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WHICH OPTION OF SUSTAINABLE MOBILITY SHOULD BE CHOSEN? – AHP METHOD APPLICATION FOR SUSTAINABLE DECISION MAKING IN TRANSPORT

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Abstract: *Sustainable development has become one of the most influential concepts worldwide, so it affects also decisions made on transport. As a result, a sustainable mobility concept was developed. In authors opinion there are many options that promote sustainable mobility, however there is lack of support for those decisions. The main objective of the paper was to present a selection's method of a transport option promoted as sustainable mobility option, available in Poland. In order to achieve the specified goal, the Analytic Hierarchy Process was used. There were determined criteria considered as important aspects of sustainable mobility in order to present the best option in polish conditions. The method may be verified in other countries.*

Key words: *Sustainable mobility, Analytic Hierarchy Process, AHP.*

1. INTRODUCTION

Lately, it may be observed an increase of interest concerning problems connected with sustainability in transport. The presented paper is focused on sustainable mobility of people in an emerging country - Poland.

People need to be moved owing to the fact that there are distances between their place where they live, spend leisure time, work, educate, etc. Mobility is not an option, it has become a requirement. Authors have defined mobility as an ability to move or be freely and easily moved from one place to another.

In order to be mobile, people need transport. It was claimed, that considering sustainability, transport presents one of the major challenges, owing to the fact that it affects people, economy and environment.

Poland as a member of European Union (UE) has to deal with legal requirements according to the European Union's (EU's) Seventh Environment Action Programme (7th EAP), which puts forward a clear vision on transport's goals. With reference to 7th EAP, in order to reduce environmental, health and climate pressures arising from transport sector, it is critical to achieve the objectives related to : reduction of GHG emissions, CO2 emissions, oil consumption, air pollution and noise and increase in renewable energy [2]. Moreover, congestion and land use which are associated with transport infrastructure are also problems for vast of European countries, posing economic costs [14] and threatening biodiversity as it may cause fragmentation of natural, semi-natural and agricultural areas [1]. According to experts, EU transport activity is expected to continue growing under current increasing trends and adopted policies. From 2010 to 2050, passenger transport is estimated to grow by about 40 %, with aviation as the fastest growing sector (more than doubling 2010 levels) [2,p.6].

Despite negative environmental impact, transport is crucial for economic competitiveness as well as for growth and employment. Furthermore, the car industry is the largest manufacturing sector in the world [6], what makes it one of the major generators of wealth and employment in the EU.

By combination of the concept of sustainable development and the need for smooth movement, the idea of sustainable mobility was created. However the 'sustainable development' concept is known from many years, the sustainable mobility is quite new term. The World Business Council for Sustainable Development defines 'sustainable mobility' as 'the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values today or in the future' [17]. It was claimed, that sustainable mobility, as sustainable development should be considered in the context of three pillars, what was described by Björn Nykvist and Lorraine Whitmarsh, who grouped dimensions of sustainable mobility [9, p.1373-1374].

The main objective of the paper was to develop a method of selection an option of sustainable mobility available in Poland with the use of Analytic Hierarchy Process.

In order to achieve the main research objective, there were defined the following research questions:

- RQ1: What possibilities of sustainable mobility are available in Poland?
- RQ2: What factors have an influence on decisions made on means of transport selection?
- RQ3: How to assess options of sustainable mobility with the use of AHP method?

The remainder of this paper has the following organization. Section 2 gives a brief description of sustainable mobility options available in Poland. In the Section 3 there was described AHP method, which was used in order to select the best sustainable mobility option in Polish conditions in the Section 4. Conclusions and recommendations for future research were set out in Section 5.

