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Preference Analysis of Light-Rail and BRT using TOPSIS Method and Delphi Analysis, Tehran Case Study

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Today the most significant issue in Mega cities is Public Transport. Citizens need to be satisfied by public Transport systems to use them more frequently than their own private vehicles. In order to make progress in public Transport Systems such as Buses and Light rail, the users' satisfaction is vitally important. There are advantages and disadvantages in every transport system, what matters more is that positive ones outcome negative ones. Hence, Systematic approach to select one of them is crucial for cities like Tehran. In this paper, it is tried to investigate the users' preference by comparing different effective indices like Benefit to Cost analysis, Passengers satisfaction, Traffic Congestion, Environmental emissions, operational costs, and time wasting in order to have BRT and light rail, particularly Monorail and Tramway prioritized. Consequently, they are compared and analyzed with TOPSIS method on SPSS. In order to have an accurate comparison each index is investigated through a question in a questionnaire. They are carefully responded by thirty experienced public transport expert. The results showed that questionnaire has high validity. Based on the experts' judgement, Monorail is prior to Tramway, while Tramway is prior to BRT itself.

1. Introduction

In general, having movement and mobility of both people and goods in various rural and urban spots is defined transport [1]. Interestingly, there is no demand in transport itself and it is considered as one of its most common elements. In order to benefit society, education and commerce, people seeking those in their certain spots generate many trips [2]. Only thanks to existence of mobility, there are accommodations as organized in our living cities these days. Furthermore, there are some activities that are complicated and separated, but interestingly these activities need to have suitable accessibility [3]. Transport system contains different parts, one of which is urban transport. In fact, for various uses in the city surroundings, this urban transport system plays the role of the link or accessibility for both goods and humans among specific spots. Time of the day is more significant that the geographic space itself in urban transport systems that is why users select different transport mode is vital [4].

With sharp growth in urbanity and township in recent decades, Mega cities are recognized as the biggest coexistence complexes with having two third of the population until 2020. With this trend, the Earth will turn into a world city. Meanwhile in late decades, mobility and transport, particularly in mega cities, have been one of the main challenge in more populated cities [5]. Urban Transport studies have been changed dramatically in the last fifty years.

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Massive urban transport systems are generally categorized as the rapid and slow ones. They are able to move 10 to 60 thousand people per hour in one direction with maximum speed of 80 km/h.

2. Literature Review

2.1. Tramway and Subway

With advances in Technology and digging underground tunnels Tramway turned into subway. This system can move larger volume of passengers and according to international standards, this can move from 12,000 to 40,000 passengers per hour. This system is completely protected and in inner city area is often underground, while it is at the same grade in the suburban areas with at least 5 wagons. Its required driving force is provided by electricity or gasoline generator [6]. Since 1990 there has been a positive and tangible change in using subway in the US and Europe, which meant public satisfaction and preference of using this rail system. Investigation represents that this trend is due to new traffic and urban policies applied in the US, Europe and Australia. In this way, designing urban networks, in particular in central business districts or CBDs, the demand for private vehicle decreased and demand for train, bicycles and pedestrian areas increased instead. Implementation of these policies among mentioned countries, France experienced more while the US went through this phenomenon gradually. One of the most important features of Tramway is the ability of moving huge number of passengers, comfort, high speed, while its disadvantages are its dependence on railway that results in limitation in maneuver in traffic in addition to its high costs of rail and wagon infrastructures [7]. Tramway as a commonly used public transport system in cities consists of 1 to 4 wagons that move along a railway by electricity, that is why it is lighter, shorter and more flexible. The width of each wagon is from 2.3 to 2.9 meters while its length is from 14 to 40 meters. Its operation speed is 50 km/h along the streets while it can be up to 80 km/h along dedicated lines out of residential districts. Its capacities ranges from 120 to 280 passengers on each trip, or 10,000 to 28,000 passengers per hour [8].

On the other hand, electrical installations and power towers are installed above the rails to provide electricity that causes visual pollution for the sight of old valuable buildings. One of the most successful models in Rail transport in cities executed in Karlsruhe, Germany in 1980. Main Traffic Stakeholders could join the inner-city Tramway moving along streets to the German state railway, this meant urban transport scope was linked to the farthest point of the suburbs. New wagons could feed on both Tramway and German state railway power systems; consequently, there was no further costs to build new railway. Nowadays passengers can use railway lines to access surrounding cities [9].

