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Topology evaluation of Tehran subway network utilizing a bi-level mixed index for subway networks ranking

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ABSTRACT: As an essential infrastructure of cities, public transit networks have special importance in decreasing traffic congestion and air pollution and subway system is considered as the most efficient mode of public transit due to being green and mass transit. In this study, a mixed evaluation index composed of two components of shape and service points is proposed. The shape point is calculated utilizing network length, topology characteristics, station density, and average edge length (integer value between zero and ten). Annual passenger and passenger per unit length are used to calculate the service point (between zero and one). The study evaluated and compared subway networks for 52 cities around the world where according to this analysis New York city subway system is ranked 1, with a score of 8.506, and Tehran is ranked 29, with the score of 4.39. We also classified subway networks into three groups based on their connectivity and complexity indices using fuzzy c-means (FCM) clustering method and Tehran's subway system is classified as partially accessibility network. Results of proposed classification based on network complexity and connectivity using fuzzy c-means methods indicate that the Tehran subway is the developed subway system but London, Tokyo, and New York are the more developed subway system. Results of regression models based on the world trend for primary predicting of the needed number of stations and length of a network show that currently, length and number of stations of the Tehran subway network should be equal to 206.3 km (31.1 km deficiency) and 147 (8 stations deficiency), respectively.

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1. INTRODUCTION

Subway plays an important role in public transit of mega-cities because it utilizes clean fuel and has a large capacity. In this paper, the topology of subway networks is evaluated and ranked using a mixed index.

2. LITERATURE REVIEW

Formally the subway network is modeled as an undirected graph G (N, E) where N is a node-set and E is an edge set [1]. The nodes and edges correspond to stations and inter-station-spacing respectively. In previous studies [1-4], a mixed index involving various aspects of the subway network topology is not provided. Therefore, proposing a mixed index for evaluating and scoring of subway networks is the main purpose of this research.

3. METHODOLOGY

Based on connectivity and complexity indices and using the fuzzy c-means clustering method, 52 subway networks are categorized into three classes: under-developed, developed, and advanced subway networks (Figure 2). based on the number of stations and the average length of lines utilizing fuzzy boundaries subway networks are classified into three groups: 1- regional accessibility (systems with longer lines and lower number of stations providing faster services), 2- local coverage (systems with shorter lines and many stations), and 3- regional coverage (a mix of the two).

Based on the equations (1) - (3) and lexicographic method, the topology point (P_N: an integer value between 0 and 10), the service point (P_S: a float number between 0 and 1), and the bi-level mixed index (P_T: is the sum of two other points) of each subway network is calculated and ranked. Annual passengers and number of passengers per unit length of network (x_{Sj}) are only effective factors on the service point while station density, average edge length, the total length of network, and average of connectivity, complexity, and cycle availability (x_{nj}) are effective factors on the topology point (all indicators scaled into [0,1]).

$$P_N = \text{round}\left(10 \times \frac{\sum_{j=1}^{4} x_{nj}}{4}\right) \quad (1)$$

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$$P_S = \frac{\sum_{j=1}^{2} x_{Sj}}{2} \quad (2)$$

$$P_T = P_N + P_S \quad (3)$$

Fig. 1. Subway network of Tehran

Table 1. Tehran subway network properties

Index	Value
Total number of stations	139
Total number of transfer stations	19
Total number of edges	143
Total length of network (km)	175.2
Cycle availability	0.03
Network Complexity	1.05
Network Connectivity	0.35
Average of edges length (m)	1200
Station density (station/km^2)	0.19

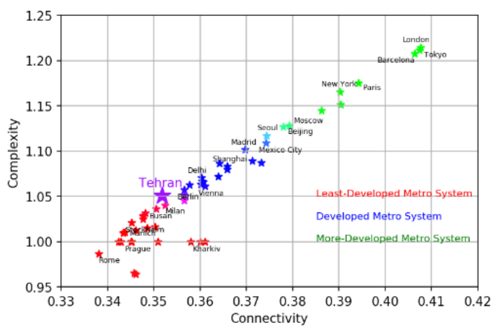

Fig. 2. Results of fuzzy c-means clustering for 52 cities in the world based on connectivity and complexity indices

Two regression models are developed for estimation of the number of needed stations and total length.

