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RESEARCH

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Factors affecting performance improvement of the metro system in cities

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Abstract

The transportation sector is considered one of the most important sectors affecting the planning and development of cities. It is the responsible sector for traffic and transport inter- and intra-cities through the mass transit systems, which reflect the civilization, urban, economic, and social levels of cities. The importance of this study lies in studying the most important mass transit systems, namely the metro system, as stated unanimously by transport experts and urban planners. It is characterized by speed, safety, and punctuality. It avoids bus drawbacks such as slowness and mixing with other types of traffic. This research aims to find a set of criteria that contribute to improving metro performance and increasing its efficiency. In this paper, some standards were collected from 29 countries with metro systems that are considered successful as they meet the needs of their communities. Conducting the principal component analysis (PCA) and multiple regression analysis (MRA) has produced three mathematical equations to explain the impact of these standards in improving the performance and efficiency of the metro system. The results showed that there is no one set of specific standards among the countries around the world that could be sufficient to rely on to monitor and evaluate metro system performance, which requires further studying and research in this area.

Keywords: Improve performance, Public transport system, Rail transport system, Underground system, Technical indicator

Introduction

Public transport systems are a reflection of the progress and urbanization of urban communities, as they create daily movement and transportation between places of residence and work as well as other practices and activities [1]. Thus, daily trips that create social relations and transactions, on the one hand, and stimulate economic activity through the exchange of goods, on the other hand, are generated. Consequently, the rates of economic and social development, especially urban development, are increasing. Hence, the importance of public transport systems for these sectors, which began to realize the importance of activating its role and integrating its plans within city schemes, emerged [2]. So, the global trends towards environmentally friendly public transport were aroused. Also, they created developed urban transportation planning strategies and approaches that aim for developing radical solutions to the eternal public transport issues of overcrowding, bottlenecks, accidents, and waste of time, effort, and money in daily trips which exhaust human energies. Hence, the importance of the research is that it studies and searches about the important criteria for improving the performance of the metro system, which is one of the most important and efficient mass transit systems, because it combines the characteristics and privileges of bus rapid transit, in terms of capacity and its tracks which separate from other types of transit systems, and railway privileges in terms of speed, accuracy, and availability [2]. In addition to that, they are not affected by rush hours because there are specific timetables for trips and ticket prices are predetermined, in addition to its implementation costs, which are considered relatively balanced with the service. So, Metro provides the optimum solution of mass transportation problems [3]. Hence, the importance of the research focuses on lighting for evaluating and improving the performance of this effective system that has a fundamental and prominent role in developing solutions for mass transportation problems in various cities, especially those that suffer from increasing rates of population growth, so increasing the demand for transportation.

Theoretical study

The efficiency and luxury of public transport is an important factor of urbanization and technological progress [3]. There are many methods that have been put by researchers and practitioners to measure the performance of the mass transit system. Efficiency is defined as the quality of doing something well and effectively due to its importance in transporting the manpower for the purposes of arriving easily, smoothly, quickly, safely, and on time [4]. In addition to being a means of rapprochement and social communication, it is a way to develop and employ thousands of employees in the transport and shareholding sectors (industry, urbanization, energy, roads ... etc.). To evaluate any public transport system, it is necessary to understand its elements and components, in order to facilitate its evaluation for purpose of assessment. Figure 1 presents the components of the public transport system. It consists of a public transport means that has certain specifications at specific ticket prices [5]. It runs on designated tracks and stops at specific stations. It also has a system for management, design, implementation, operation, follow-up, and maintenance and serves a specific urban area and consists usually from buses, metro, elevated trains, electric trains, etc. [6]. Its main goal is to transport a large number of individuals from a place to a destination. The research presents below, in detail, the components of any public transport system and the role of each element.

Components of a public transport system network

Figure 1 shows the components of the land public transport system, the role of each of them separately, and how they integrate with each other to eventually produce an efficient public transport system (Table 1) [7].

