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BRT (Bus Rapid Transit) System Evaluation by Global Comparison in World Cities

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Abstract

Bus Rapid Transit (BRT) is one of the contemporary modes of public transportation that has been developed worldwide, especially in the developing countries. In BRT system evaluation studies performed to date for different urban areas, before and after comparisons , in the BRT system deployment were made by comparing certain indicators in the studied city. However, a simultaneious evaluation of multiple BRT system deployment in several cities in the world is scarce. The main objective of this paper is to evaluate and compare various performance indicators of BRT systems in multiple urban areas throughout the world and evaluate a case study city compared to other cities in the world. In addition, BRT system of the city of Isfahan is compared with all other 193 cities. In order to get better results all of the BRT systems around the world are classified in five (5) clusters according to their continent, GDP, and density. This comparison reports high demand by passengers, high potential for using public transportation, slight deployment of system regardless of being inexpensive to implement, low frequency of service and extreme crowd especially during peak hours. The method of analysis developed in this study can be used as a new and efficient method of analysis for evaluation of BRT systems in other urban area.

Keywords: Public transportation, BRT, Cities of the world, Evaluation indicator, Comparison, Isfahan

1. Introduction

A suitable solution to decrease traffic congestion and improve traffic flow inside a city includes a public transportation system that covers large area of the city and provides a reliable service. BRT[1] is one of the contemporary modes of public transportation which is significantly utilized after the year 2000. Various researchers and organizations complemented the system and its features by stating its flexibility and low price compared to railroad systems' comfort, speed and reliability with formidable service quality etc. (Levinson et al. 2003; Kermanshahi et al. 2015; Hook et al. 2005). Due to its low total cost, this transportation system is considerably implemented by both developed and developing countries (Hook et al. 2005). In most cities of the world, in order to examine the performance of BRT, the conditions before and after initiating BRT systems are assessed by calculating some indicators such as an increase in the number of passengers and operating speed together with a decrease in travel time for public transportation. For example, Bertini and Lean (2003) conducted a study on the influence of BRT on accidents and pollution, which are indices of sustainable transportation, in Bogota. Eleven successful cities in the context of the implementation of a BRT system have been studied (Hidalgo et al. 2008). They also examined the benefits and pitfalls of BRT systems (Hidalgo et al. 2008). Callaghan et al. (2007) have compared BRT and LRT systems of Los Angles. They found that BRT is more efficient in increasing the number of passengers and reducing travel times. European Cooperation in Science and Technology (2011) studied 35 cities in Europe that use BRT systems and reported an

[1] Bus Rapid Transit

increase in the number of passengers and a decrease in the number of accidents and pollution as features of these BRT systems. Diaz et al. (2009) reviewed passenger transportation indicators for different cities in the U.S.; despite high tendency for using personal vehicle for transportation, in cities of Miami, Pittsburgh and Eugene solid growth of the indicators are observed which could lead to further use of public transportation. Khademian and Rassafi (2013) focused on the influence of BRT systems on metropolitan sustainable development. Using statistical data, they examined the satisfaction level of people when using BRT and presented solutions to better reach BRT's defined goals. Alehnouri et al. (2013) examined strengths and weaknesses of seven BRT routes in Tehran, rating them based on BRT ISO rating templates.

BRT systems differ around the world. For instance, in European countries it is known as bus with high level of service (BHLS) with high reliability and quality of service without any emphasis on speed. In other instances, in Asian and Latin American countries BRT is considered a mass transit system with a high level of quality which is fast and can carry many passengers. In this study, the difference between BRT system definitions around the world has been neglected. In other word, all of the bus rapid transit systems around the world are compared no matter what their definition is.

The main objective of this paper is to evaluate and compare various performance indicators for multiple BRT systems throughout the world and evaluate a case study city compared to other cities in the world. Through this comparison, the strengths and weaknesses of the BRT systems in different aspects like route extension, demand, fleet and service are identified. Analysis and comparisons made in this study are suitable not only for Isfahan, but also for other cities across the globe.