2. SUSTAINABLE MOBILITY OPTIONS IN POLAND – STATE – OF-ART

2.1 Car sharing

Car sharing was being grown on the basis of need of affordable access to a car [15]. It was claimed, that instead of buying and owning things, consumers want access to goods and prefer to pay for service. It is the main idea of car sharing. Shared vehicles available on polish roads are offered only by few companies like Traficar, 4mobility, Click2Go, Easyshare. One of the biggest companies in Poland, the Traficar has possessed 1100 cars so far [16]. In order to use the shared fleet, the user must set up an account in the application of a selected company, send a scan of the driving license and link the created account with the payment card, as there are some membership requirements. This type of service is based on a self-service as there is lack of human interaction to pick-up or drop-off cars. Users may drop-off vehicles anywhere within a service area as long as they follow local parking regulations. The fee for shared car includes cost of the time and distance and it is approximately 0,1€/min, 0,2€/km. It is noteworthy, that vehicles are free of charges of parking in paid zones in city center, what requires close relationships between operators and local government. This is comfortable way of travelling around the city as the fuel cos is included in the fee and user is not responsible for insurance and service. In addition, some cities have special parking spaces reserved only for such cars. According to some sources, one shared car is able to replace from 7 to even 20 traditionally used vehicles [16], what may decline the number of cars moving around the city. Car sharing fleet consists mainly of hybrid cars and those complying with the Euro6 standard, which significantly contributes to reducing the emission of harmful air pollution. There are some limitations of the presented solution, what is related to the available infrastructure. Firstly, the geographical limitation in use as the car has to be left in the city and it is not always available at the place where the user needs it, so the accessibility may be a problematic issue. Moreover, if the vehicle is damaged, sometimes there are penalties for users. As the result of the observations made by authors of the paper, it was stated that very often vehicles are dropped-off in not authorized places and they do not take care about something what is not their property, so cars are damaged.

2.2 Scooter sharing

The next option is similar to the car sharing, but it includes scooter as a means of transport, which requires the use of helmet and sanitary covers in terms of health and safety rules. The registration is similar to the car sharing with the use of appropriate application/system. Owing to the fact that scooter is smaller than a vehicle, it may be used only by maximum two people. Moreover, it may be used only in a city center because of the electric drive. There is no point using it outside the center because requirement of frequent charging the battery. Although traffic jams might be avoided, passengers are exposed to weather conditions, even bad ones. The fee includes cost of the time and distance and it is approximately 0,1€/min, 0,1€/km, however there are cities where there is only charge for time of scooter's use. The fleet of scooters is much less than cars or bicycles (e.g. in Warsaw it was around 150 scooters in 2016), so accessibility level is quite low. Use A4 format (210 x 297 mm)

2.3 Shared bicycles

Community shared bicycle programs offer an environmentally friendly, healthy and inexpensive alternative to automobile transportation, which has been very popular in Poland. There may be observed increase in number of bicycles' paths, shared bicycles and access to bicycles' stations. The first bike-sharing program was launched in Cracow, in 2008. Currently, there are 39 systems operating in Poland, in big cities but also small ones, which offer not only standard bicycles but also : tandems, children bikes, electric bicycles. The shared bicycles system is very popular through Poles, e.g. in the capital city – Warsaw, there is the biggest number of stations (366) and bicycles (5292) [4]. Only in 2016, the system operator in Warsaw noted 1,9 million rentals and 70 thousand registrations of new users . Since July 2012, when the inhabitants for the first time had an opportunity to use Warsaw City Bike, 445 thousand people made almost 8 million rentals [5]. It was stated, that growth of the system could not be possible without the engagement of sponsors, who have decided to expand it through funding the stations. There are even examples of founding by local communities (e.g. in Warsaw), what proves that people are willing to use shared bicycles. The fares for renting a bicycle are competitive as user gets very often 15-20 minutes of free ride. After that time the service will cost around 0,25-0,5€/20-60 min. There is required an account and an initial charge for using a system/application (around 2,5€). Sometimes there are some discounts for users of loyalty programs or holders of tickets for public transit system. However, there is still more and more stations, so accessibility rate has increased. The compromise that travelers must agree on is the average comfort of the vehicle, in particular in unfavorable weather conditions and the speed limited by the strength of human muscles. Even though the vehicles are regularly serviced by the fleet's owner, often their technical condition may be poor (e.g. lack of air in the tire, poor lubrication). It should be noticed that using a bicycle makes it possible to avoid traffic as bicycle paths are independent of roads.