Accordingly, we conclude that all public transport systems agree in their basic components, as each of them has an effective role in operating the system as a whole efficiently and safely, on the one hand, and has another role in achieving connectivity and integration with the rest of the different systems networks. However, public transport systems differ in their classifications according to the different urban levels that it serves or by its mixing or separation from the rest of the public transport types...etc. [8]. The

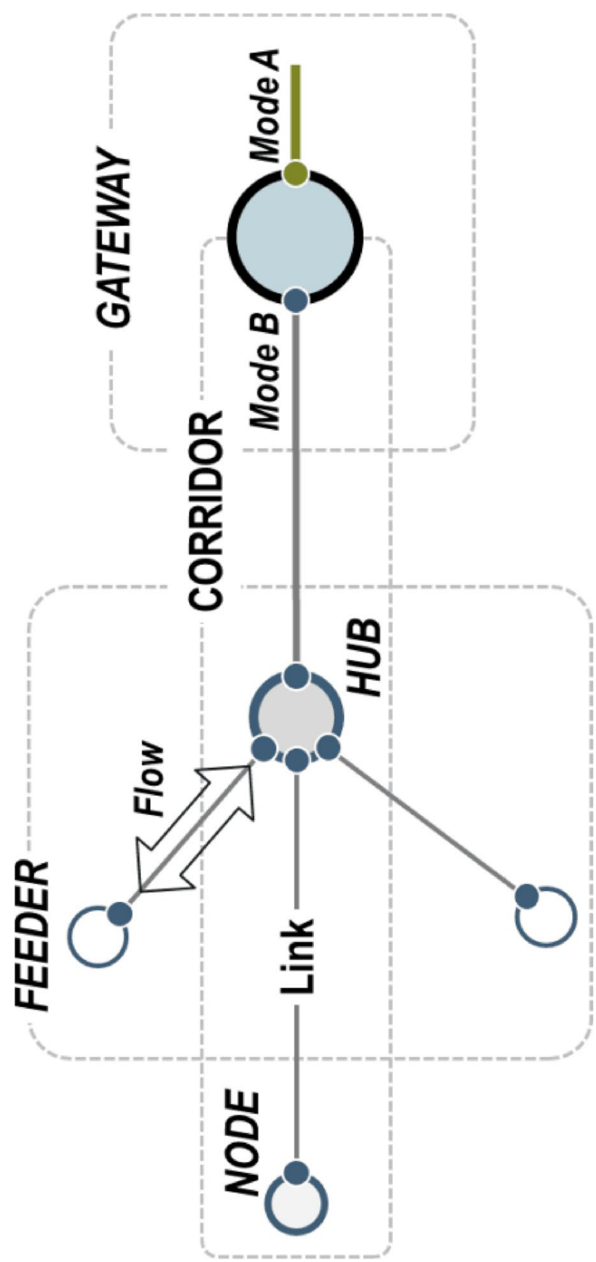

Fig. 1 Structural components of transport networks

Table 1 The main structural components of transport networks

Node	(Station) The location through which any public transport system passes, facilitating access to the rest of the public transport systems on the one hand and linking, switching, and integrating between their networks on the other.
Link	The path taken by the public transport system that links two successive stations, whether above or below ground.
Flow	The amount of traffic that goes through a link between two nodes and the amount of traffic that goes through a node. Thus, streams can be conditioned, multimodal (between modes) and mobile (between components of the same mode).
Gateway	A node that connects two different public transport systems in different paths and separate networks to achieve their integration and acts as a mandatory path and entry point for different traffic and movement flows. It is implemented and its location is chosen so that it mediates the networks of the different systems to facilitate the movement of people and goods from one system to another.
Hub	The main center that regulates the movement of large traffic volumes and the communication between the components of the same public transport system, on the one hand, and the integration between the networks of the different public transport systems, on the other hand, at the regional or international level.
Feeder	It is the site associated with the main center and its function is to regulate the directions of traffic flows along the transport path. It can be considered as the point of traffic and transport collection and distribution.
Corridor	It is a series of consecutive connected nodes and lanes of traffic flows for transporting people and goods, generally concentrated along the communication axis. It has a linear direction towards the larger node connecting two different transport systems.

Prepared by the researcher and the information is obtained from reference no. [7]

research presents below the most important of these classifications in relation to the field of research.

Classification of public transport according to the improvement of performance and investments in operation

Urban transportation systems and methods for both people and goods vary from walking and cycling on internal roads to urban highways, metro, and regional rail systems. Based on previous studies, it was found that there are several classifications of public transport systems [9] which we present some of them. The following classification is according to the performance of performance and investments in operation.

