Comparing Public Transport Alternatives Using AHP-TOPSIS and Sustainability Indicators -Case Study: City of Isfahan

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Abstract

This paper concerns the problem of decision making on the selection of public transportation modes. The problem is formulated through sustainability indicators and the objective framework is based upon AHP-TOPSIS. In this research, the city of Isfahan (Iran) is our case study. The definition of different points of view was developed through interviews to stakeholders, experts in transportation and urban planning as well as end-users. In this regard, feasible alternatives of public transport modes, such as Metro, Tramway (Light Rapid Transit) Bus Rapid Transit (BRT) and Regular Bus (RB) were compared for demand corridors with similar characteristics and operating conditions. Besides, different aspects and criteria of sustainable transportation including economic, social and environmental dimensions are taken into consideration. Our findings address different orders of desirability and the suitability of public transport modes. In the view of end-users, Metro and Tramway are the most desirable modes due chiefly to service quality factors such as minimal travel time and comfort-ability. However, the local government is more interested to reduce total costs and therefore, the recommended alternatives are BRT and RB. To consolidate these results, an interview is conducted; city council members as well as senior experts in traffic and transportation fields are surveyed.

Keywords: Transportation sustainability, public transport planning decision making techniques, criteria, indicators.

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1. Introduction

1.1 General Overview

Urban development is an ongoing process but it does not necessarily follow an ideal trend. To ensure a sustainable development in urban areas, considerable efforts are required, as it depends on a myriad of aspects, from facts and features to social and economic preconditions, and of course, governance and public capacity to improve the urban environment. Indeed, underlying problems become really complicated and costly to solve when an unbalanced growth of demand and supply fails to fit the requirements of the city and society neither present nor future. That is to say, the lack of comprehensive planning and sound decision-making (with respect to social, economic and environmental constraints and objectives) can be catastrophic.

To date, the concept of sustainability has attracted appreciable attention and much has been written concerning the sustainability, challenges and opportunities. The topic is also discussed taking “growth” concepts into consideration [Wann-Ming, 2019].

Among different aspects, “transportation” is a crucial part of urban infrastructures and it exerts significant influences on the realization of Sustainable Urban Development (SUD) For decades, mobility in urban areas has been strongly relied upon private vehicles, in such a way that it has produced severe problems and obstacles. For instance, a large part of urban areas should be allocated to streets and parking. However, there is an endless cycle that says no matter how we develop urban streets, highways and parking lots, people become more motivated to use their own vehicles.

In many Asian cities, daily trips are tied with private vehicles and only about 20% of total urban mobility is based on sustainable transport modes [Luathep, et al.2015]. For example, in the city of Delhi, the share of public transport modes is reduced from 60% (in 2001) to 45% (in 2008) due chiefly to the role of private vehicles [Jain, et al.2014].

Public Transportation Modes (PTMs) as well as non-motorized modes (walking and cycling) must fill the gap and eliminate the need for using motorized vehicles. Previous researches have revealed an important fact that in many North-American cities, an integrated urban and transportation planning can bring about a shift from private-motorized vehicles to public transport modes by giving serious attention to walking, cycling and end-users’ priorities [Boulange, et al. 2017].

Undoubtedly, non-integrated planning and ill-considered decision are unable to actualize SUD and vital links among sustainable transportation, demographic growth, urban spaces, daily activities and requirements become disconnected. As such, many questions remain to be asked and answered. For example, a decision maker is often interested to know a degree of suitability and appropriateness that a particular mode of public transport can have for a particular corridor. Meanwhile, it is of utmost importance to base decision-making on the aspects, criteria, indices and indicators that can measure and analyze the contribution of a PTM into the objectives of sustainability. However, there is no clear-cut solution to the problems of decision-making and it is often called context-specific.

For any urban area, the selection of suitable PTMs lies in the category of Multiple Attribute Decision Making (MADM) problems.

In fact, the purpose is to provide a set of appropriate and best-fit options by balancing different and sometimes competing criteria as well as conflicting objectives. Accordingly, a framework can be introduced that renders a list of candidate options (with different orders) by taking various criteria into consideration.

In the context of SUD and PTMs, a typical decision-making process is unfortunately complicated by leaps and bounds. As an illustration, utilization and development of PTMs is sizably expensive and therefore requiring huge amounts of budget, finance, and subsidies. In addition, decision-making on PTMs results in deep and long-lasting effects on an urban area as well as its social, economic and environmental characteristics.

Moreover, such a process of decision-making is dynamical and decision makers must consider numerous stakeholders, end-users and their expectations as well.

1.2 Contribution and Organization of the Paper

The core of the present study is to provide an AHP-TOPSIS framework in order to evaluate different PTMs (Metro, LRT, BRT, and RB) and prioritize them according to various criteria and indicators of SUD with respect to expert and non-expert knowledge.

In particular, the article casts new lights on a hybrid framework including an interactive process. We first acquire a good understanding of what the end-users (various social groups) of the public transport system would expect and hence, the most important aspects and elements are obtainable. Next, the priorities, expectations, and criteria are translated into a set of sustainability indices and indicators. Indicators are then evaluated taking the viewpoints of local government, experts of traffic and transportation operators. To this end, two different sets of ranked alternatives are determined. Results are finally complied and integrated in order to consolidate a set of candidate modes that are compatible with different objectives in a balanced manner.