2.4 Carpooling

The next option used by Poles is carpooling, which refers to sharing of a ride with a driver and one or more passengers. In authors opinion in this system an individual vehicle is altered to look like means of public transport. As a result, instead of journey of individuals, people who commute on the same routes, may go together to their destination. There may be considered three types of rides : occasionally, cyclic and daily (e.g. to work, school). It is noteworthy, that carpooling is a type of C2C services, instead of B2C, so ride is offered by private person, not a company. In Poland, carpooling is developed by : use of specified internet systems dedicated for carpooling, social portals (e.g. facebook), discussion forums or bulletin boards at the offices. By carpooling people usually get to other city (e.g. in different countryside). In authors opinion the most relevant issue is that, it was not made in order to generate profits for the driver but to divide travel costs and fuel between travelers. Both sides of the contract have information about the other side and they may contact. The potential passenger may choose the best match in the system (place, time, vehicle, features of the drives e.g. non-

smoker). Person who offers transport gives information, such as: the number of people are able to be carried, price per person and preferences of travelers (e.g. non-smokers, no animals, etc.). The journey should be reserved by passenger and accepted by the driver. Payment is made by cash after the trip. The safety of users who want to use carpooling is ensured by a detailed verification of personal data, as well as a system of assessments after a journey. It was claimed, that the greatest disadvantage of this option is primarily the low flexibility of the ride - in this matter the passenger depends on whether any person overcomes the desired route and when it is done. However, it should be noticed that very often it is an alternative to get to place, where there is no or is very poor public transport, in a competitive price. Moreover, people may make contact with new people and coworkers may have better relationships (social context).

2.5 Public transport

In authors opinion the sustainable mobility is also ensured by means of public transport. Each large and medium-sized city in Poland has a comprehensive bus network, while some cities also have trams and trolleybus systems. Warsaw is the only city with a metro. Each of public transport is used for transport of many people at the same time. Usually, the price for the ticket depends on the time of journey/number of stops. Availability of tickets is high as they are available at selling points, ticket machines, through a phone or via Internet (card). The basic limitation is the connection network which is tough to be changed as it requires huge investments from the local Government. As a result, passenger has to adopt to the stops' location. What is more, public transport companies are large enterprises hiring a lot of people (social context), reducing unemployment. In Poland, there have been made a lot of efforts in order to make the public transport more environmentally friendly e.g. by investments in hybrid or electric buses. According to Stefan Baguette's report, Poland in 2017 was at the fourth place in the number of electric buses in Europe with the total number of 256, while the first place – was UK with 356 buses [3]).

According to data from one of public transport operators in Poland, one bus is able to replace up to 30 single-occupancy vehicles moving through city streets every day [7]. Fleet is modern, equipped with air-conditioning, wi-fi, monitoring, etc in order to better meet passengers requirements.

Although authors are aware of other possibilities of sustainable mobility options (e.g. autonomous vehicles), due to the main objective of the paper, considerations were limited to options available in Poland.

3. ANALYTIC HIERARCHY PROCESS

Analytic Hierarchy Process (AHP) has attracted the attention of many researchers mainly because of its favorable mathematical properties and easy access to the required input data [10]. This method can be used to measure the quantitative and qualitative criteria in decision-making process [11]. AHP allows to assess the relative weight of multiple criteria or multiple options against given criteria in an intuitive manner. Through the AHP method, decision-makers can recognize whether one criterion is more important than another, even if quantitative ratings are not available. Therefore, pairwise comparisons are appealing to users and they are required in problem considered in the paper, as there are available qualitative data, very often based on feelings and judgments, and other forces that might affect decision-making in the decisions made on sustainable mobility options. Due to these reasons, in the present research, the AHP method was introduced.

The AHP method requires the following steps [8,12] :

- Step 1: Developing a model for the decision;
- Step 2: Weights determination of the criteria;
- Step3: Deriving local priorities (preferences) for the alternatives;
- Step 4: Making a final decision (summary).

