endorsed in the UN 2030 Agenda for Sustainable Development (2015) [4]. To achieve these goals, 169 specific targets have been identified and 232 indicators have been set to measure progress. In different documents, sustainable development covers three domains-economic, social, and environmental-and promotes a balance between them. However, researchers of different fields do not necessarily pay equal attention to these areas in their studies, often emphasizing the economic, social, or environmental context of sustainable development.

The EU as a comprehensive approach to developing sustainable transport systems and mobility behaviour promotes sustainable urban mobility planning. It includes all modes and forms of transport mobility in the entire urban agglomeration. Different authors agree, that although sustainability has become part of policy discourse on sustainable transport including the local and regional level [5], sustainable urban mobility remains one of the unresolved topical concerns [6–9]. Increasing demand for urban mobility has created a situation that is not sustainable: severe congestion, air, and noise pollution, and high levels of CO_2 emissions. Urban transport activities are a major contributor to those negative impacts, especially in those cities where motorization levels are high, and automobile-dependence is the dominant mode of individual travel [10]. Sustainable mobility, as a complex phenomenon, is quite difficult to implement; therefore, transport researchers tend to focus on environmental and social issues and their possible solutions through a variety of strategies [9,11,12]. To achieve a strategy for sustainable urban mobility, the European Commission's (EC) Green Paper on urban mobility (2007) promotes the use of public transport and improving its system, increasing the use of greener fuels and improving road and transport safety [13]. Brůhová Foltýnová et al. (2018) emphasize the importance of research in identifying the various groups of stakeholders within the city population and providing tailor-made measures for each group to obtain more sustainable mobility of people and goods [8]. Because of stakeholders, any urban mobility policy must cover both passenger and freight transport [13].

Currently, high dependence on motor transport is observed in Vilnius city. Here, the level of motorization is steadily increasing every year. It has grown by almost 12% since 2015 and now stands at 373 vehicles per 1000 inhabitants in 2019. The average time spent in traffic jams also increases. Since 2016, when a motorized Vilnius resident spent an average of 136 h per year (5.7 days), in 2019 this number has increased to 167 h per year (7 days). According to the data of Sustainable Urban Mobility Plan (SUMP) of Vilnius city (2018) [14] for 2017, the main means of daily (work-related) travel was by car −49%, public transport −24.1%, on foot −24.5%, by bicycle −1.5% and other transport 0.9%. SUMP is a strategic document, which is promoted by the 'Urban Mobility Package' adopted in December 2013 by the EC [7] and was prepared by the EC guidelines. The SUMP of Vilnius aims to reduce the share of car trips to 22% by 2030, but trends suggest that this is a more optimistic scenario so far. To achieve this, as well as to reduce the negative impact of cars on the city, it is important to promote sustainable urban mobility (SUM) through integrated measures, taking into account the needs of different social groups. Reducing the adverse effects of transport is an important EU policy goal. The European Commission's 2018 strategy 'A Clean Planet for all: A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy' [15] seeks to chart the course for a transition towards 'net-zero' greenhouse gas emissions across the EU by 2050. This strategy promotes better urban planning and realizing the full benefits of public transport. At present, Lithuania is committed to reducing CO_2 emissions into the atmosphere by 9% by 2030 compared to 2005 (which was 23.0 million tons). According to the data of the Ministry of Environment, 20.3 million tons of greenhouse gases were emitted into the atmosphere in Lithuania in 2018. This is about 1.7% less than in 2017. The share of transport is 30.2%.

To achieve a shift towards a SUM future, a variety of initiatives are undertaken such as enhancing the infrastructure and encouraging economic development [16,17]. Some good practices show that, for example, London has not attempted to increase road capacity in recent years, and indeed has allocated more road space to bus and cycle lanes and pedestrians. It provided the result that both car traffic and trips have declined [18].

The paper presents sustainable urban mobility planning features as a part of the environmental and social (from the better access to employment, which interrelates to social equity point of view) aspect of the sustainable development concept. For sustainable mobility research in Vilnius, the authors of the research have chosen science and technology parks, which are an object of attraction for hundreds of employees. Generally, it is possible to state that STP employees can represent a group of educated, working-age stakeholders within the city population who has an interest in sustainable mobility travel options. STPs are investments primarily focused on achieving economic and innovation outcomes but may also serve urban and perception change objectives [19]. Therefore, they require an in-detail assessment to understand their operation to generate action plans and models that new parks or those who are still in their initial growth phase may follow [20]. They must be an example of innovation and sustainable mobility of the employees for other institutions and society in general.

SUMP is one of the measures to improve urban transportation and at the same time increase urban sustainability, so two types of indicators have been chosen for infrastructure measurements and mobility services. To analyse these aspects in detail, indicators measuring sustainable mobility were used and applied to the STPs as a pilot case with areas employing many skilled workers. It can be a means of promoting intelligent modes of transport and exemplifying the accessibility of other urban areas. By ensuring a more sustainable connection to STP, a more sustainable city and an impact on the environmental, social and economic aspects of sustainability can be achieved. These indicators do not contradict the generally accepted sustainability indicators, but only deepen the adaptation of transport infrastructure and mobility services to the accessibility of STPs.

It leads to the aim of the study, which is to assess the level of development of infrastructure and transport services conducive to the sustainable mobility of STP staff. The authors of the research consider different sustainable transport modes options, which are typical for such entities. It includes an assessment of pedestrians, bicycles, public (passenger) transport, electric vehicles (EV), vehicles-sharing infrastructure accessibility, and service provision, and exclude freight transport that is less common for such entities. Also, the authors provide recommendations for the planning and sustainable development from the SUM point of view for STPs and similar institutions. Moreover, suggest the key criteria that should be considered for their development. To achieve this goal, the authors of the research use scientific empirical, theoretical research, quantitative, multi-criteria decision-making (MCDM) methods.