Herein, the city of *Isfahan* is investigated so that different viewpoints are taken into account with the help of multiple surveys as well as measured indicators of different dimensions.

The innovative contributions of this work are twofold:

- The study involves two different spectrums of viewpoints and considerations namely *local managers* and *end-users*. In addition, the combination of these multiple, competing standpoints is developed with a higher level of decision makers, *senior experts* and *city council members.*
- Coupled with various social groups and experts' knowledge, the framework contains a rather comprehensive set of aspects, factors and indicators to encounter with the sustainability in a real-world case.

The remainder of paper is organized as follows. Section .2 provides a review on literature and it addresses the main questions and tools that the present paper attempts to answer and use. A brief introduction of the case study is outlined in section .3. In section .4, the objective methodology i.e. AHP-TOPSIS is set out in detail. Implementation of the methodology, key criteria, indicators and results of the analysis are reported and discussed in section .5. The final section gives a summary of the research and key findings.

2. Literature Review and Research Overview

Sustainable development is a widespread and multi-dimensional term including various aspects and facets. In [Robert, et al.2005], concept of a sustainable development is encapsulated into two parts; "what is to be sustained", and "what is to be developed",

The answer to the first question entails the nature, life-support and community. The second question is concerned people, the society, and the economy.

On the other hand, the concept of development can be considered with respect to "quality of life" and "quality of place" [Van Kamp, et al.2003]. In urban areas, both mentioned aspects that revolve around the quality are highly affected by mobility and transport. In other words, operation of the urban transportation is in close conjunction with "urban landscape" and "land-use" as well as their mutual interactions [Jönson, et al.2006].

Generally speaking, the integration of sustainability with urban transportation has been a matter of research and development. For example, a simple interpretation of a sustainable transportation can be seen as an expression of sustainable development in the transportation sector and/or transportation in support of a sustainable society so that sustainable transportation system should [Ramani et al. 2006]:

- Introduce and promote alternative mobility choices instead of car-based trips.
- Improve freight and logistics.
- Promote the effectiveness and efficacy of transport via advanced technologies and innovative solutions.
- Reduce transportation demand through land-use management.

More formally, a sustainable transportation system must [Gilbert et al.2003]:

- Allow the basic needs of accessibility for individuals and societies. It should to be met safely and in a manner consistent with human and ecosystem health, and with quality within and between generations.
- Be affordable, operate efficiently, offer the choice of transport mode and support a vibrant economy.
- Limit emissions and waste within the planet's ability to absorb them, minimize the consumption of non-renewable resources, limit its consumption of renewable resources to the sustainable yield level, re-use and re-cycle its components and minimize the use of land and production of noise.

From the above discourse, we can put an emphasis on two important strategies as follows.

- A shift from private car-based trips to public transport.
- Integration of public transport modes as well as the most sustainable forms (walking-and-cycling)

As mentioned before, one of the most essential steps towards a sustainable city is to minimize the need for private and motorized vehicles for daily commuting. Public transport has traditionally been an appreciable solution on this issue while its performance has always been a matter of real concerns.

On the one hand, it is not very easy to motivate people to switch from private vehicles to PTMs. Public transport should be accessible, reliable, available, comfortable, and rapid with minimum delay. Nevertheless, the market of public transport is not very attractive since its incomes never cover the costs involving installation, utilization, maintenance and development [Gilbert et al.2003].

On the other hand, decision-making on public transport should encompass and address the needs of different stakeholders.

It must also contribute positively in all three scopes of a sustainable development known as “economic, social and environmental” issues.

Consequently, the problem of decision-making on the selection of appropriate PTMs can be seen as a multi-criteria and multi-sector challenge. Criteria and aspects can be adopted from the context of sustainability. Besides, the contribution of different social groups and people (with or without expertise in the field of transportation) is of major importance.

Consequently, a framework that simplifies these complexities is of interest and it includes:

- Consideration of various stakeholders
- Application of sustainability measures and indicators

2.1 Consideration of Various Stakeholders

It is essential to consider various stakeholders and the people who are actually the end-users of the public transport system. Since the key objective is to motivate people to use PTMs instead of private vehicles, we should investigate their expectations and priorities. For example, people who suffer from disabilities may have different expectations (from PTMs) compared to other social groups e.g. students. In addition, this is a context-specific issue and varies from place to place.

A study carried out in Delhi shows that “safety” is among the most important criteria and aspects to use PTMs [Jain, S., et al.2014] while in the city of Melbourne, “short distance to public transport services” and “well-connected street network” are the key factors that encourage the use of PTMs [Boulange, et al.2017].

2.2 Application of Sustainability Measures and Indicators

Relevant and tractable indicators must be used to measure some properties concerning the contribution of PTMs into the urban sustainability and transportation sector.

Broadly speaking, indicators of sustainability,- with an emphasis on urban transportation-, can be employed to quantify the interactions among transportation, society, economy and, environment [Gudmundsson, et al.2016].