The first step in an AHP analysis is to build a hierarchy for the decision, including : goal, criteria and alternatives, what may be presented as a decision tree. That approach allows to better understand the decision to be achieved, the criteria to be used and the alternatives to be

evaluated. It is a good idea to involve experts at this stage to ensure that all criteria and possible alternatives have been considered [8, p. 9].

In the following step, there are determined priorities of the criteria included into analysis. The importance of criteria are compared pairwise with respect to the desired goal. For each pair of criteria, the decision maker is required to respond to a question related to the relative importance of compared criteria with respect to each of the others using a numerical scale for comparison developed by Saaty available in [12, p.86]. Rating the relative "priority" of the criteria is made by assigning a weight between 1 (equal importance) and 9 (extreme importance) to the more relevant criterion, whereas the reciprocal of this value is assigned to the other criterion in the pair. The weighings are then normalized and averaged in order to obtain an average weight for each criterion [12]. The presented step requires to check the consistency of judgments; that is, a review of the judgments is done in order to ensure a reasonable level of consistency in terms of proportionality and transitivity. Some inconsistency is expected and allowed in AHP analysis. In order to verify judgments, there should be calculated a consistency ratio (CR), which is defined according to the Formula 1 [13]: $CR = CI / RI$ (1)
where : CI - consistency index ; RI – consistency index of a random-like matrix.
The consistency index (CI) is calculated as (Formula 2): $CI = (\lambda_{\max} - n)/(n-1)$ (2)
where : λ_{max} - max is the maximum eigenvalue of the judgement matrix, n - number of compared elements.

In order to calculate CR, CI should be compared with a random matrix, RI , that is the consistency index of a randomly generated comparison matrix (available in [13]. According to Saaty, if the CR exceeds 0,1 the set of judgments may be too inconsistent to be reliable, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it. If CR is equal to 0 so it means that the judgments are perfectly consistent [13]. Example of calculation may be found in [8].

In the next step of the AHP analysis, there should be compared alternatives considered from the perspective of each criterion in order to determine local priorities for alternatives. For each pairwise comparison within each criterion the better option is awarded a score, on a scale between 1 (equally good) and 9 (absolutely better). Each score records how well option "x" meets criterion "y" [12]. Checking and adjusting the consistency are required at this stage similar to the previous one.

Finally, the option scores are combined with the criterion weights to get an overall score for each option. The extent to which the options satisfy the criteria is weighed according to the relative importance of the criteria, what is done by simple weighted summation [12].

It was claimed, that AHP can effectively support decision making with regard to complex issues and can help to recognize and define a problem in details, what was relevant for authors of the paper.

4. WHICH SUSTAINABLE MOBILITY OPTION SHOULD BE CHOSEN?

4.1 Development of framework for AHP

In order to achieve the main objective of the paper, in Section 2, there were described available sustainable mobility alternatives in Poland, including: car sharing (A1), scooter sharing (A2), carpooling (A3), shared bicycles (A4), and public transport (A5).

As different actors involved in decision-making may have di□erent priorities for options, ranking needs should be done by a group of experts, representing people who have some sustainability awareness. In the research two representatives of academia and two students were engaged.

Table 1

Assessment criteria

ID	Criterion	Considered aspects of the factor	Desired value
C1	Travel requirements	Additional documents (e.g. a driving license), purchase of tickets, possession of an application or city card, appropriate age.	Min.
C2	Comfort level	Exposure of weather conditions, influence on the travel parameters (e.g. speed, stops), level of	Max.

		physical engagement of the user (related to e.g. level of responsibility and required concentration)	
C3	Speed	Speed in achieving the trip's goal (Time, distance, waiting time for means of transport, required stops)	Max.
C4	Cost	Average cost of 1km (fuel, initial fee, tickets)	Min.
C5	Accessibility	Number and location of infrastructure points (e.g. stops, bike stations), reliability, simplicity and promptness	Max.
C6	Influence on flow of traffic.	Number of single-occupancy vehicles on the road, use of parking spaces, street congestion, use of roads	Min.
C7	Emissions	Air pollution, noise	Min.
C8	Job creation	Number of workplaces	Max.