2. Science and Technology Parks

The Science, innovation, and technology agency of the Republic of Lithuania defines science and technology parks as a physical or virtual location where companies engaged in applied research and other innovative activities are located and where specialized value-added services such as business incubation, consulting, and technology transfer is provided. The main goal of STP is to increase the competitiveness of a region or a certain territory by promoting a culture of quality and innovation among its members, organizing the transfer of knowledge and technology from its creation to companies and the market, and actively encouraging the creation of new innovative companies.

Several features define this type of park:

- Convenient transportation (near the airport, highways, frequent public transport);
- Proximity to the university, research institutes, residential buildings, recreation parks, industrial zone;
- Highly qualified, highly experienced staff;
- Territorial development opportunity in the future.

In recent years, one aspect of Science Park development has run into some obstacles: how to attract and develop the talent needed to satisfy the growing needs of park tenants. One of the factors underpinning the success of every organization is the ability to find and then retain employees with relevant skills [21,22]. Cadorin et al. (2019) [22] research conclude, that science park managers need to understand the talent needs of tenant firms to make the attraction process more effective and reach individuals who have the characteristics that firms desire.

From an urban planning perspective, it can be assumed that one way to attract staff can be to ensure good and convenient accessibility of the STP. Time and convenience are important for educated STPs workers, as well as the ecological aspect of travel to/from work. By analysing the best practices of STPs business models in Europe, Zielinski et al. (2014) [23] research conclude that good transportation infrastructure for the tenants plays a significant role in the success of STP. According to the model proposed by the Feasibility Study for the Evaluation and Development of Science and Technology Parks (2010) [24], when initiating new infrastructures in Lithuania, such circumstances as strategic locations of STPs (near universities or other high-level research institutions, open-access centres, etc.) should be taken into account.

Recent trends show that STPs are urbanizing and becoming science districts or science urban areas. Science parks are moving some of their activities from green suburban areas to the city centre to operate in different locations by offering different services to businesses. Urban planners seek to return the city centre to the people, thus avoiding creating them for a single socio-economic purpose to turn the centre into a multifunctional one that combines life, work, and recreation.

STPs in Lithuania, compared to the European experience, are a relatively young entity. The oldest operating park of this type is in Kaunas, and it is estimated that it has been operating since 1998. Most of STPs operate in the capital. There are four STPs in Vilnius city (Figure 1, Table 1).

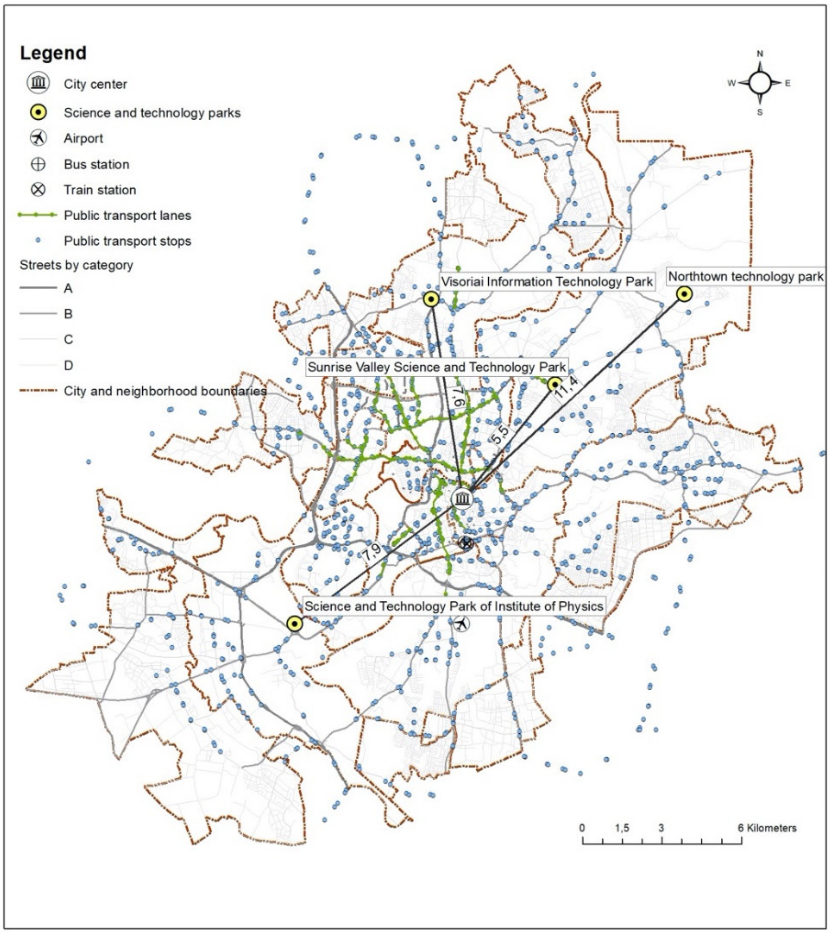

Figure 1. Science and technology parks in Vilnius city and its distances from city centre (Source: prepared by authors).

Table 1. Science and technology parks in Vilnius city.

No.	Name	Address	Distance from the City Center, km
1	Northtown Technology Park	Vismaliukų g. 34	11.4
2	Science and Technology Park of Institute of Physics	Savanorių pr. 235	7.9
3	Sunrise Valley Science and Technology Park	Saulėtekio al. 15	5.5
4	Visoriai Information Technology Park	Mokslininkų g. 2A	7.6

The authors of the research examine in detail the STPs located in Vilnius, which are distributed in different places of the city territory in relation to the central part. All these parks are located away from the centre. Geographically, the closest to the centre is Sunrise Valley Science and Technology Park, 5.5 km from the city centre, and the furthest is Northtown Technology Park, 11.4 km. Although the distance varies 2 times, access to these parks using vehicles other than the car is extremely unequal. In comparison, the frequency of public transport in Sunrise Valley STP is 2.2 min, while Northtown Technology Park is 37.5 min. These numbers vary seventeen times. Respectively, the number of public transport routes in one is 8, in the other 1.