Literature is abundant with numerous indices and indicators either in individual or hybrid forms. In [Litman, 2016] a rich set of transportation-based indicators of SUD is collated. As an illustration, “personal and freight mobility”, “land-use density”, “travel time” and “reliability” are amongst the most important criteria and indicators of the economic dimension.

Besides, “quality of transport”, “affordability”, “energy consumption”, “air-acoustic pollutions” and many more factors are often chosen to reflect the social and environmental aspects of sustainable transportation.

In [Haghshenas, et al. 2012], a comprehensive assessment and review of sustainable transportation indicators with a focus on urban studies is carried out. Authors provided a transparent classification of indicators to compare different cities around the world:

- Environmental impact indicators (emission, energy and land consumption)
- Economic impact indicators (costs for government, direct and indirect costs for users)
- Social impact indicators (safety, accessibility and, variety)

Reverting back to the previous point about the stakeholders, it becomes essential to measure and manage the indices and indicators that are the most relevant items to the objective stakeholders, context-specific issues and the case study. Importantly, the selection of indicators shall be in line with the priorities of the end-users and might vary from place to place and time to time.

2.3 The Use of MCDM

A detailed review on literature reveals the fact that individual and hybrid forms of MCDM methods can be well implemented and applied to transportation research topics [Mardani et al.2016] [Naeimi et al. 2014],[Baradaran, et al 2017],[Beheshtinia, 2018],[Jahanshahi, et al. 2019]. Techniques of MCDM can provide a manageable framework in order to combine various indices, criteria, and alternatives. Moreover, these techniques can facilitate a systematic way of weighting, ordering, ranking and developing composite indicators in order to address complex problems [Gudmundsson et al. 2016].

However, there is no panacea for complex problems of any type and any size. From a computational point of view, MCDM methods comprise a vast range of tools but each one has its own pros and cons.

In [Macharis, et al.2015] a review is conducted to analyze the applicability of MCDM within the scope of transport projects. It is concluded that every MCDM-based technique has a number of advantages and disadvantages but the most important facet is the "perception and understating" of decision makers about any underlying problem and its structure as well as transparency, consistency, and robustness. Furthermore, the diversity of stakeholders can have direct effects on the quality of results as well as the procedure of decision-making.

Among various solution techniques, two methods are found to be more tractable and easy-to-follow. As a compensatory method, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) provides a degree of priorities for a given set of alternatives considering some similarity aspects. In essence, TOPSIS assumes a number of criteria so that alternatives can be ordered in accordance with respective scores and relative distances from the positive and negative ideal solutions.

This method has gained increasing attention in various fields of interest since its outputs are fully understandable [Tzeng, et al.2011]. For instance, the TOPSIS is used for evaluating service quality of public transport and involvement of various criteria as well as different stakeholders [Hassan, M. N., et al.2013]. In [Awasthi, et al. 2011], a fuzzy TOPSIS is formulated to address the impacts of uncertainty in the process of selecting alternatives with respect to indices of service quality of public transportation.

In [Büyüközkan et al. 2018], TOPSIS and fuzzy Choquet integral approach are used to evaluate sustainable urban transportation. In [Wann-Ming ,2019], a fuzzy Delphi model is applied to account for uncertainty and some sustainable transportation indicators addressing "growth management principles" are analyzed.

Due to the fact that there is no holistic method to craft a comprehensive solution, it sounds necessary to develop hybrid techniques where the drawbacks of a method can be compensated by other approaches. For example, TOPSIS does not necessarily include a sound way for calculating relative weights of criteria. While some mathematical approaches (e.g. entropy) have been incorporated into TOPSIS, the lack of a reliable way for weighting has still remained a subject of research.

To remove this drawback, a hybrid framework could be of interest. Therefore, the AHP can be integrated with TOPSIS. In [Yu, et al.2013], evaluation of traffic congestion at intersections is performed via AHP-TOPSIS. In [Bilişik, et al.2013], a fuzzy version of AHP-TOPSIS is implemented to examine the degree of end-users' satisfaction associated with public transport quality. In the ref [Ghorbanzadeh, O. et. al. 2019] an interval-based framework of AHP is used to consider a variety of stakeholders in transportation planning.

It should be emphasized that there are also other valuable techniques to mitigate the complexity of decision-making problems. For example, MACBETH (measuring attractiveness by a categorically-based evaluation technique) is proved to be a well-established decision support system. It performs pairwise comparisons (similar to AHP) and is used in different fields [e Costa, et al.1999],[e Costa, et al.2013].

A comparative study conducted in [Ferreira, et al.2016] points out that AHP, Delphi and MACBETH are amongst the most tractable techniques but, for instance, Delphi outperforms AHP and MACBETH when the ease-of-use or applicability is a matter of concern. However, both AHP and MACBETH exceed Delphi in terms of accuracy.

In the present research, it is believed that the integration of AHP-TOPSIS can straightforwardly evaluate a multi-dimensional problem of decision-making within the context of urban public transport while the applicability of any other technique is not underestimated and the problem is still open to further investigations.

For example in [Reisi, et al.2016], a statistical model is used (instead of MCDM techniques) to develop a composite indicator of sustainable transportation so as to assess three urban planning strategies in the city of Melbourne, Australia.

