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Economical and Technical Analysis of Urban Transit System Selection Using TOPSIS Method According to Constructional and Operational Aspects

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***Abstract*—**Nowadays, one the most important problems in megacities is public transportation and satisfying citizens from this system in order to decrease the traffic congestions and air pollution. Accordingly, to improve the transit passengers and increase the travel safety, new transportation systems such as Bus Rapid Transit (BRT), tram, and monorail have expanded that each one has different merits and demerits. That is why comparing different systems for a systematic selection of public transportation systems in a big city like Tehran, which has numerous problems in terms of traffic and pollution, is essential. In this paper, it is tried to investigate the advantages and feasibility of using monorail, tram and BRT systems, which are widely used in most of megacities in all over the world. In Tehran, by using SPSS statistical analysis software and TOPSIS method, these three modes are compared to each other and their results will be assessed. Experts, who are experienced in the transportation field, answer the prepared matrix questionnaire to select each public transportation mode (tram, monorail, and BRT). The results according to experts' judgments represent that monorail has the first priority, Tram has the second one, and BRT has the third one according to the considered indices like execution costs, wasting time, depreciation, pollution, operation costs, travel time, passenger satisfaction, benefit to cost ratio and traffic congestion.

***Keywords*—**Bus Rapid Transit, Costs, Monorail, Pollution, Tram.

I. Introduction

GENERALLY, transportation means movement and mobility of people and goods among different urban and rural locations [1]. One the most usual features of transportation is that there is no demand by itself. Trips are usually generated due to taking advantage of social, recreational, educational or commercial opportunities in specific destinations [2].

Nowadays, living in cities, where there are organized accommodations, is possible only because there is daily mobility. Another feature is that they consist of special complex activities that act separately. These activities should have accessibility [3]. Urban transportation is a part of a transportation system that is an element of urban connection system. It functions as accessibility for different uses in the scope of the city in order to move people and goods among adapted locations. In urban transportation systems, selecting different transportation modes is dependent on the time rather than geographical space [4].

With the increase in world's population, urbanization has become a dominantly contemporary process. Hence, urban transportation's significance increases. Transportation in urban areas according to types of modes, numerous origins and destinations and volume of traffic is very complicated. In general, urban transportation means moving people and goods inside cities. This mobility is originated from both trading social recreational services and goods in urban areas. Not only does it affect urban construction and size of development, but a satisfying mode of transportation also depends on the size of the city and the structure of the city [1]. Evolution of transportation, which is normally formed to the response of current demands, socio-economical and technical evolutions, leads to changes in urban form and shape. The emergence of wide and rapid urbanism in all over the world includes increase in number of generated trips in urban areas. Cities respond these wide and rapid growth with constructing new highways and transportation infrastructures. At the end of this process, cities are shaped [5].

Urban transportation is basically defined in three main groups consisting public transportation, personal transportation and transportation of goods. The purpose of public transportation is to provide public mobility and accessibility in specific locations of the city. The efficiency of this type of transportation is due to move huge numbers of passengers [5]. In fact, public transportation system is a system that everyone can use under particular circumstances, like buying tickets. Public transportation systems are a subsidiary of urban transportation that is the first priority to improve mobility and urban development [6]. Nowadays, public transport systems should provide high-level services to have better efficiency. They should be as accessible as possible for more passengers. [7]. The common public transportation modes are taxis, vans, private taxis, internet taxis, rental buses, shared vehicles, shuttle buses, rapid transit (Light Rail Transit), heavy rail transit.

In all megacities, there have been serious efforts for improving the current traffic status, decreasing fuel consumption and in that consequence reducing air pollution, increasing preference of using public transportation like tram, monorail and BRT instead of private vehicles. However, it

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needs precise study for each city to realize which of public transportation modes are prior to the other ones and have more capacity for increasing trend of traveling by motor vehicles. Later studies focus mostly on safety, traffic congestion and environmental pollution. In consequence, this accelerating trend with increasing population have caused numerous problems, like traffic jam, disorders in urban transport systems, consequently there were many challenges for urban planning at the end of twentieth decade. The excessive expansion of using fast motor vehicles, especially cars, in different mega cities and not having a scientific and comprehensive have led to sever environmental pollution, boring traffic jam, huge waste of time and excessive fuel consumption, many accidents and unsafe roads. Thus, living in such areas was more difficult in terms of welfare and comfort.

II. Literature Review

In this part, feasibility of BRT and LRT systems, specifically Tram and Monorail are briefly mentioned.