3. The Selection of Performance Indicators

The aim of this chapter is to select detailed indicators that will be used to assess the level of development of infrastructure and transport services conducive to the sustainable mobility of STP staff. There are various ways to obtain applicable criteria for sustainability of transportation measures, such as experts' experiences, references of other cases, literature reviews and brainstorming [25].

The concept of sustainable mobility is designed to address the problems of the city due to traffic congestion, air pollution and noise, as well as to make urban mobility even more convenient and attractive to every inhabitant. Maintaining a sustainable mobility system in cities is a rather complex process. It is carried out by integrating various measures. Promoting sustainable mobility aims to help people find the most suitable alternative mode of transport to replace the car and thus contribute to the improvement of the living environment.

The key principles for successful SUM include the involvement of the public and stakeholders in the planning and implementation of processes, the promotion of institutional cooperation in transport links to address other aspects of urban life, the identification of the most efficient urban infrastructure and sustainable mobility measures. More and more cities around the world are facing challenges in developing solutions that ensure the vital movement of people, goods and services, mitigating climate change and creating climate-friendly cities.

Researchers distinguish 3 dimensions of sustainable mobility: social, economic, environmental [12,26–30]. However, some researchers point to more than three dimensions. Each dimension has its own set of indicators. Each author provides indicators according to the need to investigate the object under consideration.

The set of indicators developed in this article is dedicated to the object of research, based on sustainable mobility indicators provided by scientific sources. Sources of the sustainable mobility indicators were searched in the Web of Science (Clarivate Analytics) database and on the website https://scholar.google.com/. The search was performed with the keywords: Sustainable Transport Indicators, Sustainable Mobility Indicators, Sustainable Transport, Sustainable Mobility, Multicriteria transportation systems. Article search by keywords is detailed in Figure 2.

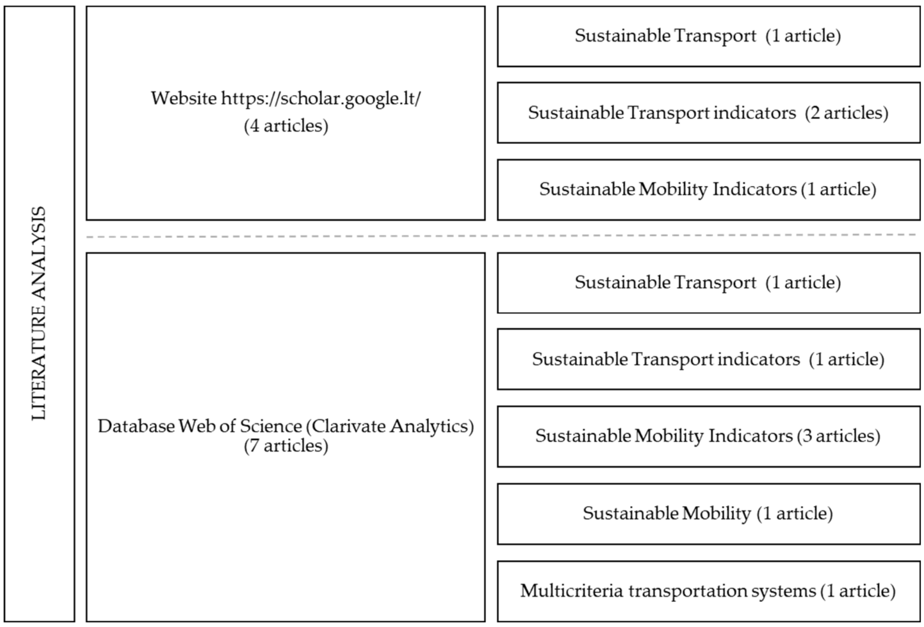

Figure 2. Scientific literature search analysis by keywords.

There are seven articles in the database of Web of Science (Clarivate Analytics) and four articles on the website https://scholar.google.lt/. Eleven literature sources were analysed, in which 355 indicators of sustainable mobility were found. Some of the indicators repeated in various sources. Information related to 11 sources is given in Table 2.

Table 2. Reviewed articles presenting different indicators.

No.	References	Authors	Number of Indicators
1	A preliminary study of sustainable transport indicators in Malaysia: the case study of Klang valley public transportation	Bachok, Ponrahono, Osman, Jaafar, Ibrahim & Mohamed, (2015) [26]	30
2	An evaluation for sustainable mobility extended by D numbers	Mo & Deng (2019) [25]	9
3	Developing the sustainable urban transport index	Gudmundsson & Regmi (2017) [31]	10
4	Developing Indicators for Sustainable and Livable Transport Planning	Litman (2019) [12]	42
5	Composite indicators of sustainable urban mobility: Estimating the rankings frequency distribution combining multiple methodologies	Danielis, Rotaris, & Monte (2017) [27]	29
6	Sustainability assessment of a transportation system under uncertainty: an integrated multicriteria approach	Ngossaha, Ngouna, Archimède & Nlong (2017) [28]	13
7	Indicators for sustainable mobility in the cities	Amoroso, Caruso & Castelluccio (2011) [29]	34
8	Indicators to Assess Sustainability of Transport Activities	Dobranskyte-Niskota, Perujo, Jesinghaus & Jensen (2009) [32]	55
9	How to Monitor Sustainable Mobility in Cities? Literature Review in the Frame of Creating a Set of Sustainable Mobility Indicators	Gillis, Semanjsk& Lauwers(2016) [33]	22
10	Decision-Making in the Transport Sector: A Sustainable Evaluation Method for Road Infrastructure	Henke, Cartenì, Molitierno & Errico (2020) [30]	10
11	Sustainable urban mobility indicators: policy versus practice in the case of Greek cities.	Tafidis, Sdoukopoulos & Pitsiava-Latinopoulou (2017) [34]	81