A simultaneous study reviewing BRT systems in all cities around the world is scarce. One reason may be the absence of a comprehensive database. The innovative aspect of this study is to use official BRT database containing the information from 190 cities and making indicators in order to compare BRT conditions in Isfahan with other cities in an intercontinental scale (BRT data 2015).

Twelve (12) indicators in four categories of "demand", "route extension", "fleet" and "service" are introduced and calculated based on the presented variables. Then, cities are clustered in 5 classes. Finally, results are analyzed to compare and assess Isfahan's BRT system with other classes, in order to evaluate Isfahan BRT system.

2. Database

In order to gather data for this study, BRT data website[1] was used. This database was developed with cooperation of the Internal Energy Agency, EMBARQ Institute and Latin American Association of Integrated Transport System and BRT (BRT data 2015). Some of the information that seemed to be incorrect are verified with reliable sources such as city's public transportation organization website.

2.1. Cities of database

Data used in this study was gathered from 193 cities in six continents. Of these 193 cities 62 and 56 cities in Latin America and Europe, respectively, used BRT system while 62% and only 6% of daily trips are made using BRT in Latin America and Europe, respectively. Latin America holds the first place in using BRT systems with regards to

[1] www.brtdata.org

daily passenger and system length among all the six continents, whereas Asian and European cities tend to extend this system by ranking second and third, respectively.

2.2. Database variables

Most of the available variables refer to operation indicators. Some variables are available for all cities, whereas others are available for a limited number of cities. Table (1) presents variables used in this study.

TABLE 1. Database Variables

Item	Variable	Abbreviation	Unit
1	Daily passengers	PASS	passenger/day
2	Fleet	NUMF	bus
3	BRT system route length	LENG	kilometer [km]
4	Passengers during peak hours	PAHD	passenger/hour/direction
5	Frequency during peak hours	BUHD	bus/ hour/direction
6	Population	POPU	person
7	Fare	STDF	$
8	Gross domestic product	GDP	$/person
9	Total cost	COST	$
10	City area	AREA	km^2
11	Operation Speed	APTS	km/hour

2.3. Collected data from Isfahan BRT

Isfahan is the third most populous city in Iran with over 2 million residents. More than 20% of daily trips are made with bus. Therefore, five routes were designed for Isfahan BRT system, of which only one is operational. Currently Isfahan has only one 21-kilometer route from Quds square to Yazdabad Bridge using BRT system while establishing other routes is under consideration. Number of daily transported passengers, frequency, and passenger number during peak hours, total cost of initiating, city area and population are the most important data that were obtained from Isfahan Bus Company and Isfahan annual Statistics. Table (2) presents information associated with BRT Route 1 in Isfahan and Figure 1 shows the path for Isfahan BRT Route 1. .

TABLE 2. Information and variables for Route 1 Isfahan BRT

Variable	Value
Population (p)	1,756,129
Density (p/km^2)	7,024
BRT system length (KM)	21
Passengers during peak hour (passenger/hour/direction)	10,800
Daily BRT passengers	150,000
Fleet	100
Gross production (USD)	4,600
Total cost (Million USD)	2
Operation Speed (Km/h)	23
Frequency during peak hour (bus/hour)	60

Figure 1. Isfahan line 1 BRT route.

3. Defining evaluation indicators

An indicator is a variable defined to assess conditions and performance of a system. Therefore, it needs to be comparable among various systems under study. In this study, some comparable indicators have been defined that can be used for extension, operation, and condition of a BRT system. Most of the databank's variables are not single-handedly sufficient to act as an assessment indicator. However, when considered with a combination of other variables, they can introduce a significant indicator. For example, indicators such as "number of passengers transported daily per population of the city", or "trip length per city area" are indicators achieved by division of two separate variables. These indicators indicate system extension and are comparable across various cities. Twelve (12) indicators developed by database variables with their calculation methods have been presented in Table 3. In order to compare the system in different cities, the indicators are divided into four general categories of "BRT route extension", "Demand", "Fleet" and "Service" (benefit for users.)