A. Tram

Since 1980, there has been a major change in tram in the US and Europe. It is reported that public preference and interest is in Rail Transit. This trend change is owing to both new urbanism and new traffic policies. Thus, in urban design, especially in city centers and cores, the dedicated areas for private vehicles are decreased, while the dedicated areas for tram, bicycle, and passenger are increased. Implementing these policies in European countries has been affected sharply in France and has been affected gradually in the US. The special features of tram consist of comfort, higher speed in comparison to bus if it is not conflicted with traffic flow while moving along the streets. Moreover, the trip capacity is more than bus. However, the length of tram cannot exceed 75 meters in Germany according to German law. The disadvantages of tram are being dependent on the rail, which makes it limited and is not able to maneuver in traffic flow. In addition, their expensive wagons are one of the disadvantages.

Tram is one the common urban public transportation systems in small and medium cities that moves along a rail track mostly by electrical energy. It usually consists of one to three wagons, that is why it is cheaper, lighter, shorter and more flexible than the usual subway trains. Its wagons are 2.3 to 2.9 meters wide, and 14 to 40 meters long and maximum up to four wagons are capable of joining with each other [8]. Their operation speed alters from 50 km/h on the street surfaces, up to 80 km/h on bus dedicated lanes out of residential areas. Their capacity is between 10000 to 28000 persons per hour. The track path is 8 to 24 kilometers long with maximum speed of 70 km/h to 80 km/h.

B. BRT

From the functional and design point of view, BRT is an urban public transportation system equipped with intelligent transportation system (ITS), while in terms of speed and precision it functions like Rail systems and is flexibility like buses. The operation possibility of one to three years is also one of its significant advantages. Environmentally speaking expanding BRT lines lead to fall in using private vehicles, in consequence it results in less fuel consumption and air pollution. Developing and expanding public transport fleet can both facilitate passengers commuting and encourage them not to use private vehicles to decrease air pollution and fuel consumption. In recent years using BRT systems have caused passengers satisfaction to some extent [9].

C. Monorail

One of the rail transit systems is monorail. Monorail is a train that its wagons move along a continuous air rail in a suspended way. In most cases, rail is higher than ground surface; however, it can be on the ground surface or even in an underground tunnel.

The word Monorail has been used since 1895; it is the combination of two words, mono that means one and rail. Monorail association has come up with another definition of this vehicle. Monorail is a system that is narrower than train. Monorail includes elements like track, passengers' cabin, stations, power supply equipment and controlling system. The structure on which monorail moves can be made of concrete or steel, the wheels of the monorail can be made of rubber or metal. Monorail, which moves along a concrete track, uses rubber tires while the ones moving on steel track use metal wheels. Superior feature of rubber wheels to metal wheels is that they do not make a lot of noise and they move more smoothly. If monorail is considered as a tourist attraction tool, it is definitely because of its appearance like the ones in Italy and Malaysia. Nevertheless, if it is considered as mass transit mode that is able to decrease traffic congestion in a megacity like other public transportation (subway and so on), it will not be able to attract tourists, however it is constructed on a very large scale. Monorail in populated cities like Tehran or in cities with adverse weather conditions like Ahwaz is a sufficient transportation mode to carry passengers from one point to another. Although, due to special features of two systems including easy accessibility, safety and comfort, this rail system has been a very attractive choice for urban planners in terms of technology of execution and less operation costs. In Iran, there has never been any consideration for tram and monorail as a public transportation mode, except for a few cities.

(a) (b)

Fig. 1 (a) Monorail (b) Tram

In other words, Monorail is a kind of air rail that is used to carry passengers (or cargo). Monorail is based on a single rail.

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This single rail functions as a holder and a navigator. Its commercial speed is between 30 to 35 km/h; its pathway is more in comparison to Bus and Tram. In case it has an air pathway, its protection and monopoly is the similar to subway [10].

III. Methodology

In this paper, with comparison of Tram, Monorail and BRT in different aspects based on construction and operation including travel demand, effective variables on travel time, traffic congestion, environmental pollution, by TOPSIS and SPSS analytical software, feasibility and prioritizing LRT and monorail to BRT are defined. The process of research is as the following table. First, it should be considered that research criteria consist of terms of terms of functions and execution, execution costs, operation costs, construction and execution period, construction costs, trip attraction (passengers' satisfaction), benefit to cost, wasting time, depreciation, pollution and traffic congestion. Questionnaires are created based on Delphi method on SPSS. Delphi is a systematic approach in research for extracting opinions of a group of experts about a specific topic or question [11].