2.2. Bus Rapid Transit (BRT)

The required infrastructure for executing a comprehensive fast bus transit is one or so dedicated lines of streets or motorways in addition to stations and intelligent control system. Emergency services and some vehicles with high occupancy sometimes use these dedicated lines. The unique advantage of this system includes completely dedicated bus lines, fast boarding and disembarking, efficient method of taking travel fares, comfortable stop and shelter, integrated with other modes of transport, non-polluting bus technology. From operational point of view, designing Urban BRT system are equipped with Intelligent Transport Systems (ITS), besides it has speed and punctuation of rail systems and flexibility of bus systems. Possibility of operation in short term (one to three years) is also one of its advantages [10].

Table 1. BRT costs and operations in comparison to types of routes

Types of BRT Routes	Capital Costs per Miles	Hours
BRT in the whole traffic	20	20
BRT in the middle lane	15	30
BRT in dedicated lane	15-20	35
BRT without intersections	25	45

2.3. Monorail

Monorail was created in 1821 in Europe. The first Monorail was used as a machine that carrying bricks and some construction materials in the UK. The first operation occurred after years of experiences in industries and mines. The

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first Monorail actually carried passengers in urban areas was in 1950s. It became more frequently used in 1980s and 1990s [11].

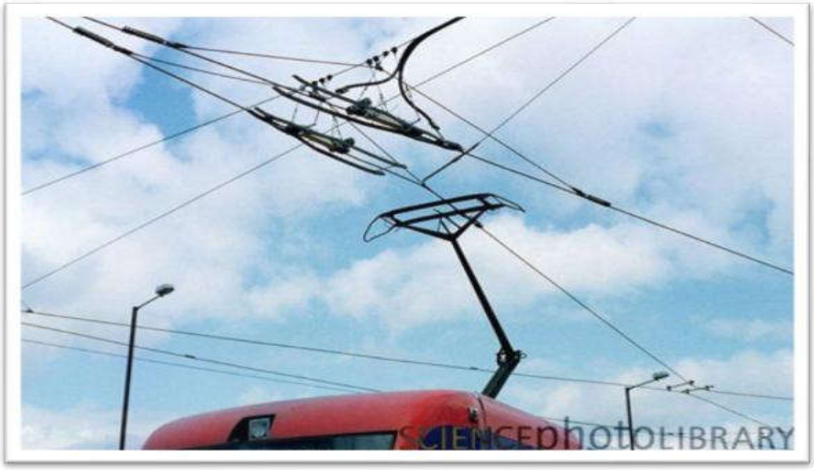

Figure 1. Overview of inner-city tramway using a pantograph [12]

Figure 2. Bus rapid transit

Figure 3. Monorail on its track

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3. Methodology

There is a comparison between Tramway, Monorail and BRT in various aspects according to construction and operation costs including pollution, traffic congestion, travel time, travel demand in this research. The analytical software SPSS and TOPSIS method, Delphi Method are used to define feasibility and priority of them in Tehran. Firstly, research criteria including terms of execution costs, operation costs, construction costs, construction period, execution period, trip attraction or passengers' satisfaction, benefit to cost ratio, wasting time, depreciation, pollution and even traffic congestion. Based on Delphi method, which is a systematic approach in research to extract the experts' opinions about a certain question, questionnaires are made on SPSS Software.

Table 2. A sample of gauge in scale of Lacerate

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

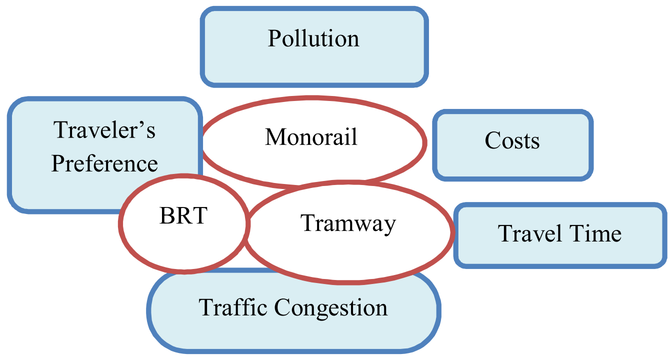
3.1. Selecting Experts

The experts' team, who answer and fill out the questionnaires, consist of thirty people. A couple of them are female (6.67%), the rest of the mare male (twenty-eight or 93.33%). They are put into three different categories based on their age. The first category includes 13.33% of experts, who are aged from 35 to 40. The second category, who are aged from 40 to 45, includes 50% of the experts. In addition, the third category, who are aged more than 45, includes 36.67% of them. Furthermore, they are also divided into three different educational grades. Bachelor educated grade consist of 50%, master educated one consist of 30% and PhD educated group consist of 20%.

