Evaluation of the Impact of Sustainable Transportation Alternatives on Environment Using Fuzzy PROMETHEE Method

Hüseyin Gökçekuş, Dilber Uzun Ozsahin, Dania Al-Othman

Abstract*: Due to the increasing global population as well as quick expansion, transportation requirement has increased respectively. Presently, the demand for establishing conveyance technologies and infrastructural systems targeted at meeting this growing need is currently crucial. Following the Industrial Revolution, the number of private vehicles has escalated regardless of the lack of infrastructural capacity, in which the traffic issues are now being tackled. Moreover, expansion can be viewed as an approach for sustainability, as well as a quality of life with reduced waste, fewer resource utilization, a smaller amount of carbonated gases, and further energy proficiency. In urban regions and surrounding areas, traffic emissions and their pollutants are considered to be a disturbing matter due to their association among the total death increase, lung cancer hazard and deteriorating of respirational well-being. In order to resolve the aforementioned issues, conveyance technologies require enhancement, which also includes promoting the utilization of sustainable transportation like walking/cycling and encouraging authorities and representatives to progress compulsory regulations to perform such sustainable transportations. The following research objective is to integrate the theory of multi-criteria decision making method within green transport as well as enhancing traveling by means of public commute, bicycles and walking. Moreover, this research works towards assessing and comparing the more conventional sustainable transport substitutes by utilizing multi-criteria decision methodology. Fuzzy PROMETHEE is the decision-making methodology implemented within the study.

Index Terms*: Sustainable transportation alternatives; PROMETHEE; multi-criteria decision making; Fuzzy PROMETHEE (F- PROMETHEE).

I. INTRODUCTION TO SUSTAINABLE TRANSPORTATION ALTERNATIVES

A. Private Vehicles

In industrialized regions, the growing utilization of active vehicles within and throughout the cities resulted in intensifying convenience complications which can be perceived from the traffic congestions and parking difficulties. In addition to road blockages, private vehicles are also responsible for serious conflicts such as greenhouse gas emissions, global warming as well as noise (disturbance) [1]-[5]. Throughout a universe, private vehicles are considered to be one of the main forms of personal transportation, primarily due to its affordability and reliance in comparison to other forms of transportations accessible. The vehicle can be seen as a crucial component of the transportation structure which has provided advanced movement and accessibility, higher employment, technological developments and economic affluence [6].Even though the thought of a universe with no vehicles is unbearable, various cities have been altering their transportation resolutions far from private vehicles and more to the sustainable and people-targeted transportation methods [6]. Substructures involved with vehicles and the vehicles themselves are additionally associated with various damaging ecological contacts particularly high temperature and sound pollution [6].

Furthermore, the use of vehicles may well be considered inactive comportment linked with a decreased level of functional transportation as well as physical motion [7]. Some consequences of using vehicles include driving stress is due to traffic jams, speeding, and typical overstimulation, as well as severe health deficiency triggered by air contamination [8]. Regardless, some advantages of vehicle use include better -enhanced approachability, speed, as well as manipulation of our beings [9].

B. Public Transport

Recently, several types of researches have been carried out to expose the elements that are capable of minimizing the utilization of private transportation while simultaneously increasing the number of users for the public commute in various municipalities. Coherent to the global warming complications, an advanced comprehension of the effects of an eco-friendlier transportation method such as the public commute is crucial, since these approaches can generate minimal emission in relation to private vehicles [10].

Various researches correspond to the circumstance that public commute structures within the urban framework able to be pertained as a vigorous structure [11]-[13]. The function of implementing public commute is to enhance facilities and the mobility stipulation that is harmless, cohesive, systematic, efficient, secure, conventional, proficient, operative and inexpensive for the public society [14].