It should be noted that the purpose of the current study was not to prove the rationale behind a particular technique like AHP or to compare its results to any other technique(s). Indeed, the usefulness of the proposed techniques has been validated in the previously published literature. In short, the proposed framework involves the advantages brought by both AHP and TOPSIS. By using the AHP, qualitative pair-to-pair comparisons are applied to determine relative weights. By using TOPSIS, a quantitative assessment lets us to analyze the distances between the potential alternatives from the positive and negative ideals.

3. Case Study and the Relevant Researches

The city of Isfahan is located at the central part of Iran which has traditionally been a rich source for absorbing the national and international visitors. As the capital of the province, this metropolitan area is the third largest city in Iran after Tehran and Mashhad.

3.1 Urban Planning in the City of Isfahan

The first period of implementing oriented policies was between 1979 and 2000. In this stage, early policies were put in place, following the guidelines and rules that were introduced by the government.

For instance, project of the Isfahan Metro was planned and started in this period and it still continues to develop. Between 2000 and 2010, some specific policies were carried out such as intra-urban highways, traffic rings, non-level intersections and parking lots. As can be inferred, the theme of the policies followed in 2000-2010 was to increase the "travel speed" to facilitate motorized trips. Therefore, a reduction in the levels of safety and environmental quality were expected to occur.

In other words, demand-side management, environmental concerns, and many more issues had been neglected. Since 2010, a move has been accelerated to consider more important objectives and goals.

In the same period, good attention has been given to Intelligent Transportation Systems (ITS) to improve the performance and management traffic flows. Thus, intelligent controllers, surveillance systems, enforcement devices, detectors, sensors and etc. have been installed and utilized in the city of Isfahan.

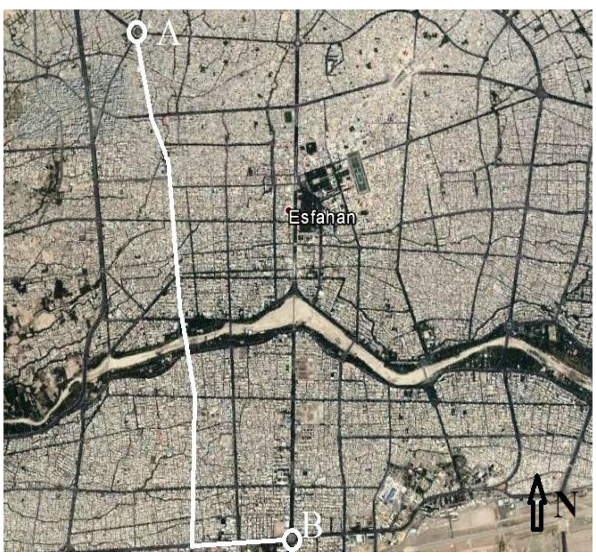

Figure.1. Case study: A: Jomhouri-Eslami Sq., B:Azadi Sq.

Along with this trend, non-motorized modes are being revitalized. Dedicated lines (for bicycles) have been planned and are developed encouraging people to use environmentally-friendly modes for inter-urban trips. The most recently established policy is to develop pedestrianization so that a part of "Chahar-Bagh" corridor is selected to become a fully non-motorized area.

According to the above paradigm, a threefold strategy to meet the needs of the Isfahan may contain:

- Traffic Calming.
- Traffic Balancing.
- Transit-Oriented Development (TOD)

The central part of the city, which encompasses the main historical and non-extendable areas is supposed to be facilitated by traffic calming strategies. In such areas, there is not enough space to develop new streets and intersections while there is a high level of demand for visits. Accordingly, “traffic calming”, “complete street and non-motorized trips” are of great interest. By “traffic balancing”, policymakers intend to provide the facilities that contribute positively to switch from the private-motorized based trips to public transport ones. Within this section, the reliability, availability, and connectivity to public transport stations, stops and the coverage rate are important factors to consider.

3.2 Sustainability in the Urban Transportation of Isfahan

Similar to other urban areas in Iran that have followed the concepts of sustainability, Isfahan has also attempted to provide balanced development. Following is a list of goals that are set to achieve by the Isfahan City Council and the Isfahan Municipality up to 2025 horizon.

- Preserving the historical context and developing the tourism industry.
- Integrating the traffic and transportation management systems, devices, processes, and procedures.
- Minimizing the level of environmental concerns and issues such as pollutants.
- Developing public transportation systems in a cost-effective manner with desirable levels of services and quality.
- Minimizing the motorized trips in overall and private-cars in particular.
- Improving the safety and the serviceability of streets.
- Providing parking lots and managing the on-street parking.
- Promoting the traffic calming, conscious driving and transportation culture.
- Providing equitable and safe mobility for different groups of society as well as disabled people, children, et.al.

As is clear, sustainability has a dynamic nature (past-present-future) Besides, it attempts to cover different dimensions as well as economic, environmental and social aspects.