In order to make the analysis, it was important to define the list of criteria based on which the comparative judgements were made. The following criteria have been selected on the basis of the literature review on sustainable mobility issue and brainstorming session made by three researchers with the research interest area of sustainability (Table 1).

With reference to data presented in the Table 1, there were considered eight criteria (C1-C8) in order to achieve the main objective of the paper. The main remark refers to C3 criterion related to the time and speed of transport. The urban distance of 15 km was adopted to be assessed. Moreover, there were included in the Table 1, data about the desired value of each criterion, which might be maximized (C2,C3,C5, C8) or minimized (C1, C4, C6,C7).

4.2 Construction of AHP tree

Considering the framework of AHP described in the previous section (4.1), there was prepared a decision tree for selection an appropriate option from available sustainable mobility options, presented in the Fig. 1. According to Fig. 1, in order to achieve the goal of choosing a sustainable means of transport, there were established 8 criteria (C1-C8) through each of them, there were compared 5 alternatives (A1-A5), describ in the Section 2.

4.3 AHP analysis

Following the procedure of AHP analysis use described in Section 3, after problem's decomposition (Fig.1), in the second step criteria affected decisions on sustainable mobility were compared each to other in order to calculate their weights. The results of the step were presented in the Table 2:

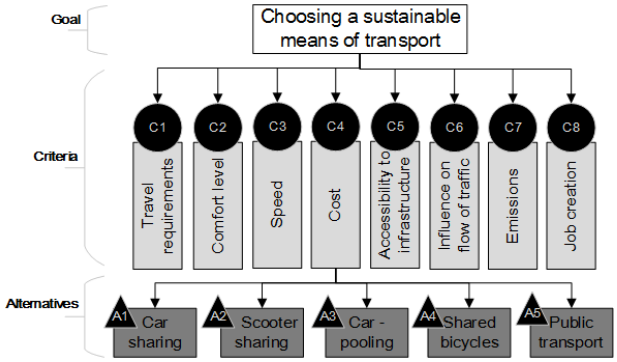

Fig. 1. Decision tree for selection a means of transport

Table 2

Pairwise comparison matrix of criteria

Goal	C1	C2	C3	C4	C5	C6	C7	C8	weight
C1	1,00	0,20	0,20	0,33	0,20	0,20	0,11	0,13	0,019
C2	5,00	1,00	0,50	3,00	3,00	0,50	0,17	0,20	0,072
C3	6,00	2,00	1,00	3,00	5,00	0,50	0,14	0,17	0,092
C4	3,00	0,33	0,33	1,00	3,00	0,33	0,13	0,17	0,045
C5	5,00	0,33	0,20	0,33	1,00	0,25	0,13	0,17	0,038
C6	5,00	2,00	2,00	3,00	4,00	1,00	0,17	0,20	0,099
C7	9,00	6,00	7,00	8,00	8,00	6,00	1,00	4,00	0,393
C8	8,00	5,00	6,00	6,00	6,00	5,00	0,25	1,00	0,241

Following guidelines presented by Saaty [12] with the use of brainstorming method, there were made pairwise comparison between criteria included into analysis, what resulted in the priorities determination of the considered criteria. It was assumed that analysis should be made in order to ensure sustainable policy realization, what was major limitation of the research.

Experts have decides that requirements of the travel (C1) are less important than other criterions because we should be ready to make something more in order to take care of the Environment and for other people. There was similar approach to the comfort level (C2), however people may pay more and accept less accessible option for more comfortable journey. The presented results of comparisons confirm that care of the Environment is the most relevant considering other options. Moreover it

was stated, that aspect of the job creation (C8) as well as influence on traffic (C6) are also more important because they consider the population not interests of single person. Considering results of the comparisons, there was made normalization and averaging, and finally there were obtained weights of factors, which prove that ecological and social criteria were the most relevant ones.