TABLE 3. Defined indicators based on database variables

section	Details	Calculation method	Unit
Route extension	Route Length per one million people	(LENG/ POPU)*1,000,000	km/person
	Route Length per city area	LENG/ AREA	km/(km^2)
	One kilometer of BRT implementation cost per gross product per capita	COST/ LENG/ GDP	$/km/($/person)
Demand	Passenger per population	PASS/ POPU	passenger/person
	Passenger transported per route length per day	PASS/ LENG	passenger/day/km
Fleet	Passenger transported by a bus per day	PASS/ NUMF	passenger/bus/day
	Fleet per 1 KM of the route	NUMF / LENG	Bus/km
	Fleet per 100 passengers during peak hours	100*(PAHD / BUHD)	Bus/passenger
Service (benefit for users)	peak hours dispatch frequency	BUHD	Bus/hour
	Number of passengers using a bus during peak hours	BUHD /PAHD	passenger/hour/bus
	operating speed	Available in database	Km/hr
	Fare per gross domestic product (per 10,000 people)	10,000*(GDPP /STDF)	$/ ($/person)

4. Clustering cities

Simultaneous analysis of indicators in 193 cities of the database with various features do not lead to meaningful results. For instance, GDP in studied cities vary from 1299 to 80000 USD. In order to get more meaningful results, in this study all of the 193 cities have been categorized. Clustering is a statistical method to regiment observations in similar subgroups based on one or several features. Regimentation of cities on the one hand facilitates the comparison of results and on the other hand, removes the lack of information for some cities in the database. Two-step clustering is used in this study. Two-step clustering is an appropriate method for clustering extensive data that contains both quantitative and qualitative data such as continent name and GDP as qualitative and quantitative data, respectively (Tabachnick et al. 2001). After several reviews and checking all variants which are suitable variables for clustering, it was discovered that the best way to cluster the cities is to cluster continents, and density and gross domestic production per person. Other studies also emphasize the role of these variables in city regimentation (Edelstein 1999, Haghshenas et al. 2015). Figure 2 represents importance of each of these factors in city clustering. Even though continent containing a city is the most important factor for clustering, this does not mean all the cities located in one continent come in the same group. GDP and population density also influence the regimentation. Table 4 presents features of various clusters.

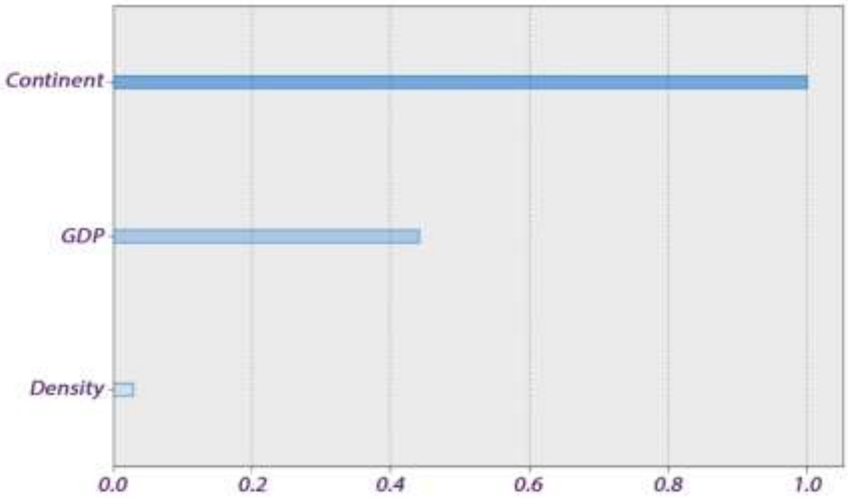

FIGURE 2. Importance of the used factors in clustering

TABLE 4. Clustering of cities available in the database

Cluster	Number of cities	Region	Average GDP	Average density (People per Km²)
1	33	Asia	6,000	9,035
2	54	Latin America	10,700	5,449
3	48	Europe	42,000	4,344
4	14	Oceania, Africa, Some Asian Cities	34,000	4,028
5	22	North America	53,000	2,490

5. Results

In this section, the values of proposed indicators for each cluster and the city of Isfahan are analyzed which are presented in table 5.