The indicators used in the sources are usually adapted to city-wide sustainable mobility or a specific area of city infrastructure. In the case of this study, all sustainable mobility indicators that describe sustainable mobility for the whole city were rejected because their impact on all STPs is the same. Due to the specifics of the research object, indicators not used in the indicated scientific articles were included. The main criteria according to which the set of indicators was compiled were the infrastructure adapted to the sustainable mobility of park employees, the availability of convenient public transport, and the possibility to choose a sustainable travel mode. The authors of the research propose a set of indicators to assess the facilities for sustainable mobility provided by individual locations within the territory of Vilnius city. Twelve indicators were selected and divided into two groups-Infrastructure measures and Mobility services (Table 3). It is important to find out which group of indicators is more relevant to the sustainable mobility of STP workers. On this basis, targeted development could be justified.

Table 3. Selected indicators divided into groups.

Designation	Indicators	Explanation
Infrastructure measures		
I1	Convenient public transport infrastructure [34]	Are there bus lanes to the city centre?
I2	Parking spaces for bicycles and low power vehicles	Are there racks and storage facilities in the park area?
I3	Bicycle paths [34]	Are there bicycle paths to the city centre?
I4	Pedestrian paths-sidewalks [31]	Are there uninterrupted sidewalks to go to work on foot?

I5	Electric vehicle charging accesses	Is there an access to charge electric vehicles in the park?
I6	Accessibility for people with reduced mobility [12,26–28,30]	Is the park infrastructure adapted for people with disabilities?
Mobility services		
S1	Number of public transport routes [34]	How many routes does have stops within 500 m distance?
S2	Public transport frequency [29,34]	How often does public transport run?
S3	Convenient transportation by public transport [12,27,29,31,33]	Is it possible to reach the city centre without transfers (to minimize the length of the trip in terms of time)?
S4	Car sharing [12,27,29]	Is car sharing available in the area? What is the distance to the car sharing area?
S5	Bicycle sharing [12,27,29]	Is bicycle sharing available in the area?
S6	Low power vehicle sharing [12,26,29]	Is low power vehicle sharing available in the area?

The classic definition of the term sustainability, adopted in an international context, has three main aspects-social, environmental and economic. For which aspect the indicator affects, see Table 4.

Table 4. The impact of the indicators on each aspect of sustainability.

Indicator Group	**Indicator**	**Sustainability Dimensions**		
		Social	**Environmental**	**Economic**
Infrastructure measures	I1. Convenient public transport infrastructure	V	V	V
	I2. Parking spaces for bicycles and low power vehicles	V	V	
	I3. Bicycle paths	V	V	V
	I4. Pedestrian paths - sidewalks	V	V	V
	I5. Electric vehicle charging accesses	V	V	
	I6. Accessibility for people with reduced mobility	V	V	
Mobility services	S1. Number of public transport routes	V	V	V
	S2. Public transport frequency	V	V	V
	S3. Convenient transportation by public transport	V	V	V
	S4. Car sharing	V	V	V
	S5. Bicycle sharing	V	V	
	S6. Low power vehicle sharing	V	V	

The indicators proposed by the authors, although not assigned to a specific dimension of sustainability, they do not contradict its essence. Also, most indicators can be assigned to environmental or social or both. Moreover, usually, they have an indirect or direct impact on all three dimensions of sustainability.

Indicators are often grouped according to social, economic and environmental aspects, when the research is used to compare different cities but not individual urban areas. In the case of the research object of this article, the economic conditions in the city are equal.

4. MCDM Methods

An important tool in solving sustainable engineering problems is MCDM [35]. There are many methods for multi-criteria analysis. The question arises, which of these methods is most suitable for solving specific tasks? Determining the best method for multi-criteria analysis has always caused a lot of controversies and endless discussion. Zavadskas et al. (2018) [36] performed an analysis of MCDM methods that showed that AHP and TOPSIS are among the most well-known methods. However, there is no single best method for MCDM to guarantee the accuracy of estimation [37].

For solving complex problems when faced with large amounts of information, more accurate results can be obtained using the hybrid MCDM method [38]. This is a method where sets of methods are applied to solve a problem. Thus, two tasks can be performed: to calculate the significance of the selected indicators and integrate them to the multi-attribute utility function value [39]. In combination with other MCDM methods, the AHP method is one of the most used [40].

Several MCDM methods can be used simultaneously to increase the reliability of the calculation results. Often, using different methods to solve the same problem with identical indicators, their values and significances, different results are obtained. Then, an integrated application of MCDM methods can be used, where the results of different MCDM methods are analysed using a weighted average, Borda, or Copeland methods, which summarize the findings [41].

Several of the most popular MCDM methods were chosen for the calculations: AHP (Analytic Hierarchy Process), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), SAW (Simple Additive Weighting) and COPRAS (Complex Proportional Assessment).

4.1. AHP Method

AHP (Analytic Hierarchy Process) was proposed by T. Saaty (1980) [42]. Using the AHP method, a complex task can be broken down into individual parts, making the method simple to use. The indicators can be divided into criteria and sub-criteria. This reduces the number of criteria to be assessed simultaneously. Experts compare the criteria in pairs, not all at once. Saaty suggested using a five-point (1–3–5–7–9) or nine-point scale (1–2–3–4–5–6–7–8–9) (Table 5).