Table 1. Factors involved in Decision Making and Sustainability Indicators

Dimension	System (expert)	End-users (non-expert)
Environmental	- Pollution - Fuel Consumption	- Pollution
Economical	- Ease of Installation - Cost of Installation - Cost of Maintenance and Operation - Privatization	- Fare - Speed - Land Consumption
Social	- Intelligent Monitoring - Maneuver-ability and Flexibility - Domestic Development	- Travel Information - Security - Social Acceptability - Comfortability - Physical Accessibility - Time Accessibility - Safety - Waiting Time and Reliability

Table 2. Decision Matrix

Indicator	Metro	Tramway	BRT	RB
Physical-Accessibility	6	7.2	7.6	8
Time-Accessibility	8.22	8.22	8.44	8.33
Speed	9.22	8.33	8.44	6.44
Waiting Time and Reliability	10	9	9	7
Fare	8.5	8.5	8.5	10
Security	8.9	8.83	8.9	9.5
Comfortability	8	8	8	8
Safety	10	8.5	9	8.5
Social Acceptability	9.5	9.25	9	7.75
Travel Information	9.5	9	9	8
Land Consumption	10	7	6	7.5
Pollution	10	10	5	4
Maneuver-ability	0.11	0.22	4.56	6.22
Privatization	1.78	2.89	7	7.67
Intelligent Monitoring	10	9.11	7.78	7.11
Ease of Installation	3.89	4.33	5.89	7.44
Domestic Development	4	4.22	6.22	7.33
Cost of Maintenance	395	390	454	745
Cost of Fuel	0.08	0.1	0.4	0.5
Cost of Installation	33.33	17.78	13.33	4

In case of the Isfahan, little is written regarding SUD particularly within the scope of urban and public transportation.

The most relevant work is published by [Haghshenas, et al.2016] analyzing transportation sustainability of Isfahan with the help of a system dynamics model.

Urban transportation causal loops were conceptualized and the dynamic relations among urban transportation variables were created to develop the pertinent urban dynamics model. Trip generation, modal share, transportation supply and equilibrium between supply and demand were the key modules of the developed model. The results of the above-referenced research show that urban transportation policymakers should develop policies pertinent to “public and non-motorized transportation infrastructures”, Moreover, the integration of various modes, effective pricing, and control of automobile usage can improve sustainable transportation in the city of Isfahan. Besides, the best sustainable transportation situation will be occurred by developing the transit network and the worst one will appear by the construction of road and parking. In addition to the above study, another research is conducted in [Salavati, et al.2016] regarding public transport decision making in the city of Isfahan. In this study, the applicability of different modes for different corridors was analyzed. In [Mansourianfar, et al.2018], a composite sustainability index is derived and the study points out that public transportation development projects are the most complaint scenarios with sustainable development and future urban planning of Isfahan.

To the best of our knowledge, there is no case in the literature concerning a sustainability-based analysis of different PTMs at the city of Isfahan and its corridors using a hybrid MCDM involving different stakeholders as well as expert and non-expert knowledge, which is covered in the present study.

3.3 Case Study

In this research, a corridor is selected to evaluate the applicability of the proposed model. The objective corridor connects two main squares of the city (*Azadi- Jomhouri Eslami*) where the estimation of two-way daily volume exceeds 62000 and its length equals 6.9 km (see Figure.1)

4. Formulation of Hybrid MCDM

In the present study, we examine the problem of decision-making on PTMs in the city of Isfahan, where sustainability indicators are used and the methodology is based on AHP-TOPSIS.

In a nutshell, the purpose is first to employ AHP for weighting the criteria using expert and non-expert knowledge. Second, weighted criteria are fed into TOPSIS for ordering the alternatives.

The procedures of AHP and TOPSIS are set out as follows [Tzeng, et al.2011].

To perform an AHP analysis, four steps should be taken.

1) Decomposing the problem into hierarchical and top-down relations.
2) Developing mutual (reciprocal matrix) describing comparative weights.
3) Computing the relative weights.
4) Aggregation of relative weights to determine suitable alternatives.

Ratio scales of an AHP analysis are 1 (equal) 3(moderate) 5(strong) 7(demonstrated) 9(extreme) and 2,4,6,8 (intermediate values) Once the largest eigenvectors (λ_{max}) of attribute matrix are known, Consistency Rate (CR) and Consistency Index (CI) can be calculated as below.

$$CI = (\lambda_{\max} - n) / (n-1) \quad (1)$$

Table 3. Distribution of Sample and Population in Survey of 830 Persons

Social Group	The percentage in population (city of Isfahan)	The percentage in sample (survey)
Student	26.4	15.3
Teacher	1.35	3.86
Clerk	12	31.08
Doctor/Nurse	0.8	3.01
Shopkeeper	1.31	15.06
Retired	5.7	8.07
Disabled	2.3	0.24
Labor	18.04	12.77
Housekeeper	32.1	4.94

Note: Around 5% of the samples did not provide us complete information about their social-demographic categorization.

$$CR = CI / RI \quad (2)$$

Herein, RI stands for Random Index. To develop a weighted TOPSIS, the following steps are in order.

Table 4. End-users (Non-Expert)

Indicator	Weight
Social Acceptability	7.3821
Land Consumption	7.6555
Speed	7.7853
Travel Information	7.8886
Fare	7.8896
Comfort-ability	8.0124
Security	8.1919
Physical Accessibility	8.3574
Safety	8.3683
Time Accessibility	8.4246
Reliability and Waiting Time	8.6870
Pollution	11.3573
Alternative	Final Score (%)
RB	13.89
BRT	19.28
Tramway	30.52
Metro	36.31

Note: The upper (weights) and the lower (normalized final scores) parts of the table are obtained by AHP and TOPSIS respectively.