It should be noticed, that data from Table 2 were verified that they were consistent, with reference to the theoretical background of the AHP analysis described in Section 3 of the paper. Following appropriate guidelines, there were obtained the results of the consistency of judgments analysis, presented in the Table 3:

Table 3

Parameters of consistency of judgments analysis

Parameter	λ_{max}	n	CI	RI	CRI
Value	9,587	8	0,227	1,4	0,096

CI is the consistency index with a value of 0,227. It can be seen that for n = 8, RI = 1,40. Using these values for CI and RI, it can be calculated that CR is less than 0,10, so it was assumed that judgments matrix was reasonably consistent so the process of decision-making using AHP could be continued. In the following step there were derived local priorities (preferences) for the alternatives. The example for C6 criterion was presented in the Table 4.

Table 4

Pairwise comparison matrix of alternatives for C6

C6	A1	A2	A3	A4	A5	Average
A1	1	0,33	1,00	0,11	0,14	0,04
A2	3,00	1	3,00	0,20	0,20	0,11
A3	1,00	0,33	1	0,11	0,14	0,04
A4	9,00	5,00	9,00	1	4,00	0,52
A5	7,00	5,00	7,00	0,25	1	0,29

The basis for this step was to do comparisons through a series of questions, depending on examined criterion. Comparison question for criterion C6 was: With respect to Influence on flow of traffic, which alternative is preferable?

According to data in the Table 3, the A4 and A5 alternatives are better choices than other in respect of considered criteria C6.

Following previous guidelines, also at this step the consistency of judgments analysis was verified, however it was made on the basis of the judgment of each alternative, so n=5, presented in the Table 5:

Table 5

CRI values for alternatives

Criterion	C1	C2	C3	C4	C5	C6	C7	C8
CRI	0,091	0,083	0,089	0,088	0,095	0,058	0,098	0,099

With reference to data in Table 5, it was stated that judgments matrix was reasonably consistent so the process of decision-making using AHP could be continued.

As a result of pairwise comparisons of all considered alternatives there were obtained the following results, presented in the Table 6.

Table 6

Synthesis of the model

Alternative	Overall priority
A1	0,139808304
A2	0,148794521
A3	0,083118115
A4	0,377413619
A5	0,250865441

Following the convention the local priorities of alternatives and the weights for each criterion (Table 3), there were obtained final results of overall priority in the Table 6.

As a result of the AHP analysis it was stated that the shared bicycles are the best option from the considered criterions, which should be chosen in order to support sustainable policy realization.

5. CONCLUSIONS

To sum up, it was stated that the sustainable mobility issue is becoming more important in daily life and daily decisions of people who have to move. However, AHP and sustainability mobility are not original, their combination is an answer for a research gap as there is no research on that topic.

In authors' opinion, the proposed approach may be used in order to make decisions, which refer to sustainability policy supporting.

It should be noticed, that alternatives and criterions as well as priorities were designed for a developing country from the perspective of sustainable aware man. However, in Poland sustainability is still in a state of infancy, law

regulations of UE and worldwide requirements have made it more relevant. It needs time to be common approach.

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Ce varianta de mobilitate sustenabila sa alegem - Metoda AHP aplicata pentru luarea deciziilor in domeniul transporturilor

Rezumat: Dezvoltarea durabilă a devenit unul dintre cele mai influente concepte din întreaga lume, deci afectează și deciziile luate în domeniul transporturilor. Ca rezultat, sa dezvoltat un concept de mobilitate durabilă. În opinia autorilor, există numeroase opțiuni care promovează mobilitatea durabilă, însă există o lipsă de sprijin pentru aceste decizii. Obiectivul principal al lucrării a fost de a prezenta o metodă de selecție a opțiunii de transport promovată ca opțiune de mobilitate durabilă, disponibilă în Polonia. Pentru atingerea scopului specificat, a fost utilizat Procesul de ierarhie analitică. Au fost stabilite criterii considerate aspecte importante ale mobilității durabile pentru a prezenta cea mai bună opțiune în condițiile poloneze. Metoda poate fi verificată în alte țări.

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