Table 5. Pairwise comparison rating scale.

Significance Coefficient	Definition
1	Equal Importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	Intermediate values

Elements of the matrix P are numbers from $p_{ij} = 1$, where the meanings of the two compared criteria are equal to $p_{ij} = 9$, when the criterion w_i is incomparably more important than the criterion w_j. The elements p_{ij} of the matrix P can be regarded as ratios of the weights w_i and w_j:

$$p_{ij} = \frac{w_i}{w_j}, \tag{1}$$

$$P = \begin{pmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{mm} \\ \vdots & \vdots & \ddots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{pmatrix} = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_2}{w_1} & \cdots & \frac{w_1}{w_m} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_m} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_m}{w_1} & \frac{w_m}{w_2} & \cdots & \frac{w_m}{w_m} \end{pmatrix}, \tag{2}$$

The matrix is reciprocal $p_{ij} = 1/p_{ji}$. For the determination of weights, the problem of the real values of the matrix P and the real vectors $w = (w_1, w_2, \ldots, w_m)^T$ is solved.

The degree of compatibility of the individual assessments of each expert is determined by the consistency index *C.I.* and the consistency ratio *C.R.* Index C.I. calculated according to the formula:

$$C.I. = \frac{(\lambda_{max} - m)}{(m - 1)}, \tag{3}$$

The closer the compatibility index is to zero, the more consistent the matrix is.

Consistency ratio C.R. calculated according to the formula:

$$C.R. = \frac{C.I.}{R.I.} \leq 0{,}1 \quad (4)$$

The matrix is considered compatible when compatibility ratio *C.R.* is less than 0.1 [42].

4.2. TOPSIS Method

The TOPSIS method was created by Yoon and Hwang [43]. This method is called determining the rationality of variants by the method of proximity to the ideal point. The principle of this method is to choose the option with the shortest distance from the best values of indicators and with the longest distance from the worst values of indicators maximized [44]. The TOPSIS method is easy to understand, the calculation is simple.

Normalization of vector data is performed according to the formula:

$$\bar{x}_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}};\ i = \overline{1,m};\ j = \overline{1,n} \quad (5)$$

where: x_{ij}-members of the decision-making matrix; $\bar{x}_{ij}$-members of the normalized matrix; i-alternative; m-number of alternatives; j-indicator; n-number of indicators.

The weighted normalized matrix is formed by the formula:

$$\overline{P^*} = [\bar{P}] \cdot [q], \quad (6)$$

where: q-integrated significance.

The determination of the best and worst alternative is calculated according to formulas:

$$a^+ = \left\{\left[\left(\max_i \bar{x}_{ij}\ |j \in J\right), \left(\min_i \bar{x}_{ij}\ |j \in J'\right)\right] / i = \overline{1,m}\right\} = \{a_1^+, a_2^+, \ldots, a_n^+\}, \quad (7)$$

$$a^- = \left\{\left[\left(\min_i \bar{x}_{ij}\ |j \in J\right), \left(\max_i \bar{x}_{ij}\ |j \in J'\right)\right] / i = \overline{1,m}\right\} = \{a_1^-, a_2^-, \ldots, a_n^-\}, \quad (8)$$

where: a^+-ideally the best alternative; a^--ideally the worst alternative; J-the set of indices is for indicators with higher values accepted as better; J'-the set of indices is for indicators with lower values accepted as better.

The determination of the distances between the comparative and ideally the best and worst alternatives is calculated according to the formulas:

$$L_i^+ = \sqrt{\sum_{j=1}^{n} \left(\bar{x}_{ij} - a_j^+\right)^2};\ i = \overline{1,m}\ , \quad (9)$$

$$L_i^- = \sqrt{\sum_{j=1}^{n} \left(\bar{x}_{ij} - a_j^-\right)^2};\ i = \overline{1,m}\ , \quad (10)$$

where: L_i^+-the distance between the comparative and ideally the best alternative; L_i^--the distance between the comparative and ideally the worst alternative.

The determination of the relative distance to the ideal of the alternative is calculated according to the formula:

$$K_i = \frac{L_i^-}{L_i^+ + L_i^-},\ i = \overline{1,m}, \quad (11)$$

where: K_i-the relative distance of the alternative to the ideal.

4.3. SAW Method

The SAW method rules of the method were summarized by MacCrimmon [45]. The SAW method is often also known as the weighted summing method. The basic concept of the SAW method is to find the weighted sum of performance ratings on each alternative on all attributes. The SAW method requires the process of normalizing the decision matrix to a scale comparable to all existing alternative ratings [46].

The calculation of the normalized matrix is performed according to the formulas, depending on the indicator-min. or max.

$$\bar{x}_{ij} = \frac{x_{ij}}{x_j^{max}}, \tag{12}$$

$$\bar{x}_{ij} = \frac{x_{ij}}{x_j^{max}}, \tag{13}$$

where: x_{ij}-members of the decision-making matrix; $\bar{x}_{ij}$-members of the normalized matrix; m-number of alternatives; *j*-indicator; *n*-number of indicators; x_j^{max}-maximum value of the indicator; x_j^{min}-minimum value of the indicator.

In determining the rationality of the variant, the respective members of the normalized decision matrix are multiplied by the significances of the indicators and the resulting products are summed:

$$A = \left\{ A_i | \max_i \sum_{j=1}^{n} q_i \cdot \bar{x}_{ij} / \sum_{j=1}^{n} q_j \right\}, \tag{14}$$

where: q_j-integrated significance.

The sum of the products of the rational variant will be the maximum.