1) The hierarchical structure of decision making

The procedure starts with a relation-based framework in which the objective problem (as well as criteria) is transformed into a hierarchical structure. Stated differently, the elements of any decision including criteria, sub-criteria, and alternatives are conceptually drawn to show possible relations that may occur amongst them. The objective structure of decision elements is given in table 1. Criteria affecting the selection of a public transport system are identified from two perspectives: local managers and end-users. It is carried out on the basis of reviewed literature, interview with system experts and end-users as expressed in Table 1. Ref [Vuchic, V. R. 2007] gives a broad understanding of these factors in definition and use. The first column refers to system management and the second column stands for end-users criteria.

2) Compiling a decision matrix

In this stage, we develop status matrix for each one of the objective alternatives (modes of public transport) taking into account the criteria. In this regard, positive-negative aspects of indicators should be treated with care. Correspondingly, “cost of installation”, “fuel consumption”, and “cost of operation-maintenance” are to be considered as negative and the rest of them should be treated as positive. With the exception of all negative indicators, the reminders are extracted from the results of surveys (expert and non-expert) in the city of Isfahan. We compile the Information into a set of scores in the range of 0 to 10. In case of costs (e.g. operation and maintenance) the information is extended to account for the passenger transfer capacity. Indeed, by taking the passenger factor into account as well as sharing the costs of operation and maintenance, it is possible to calculate the amount of cost associated with the one-kilometer trip for one passenger per mode.

Table 5. Experts (System)

Indicator	Weight
Maneuver-ability	4.4141
Privatization	6.9653
Domestic Development	7.5468
Fuel Consumption	7.8257
Intelligent Monitoring	9.4029
Pollution	11.6093
Ease of Installation	11.9596
Cost of Operation and Maintenance	19.8495
Cost of Installation	20.4298
Alternative	**Final Score (%)**
Metro	16.13
Tramway	25.50
RB	29.10
BRT	29.27

Note: The upper (weights) and the lower (normalized final scores) parts of the table are obtained by AHP and TOPSIS respectively.

Similarly, the costs for installation and fuel can be computed. Scores and properties associated to the systems are derived from previous studies as well as those carried out in Isfahan [Vuchic, V. R. 2007],[Salavati, A., et.al., 2016], [Mahmoudi, R., et al.2019]. It should be mentioned that these values are not based on pair-to-pair comparisons and expert knowledge but real-world calculations. Table 2 reports the values.

Taking into account the variation of costs from place to place and time to time, overall costs associated with the objective modes are calculated according to local data and in-site operation in the city of Isfahan.

3) Normalizing the matrix

A normalized matrix can be achieved as below.

$$x_{ij} = \frac{r_{ij}}{\sqrt{\sum_i (r_{ij})^2}} \quad (3)$$

,where r_{ij} stands for the score given to alternative *i* with criterion *j*.

4) Pair-to-Pair comparison

As a matter of fact, comparisons are to be made concerning the importance of decision criteria among together and respective weights are obtained from the pair-to-pair comparisons. Indeed, comparisons are established according to expert knowledge. Besides, the preferences of criteria are elicited from the survey of end-users.

5) Weighted matrix

Once the weights of indicators are determined, the weighted-normalized matrix V can be computed by the following relation.

$$v_{ij} = w_{ij} \times x_{ij} \;\; i = 1, \cdots, n \; ; \; j = 1, \cdots, m \quad (4)$$

, where x_{ij} is the normalized matrix produced by Eq.3 and w_{ij} is a diagonal matrix including the weights obtained from the previous steps and the rest of the elements are set as zero.

Table 6. Mutual Weights and Final Scores (Integrated Results)

Indicator	Weight
Maneuver-ability	1.0089
Privatization	1.0155
Domestic Development	1.7249
Ease of Installation	1.7431
Intelligent Monitoring	2.1491
Cost of Maintenance	2.8938
Cost of Installation	2.9784
Land Consumption	3.4025
Speed	3.4601
Fare	3.5065
Cost of Fuel	4.4311
Social Acceptability	5.1437
Travel Information	5.4966
Comfort-ability	5.5828
Security	5.7079
Physical-Accessibility	5.8232
Safety	5.8308
Time-Accessibility	5.8701
Reliability and Waiting Time	6.0529
Pollution (system)	6.5734
Pollution (end-user)	19.6046
Alternative	**Final Score (%)**
RB	13.74
BRT	18.40
Metro	32.42
Tramway	35.44

6) Ideal solutions (positive and negative)

Ideal and negative-ideal solutions can be expressed as follows.

$$A^{+} = \{v_1^{+}, \cdots, v_n^{+}\} = \{(\max_j v_{ij} \mid i \in N'), (\min_j v_{ij} \mid i \in N'')\} \quad (5)$$

$$A^{-} = \{v_1^{-}, \cdots, v_n^{-}\} = \{(\min_j v_{ij} \mid i \in N'), (\max_j v_{ij} \mid i \in N'')\} \quad (6)$$

7) *Distances from ideals (positive/negative)*

Ensuing relations calculate the distances from ideal solutions.

$$D_j^{+} = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^{+})^2} \qquad j = 1, \cdots, m \qquad (7)$$

$$D_j^{-} = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^{-})^2} \qquad j = 1, \cdots, m \qquad (8)$$

8) Determining final scores and ordering

Taking into account the above-mentioned distances,-from positive (D^{+}) and negative (D^{-}) solutions-, it is now possible to compute the scores as given below.

$$CL_j = \frac{D_j^-}{D_j^- + D_j^+} \tag{9}$$

The final order of alternatives can conveniently be obtained with respect to CL and preferred alternatives are those received higher values of CL.