As shown in the following diagram, the three categories of ROW (an abbreviation of right-of-way) — A, B, and C — define three general categories of transport (4), respectively: [9] street transit, semi-rapid transit, and rapid transit. The following chart shows the transportation performance and the required investment cost. Performance is expressed in line capacity and operation speed, while investment cost is expressed in dollars per kilometer. The types of road public transport systems according to ROW can be classified into category C which has very low investment and also offers relatively low performance, then category B which includes semi-expressive transport and its performance is much higher and therefore requires higher investment, until we reach category A, which is the highest investment category, the fastest, and the most efficient public transport systems, including rapid transit or metro systems (Fig. 2, Table 2).

The importance of the metro system

According to the previous classification, the importance of the metro system appears, as it is the most attractive system for investments of governments and countries, on the

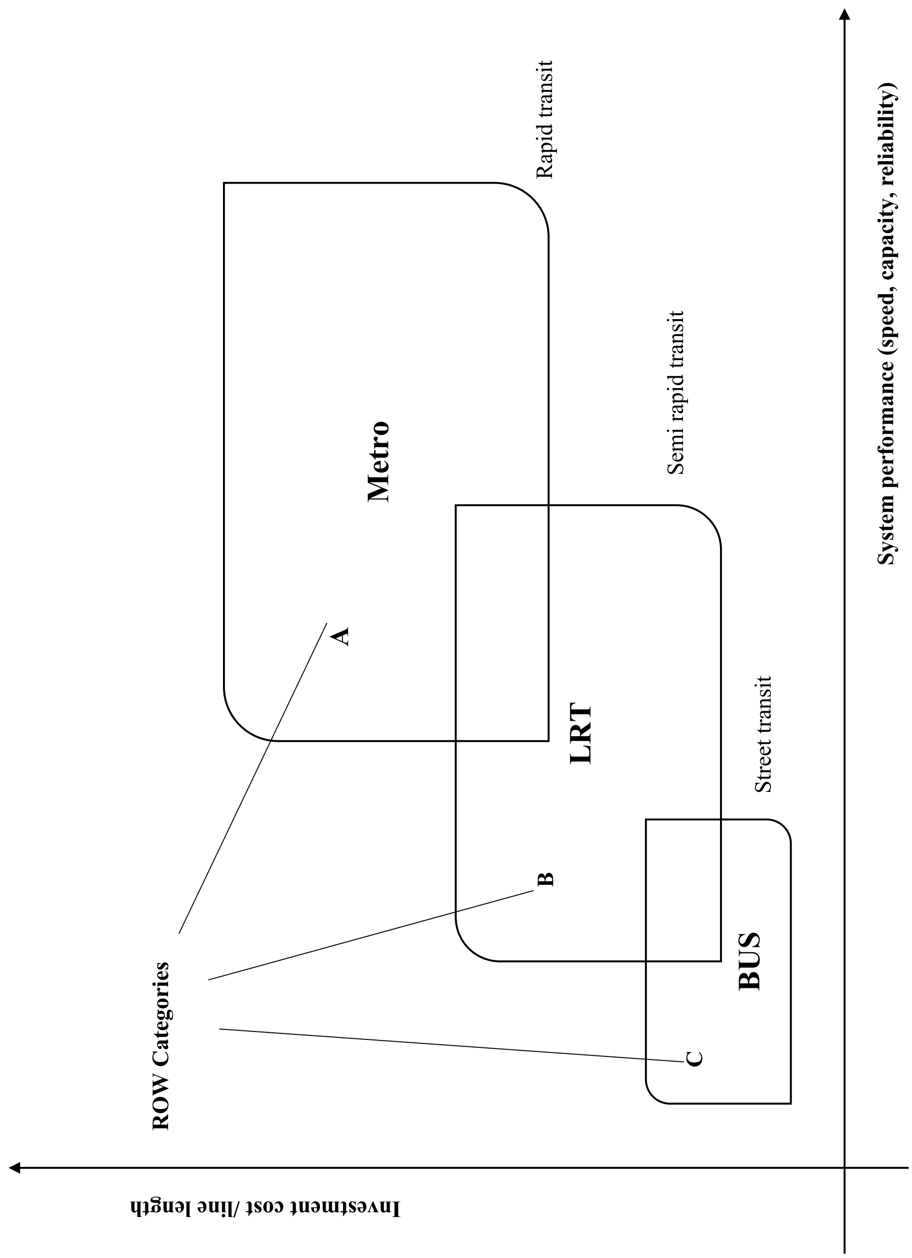

Fig. 2 Right-of-way categories and generic categories of transit modes

Table 2 Right-of-way categories and generic categories of transit modes

Street transit	This category includes most public transport buses, trolley, and trams, which are the lowest categories in terms of implementation and operating costs as well as speed. Therefore, the quality of their services in terms of speed and reliability is lower than other types of transport in the streets. Consequently, this type of transport cannot compete with private cars or even minimize them, unless other conditions discourage the use of private cars.
Semi-rapid transit	The clearest example of a mass transit system representing this category is the Light Rail Transit-Bus Rapid Transit.
Rapid transit	The clearest examples of this category are Rail Rapid Transit—or metro systems; Light Rail Rapid Transit (LRT with Class ROW A only), Automated Guided Transit and Monorails, which may have different technologies, such as supported, suspended, etc.

Prepared by the researcher and the information is obtained from reference no. [9]

one hand, and for individuals and goods on the other hand. Some previous studies of public transport systems in urban areas over the past century stated that it was found, by analysis and comparison, that metro systems were the best solution and choice to handle public transport issues. There is a clear agreement among planners, policymakers, and transport and traffic experts that the metro system is the most flexible and convenient solution to transport and traffic problems within cities and capitals. The metro system has proven its efficiency and effectiveness in addressing public transport and traffic issues in China, Hong Kong, India, Paris, London...etc. Metro combines the advantages of trains in terms of speed, reliability, distances it travels, and passenger capacity, and the advantages of buses in terms of cost, connectivity, speed of movement, frequency, availability, operating cost ... etc. This is due to the ease of its integration into public transport schemes and its integration with other public transport systems [10]. It is used schematically along the land uses to direct the urban mass and limit its extension, and it can be reliable and predict its trips and ensure the completion of daily trips easily, flexibly, and safely. Moreover, it has timetables and specific ticket prices that can be booked in advance before going to the station, which saves time and effort and reduces waiting time.

Literature review