4.4. COPRAS Method

The principle of the COPRAS method is the relative significance of comparative alternatives, which is determined based on their positive and negative characteristics [47]. In 1996, the researchers of Vilnius Gediminas Technical University (Vilnius Tech) [48] created a method of complex proportional evaluation, COPRAS. The COPRAS method is used by researchers to evaluate complex processes. The main advantage of the COPRAS method over other MCDM methods is the ability to demonstrate the degree of utility.

Matrix normalization is calculated according to the formula:

$$d_{ij} = \frac{x_{ij} \cdot q_j}{\sum_{i=1}^{m} x_{ij}}; i = \overline{1, m}; j = \overline{1, n} \tag{15}$$

where: x_{ij}-members of the decision-making matrix; d_{ij}-members of the normalized matrix; *i*-alternative; *m*-number of alternatives; *j*-indicator; *n*-number of indicators; q_j-integrated significance.

The sums of maximizing and minimizing normalized indicators describing alternatives are calculated according to formulas:

$$S_{+j} = \sum_{j=1}^{n} d_{+ij}, \tag{16}$$

$$S_{-j} = \sum_{j=1}^{n} d_{-ij}, \tag{17}$$

The relative significance (effectiveness) of the alternatives is calculated according to the formula:

$$Q_i = S_{+i} + \frac{S_{-min} \cdot \sum_{i=1}^{m} S_{-i}}{S_{-i} \cdot \sum_{i=1}^{m} \frac{S_{-min}}{S_{-i}}}; i = \overline{1, m}, \tag{18}$$

where: S_{+i}-maximizing the sum of the indicator; S_{-i}-minimizing the sum of the indicator; S_{-min}-minimum sum of minimizing indicators.

The degree of efficiency of the alternatives is calculated according to the formula:

$$N_i = \frac{Q_i}{Q_{max}} \cdot 100\%, \quad (19)$$

where: Q_i-the relative significance of the alternative; Q_{max}-the highest relative significance of the alternatives; N_i-the degree of efficiency of the alternative.

5. Determination of the Significance of Indicators and Verification of the Consistency of Expert Opinions

The importance of sustainable mobility indicators varies. The significance of indicators can be determined using MCDM methods based on experts' opinions. Experts, after comparing the presented indicators, assign them significance or ranks. One of the most used methods for determining the normalized weights of indicators is the AHP method proposed by T. Saaty (1980) [42]. The AHP method allows comparisons of individual indicators (criteria) in pairs, giving them importance in relation to each other [49].

Based on the indicators presented above, two questionnaires were developed for expert evaluation. Questionnaires were developed according to the AHP method and submitted to experts. In this case, it is necessary to interview at least seven experts (2 groups of 6 questions each).

In the research, it was important to select experts who know the essence of the object, as well as those who are familiar with the AHP method and would be able to fill in the pairwise comparison matrix. At the beginning of the research, eleven experts with practical and scientific experience in the fields of civil or transport engineering were selected. Only competent specialists in this field were selected as experts. Seven of them are researchers of the Department of Roads of the Faculty of Environmental Engineering of Vilnius Tech. Among them, three work at the Urban Planning Institute, have extensive experience in preparing SUMPs for Lithuanian cities, perform other scientific work related to the Urban Mobility System. Two experts are researchers from the Vilnius Tech Faculty of Transport Engineering, with long-term work experience, good knowledge of MCDM methods and their application. The interviewed experts conduct research and publish articles on sustainable mobility, have at least five years of work experience, four of which have more than 20 years of work experience. Each expert independently ranked the criteria and completed a pairwise comparison matrix. 2 questionnaires were declared invalid because the consistency ratio of C.R. value was > 0.1.

The significance and compatibility ratios of the indicators calculated by each expert are presented in Table 6.

Table 6. Significance and compatibility ratios of the indicators were calculated.

Indicators	Experts									Average	Rating
	E1	E2	E3	E4	E5	E6	E7	E8	E9		
	Infrastructure measures									0.5722	
I1	0.4042	0.4295	0.0677	0.2694	0.3133	0.3407	0.4099	0.4750	0.4880	0.3553	1
I2	0.0945	0.0642	0.1688	0.0474	0.0692	0.0569	0.0473	0.0487	0.1127	0.0789	5
I3	0.1994	0.1376	0.1322	0.1366	0.4054	0.2261	0.1258	0.0912	0.2105	0.1850	3
I4	0.1871	0.2364	0.3250	0.3840	0.0362	0.1898	0.3080	0.2029	0.1010	0.2189	2
I5	0.0480	0.0365	0.0290	0.0300	0.1504	0.0359	0.0754	0.0268	0.0356	0.0520	6
I6	0.0669	0.0957	0.2774	0.1326	0.0255	0.1506	0.0336	0.1554	0.0521	0.1100	4
C.R.	0.0662	0.0392	0.0843	0.0628	0.0894	0.0515	0.0226	0.0971	0.0168		
	Mobility services									0.4278	
S1	0.1952	0.4127	0.2889	0.4356	0.3087	0.2335	0.1679	0.5069	0.2900	0.3155	1
S2	0.3698	0.2275	0.4058	0.2516	0.0292	0.2783	0.2697	0.2544	0.4381	0.2805	2
S3	0.2102	0.1890	0.1362	0.1767	0.0637	0.3055	0.3586	0.1371	0.1376	0.1905	3
S4	0.0392	0.0875	0.0311	0.0665	0.3280	0.0727	0.0354	0.0366	0.0292	0.0807	4
S5	0.0876	0.0478	0.0802	0.0428	0.1024	0.0621	0.1185	0.0386	0.0579	0.0709	5
S6	0.0980	0.0356	0.0579	0.0268	0.1680	0.0479	0.0499	0.0264	0.0472	0.0620	6
C.R.	0.0556	0.0641	0.0966	0.0398	0.0894	0.0200	0.0873	0.0849	0.0674		

The Saaty (2008) [50] methodology is used to calculate the final significance of the indicators (Table 7).