TABLE I
A Sample of Assessment in Likert Scale

Completely agree	Agree	Neither agree nor disagree	Disagree	Completely Disagree
+2	+1	0	-1	-2
1	2	3	4	5
5	4	3	2	1

A. Selecting Experts

There are thirty people called experts responding questions in the questionnaire. Two of them are female (6.67%), twenty-eight of them are male (93.33%). They are categorized into three different age groups. The first group consisting 13.33% of experts aged from 35 to 40 years old. The second group is aged from 40 to 45 consisting 50% of them, while the third group age more than 45 consisted of 36.67% of experts. Moreover, they are categorized into three different educational grades including bachelor, master, and PhD. The bachelor, master and PhD consisted 50%, 30% and 20%, respectively.

B. Delphi Analysis

Delphi Analysis was named after a famous temple in the ancient Greece. Those days' priests used to get together and have some predictions about the future. However, at first it was based on guess, inspirations, and speculations. Eventually it was designed and used to investigate experts' hypothesis in a defense project in the US army by RAND Corporation. The results of this research were not published until twelve years later owing to security reasons. Historically speaking, the most basic basis of developing Delphi method and even other qualitative methods was that it was more reliable to rely on an expert's choice rather than anyone else. On the first step, Delphi questionnaire is given to the experts. This questionnaire required the experts to consider all items while responding based on Likert Spectrum. After averaging experts' results and distributing it among experts to fill them out, the data achieved with the weight of each. In the following, SPSS is used in order to investigate and analyze the data and answers to the hypothesis.

Conceptual Model on which comparison between Monorail, Tram, and BRT is based on urban transit criteria which was illustrated in Fig 2.

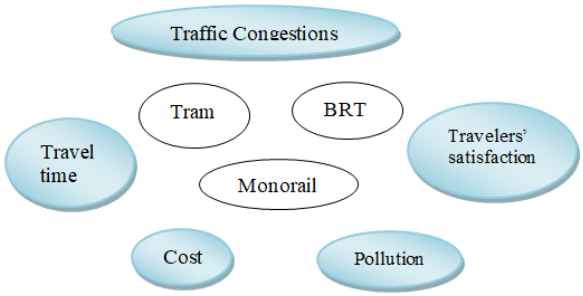

Fig. 2 Urban transits related criteria

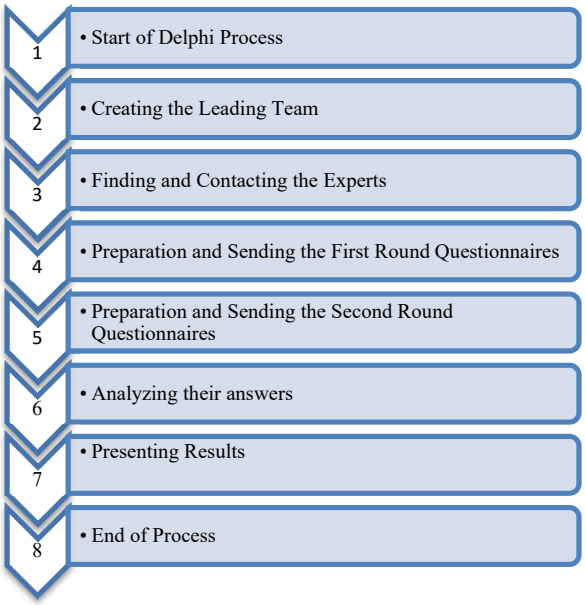

Fig. 3 Delphi Process

TOPSIS Method Process

- 1st step: Normalizing the decision matrix [12].

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad (1)$$

- 2nd Step: Weighting the normalized matrix:

W= (w_1, w_2, w_j, w_n), ∑_ (j=1)^n▒w_j =1

- 3rd Step: creating Matrix V for defining weight indices:

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & & & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (2)$$

- 4th step: Defining the magnitude of distances:

$$Negative\ Ideal\ option\ A^- = \left\{\left(\min_i V_{ij} \mid j \in J\right) و \left(\max_i V_{ij} \mid j \in Ĵ\right) i = 1,2,\dots,m\right\} = \left\{V_1^-, V_2^-, \dots V_j^-, \dots V_n^-\right\} \quad (3)$$

$$Positive\ Ideal\ option\ A^* = \left\{\left(\max_i V_{ij} \mid j \in J\right) و \left(\min_i V_{ij} \mid j \in Ĵ\right) i = 1,2,\dots,m\right\} = \left\{V_1^*, V_2^*, \dots V_j^*, \dots V_n^*\right\} \quad (4)$$

- 5th step: calculating relative proximity: Calculating relevant proximity by ideal solution:

$$C_{I*} = \frac{S_{I-}}{S_{I*} + S_{I-}} \quad (5)$$

- 6th step: prioritizing the options: ranking the options according to c*i which fluctuates from 0 to 1:

$$(0 \leq C_i^* \leq 1) \quad (6)$$

IV. Results and Discussions

Table II represents the ability to attract passengers' satisfaction in public Transportation systems. Safety, comfort, reliability and beauty are the considered indices.