There are various indicators to evaluate the performance of metro systems; therefore, the authors searched for previous studies in this field and found that there are fewer research studies that have examined efficiency standards responsible for improving mass transit systems performance. The main reasons behind this are the difficulty of obtaining data and lack of evaluation techniques or certain performance indicators of the metro system. However, there are some previous studies that identified some factors that may contribute to improving the performance of the metro system.

Various indicators have been provided to evaluate the performance of metro systems from the technical, financial, social, and economic aspects. There are many different criteria that have been deduced from previous studies to improve the performance of the metro system in many cities [10].

There is a study that considers metro systems as one of the most important systems in line with sustainable transportation approaches, especially in urban cities where traffic congestion and pollution problems are exacerbated, for instance, Tokyo metro, Hong Kong subway, and others. Some of these systems have been recommended as a standard for planning new metro projects. This paper presents four indicators for evaluating the performance of metro systems, which are urban population sizes, the length of the metro system network, annual passenger volume, and ticket price, considering them effective indicators for evaluating the efficiency of metro systems from a social, economic, and technical perspective [11].

In another study, the relationship of the metro system's frequency with its efficiency was measured, as the increase in frequency periods reflects the extent to which passengers are willing to use the system and rely on it for transportation and completion of daily trips. The demand for most metro rail systems is increasing annually. With the increasing demand for mass transit, the frequencies increase and thus increase the efficiency of the system and increase its reliability, by attracting more passengers and making current trips faster. This paper is based on a study conducted for a global group of metro systems, which surveyed 17 high-frequency lines. This paper provides recommendations for those involved in operating, financing, planning, and designing metro systems on how to maximize frequency and availability and thus deliver greater benefits to passengers, transportation agencies, and stakeholders [12].

This study presents the current situation in China and examines three major gaps that must be addressed to improve the performance, implementation, and planning of metro systems. They are namely the financing gap, the technology gap, and the affordability gap. Finally, the study concludes that early planning and careful studies are important in developing and improving the performance of metro systems in China. In addition, demographic and economic criteria are insufficient to be relied upon in assessing the efficiency of metro systems and should be supplemented by more stringent and accurate assessment criteria [13].

The metro system is the most important transportation system in urban infrastructure. It plays a crucial role in urban social and economic development, specifically in reducing urban traffic congestion. This study presents a model for assessing the level of congestion in metro stations because of its negative impact on its performance and service efficiency. This model is considered an effective mechanism to help the metro operators understand the level of congestion, and take appropriate measures to reduce congestion, thus improving metro performance, efficiency, and quality of service [14].