5.1. Route extension

Route extension of a BRT system contains three indicators of route length per population, route length per surface area, and total cost of one kilometer BRT implementation per gross domestic product per capita (GDP). Cities in cluster 5 (North America) and cluster 3 (Europe) have the highest route length per population and route length per city area while total cost of one kilometer BRT implementation per GDP for these clusters are lower than others. These results indicate that due to financial prosperity extended BRT routes throughout European and North American cities have been extended, regardless of low demands in North America.

Latin American cities (cluster 2) obtained the highest total cost of one kilometer BRT implementation per GDP while it has the lowest rank both in route length per population and in route length per city area. However, demand for using BRT systems is high. Therefore, regardless of the high costs, public officials established the policy to develop and extend BRT routes as much as possible. It is noted that the total cost of one kilometer BRT implementation per GDP of Isfahan is similar to global average. Extreme route shortage with high demand supports the necessity of BRT extension in Isfahan. Route extension and route length per city area in Isfahan are one fourth and one half of global average, respectively. Delay in construction of the subway system in Isfahan increases the importance of extending BRT. Although less Asian cities operate BRT systems compared with Europe and Latin America, success in operating the system in cities like Guangzhou, Jakarta and Tehran encourages other cities in the continent to initiate or extend their BRT routes in the future. Figure 3 presents total cost of one kilometer BRT implementation per GDP and figure 4presents route length per city area for different clusters.

TABLE 5. Results from assessment of indicators in different city clusters

	Service (benefit for users)				Fleet			Demand		Route extension		
	Dispatch frequency during peak hour	Operation Speed	Fare per GDP	Number of passengers using one bus during peak hour	Passenger transported by a bus per day	Fleet for 100 passengers during peak hours	Total number of fleet per 1 km of the route	Daily passenger transported per 1 KM of the route	Passenger per population	Total cost of one kilometer BRT implementation per GDP	Route Length per one million people	Route Length per city area
Cluster 1 (Asia)	60	21	0.79	80	1443	1.54	5	6513	0.06	0.690	16.27	0.107
Cluster 2 (Latin America)	115	21	0.84	145	2083	0.90	13	11354	0.16	1.128	17.26	0.083
Cluster 3 (Europe)	18	21	0.53	115	1253	1.13	3	2693	0.11	0.267	76.80	0.259
Cluster 4 (Oceania, Some Asian Cities)	77	33	0.72	76	600	1.69	10	3694	0.03	0.533	33.75	0.117
Cluster 5 (North America)	13	27	0.43	132	525	0.83	2	1125	0.06	0.231	103.68	0.207
Average	65	23	0.73	113	1382	1.22	6	6153	0.10	0.512	45.87	0.155
Isfahan	60	23	0.21	180	1500	0.56	5	7143	0.09	0.435	11.96	0.084
Number of case	114	104	115	63	105	63	114	145	171	47	170	160