Communal transportation facilities encounter sustainable confrontations for incorporating ecological "eco-efficiency" as well as social sustainability by

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including all the investors to deliver improved service and efficacy [15]. The citizens and humankind embody chief complications in regards to the macroclimate and environment catastrophe. Within the setting of communal transportation services, modifications of client encounters entail convincing clients to use communal transportation facilities by means of eco-friendly approachability or an open discussion on concealed hazards.

C. Car –Sharing

At this time, the definite complication is to rupture the custom of employing vehicles, in which one resolution is exemplified through altering from private vehicles to substitutive environmental methods of transport, like carpooling [16],[17]. The concept of carpooling stimulates the decreasing of automobile possession as well as car miles driven, reduced CO_2 emissions since trips alter to transportation, cycling, and walking [15]. Furthermore, these advantages are enhanced when employing the concept of carpooling with electrified/hybrid vehicles. Carpooling is capable of exemplifying a stimulating transitional alternative that allows individuals to modify their behaviors increasing the employment of an intermodal structure in the urban framework. There are many benefits to car-sharing, one of which is saving money; where the more you carpool, the less money you will be spending on fuel. When carpooling the fuel expenses are divided upon the members of the carpool, which allows each individual to save money.

Additionally, in car-sharing, the budget spent on car reparations and maintenances is minimized in which members of the carpool are able to rotate the vehicle use between one another. Moreover, members of the carpool save money on the road fees, since the employment of car-sharing lessens the number of vehicles used, fewer vehicles are on the road.; hence, minimizing corrosion and destruction to the highways/roads that require to be restored annually by means of taxpayer's money. Car-sharing also aids the environment and minimizes the number of vehicles on the roads. The fewer cars used, the fewer carbon emissions and other pollutants are spread throughout the environment. This safeguards the environment by maintaining cleaner air, land, and water.

D. Taxis

The term "Taxi" is referred to a car with an available driver to be hired for the public. Generally, the vehicles used are smaller than buses/coaches and are registered for the utmost capacity about nine passengers [18]. There are various definitions for the term depending on the region and functionality of a taxi.

The qualities may fluctuate from one area to another and in some situations from one city to another [18]. The majority of transportations are implemented to assist individuals who want to travel from one point to another, and taxi's here are considered to be one of the several methods to do so. Moreover, taxis ought to be involved within the transportation structure of cities, since they serve a necessity which is available in all cities in various forms. Judged against the other forms of public transportation, taxis are capable of offering high mobility and accessibility for small transportation capacities at high prices. Moreover, taxis offer door-to-door services, which are available 24/7 [18].

In the countryside, areas where with low population inhabitants, taxis are typically the lone method of transportation obtainable to the public. This form of transport is not restricted to a certain route or pre-determined stations; hence they function compliantly and may immediately encounter a new request.

E. Cycling and Walking

Cycling and walking were viewed as one of the inexpensive substitutes for public transportation due to its incorporation among non-motorized methods. This form, non-motorized like bikes and walking, associated along with communal transport methods, such as buses/metros, can serve as a challenging manner for private motorized transport, whilst drastically decreasing carbon emissions [19]. In various countries, cycles are the primary method of transport. Bicycles are the most convenient type of transit, the less costly method, eco-friendly, use the least volume for riding and parking, as well as offering daily exercise for users. In order to widely promote the implementation of cycles, towns and cities must be made into cycle-friendly.

Minimizing the utilization of automobiles and enlarging the walking/cycling distances may have significant health co-advantages through decreasing city air contamination as well as the occurrence of physical inactivity and the incorporated challenge of constant non-contagious viruses [20]. Correspondingly, there has been some facts specifically on the advantages of bicycling on health results in which it was claimed to reduce both mortality and overweight [21], [22].