We find another study concerned with measuring the management factor of the metro system as a whole and considered it an important part in the process of safe operation of the metro and developed strategies to improve the operational quality and increase the safety factor of metro trips [15]. Another study mentioned the ventilation factor of metro stations and its importance in those closed underground stations, as they are congestion spots and gatherings of individuals, especially in recent times due to the Corona pandemic, which targets these poorly ventilated places. This research presents the environmental and health effects caused by poor ventilation of metro stations. It also discusses the related engineering, environmental, and medical aspects together, to put, at the end of the study, mechanisms for designing, implementing, and maintaining ventilation systems to reduce the concentration of pollutants [16].

This study proposed a service satisfaction index to assess the quality of the metro service and improve its performance by applying to the Shanghai metro. The study concluded with seven essential indicators measuring performance improvement, including four indicators related to accuracy, efficiency, speed and ease of purchasing tickets, and length and speed of the train track, and three other indicators related to the management of service and public utilities in the metro, number of signs guiding passengers and security doors [17].

This study concluded that security checks and waiting time for passengers to board have a strong impact on the overall satisfaction of passengers. By studying and analyzing the importance and performance, some practical solutions have been proposed to improve service quality and performance, such as making women-only vehicles and booking a 1-day ticket, with the aim of reducing overcrowding and thus improving service quality and the efficiency of daily operation of the metro (https://www.railway-technology.com/projects/new-york-subway modernisation/).

All of the above are criteria that must be taken into account when planning and implementing metro projects. In this research, these criteria are measured in addition to other criteria added by the researcher that were deduced from previous experiences such as the total annual income/person, the number of metro stations, the trip time between the two successive stations, the possibility of integration with the rest of public transport systems, and the individual's feeling of safety both at the station or in the train…etc. (http://www.seoulmetro.co.kr/en/index.do?device=PC).

Following is the methodology that the research will follow to determine the most important factors that might affect the improvement of the performance of the metro system to be taken into account when making a decision to plan and implement metro construction projects.

Methods

The research begins by following the inductive approach, which is based on previous theoretical studies, the theoretical concepts of public transport they concluded, the theoretical thought of public transport, what are its components and the role of each component separately, and what are the classifications of public transport. Because they are multiple and different (https://www.railway-technology.com/projects/beijing_subway/), only two types of classification were presented as they are related to the field of research. By studying and reading some of the previous researches, some of the factors they reached in to improve the performance of the metro system were deduced. Other factors were added by the researcher from different countries such as London, Paris, Japan, New York, and Germany ... etc. [21]. They depend on the metro as one of the public transport systems followed in them. Some of such systems are characterized by efficiency and quality of service provided to passengers, while others need development, maintenance, and modernization to keep pace with the current global transport trends, and their number is 28 variables ranged between environmental, demographic, economic, security, and technical variables ... etc.

The researcher resorted to collecting data from each city separately to investigate accuracy. Some criteria were taken from previous studies and deduced from environmental, security, technical factors, etc., from the experiences of similar cities, attributing some hard-to-obtain data to the data of the leading cities in this field [18].

In addition to the official websites of each metro system in each city separately, some international sources specialized in the areas of mass transit systems in general and the metro system in particular were also used as a reference to compare data and choose the most updated and accurate one. With regard to the data of the annual number of passengers in this study, the latest official websites of the operating companies were consulted. The fare-related data is from the UBS report (https://www.ubs.com/global/en/wealth-management/chief-investment-office/market-insights/2021/year-ahead.html, https://www.ubs.com/global/en/global-family-office/reports/gfo-r-21-4-client/_jcr_content/mainpar/toplevelgrid_2011378/col2/textimage_copy.1798619115.file/PS9jb250ZW50L2RhbS9hc3NldHMvd20vZ2xvYmFsL3VobncvZG9jL3Vicy1nZm8tcmVwb3J0LTIwMjEtc2luZ2xlLXBhZ2VzLnBkZg==/ubs-gfo-report-2021-single-pages.pdf). Due to different price policies in different parts of the world, metro system fare for 29 cities has been selected from official websites and all prices are converted from local currency to American dollar. Then, most of the updated data for the official population census were collected from different cities, and the following table shows all the criteria studied in the research, their units of measurement, and the source they were taken from. In order to build a mathematical equation, both sides of the equation must be present. The annual number of metro passengers, measured in million/year, represents the dependent variable for this mathematical model.