TABLE II
PASSENGERS' SATISFACTION IN PUBLIC TRANSPORTATION

Model	Number of Samples	Average	Standard Deviation
Passengers' desirability toward monorail	30	3.9000	0.30850
Passengers' desirability toward tram	30	3.8333	0.50465
Passengers' desirability toward BRT	30	3.0800	0.43815

Table III represents if replacing BRT into tram and monorail is economical. Safety, Benefit to costs (B/C) is the considered indices. Variance analysis (F-ANOVA) is used to test this hypothesis.

TABLE III
VARIANCE ANALYSIS TEST (F-ANOVA)

	Sum of squares	Degrees of freedom	Average of Squares	F Statistics	Significance level
Among Groups	928.49	2	24.964	170.129	0.000
In groups	12.776	87	0.147		
Total	62.694	89			

Table IV represents ability of tram and monorail in decreasing Tehran air pollution. Carbon monoxide, hydrocarbon, nitrogen oxide and sulfur dioxide are the pollution indices.

TABLE IV
SINGLE SAMPLE T STATISTICS

Number of Samples	Average	Standard Deviation	Average Standard Error
30	3.8000	0.60572	0.11059
30	3.7441	0.49587	0.09053
30	3.2283	0.75652	0.13812

Table V represents the Economic justification in terms of fuel consumption.

TABLE V
SINGLE SAMPLE T STATISTICS

Model	Number of Samples	Average	Standard Deviation	Average Standard Error
Monorail fuel consumption	30	3.8750	0.51172	0.09343
Tram fuel consumption	30	3.3200	0.42520	0.07763
BRT fuel consumption	30	2.3217	0.33648	0.06143

V. Conclusions and Recommendations

Based on the achieved results, the relative weights of execution costs are 2.4, 2.1212, and 2.1488 for switch machine in Monorail, wagons and line, respectively. The aggregation is 6.5111 in total for monorail. From the experts' point of view, BRT has the least execution costs, while tram has the most ones. The relative weights of operation items are 6.3509, 6.4287, and 6.1198 for monorail, tram and BRT respectively. From the experts' point of view, tram has the most operation items, while BRT has the least ones. The relative weights of wasting time are 5.9797 and 7.796 for monorail and BRT, respectively. From the experts' point of view, BRT has the most wasting time, and monorail has the least one. Relative weights of travel time are 1.5898, 1.5955, and 1.6013 for monorail, tram, and BRT, respectively. From the experts' point of view, monorail has the least travel time, and BRT has the most one. Relevant weights of passengers' satisfaction are 1.3687 and 1 for tram and BRT, respectively. From the experts' point of view, monorail has the most preference, and tram and BRT are the same and less than monorail. Relevant weights of depreciation are 6.2742, 5.7688, and 6.8317 for monorail, tram, and BRT respectively. From the experts' point of view, tram has the least depreciation, and BRT has the most one. Relevant weights of pollution are 7.1598, 7.3403 and 7.7018 for monorail, tram and BRT respectively. From the experts' point of view, Monorail has the least pollution, while BRT has the most one. Relevant weights of traffic congestion are 1.3687, 1.4226, and 1.7226 for monorail, tram and BRT, respectively. From the experts' point of view, monorail has the least traffic congestion, while BRT has the most one. In the discussion on selecting the best option using TOSIS, executing costs, wasting time, pollution, operation costs, travel time, passengers' satisfaction, benefit to cost, traffic congestion indices are used to prioritize tram, monorail and BRT. Therefore, experienced experts in Transportation field for each transportation mode filled a Matrix questionnaire. Based on the achieved results, Monorail, Tram and BRT are first, second and third priority, respectively.

Responses to different questions revealed that there was a meaningful in users' satisfaction between monorail and tram.

While selecting the best option with TOPSIS, based on literature review, in order to achieve the intended goal, operational costs, wasting time, depreciation, air pollution, operation items, travel time, passengers' satisfaction, benefit to cost ratio, traffic congestion are considered to prioritize

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tramway, monorail and BRT in terms of passengers' preference. In order to investigate effective indicator in selecting each public transport modes (light rail and BRT) in cities, matrix questionnaires were filled in by experts in public transport field.

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