4. RESULTS AND DISCUSSION

Tehran subway network operating since 1998, currently consists of 7 lines (Figure 1). Line 5 serves suburban area between Tehran and Karaj (Table 1).

Based on connectivity and complexity indices utilizing fuzzy c-means clustering method (Figure 2), approximately the Tehran subway is recognized as a developed subway network while London and Tokyo subways are identified as advanced subway systems (network with many alternative routes [4]). Some cities like Rome and Prague have a least-developed subway network (network with few alternative paths [4]).

In this paper subway networks are classified utilizing

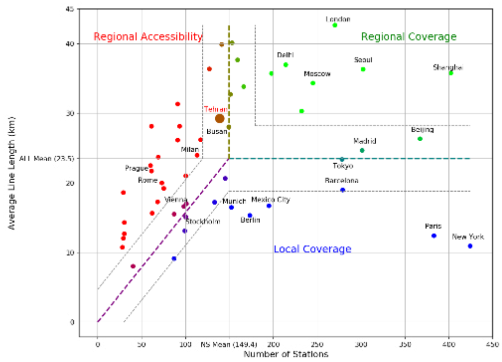

Fig. 3. Results of subway networks classification based on average line length and number of stations with fuzzy boundaries

Table 2. Ranking and details of scores of 52 subway networks in the world

Rank	City	Type*	Topology Score	Service Score	Total Score
1	New York	LC	8	0.51	8.51
2	London	RC	7	0.55	7.55
3	Barcelona	LC	6	0.48	6.48
...					
29	Tehran	RA	4	0.39	4.39
...					
52	Minsk	RA	2	0.06	2.06

- LC: Local Coverage, RC: Regional Coverage, RA: Regional Acc

Table 3. Results of regression model for total length of subway network based on world trend

Independent Variable	Coefficient	p-value
Constant	27.89	0.12
GDP (USb$)	0.18	0
Asia * GDP	-0.16	0.03
Population (millions)	16.98	0
America * Population	-12.45	0.09
Europe * Population	17.87	0.05
Area of city (km^2)	0.03	0.01
Europe * Area of cities	-0.09	0.01
Model Significance	Adj R^2 = 0.797	F=29.01

proposed fuzzy boundaries (subway networks place on fuzzy boundaries get traits of both groups). Results indicate that the Tehran subway network places on the fuzzy boundary within regional accessibility and regional coverage groups.

According to the proposed mixed topology evaluation index (Table 2), the New York subway is the best network from topological aspects (with a score of 8.506). The rank of the Tehran subway is equal to 28 among 52 cities (with a score of 4.390).

5. CONCLUSIONS

- Results indicate that the Tehran subway is the developed subway system but London, Tokyo, and New York are the more developed subway system.
- Results show that Tehran subway network places on the boundary within the regional accessibility and the regional coverage class.

Table 4. Results of regression model for total number of subway network stations based on world trend

Independent Variable	Coefficient	p-value
Constant	26.58	0.05
GDP (USb$)	0.15	0
Asia * GDP	-0.07	0.1
Population (millions)	12.12	0
Europe * Population	4.86	0.1
Model Significance	Adj R^2=0.73	F=34.71

- Ranks of Tehran and New York subway networks are equal to 29 (with a score of 4.390) and 1 (with a score of 8.506), respectively.
- GDP, continent (dummy variable), city area, and population are the only significant variables in estimating the needed length of a subway network (with adjusted R^2 = 0.797).
- In estimating number of stations, significant variables are GDP, continent, and city population (with adjusted R^2 = 0.73).

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