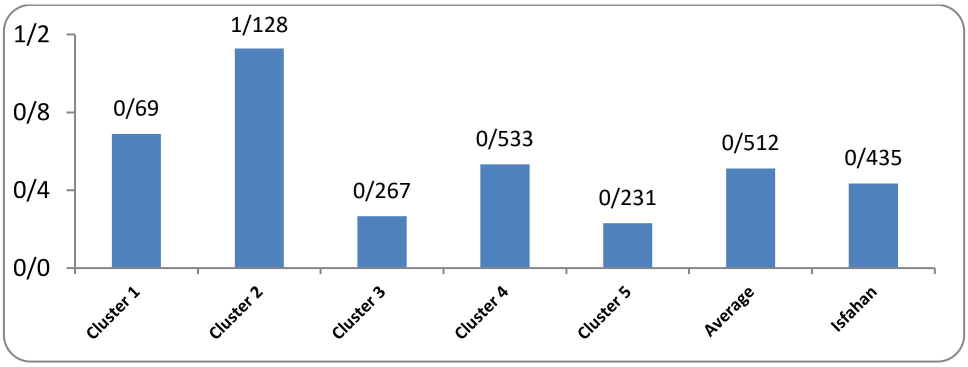

FIGURE 3. Total cost of one kilometer BRT implementation per GDP

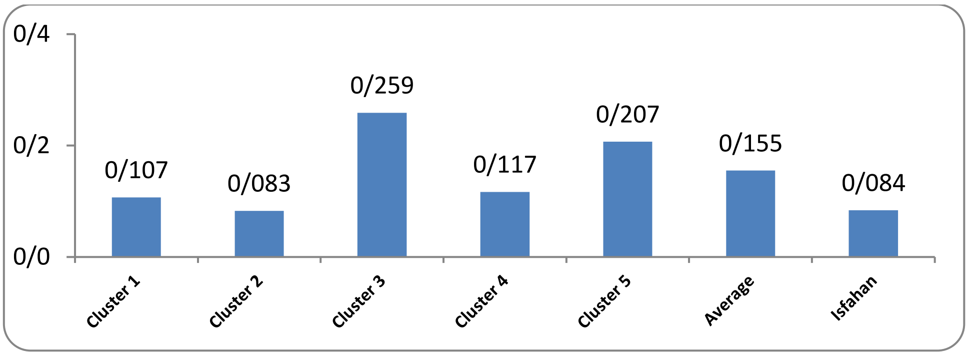

FIGURE 4. Route length per city area

5.2. Demand

Demand is evaluated using two indicators: BRT passengers per population and BRT daily passengers transported per kilometer (km) of the route. The former indicates BRT use per-capita while the latter indicates daily demand (performance). BRT passengers per population is the highest for Latin American cities and European cities in a descending order, which represents the high demand for BRT in daily public transportation. Latin America has the greatest number of daily passengers transported per one km of BRT route, which is almost twice the global average. The daily passengers transported per one km of BRT in European and North American cities shows adequate route length for the population and passengers. Isfahan has 150,000 daily demands and 7100 daily passengers for every kilometer of BRT, which transports almost 16% more passengers than other cities in the world as well as in comparison with Asian cities (cluster 2), which indicates high demand for public transportation. Figure (5) presents the number of transported passengers per one kilometer of BRT route.

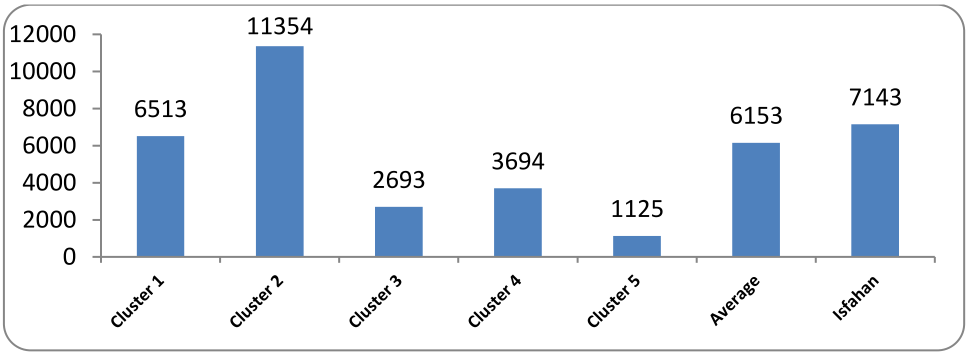

FIGURE 5. Daily passengers per route length

5.3. Fleet

Fleet has three indicators of 1) passengers transported by one bus per day, 2) fleet per one km of the route and 3) fleet per 100 passengers during peak hours. Fleet per kilometer is an indicator that should be considered together with passenger demand and route length to represent fleet conditions. However, fleet per 100 passengers during peak hours is an appropriate indicator of fleet adequacy. Global average for this indicator is 1.2 while cities in Asia and Oceania have better ratings. It is worth noting that since the data regarding fleet quality is not accessible, this indicator might have a small percentage of error. For example, if the fleet consists of three-joint or two-joint articulated buses or just single decker buses, their dispatch and numbers vary conditionally. This indicator was calculated as 0.55 for the city of Isfahan, which indicates shortage in number of fleet during peak hour. Capital productivity (indicator of transported passengers by one bus) indicates efficiency of each bus per day. Average global value for this indicator is 1382 passengers, while Latin American cities with 2080 passengers hold the first place and Isfahan with 1500 passengers transported by one bus holds a significant efficiency, which ranks almost equal amongst other Asian cities (Cluster ??). Figures 6 and 7 indicate daily passengers transported by a bus and fleet per 100 passengers during peak hours, respectively.