A panel of 29 cities were chosen on the basis that they are pioneer cities in the field of mass transportation, as they have successful subway networks that meet the needs of their communities and therefore can be considered as role models, and indeed, they are consistent with cities mentioned in previous studies in the same field. All variables will be measured for 29 cities diverse in social, economic, and urban characteristics using one of the statistical methods of analysis, which is the principal component analysis [19, 44] and its results will be analyzed using multiple regression analysis [20], to eventually produce a mathematical model consisting of the strongest factors affecting the improvement of the performance of the metro system. But not alone, all factors must be taken into account when evaluating performance, because it was found, based on the study and analysis, that each community has its own priorities and requirements that must be met in the public transport system to satisfy it. The following is a methodology that shows the research steps to determine the most important and most influential of these factors in assessing the performance of the metro by study and statistical analysis (Fig. 3).

Empirical study

According to the previous theoretical and empirical studies, the research concluded some factors that may affect the improvement of the performance of the metro system, which are 28 variables, distributed into environmental, demographic, security, technical factors, etc.

Below, the research will use the principal component analysis to conclude the most important of these factors that may affect performance.

The principal component analysis is a data analysis process conducted by converting a large set of correlated variables into a small set of unrelated variables (the principal component matrix), which accounts for most of the variance in the original variables; below is a table that shows the results of the first phase of the principal component analysis. This phase resulted in the reduction of 9 main factors. We will notice in Table 3 that the Eigenvalues for the first three factors are greater than the rest of the factors and equal to

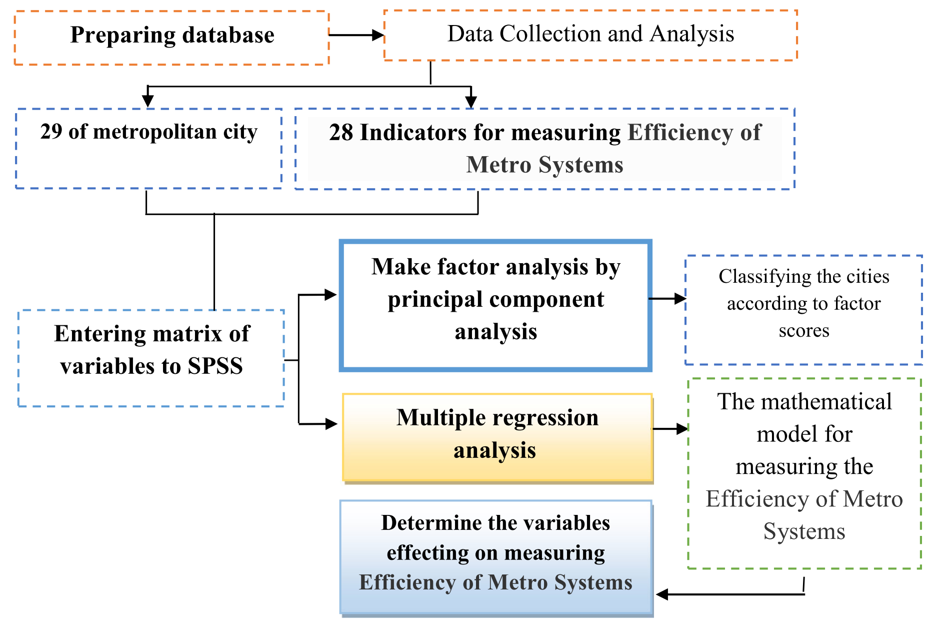

Fig. 3 The methodology steps for analytical and applied study

43%, and accordingly, the results will be analyzed for these three values only as they are the most influential.

From the previous table, it was found that the percentage of factors' interpretation of the variance between the variables is close. Thus, there is no dominant variable package over the rest of the packages, meaning that when improving the performance of the metro system, the three packages should be taken together in the evaluation. Table 4 shows the results of the analysis, which is the division of factors into three groups according to the extent of their influence in improving the performance of the metro system. We find that the group of technical and security factors comes in the first and second places, while environmental factors are in the third place. This explains the lack of interest, by all public transport systems, in the luxury of passengers compared to their interest in completing trips.