3.2. Delphi Analysis

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 [13]. 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.

Figure 4. Conceptual model of comparison between monorail, tramway and BRT



3.3. TOPSIS Process

Step 1: Normalizing the decision matrix, in this step, the scales of the decision matrix become scale less. That way each of value is divided to its relative vector size. In consequence, every entry r_{ij} will be achieved as following [14]:

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

Normalizing Decision Matrix

Step 2: Weighting the normalized matrix: Defining weight of each index w_i based on $\sum_{i=1}^{n} w_i = 1$, accordingly indices with more priority have more weights. In fact, (V) matrix is multiplication of standard values of each index and its relevant weight.

Sum of weights are multiplied by normalized matrix (R):

$$W = (w_1, w_2, \ldots w_j, \ldots, w_n),\ \sum_{j=1}^{n} w_j = 1 \qquad (2)$$

Regarding W_n*1 can not be multiplied by normalized matrix (n*n), weight matrix is converted into a diagonal matrix (n*n) before multiplying.

Matrix V for defining weights of indices

$$V_{ij} = \begin{bmatrix} w_1 r_{11} & w_2 r_{12} & \cdots & w_n r_{1n} \\ w_1 r_{21} & w_2 r_{22} & \cdots & w_n r_{2n} \\ \vdots & & & \vdots \\ w_1 r_{m1} & w_2 r_{m2} & \cdots & w_n r_{mn} \end{bmatrix} \quad (3)$$

Step 3: Defining the magnitude of distances: defining i^{th} ideal alternative (highest function of each index) which is shown by (A*).

$$A^- = \left\{ \left(\min_i V_{ij} \,\middle|\, j \in J \right) \text{و} \left(\max_i V_{ij} \,\middle|\, j \in \acute{J} \right) i = 1,2,\dots,m \right\} = \{V_1^-, V_2^-, \dots V_j^-, \dots V_n^-\} \quad (4)$$

Negative Ideal option

$$A^* = \left\{ \left(\max_i V_{ij} \,\middle|\, j \in J \right) \text{و} \left(\min_i V_{ij} \,\middle|\, j \in \acute{J} \right) i = 1,2,\dots,m \right\} = \{V_1^*, V_2^*, \dots V_j^*, \dots V_n^*\} \quad (5)$$

Positive Ideal option

Step 4: Creating Matrix V for defining weight indices:

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

$$= \left\{ \begin{matrix} \left(\max_i V_{ij} \,\middle|\, j \in J \right) \text{و} \left(\min_i V_{ij} \,\middle|\, j \in \acute{J} \right) \\ i = 1,2,\dots,m \end{matrix} \right\} = \{V_1^*, V_2^*, \dots V_j^*, \dots V_n^*\} \quad (6)$$

Step 5: Calculating relative proximity: Calculating relevant proximity by ideal solution is as following:

$$C_{i*} = \frac{S_{i-}}{S_{i*} + S_{i-}}, \; 0 < C_{i*} < 1 \quad (7)$$

Step 6: Prioritizing the options: ranking the options according to C*i which fluctuates from 0 to 1(0≤C_i^* ≤1). One is the highest priority while zero is the least. Since this research seeks priority, Shannon Entropy Methods are used Giving weight to the priority of options on TOPSIS method. Furthermore, weight of each index will be calculated on Microsoft EXCEL.

3.4. Shannon Entropy

Step 1: Data collection

First, data are collected from filled-out questionnaires by experts. According to scoring table, indices are converted into quantitative from qualitative [15]

Step two: Making Indices Positive

In order to investigate the effective indices in choices of each public transport (Monorail, BRT and Tramway) in cities, a matrix questionnaire is prepared and filled out by experts in transport field. Then according to each expert's response is turned into a quantitative index from a qualitative one based on scoring table. Since the questionnaire including operation costs, wasting time, depreciation, and pollution are negative indices, they are made positive and quantitative questionnaires only have positive indices [15]

Step 3: Calculating Geometric Mean; Relative weight of indices is result of seven experts' judgments using Geometric mean is calculated from formula 8 [9].

$$\bar{x} = \sqrt[n]{(X_1 * X_2 * \dots * X_n)}$$

Calculating geometric mean (8)

4. Results

The first question that has been answered was if Monorail is able to satisfy people from public transport system. The considered indices are safety, comfort, reliability and beauty.