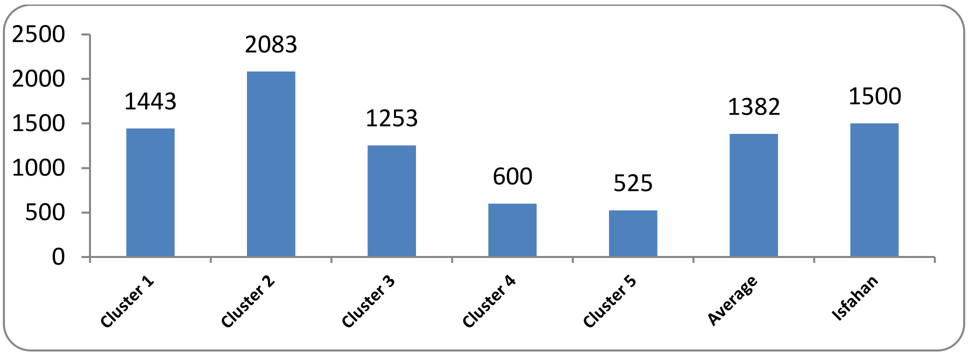

FIGURE 6. Transported daily passengers by one bus

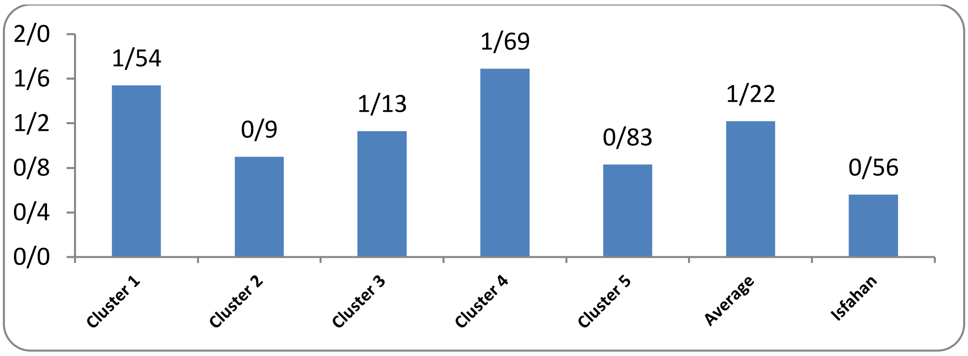

FIGURE 7. Fleet per 100 passengers during peak hours

5.4. Service (benefits for users)

In the database, quality of service or benefits for users are important factors which are represented by indicators of operation speed, peak hour passenger, dispatch frequency during peak hours and fare per GDP. The number of transported passengers with one bus during peak hours can represent the quality of service and buses crowededness during peak hours. The global average for this indicator is 113 passengers, whereas Latin American cities hold the first place by 145 passengers. North American and Asian cities come in second and third places. Transported passengers with one bus In Isfahan BRT is 180, which indicates excessive overcrowding during peak hours. Since fleet type information does not cover all the cities in the database, values for this indicator may vary depending on the type of fleet.

Operation speed is influenced by distance between stops, number of stops in each station -the number of buses that can simultaneously stop at a station- and the quality of the separation of BRT lanes from traffic flow. Most data gathered in the database show a speed between 21 and 27 kilometers per hour. The only exception is cluster 4, since buses in the BRT system in the City of Adelaide run on guided wheels, they exceed 80 kilometers per hour, and therefore, the average indicator value for this cluster is