Table 7. Final significance and ratings of indicators.

Designation	Indicator	Significance Factor	Rating
I1	Convenient public transport infrastructure	0.2033	1
I2	Parking spaces for bicycles and low power vehicles	0.0451	8
I3	Bicycle paths	0.1058	5
I4	Pedestrian paths-sidewalks	0.1253	3
I5	Electric vehicle charging accesses	0.0297	11
I6	Accessibility for people with reduced mobility	0.0629	7
S1	Number of public transport routes	0.1350	2
S2	Public transport frequency	0.1200	4
S3	Convenient transportation by public transport	0.0815	6
S4	Car sharing	0.0345	9
S5	Bicycle sharing	0.0303	10
S6	Low power vehicle sharing	0.0265	12

The compatibility of evaluations can be determined using Kendall concordance coefficient [51], which is calculated by the following formula:

$$W = \frac{12S}{p^2(m^3 - m)}, \tag{20}$$

where: S-sum of the squares of the total deviation from the evaluation results; p-the number of experts; m-the number of criteria.

The sum of squares of the deviation from the overall mean is calculated using the formula:

$$S = \sum_{j=1}^{m} \left(R_j - \bar{R}\right)^2, \tag{21}$$

where: R_j-the sum of the criteria rank; $\bar{R}$-the overall average.

The concordance coefficient W is a calculated variable that may take a random value. Therefore, the significance of the coefficient must be calculated. The significance of the concordance coefficient is determined by the formula:

$$\chi^2 = p(m-1)W, \tag{22}$$

The consistency of the expert evaluation is determined by calculating the minimum value of the concordance coefficient using the formula:

$$W_{crit} = \frac{\chi^2{}_{v\propto}}{p(m-1)}, \tag{23}$$

If W > W_{crit}, it confirms that the expert opinions are harmonised.

W_{crit}, was first calculated, with a significance level of α = 0.05 and v = 6–1 = 5. In our case, for the groups of infrastructure measures and mobility services, W_{crit} = 0.3722.

After receiving 9 completed questionnaires, calculations of the consistency of expert opinions were performed. It was found that the Kendal concordance coefficients W = 0.5781 were calculated for the indicators of infrastructure measures, W = 0.5556 for the indicators of mobility services. In both cases, $W > W_{crit}$ was obtained, which means that the expert opinions are consistent, and the results can be applied to the MCDM calculations.

6. Determining the Level of Development of Infrastructure and Mobility Services Favourable for the Sustainable Mobility of STP Employees by MCDM Methods

A matrix of solutions was developed based on the calculated significance of the sustainable mobility indicators and their values. Calculations were performed using three MCDM methods: SAW, COPRAS and TOPSIS. The results obtained are presented in Table 8.

Table 8. Assessment results applying MCDM methods.

Science and Technology Park	MCDM Methods						Significance Average	Rank
	SAW		COPRAS		TOPSIS			
	Weight	Rank	Weight	Rank	Weight	Rank		
Sunrise Valley Science and Technology Park	0.9312	1	0.3780	1	0.7720	1	0.6937	1
Science and Technology Park of Institute of Physics	0.5548	3	0.1875	3	0.4367	3	0.2948	3
Northtown Technology Park	0.5052	4	0.1572	4	0.0000	4	0.2364	4
Visoriai Information Technology Park	0.8124	2	0.2774	2	0.7036	2	0.5978	2

After the above calculations, in all three cases, the rankings of science and technology parks according to the adaptation to sustainable mobility coincided. Sunrise Valley Science and Technology Park has the best-developed infrastructure and mobility services to encourage workers to move in a sustainable way.

7. Survey of Employees of Science and Technology Parks

To identify the habits of STP staff related to sustainable mobility, a survey was conducted. Employees were interviewed using the online survey method in July/August of 2020, and 78 respondents participated. Most respondents were men −60%, the rest-women. 51% of them were people aged 26–45, and in general, they all fit into the working-age range of 18-65. When assessing mobility habits, it is necessary to mention that most respondents are motorized and have their car−78%. The survey also revealed that employees give priority to petrol (53%) and diesel (35%) cars, and 8% of them choose more environmentally friendly cars-hybrid or electric. STP workers had been chosen as the subjects because they represent the typical mobility behaviour of an educated, working person. The results revealed how they travel to work daily (see Figure 3).

It is necessary to mention that the employees of the North Town Technology Park were not included in the survey because, according to the administrator, they do not have an established community yet. This park is still in the development stage, so it was evaluated only on a theoretical level, in the previous section.

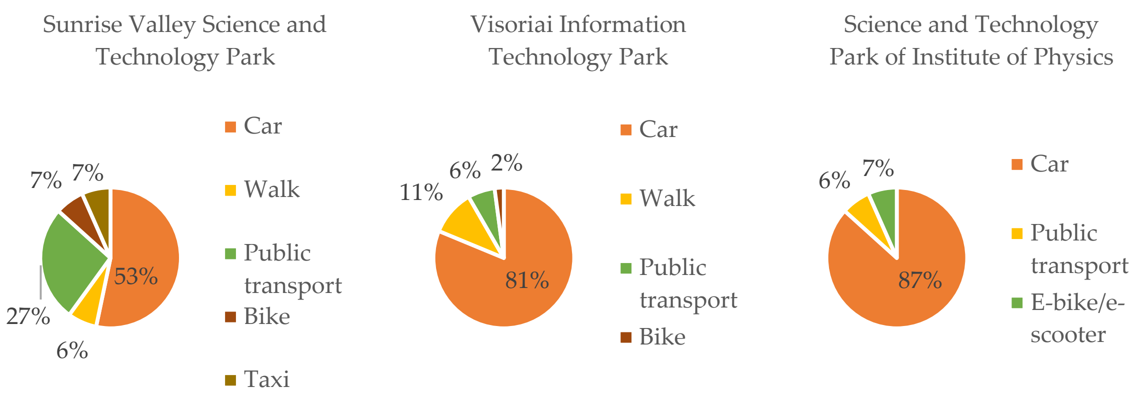

Figure 3. Modal split of employees of different STPs in Vilnius (Source: STPs' employees' survey, 2020).