Based on Table 3, according to single-sample t test for citizens' preference for Monorail, tramway and BRT are 3.9, 3.8 and 3.08 respectively. Since this questionnaire is answered based on Likert spectrum, average answering each question is three. Accordingly, as average single-sample statistics of citizen's preference in all three of Monorail, Tramway and BRT is more than three, it can be said that these three transport modes are preferred by citizens. Nonetheless, citizen's preference in Monorail is a bit more than Tramway and their preference of Monorail was more than Tramway and BRT. Moreover, as t-test in both Monorail and Tramway is more than critical statistics of table, meaningfulness of this statistics is 0.00, which is less than 0.05, it can be said that

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Table 3. Single-sample t test for

	Number of Samples	Average	Disagree	Totally Disagree
Passengers' preference for Monorail	30	3.9000	0.30850	0.05632
Passengers' preference for Tramway	30	3.8333	0.50465	0.09214
Passengers' preference for BRT	30	3.0800	0.43815	0.09214

Table 4. Variance Analysis Test (F-ANOVA)

	Sum of Squares	Degrees of Freedom	Average of Squares	F Statistics	Significance Level
Inter-groups	49.928	2	24.964	70.129	0.000
In groups	12.766	87	0.147		
Total	62.694	89			

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citizen's preference in both Monorail and Tramway has a meaningful difference. Thus, the citizen's preference of Monorail and Tramway is different.

The Second question that has been answered was that if it is economical to construct Tramway and Monorail instead of BRT. The considered indices for being economical were safety, benefit to cost ratio (B/C). To test this hypothesis, analysis of variance test (F-ANOVA) is used. This test is used to investigate the average difference of a variable (being economical) in three groups and more. In this test the variance of whole samples are decomposed into their primary factors. The results achieved from this test are as following: The results of analysis of variance represents Monorail economic status, Tramway and BRT in table 3. Since F is 70.129, and it is bigger than the critical statistics of the table and meaningfulness is 0.00 that is less than 0.05. As a result, it can be said that there is a meaningful difference in Monorail, Tramway and BRT economic status.

Table 5. Single-sample t statistics

Statistical Index	Number of Samples	Average	Standard Deviation	Mean Standard Error
Traffic Volume of Monorail	30	3.6867	0.43576	0.07956
Traffic Volume of Tramway	30	3.6278	0.30964	0.05653
Traffic Volume of BRT	30	2.7900	0.43419	0.07927

Table 6. Single-sample t statistics

Statistical Index	t	Degrees of Freedom	Meaning-fullness	Difference in Averages	Lower Bound	Upper Bound
Traffic Volume of Monorail	8.656	29	0.000	0.68867	0. 5260	0 8514
Traffic Volume of Tramway	11.115	29	0.000	0. 62778	0. 5122	0.7434
Traffic Volume of BRT	-2. 649	29	0.013	-0. 21000	0. 3721	-0.0479

Table 7. Single-sample t statistics

Model	Number of Samples	Average	Standard Deviation	Mean Standard Error
Monorail Pollution	30	3.800	0.60572	0.11059
Tramway Pollution	30	3.7441	0.49587	0.09053
BRT Pollution	30	3.2283	0.75652	0.13812

Table 8. Single-sample t statistics

Statistical Index	t	Degrees of Freedom	Meaning -fullness	Difference in Averages	Lower Bound	Upper Bound
Monorail Pollution	7.234	29	0.000	0.80000	0.5738	1.0262
Tramway Pollution	8.219	29	0.000	0.74411	0.5589	0.9293
BRT Pollution	1.653	29	0.109	0.22833	0.0542	0.5108

The third question that has been answered is that whether Tramway and Monorail are able to reduce Traffic of Tehran. The traffic volume is considered as the number of passengers traveled usually in a track in a certain period (usually one hour) in one direction.

Based on Table 5, the average of single-sample t statistics for traffic volume reduction is 3.7, 3.6 and 2.8 for Monorail, Tramway and BRT respectively. Since this questionnaire is answered based on Likert spectrum, average answering each question is three. In consequence, since the average single-sample statistics for Monorail and Tramway is more than three, it can be said that these two transport modes cause traffic volume reduction. Nonetheless, traffic volume reduction of Monorail is more than Tramway.