higher than other clusters.
Since there should be a delicate balance between demand and supply, in order to avoid overcrowding, fleet dispatch frequency indicator during peak hours is an important factor determining passenger satisfaction. Overcrowding can decrese the share of BRT system in transportation. Latin American cities with 115 buses per hour and North American cities with 13 buses per hour hold the highest and lowest ranks for fleet dispatch frequency, respectively, which indicates the difference between demand and dispatch among these clusters. Isfahan BRT with 60 buses per hour during peak hours holds a lower rank compared to the global average value. The more dispatching of the buses, the better the service that could be achieved.
Fare over GDP is used to make comparisons between ticket prices and people's average income. Even though a better method is to use the income of passengers, since there were a vast number of cities and missing information about incomes, we used GDP. As data shows, all continents gain almost the same value of 0.72 for this indicator. In Isfahan, the value is 0.21 that indicates suitable ticket pricing, which on the one hand indicates the inexpensive service, and on the other hand, potential for raising the price in order to assist with the maintenance costs. Figures (8) and (9) represent dispatch frequency during peak hours and fare per GDP, respectively.

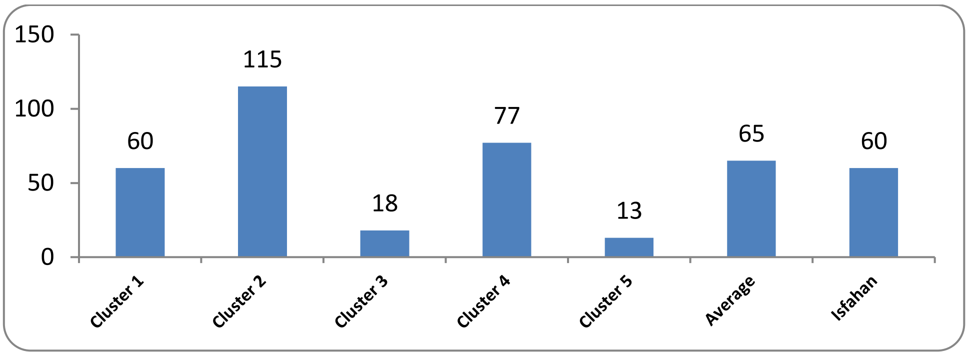

FIGURE 8. Dispatch frequency during peak hour

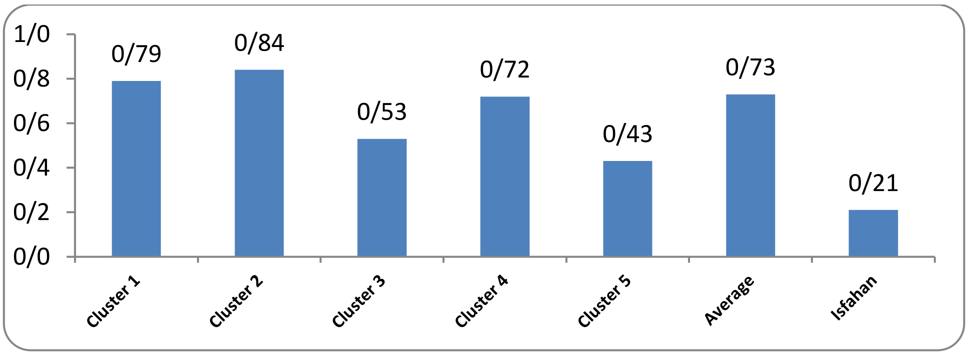

FIGURE 9. Fare per GDP

6.Conclusion

In the present research, Isfahan BRT system's performance indicators are studied and analyzed in comparison with different clusters of cities. Isfahan holds a 16% lead in the indicator of transported passengers per route length over the global average value, which indicates a high demand. Ratio of passengers per total population of the city is higher than other Asian cities which indicates a high potential for using public transportation. In the field of route extension, Isfahan's route length per population, route length per city area, and total cost of one kilometer BRT implementation per GDP

indicators are lower than other cities. Since subway construction reached difficulties, Isfahan BRT system needs to be deployed in other high-demand corridors. Isfahan faces fleet inadequacy and deficiency in both normal and peak hours. Operation speed of BRT system in Isfahan is almost the same as the global average value, while fleet frequency in peak hours is low and the number of passengers per BRT bus is high. Therefore, overcrowding happens and service does not hold suitable quality. This indicator could be improved by efficient planning and monitoring using intelligent devices as well as increasing the number of buses in the fleet during peak hours.
Analysis and comparisons made in this study are suitable not only for Isfahan, but also for other cities across the globe.

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