By the analysis results of the survey, according to the modal split, one stands out from a sustainable mobility point of view-the Sunrise Valley Science and Technology Park. The lowest dependency on cars was determined here. In this way, about half −53% of employees travel to work, which is still far behind the goals of Vilnius city. For comparison, the SUMP of Vilnius (2018) sets targets for the modal split for 2030. It aims to increase the share of walking to 35%, cycling to 10%, public transport to 25%, car sharing to 3%, and decrease the usage of a car to 22% of all journeys. In the Visoriai Information Technology Park and the Science and Technology Park of the Institute of Physics, most employees travel to work by car, 81%, and 87% of the employees, respectively. The first park (Sunrise valley STP) also had the highest share of trips made by public transport, almost a third −27%, while in Visoriai and the Institute of Physics STPs', respectively, 6% each. The modal distribution of travel in Vilnius is not the same due to the different purposes of the city's functional zones, infrastructure development, quality of services provided, public habits, distances, etc. Such a small share of journeys made by public transport may also be related to the fact, that the survey was conducted under the threat of COVID-19. Some respondents commented on their concerns and fears about going to work in this mode of transport due to possible infection. As a result, the number of car trips could increase significantly.

Employees of Visoriai Information Technology Park travel the most on foot out of all STPs' −11%. This park is adjacent to residential areas, so some employees have likely chosen their place of residence nearby to save their time and money. Almost twice as few commuters go to work in the Sunrise Valley STP. This park is located on campus, and the apartment buildings from which it would be convenient to reach the workplace if a potential worker would live there (except for the adjoining block of private houses) are a little further away. There is no staff to travel to work on foot in the Science and Technology Park of the Institute of Physics. This park is developed far from the city centre and residential areas and is connected to the city by a nearby category B street. It provides communication between the city's functional zones, districts, centres, major transport stations and is connected to the suburban roads. Meanwhile, employees do not have access to pedestrian infrastructure because it is almost non-existent.

8. Discussions and Conclusions

In this article, the authors evaluate the correspondence of STPs to the sustainable mobility of staff, using MCDM methods. Two groups of indicators were selected after the comprehensive scientific literature research. These groups include indicators for infrastructure measures and mobility services. According to the AHP method, the most important measures for sustainable mobility are convenient public transport infrastructure, the number of public transport routes, a sufficiently developed pedestrian infrastructure network, etc.

The authors found that the Sunrise Valley STP has the best-developed infrastructure and transportation services that encourage employees to travel in more sustainable ways. It is easier to offer better services and infrastructure, as this STP is in the heart of the student campus, next to the universities, where accessibility is particularly important for the whole community. Unlike other STPs which are in more remote areas.

The authors of the research observed the link between the distance from the developed STP site to the city centre and the more sustainable mobility of workers. The closer the STP is to the city centre, the more workers travel to and from work in more sustainable means. Places such as STPs often do not require large-scale development, nor do they engage in the polluting industry, so the authors propose to develop them closer to the urban centre.

The STPs ratings calculated by the MCDM methods were confirmed by the results of the employee survey. Here, the modal distribution of travel in terms of sustainable mobility was in line with the results of the expert study. The least dependent on the car are the employees of the Sunrise Valley STP (53%) and the most dependent are the employees of the Institute of Physics STP (87%). This research excluded the North Town Technology Park, whose community is still forming and did not participate in the quantitative study. The modal distribution of travel in Vilnius is not the same due to the different purposes of the city's functional zones, infrastructure development, quality of services provided, public habits, distances, etc.

STP is a relatively large object of attraction with many employees/visitors. When planning such areas, the authors of the research suggest considering the proper provision of mobility services and infrastructure. The aim of STPs, in terms of employees' travel, should be to maximize the number of trips to/from it in a sustainable way, i.e., accessibility by walking, cycling, using public transport, etc. is ensured. Quality assurance of these services is simpler when such institutions are developed in the vicinity of the existing infrastructure, closer to the functional centres of the city. Besides, the promotion of sustainable mobility of workers should be achieved not only through the improvement of infrastructure and services but also through other incentives, such as employer incentives or education.

This authors' study contributes to research on SUM and urban planning. Selected and ranked indicators can help policymakers and urban planners to prioritize the development of new STPs and choose the most efficient and cost-effective project solutions. Such innovative sites should set an example for others and contribute to the vision of a sustainable city without overloading the city streets with even more cars. Providing access to alternative means of transport contributes not only to the reduction of air and noise pollution and congestion caused by transportation but also provides better access to employment. And this closely interrelates with the improvement of the social equity goal, which is part of the sustainable development concept from the social point of view. Following the research, guidelines/recommendations can be developed on where it is best to plan the STP, what are the most important, and what are needed in the planning of the STP. Regarding limitations, data were gathered from one specific industry, so generalizing the results to other industries requires further research.

By 2018, strategic documents-SUMPs of 20 cities were prepared in Lithuania. Now they are being monitored constantly. The results obtained in this article will be used to improve the sustainable accessibility of STPs and at the same time affecting the sustainable environment of the whole city.

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