Moreover, as s statistics of traffic volume reduction in Monorail and Tramway is more than

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Table 9. Single-sample t statistics

Statistical Index	Number of Samples	Average	Standard Deviation	Mean Standard Error
Fuel Consumption of Monorail	30	3.8750	0.5172	0.09340
Fuel Consumption of Tramway	30	3.3200	0.4250	0.07763
Fuel Consumption of BRT	30	2.3217	0.33648	0.06143

Table 10. Single-sample t statistics

Statistical Index	t	Degrees of Freedom	Meaning -fullness	Difference in Averages	Lower Bound	Upper Bound
Monorail Pollution	9.366	29	0.000	0.87500	0.6839	1.0661
Tramway Pollution	4.112	29	0.000	0.32000	0.1612	0.4788
BRT Pollution	-11.042	29	0.000	-0.67833	-0.8040	-0.5527

critical statistics of the table, also meaningfulness of it equals 0.00 that is less than 0.05, it can be said that there is a meaningful difference in traffic volume reduction in both Monorail and Tramway. Thus, traffic volume reduction in Monorail and Tramway is different.

The Fourth question that has been answered is if Monorail and Tramway are able to decrease air pollution in Tehran. Pollution indices are Carbon Monoxide, Hydrocarbon, Nitrogen Oxides and Sulfur Dioxide.

Based on Table 7, the average single-sample t statistics for air pollution reduction is 3.8, 3.7 and 3.2 for Monorail, Tramway and BRT respectively.

Since this questionnaire is answered based on Likert spectrum, average answering each question is three. Accordingly, as the average single-sample statistics for Monorail, Tramway and BRT is more than three, it can be said that all of them cause air pollution reduction. Nonetheless, air pollution reduction for Monorail is more than Tramway and BRT and Air pollution reduction for Tramway is more than BRT.

Moreover, as t statistics of air pollution reduction for Monorail and Tramway is more than critical statistics of table, also significance level of statistics is 0.00 that is less than 0.05, it can be said that there is a meaningful difference in air pollution reduction for both Monorail and Tramway. Thus, air pollution reduction in Monorail and Tramway is different.

The fifth question that has been answered is if Tramway and Monorail are economically justifiable in terms of fuel consumption. Based on Table 9, the average single-sample t statistics for fuel consumption reduction for Monorail, Tramway and BRT is 3.8, 3.3 and 2.3 respectively. Since this questionnaire is answered based on Likert spectrum, average answering each question is three. Accordingly, as the average single-sample statistics for

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Monorail and Tramway is more than three, it can be said that these two are economic justifying in terms of fuel consumption. Nonetheless, fuel consumption in Monorail is less than Tramway and fuel consumption in Monorail is less than BRT.

Moreover, as t statistics of fuel consumption in Monorail and Tramway is more than critical statistics of the table, also significance level of the statistics is 0.00 that is less than 0.05, it can be said that there is a meaningful difference in fuel consumption for Monorail and Tramway. Thus, fuel consumption in Monorail and Tramway is different.

After Analyzing data with SPSS, data analysis is done by using achieved indices in order to have a technical and economical comparison of Monorail, Tramway and BRT according to construction and operation aspects from matrix questionnaire that contains indices and choices in order to rank each index. At first step, the data achieved from the questionnaires are entered in Microsoft EXCEL.

5. Discussion

In this paper, thirty samples of judging experts in the field of transport planning and engineering answered the questions to test research hypothesis. Cronbach's alpha is 0.7, which means the questionnaire is highly valid. Based on this research 28 of those answering the questionnaire were men (93.33) and two of them were women (6.67%). In addition, it has been observed that four of them (13.33%) were between 35 to 40, 15 of them(50%) were between 40 to 45, and 11 of them(36.76%) were older than 45. Besides 17, 9, and 4 of them were bachelor, master and PhD holders respectively. In order to achieve this paper’s goals, which is identifying and investigating technical and economical BRT, Light rail (Tramway and Monorail) to realize the users’ preference, the results are as following:

- Analysis of If Tramway and Monorail are able to satisfy passenger in public transport is as following. Based on the achieved results, t statistics of passengers’ satisfaction in Tramway and Monorail is more than critical statistics, and also the significance level of this statistic equals to 0.00 that is less than 0.05, it can be said that there is a meaningful difference in passengers’ preferance between Tramway and Monorail. It means their preference is completely different in using each item.
- Analysis of if it is economical to replace BRT with Tramway and Monorail is as following. The results of analysis of variance suggests economical modes among Monorail, Tramway and BRT. According to statistics, F value is 179.129 that is more than the critical statistic of the table; also, its significance level is 0.00 that is less than 0.05. Hence, the zero hypothesis based on the absence of any difference between three statistical societies with 95% certainty is failed and the alternative hypothesis is accepted. So it can be seen that the average of being economical of Monorail, Tramway and BRT has a meaningful difference.
- Analysis of if Tramway and Monorail are able to decrease traffic volume of Tehran is as following. As it can be observed from the obtained results, t statistic for decreasing the traffic volume in Monorail and Tramway is more than critical statistic; also, significance level of this statistic is 0.00 that is less than 0.05. It can be said that decrease in traffic volume between Monorail and Tramway has a meaningful difference. In other words, decrease in traffic volume is different in using Monorail or Tramway.
- Analysis of if Tramway and Monorail are able to decrease air pollution in Tehran is as following. Based on conducted research, t statistic for decreasing air pollution in Monorail and Tramway is more than the critical statistic, also the significance level is 0.00 which is less than 0.05, it can be said that there is a meaningful difference between Monorail and Tramway for decreasing air pollution. In other words, decrease for air pollution in Tramway and Monorail is different.
- Analysis of if Tramway and Monorail have economic justification for fuel consumption is as following. Based on the achieved results, t statistic of fuel consumption in Monorail and Tramway is more than critical statistic of the table. In addition, significance level of this statistic is 0.00 that is less than 0.05, it can be said that fuel consumption in Tramway and Monorail has a meaningful difference. In other words, fuel consumption in Monorail and Tramway is different.

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 Tramway, Monorail and BRT in terms if 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. According to the experts' judgements, the investigated indicators represented that Monorail, Tramway and BRT has the first, second and third priority respectively.

6. Conclusions

According to the results achieved the relative weight of execution costs for switch in Monorail, wagons and line are 2.4, 2.1212 and 2.1488. In total, aggregation is 6.5111 for Monorail. As far as experts' view is concerned, BRT is the cheapest while Tramway is the most expensive. The relative weights of operation items 1198 for Monorail, Tramway and BRT are 6.3509, 6.4287 and 6.1198. As far as experts' view is concerned, Tramway has the highest operation items while BRT has the lowest. The relative weights of wasting time for Monorail and BRT are 5.9797 and 7.796. As far as experts' view is concerned, BRT has the highest wasting time while Monorail has the lowest. Relative weights of travel time for Monorail, Tramway and BRT are 1.5898, 1.5955 and 1.6013. As far as experts' view is concerned, Monorail has the lowest travel time while BRT has the highest. Relevant weights of passengers' desirability for Tramway and BRT are 1.3687 and 1. As far as experts' view is concerned, Monorail has the highest desirability while Tramway and BRT are the same ad less than Monorail. Relevant weights of depreciation for Monorail, Tramway, and BRT are 6.2742, 5.7688 and 6.8317. As far as experts' view is concerned, Tramway has the lowest depreciation while BRT has the highest. Relevant weights of pollution for Monorail, Tramway and BRT are 7.1598, 7.3403 and 7.7018. As far as experts' view is concerned, Monorail has the lowest pollution while BRT has the highest. Relevant weights of traffic congestion for Monorail, Tramway and BRT are 1.3687, 1.4226, and 1.722. As far as experts' view is concerned, Monorail has the lowest traffic congestion while BRT has the highest.

In order to select the best option while using TOPSIS for prioritizing Tramway, Monorail and BRT, executing costs, wasting time, pollution, operation costs, travel time, passengers' desirability, benefit to cost, traffic congestion indices are considered. Hence, Transport experts filled a Matrix questionnaire for each transport mode. Monorail is the first, Tramway is the second, and BRT is the third priority based on the results achieved from the filled Matrix questionnaires.

Recommendation are investigation of air pollution periods in Tehran in recent years, coming up with a multivariate model to achieve the aggregation model of various pollution variables using statistical software SAS based on the achieved results from investigating hypothesis and inferential statistics.

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