II. PREFERENCE RANKING ORGANIZATION METHOD FOR ENRICHMENT EVALUATIONS (PROMETHEE)

The PROMETHEE methodology, which is a multi-criteria decision - making method based on a shared assessment of the alternative pair's while considering each chosen criterion was established by [23],[24]. Comparing the PROMETHEE with other MCDM techniques, this technique is considered to the simplest and most proficient approach in perception and appliance simultaneously. This approach necessitates only two forms of data; the first being the data on the weights of the chosen criterions and the second being the partiality function to relate the substitutions involvement in terms for each criterion individually [25]. By this approach, various preference functions were provided to identify the various criterions. This function, preference function (Pj), symbolizes the differentiation among the assessments received with two substitutions (a and at') respectively of the specific criteria, among a preference extent which ranges from (0 to 1). Various preference functions forms are exist, which may be employed to execute the PROMETHEE technique, usual function, V-shape function, level function, Gaussian function, U-shape function, and a linear function.

The fundamental procedures of the PROMETHEE approach

PROMETHEE method steps were defined by [24], [26] as follows:

1. For every criterion; represented by *j*, establish a precise *Pj*, preference function (*d*).
2. Specify the weights for the individual criterions $w_t = (w_1, w_2, \ldots, w_K)$. Depending on decision maker's judgment, if every individual criterion weight's significance is equal, their weight can be equally taken. In addition, normalization may be applied with regard to the weights;

$$\sum_{i=1}^{k} wk = 1 \quad \textbf{(1)}$$

3. The outranking relation (π) for whole the alternatives that symbolized as, a_t, $a_{t'}$, $\in$ A is defined as:

$$\pi(a_t, a_{t'}) = \sum_{k=1}^{k} wk.\left[pk\left(fk(at) - fk(at')\right)\right], AXA \rightarrow [0,1] \quad \textbf{(2)}$$

In this function, the symbols π (a, b) represent the "preference index" which quantifies the decision- maker's preference intensity of the alternate (a_t) compared to the alternate ($a_{t'}$) during which all criterions are simultaneously considered.

4. The outranking flows for leaving and entering are determined as follows:

(a) Positive (leaving) flow for the alternative a_t:

$$\Phi^{+}(a_t) = \frac{1}{n-1} \sum_{t'=1, t' \neq 1}^{n} \pi(a_t, a_{t'}) \quad \textbf{(3)}$$

(b)Negative (entering) flow for the alternative a_t:

$$\Phi^{-}(a_t) = \frac{1}{n-1} \sum_{t'=1, t' \neq 1}^{n} \pi(a_t, a_{t'}) \quad \textbf{(4)}$$

In the previous two equations of finding flow, n: is defined as the total number of the all alternatives. In this step, the individual alternative is set against (*n*-1) which is the number of different alternatives. The positive flow $\Phi^{+}(a_t)$ reveals the strength of alternative $a_t \in$ A. whilst, the negative flow $\Phi^{-}(a_t)$ expresses the weakness of alternative $a_t \in$ A. The PROMETHEE technique I provided the partial pre-order of the all alternatives while PROMETHEE method II provided the complete pre-order which is depend on net flow. However although, the PROMETHEE method doesn't provide plentiful information on the preference relations.

5. Specify the partial pre-order according to PROMETHEE method I depending on the following assumption:

Alternative (a_t) is favored to alternative $a_{t'}$ (a_t $Pa_{t'}$) if it convinces one of the subsequent provisions:

$$\begin{cases} \Phi+(at) > \Phi+(at') \text{ and } \Phi-(at) < \Phi-(at') \\ \Phi+(at) > \Phi+(at') \text{ and } \Phi-(at) = \Phi-(at') \\ \Phi+(at) = \Phi+(at') \text{ and } \Phi-(at) < \Phi-(at, at') \end{cases} \quad \textbf{(5)}$$

If there are two alternatives (a_t and $a_{t'}$) having similar negative and positive flows,

Consequently a_t is in- different to $a_{t'}$ ($a_t I a_{t'}$):

($a_t I a_{t'}$) if: $\Phi^{+}(a_t) = \Phi^{+}(a_{t'})$ and $\Phi^{-}(a_t) = \Phi^{-}(a_{t'})$

a_t is incomparable to $a_{t'}$ ($a_t R a_{t'}$) if;