5. Implementation of AHP-TOPSIS on Case Study

As stated before, the proposed framework involves combination of AHP and TOPSIS. In this regard, different viewpoints as different scenarios are evaluated.

5.1 End-Users

The first view focuses on the considerations of end-users. To evaluate the priority and importance of different criteria from the clients' standpoints, an online survey was undertaken and 830 persons were interviewed via social media. The aim was to gain a good understanding of the viewpoints of the end-users and their expectations from the PTS. Accordingly, a questionnaire-based evaluation was carried out and different dimensions of sustainability were analyzed given a number of criteria and aspects.

More precisely, in order to provide a real picture of clients and their expectations, it is also essential to consider various social groups and a diverse range of stakeholders' viewpoints. Therefore, the questions were disseminated among various layers of society in the city of Isfahan. Table .3 outlines the objective groups.

Table 7. Eigen vectors

Economic Parameters	0.155
Social Parameters	0.242
Environmental Parameters	0.603
System (experts)	0.247
End-users (non-experts)	0.753

Given the first scenario, the results of the AHP-TOPSIS model are reported in Table .4. As can be seen, "Reliability and Waiting Time" are found to be the most important aspects and indicators from the clients' viewpoints. Besides, it underlines the significance of service quality and how the performance of PTS is judged in the public mind. Factors of "Accessibility" and "Security" are also other necessary features to consider. The least important issues are related to "Social Acceptability",

In the next step, we are interested in finding the orders of PTS and its different modes. According to the ranking obtained from AHP-TOPSIS, the "Metro" is the most desirable mode of PTS and the second order is given to "Tramway" and the third rank is occupied by "BRT",

It should be mentioned that, there are several corridors that the trip distribution of the interviewed people can match with them. Amongst all, *Jomhouri-Azadi* is considered here since this corridor is potentially feasible for all four modes and about 40% of 830 persons use this corridor for daily trips.

5.2 Experts (Managers of PTSs and Local Government)

The second scenario is concerned with the same problem but taking expert and managers of PTS into account. As is pointed out in Table .1, some differences can be seen in the definition of indices. For instance, “fuel consumption” is a matter of concern and expert knowledge is required to ponder this issue so we asked experts to leave comments about these aspects of PTS but excluding end-users. In fact, managerial issues are brought into focus such as “privatization”, “domestic development” and so forth.

Table .5 addresses the relative weights of indicators from the viewpoints of experts. The weights and scores are calculated by AHP and TOPSIS respectively. It can be observed that economic factors such as “costs of installation, operation and maintenance” are the most important aspects of decision-making. “Ease of Installation” is too ranked high due mainly to restrictions and limitations of a historical city like Isfahan.

The upshot of AHP-TOSIS in this scenario is illustrated in the same table. As can be inferred, “BRT” is found to be the most desirable mode of PTS when we consider the expert and managerial points of view. Meanwhile, “metro” or “tramway” achieves a low level of desirability because of the dominant role of costs.

5.3 Integration of Non-Experts and Experts

Till now, we have assessed two different sets of viewpoints:

- End-users of PTMs.
- Local government and system managers.

Clearly, these two layers can have rather different and sometimes competing points of view. For instance, end-users would expect the minimum waiting time and maximum coverage of the network but the managers seek to minimize the overall costs of operations and maintenance. The differences among the ranking emphasize this issue as well. To arrive at coherent results, it is reasonable to integrate these standpoints. Members of the city council and senior experts can fairly incorporate these two sets. Since they are the representatives of the end-users (elected

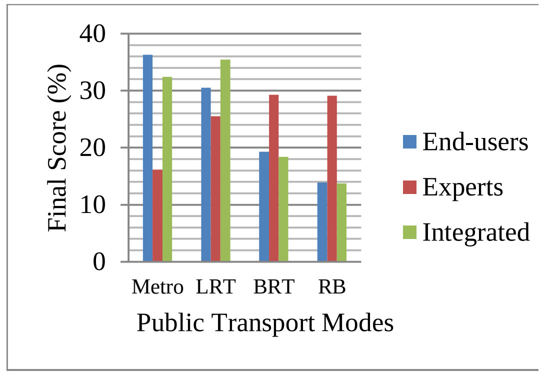

Figure.2. Final results and ranking of different PTMs.

by public votes) they can reflect public demands. On the other hand, they are familiar with the challenges of urban and transportation planning and thus understand the concerns of local government, and system managers. For this purpose, an AHP questionnaire is conducted and 13 senior experts of city council and municipality are surveyed. They are the elected representatives of the people and also fully aware of system operation and needs. Table .6 and Figure.2 show the mutual weights and rankings obtained for an integrated set of indicators and alternatives. It is interesting to note that neither “Metro”, nor “BRT” is obtained from the integration and a mode that is the most similar one to both of them is selected i.e. “tramway”, Computations were carried out via *Expert Choice software*. We note that the inconsistency ratios of the integrated analysis are 0.0098 and 0 for sustainability and managerial parameters respectively. Eigenvectors are reported in Table .7.