$\Phi^{+}(a_t) > \Phi^{+}(a_{t'})$ and $\Phi^{-}(a_t) > \Phi^{-}(a_{t'})$

$\Phi^{+}(a_t) < \Phi^{+}(a_{t'})$ and $\Phi^{-}(a_t) < \Phi^{-}(a_{t'})$

6. The net outranking flow was specified for each individual alternative by applying the equation below.

$$\Phi^{net}(a_t) = \Phi^{+}(a_t) - \Phi^{-}(a_t) \quad \textbf{(6)}$$

The complete pre-order net flow according to PROMETHEE II can be determined and defined by:

a_t is preferred to $a_{t'}$ ($a_t Pa_{t'}$) if $\Phi^{net}(a_t) > \Phi^{net}(a_{t'})$

a_t is in- different to $a_{t'}$ ($a_t I a_{t'}$) if $\Phi^{net}(a_t) = \Phi^{net}(a_{t'})$.

Essentially, the one with higher $\Phi^{net}(a_t)$ value is the better alternative.

III. FUZZY PROMETHEE (F-PROMETHEE)

Not much research regarding the fuzzy PROMETHEE (F-PROMETHEE) has been conducted. The following researchers; [26]-[31] are of the few whom implemented the F-PROMETHEE method. Under actual circumstances, the gathering of crisp information to identify a complication accurately and obtain an ideal decision is usually challenging. The application of Fuzzy sets grants the decision - maker to identify the issue within the imprecise situation which is more rational. The primary objective of this structure is to suggest an evaluation of two fuzzy sets. During the year 1981, researcher Yager discovered the index that is acquired accompanied by the center of surface weight concerning the function of membership to evaluate the fuzzy values.

He identified the significance values for the triangular fuzzy as *F= (N, a,b)* conformable to the center of the triangle escorted by the *YI =(3N-a+b)/3* formulation. In the F-PROMETHEE technique implemented within this research paper, the Yager index was applied to match the fuzzy values.

IV. METHODOLOGY

The Yager index was utilized to determine the magnitude of the triangular fuzzy integers. This was followed with the linguistic approach to specify the weights of each criterion concurring to the fuzzy scale, shown in Table 1, then the Yager index was implemented once more in order to obtain the crisp weights for sustainable transportation alternatives limitations. Table 2 shows the impact of each sustainable transport alternative on each criterion. All the data for the alternatives were collected, after that all the data were applied to the Visual PROMETHEE Decision Lab program as shown in Table 3.

Table I. LINGUISTIC SCALE FOR IMPORTANCE

Linguistic scale for evaluation	**Triangular fuzzy scale**	**Importance ratings of criterions**
Very high (VH)	(0.75, 1, 1)	Toxic gases, Air quality, climate change
Important (H)	(0.50, 0.75, 1)	Fuel use
Medium (M)	(0.25, 0.50, 0.75)	Noise
Low (L)	(0, 0.25, 0.50)	
Very low(VL)	(0, 0, 0.25)	Volume

Table II. The Scale of the Effect of Sustainable Transportation Alternatives on Each Criterion

Complete Ranking	Alternatives (a)	Positive-outranking-flow $\Phi^{+}(a_t)$	Negative-outranking-flow $\Phi^{-}(a_t)$	Net-flow $\Phi^{net}(a_t)$
1	Walking	0.5687	0.000	0.5687
2	Cycling	0.5387	0.0150	0.5237
3	Public Transport	0.2401	0.2331	0.0070
4	Taxies	0.0599	-0.3331	-0.2732
5	Carpooling	0.0449	-0.4032	-0.3583
6	Private Car	0.000	-0.4679	-0.4679

Table III. VISUAL PROMETHEE Application for the Sustainable Transportation Alternatives

Criteria	**Toxics Gases**	**Noise**	**Climate Change**	**Fuel Use**	**Air Quality Health Index**	Capacity **(Volume)**
Unit	Micrograms per cubic meter ($\mu g/m^3$)	Decibel db(A)	Y/N	Quadrillion British thermal units(Btu)	Y/N	Y/N
Preferences						
(min/max)	min	min	min	min	max	min
Weight	0.92	0.5	0.92	0.75	0.92	0.08
Preference Fn.	Linear	Level	Level	Linear	Level	
Evaluations						
Cycling	…	40	No	……	No	
Walking	….	30	No	…..	No	
Public Transport	Nox:36.67	80	Yes	6	Yes	
Private Cars	PM2.5: 10.76	75	Yes	6	Yes	
Carpooling	CO:19.09	75	Yes	6	Yes	

VI. RESULTS

Table 4 shows the whole ranking of the sustainable transportation alternatives depending on a chosen criterion which is very indispensable for environmental assessment. The Result from Table 4 shows that walking and cycling with the lowest noise level and no fuel consumption top the catalog of alternatives and subsequently, it will be more advantageous to the environment and road user. Fig. 1, shows the positive/negative aspect of the sustainable transport alternatives for each chosen criterion is shown. To attain the outcomes, the program Decision Lab visual PROMETHEE was implemented. This database is operator responsive and the decision-maker is able to modify the criterion's as well as their weights easily, in addition to comparing the alternatives against the criterions they desire.

Alternatives	**Criteria**					
	Fuel Use	Toxic Gases	Volume`	Noise	Climate Change	Air Quality
Walking	Very Low	Very Low	Very Low	Low	Very Low	Very Low
Bicycle	Very Low	Very Low	Low	Low	Very Low	Very Low
Public Transport	High	High	Medium	High	High	High

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Table IV. The Ranking Results of the PROMETHEE

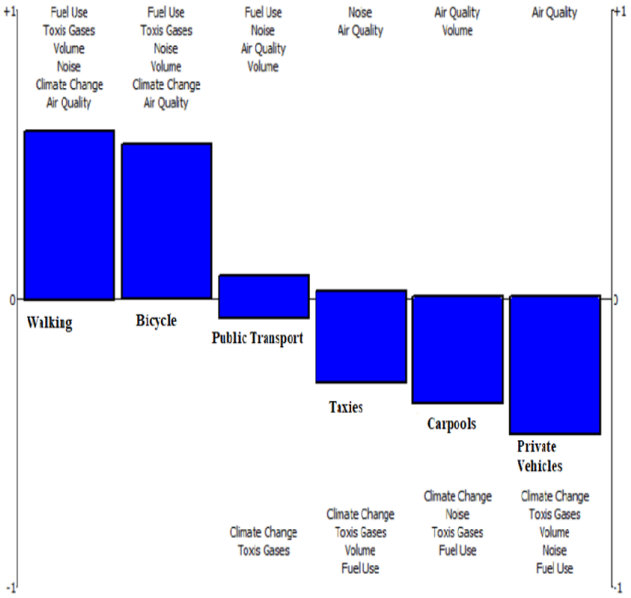

Figure 1. PROMETHEE Estimation Results

VII. CONCLUSIONS

By implementing the fuzzy PROMETHEE as a multi-criterion evaluation method, great outcomes were obtained through the integration of fuzzy input figures. This approach was employed among several environmental transport substitutes. The following research proved that the suggested methodology easily and rationally bestows progressed alternate resolutions for decision-making complications. The outcomes attained allow decision-makers, or in some cases the associations, the capability of selecting or enhancing the transport divisions.

Through the Fuzzy PROMETHEE approach, the challenge of decision-making for the fuzzy figures is resolved. This approach has verified its efficiency in various areas, especially when associated with other decision-making methods. The result of the research will be capable of assisting the road operators, similarly the transport organizations in taking appropriate decisions for handling the transport divisions.

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