6. Conclusion

In this paper, a hybrid framework including AHP-TOPSIS is developed to evaluate different PTMs with respect to sustainability indicators and criteria. The research involves a vast range of viewpoints including end-users, experts of traffic and transportation, local managers and decision makers. Results are applicable to the corridors that have a similar level of demand for implementing Metro and Tramway. With respect to interviewed people of various social groups and their trip distribution, the model is validated on a corridor that meets the abovementioned level of demand.

In previous studies, little is written about a comprehensive consideration of different stakeholders, decision makers from the sustainability point of view.

For example, in [Salavati et.al., 2016] the priorities of public transportation *corridors* were determined for policy implementation via available data from the city transportation system, interviews with passengers, and polling of experts, practitioners, planners, and city managers.

The proposed framework was based on AHP incorporating clustering approaches. In the present study, the focus is directed towards *sustainability* indicators with a particular emphasis on the selection of *mode* and *various stakeholders*. In addition, TOPSIS and AHP are used to form the study tools and techniques.

In fact, we have assumed two hypothetical transport systems with best/worst possible fit to the objective indices and indicators. Then, we have evaluated available systems with respect to these positive and negative ideals.

Taken together, the present study arrives at the following remarks and key findings.

- There are rather large discrepancies among the viewpoints of end-users of PTMs on the one side and local managers on the other side. For example, the metro is found to be the most desirable PTM from the viewpoints of end-users due mainly to factors that are somehow related to the quality of service. However, the metro fails to satisfy the experts unless with an acceptable level of demand. High burden of costs and difficulties in installation and development are the main obstacles that decision makers would prefer other alternatives. In fact, BRT and RB are desirable alternatives from the standpoint of experts. To provide a coherent set of results, city council members and senior experts are asked to integrate the viewpoints of end-users and local managers. Their assessment has led finding an in-between option; tramway. Importantly, the experts we surveyed have been fairly familiar with the tramway systems as they have analyzed various systems and modes around the world based on available experiences and data. Arguably, the people may have a very little knowledge on the tramway and therefore they were not asked to leave comment on this mode. Phrased differently, we did not ask them to respond about tramway or compare it to other possible modes of public transport. We, in turn, asked about criteria, factors and objectives that they would expect. Criteria and alternatives were then scored and ranked according to the expert knowledge, former experiences and resources.
- In this research, electrified buses, environmentally-friendly and advanced

technologies are not investigated which can have influences on the final ranking and results.

- Since the scope of the study covers the issues at the level of decision-policy making, microscopic features such as travel time and pollutions can be analyzed in fine detail with respect to any corridor of interest.
- Generally speaking, it seems that the concept of sustainability should become a major part of social discourses and it is necessary to make people more familiarized with the aspects, factors, and dimensions of sustainable transportation. If so, the convergence and consistency among experts and non-experts could be enhanced.
- This research framework can be generalized to evaluate and compare other corridors under similar conditions. Moreover, the objective approach can be well merged with a simulation-based analysis and an integrated model can provide new insights into the urban planning strategies particularly in the transport sector.

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Appendix: City of Isfahan, Iran.

General overview	Population		Up to 2,000,000
	Area		550 Km^2
Bus Network	Regular	Number of Vehicles	1700
		Diesel Fuel	1300 of 1700
		Natural Gas Fuel	400 of 1700
		Average Age	7-8 (Year)
		Number of Daily Passengers	Up to 950,000
		Number of Stations/Stops	1800
		Number of Bus equipped with AVL	1100
	BRT	Length of Lines	150Km
		Available Lines	35Km
Taxi	Number of Vehicles	25769	
	Number of agencies	6576	
	Number of School Services	6866	
	Average age	7(Year)	
	Number of Daily Passengers	750,000	
Subway (Metro)	This project is now under development.		
	Lines	Urban	3 lines - 50 Km (1line:21Km available)
		Suburban	3 lines-116 Km (under planning)
	Number of Stations	For the first line North-South includes of 21 Stations/stops	
	Number of Intersections	2	
Parking and Car Parks	Number of Active Parking and Car Parks		101
	Total Area		323965 m^2
	Capacity		14749 (Vehicles)
	Number of Active Parking and Car Parks governed by Isfahan Municipality		30
	Capacity		6535
The Portions of Vehicles	Auto		35.8%
	Pickups		2.5%
	Taxi		22.1%
	Mini-Bus		1.9%
	Regular Bus		19.2%
	Bus		2.1%
	Motorcycle		10.4%
	Bicycle		6%
Daily Trips	Total Number of Travels in Isfahan City		3,600,000
	Travel Rate		1.9(Travel/Person)