Based on the previous table (Table 5), we conclude that there is no dominant set of factors in evaluating the performance of the metro system, but rather they are distributed to environmental factors and other technical or environmental factors. So, we cannot assure that there are specific factors that represent the ruler by which efficiency is measured. This may be due to the different cultures between societies and their different demands, desires, and priorities. Thus, in the evaluation process, it is better and safer to take all criteria into account to ensure the implementation of an efficient public transport system.

Results and discussion

Based on the previous analysis, it resulted in the following classification of cities, according to the value of each factor separately, into three levels: a high level, a medium level, and a low level of efficiency. We find that high-level cities such as Beijing, New York, Seoul, Hong Kong, Dubai, etc., are in fact characterized by the efficiency of their public

Table 3 Factors improving the performance of the metro system in the study (https://www.intelligenttransport.com/transport-articles/118931/10-busiest-metro-systems/)

	Factors	Units	References
V1	Area/thousand	Square kilometer	(https://www.britannica.com/topic/list-of-the-total-areas-of-the-worlds-countries-dependencies-and-territories-2130540)
V2	Population	Million	(https://www.worldometers.info/world-population/population-by-country/)
V3	Gross annual income	Dollar/person	(https://www.worlddata.info/average-income.php)
V4	Number of stations	Number	(https://www.intelligenttransport.com/transport-articles/118931/10-busiest-metro-systems/)
V5	Distances between stations	Kilometers	(https://metro.fandom.com/wiki/List_of_rapid_transit_systems)
V6	Network length	Kilometers	(https://www.arcgis.com/apps/Cascade/index.html?appid=82e04b822de9437792a07f2309e6f4b6)
V7	Number of lines	Number	(https://metroautomation.org/wp-content/uploads/2019/05/Statistics-Brief-Metro-automation_final_web03.pdf)
V8	Travel time between stops	Minutes	(https://www.hindawi.com/journals/jat/2018/3690603/)
V9	Operational speed	Kilom/eterhour	(https://www.researchgate.net/publication/238001286_Study_on_the_maximum_operation_speeds_of_metro_trains_for_energy_saving_as_well_as_transport_efficiency_improvement)
V10	Ticket price	Dollars	(https://www.ubs.com/global/en/wealth-management/chief-investment-office/market-insights/2021/year-ahead.html)
V11	Flexibility	Percentage	(https://cms.uitp.org/wp/wp-content/uploads/2020/06/Statistics-Brief-Metro- automation_final_web03.pdf)
V12	Frequency	Minutes	(https://journals.sagepub.com/doi/abs/10.1177/0361198119845356)
V13	Integration with other systems	Percentage	(http://www.urbanrail.net/)
V14	Population density	Person per square kilometer	(https://en./List_of_countries_and_dependencies_by_population_density)
V15	Sustainability pollution and noise ratio	Percentage	(http://www.urbanrail.net/; http://mic-ro.com/metro)
V16	Accessibility	Percentage	(http://www.urbanrail.net/)
V17	Reliability	Percentage	
V18	Safety from crime at stations/stops	Percentage	(https://www.essentialliving.co.uk/blog/the-worlds-best-subway-systems-revealed/; http://mic-ro.com/metro)
V19	Safety from crime on trains	Percentage	
V20	Accident rate	Percentage	(https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Railway_safety_statistics_in_the_EU)
V21	Emergency exits	Percentage	(http://www.cityrailtransit.com/)
V22	Wheelchair accessible	Percentage	
V23	Convenience	Hours of operation	(http://mic-ro.com/metro)

Table 3 (continued)

	Factors	Units	References
V24	Pet friendly	Percentage	(http://www.cityrailtransit.com/)
V25	Connectivity (WIFI)	Percentage	
V26	Age of infrastructure	Years	(https://www.itf-oecd.org/sites/default/files/docs/dp201333_0.pdf)
V27	Comfort (bathrooms)	Percentage	(https://www.essentialliving.co.uk/blog/the-worlds-best-subway-systems-revealed/; http://mic-ro.com/metro)
V28	Comfort (air conditioning)	Percentage	(http://mic-ro.com/metro)

Table 4 Part of total variance explained

Component	Initial Eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total
1	4.74	16.944	16.94	4.7	16.94	16.94	4.1
2	4.41	15.778	32.72	4.4	15.77	32.72	3.9
3	3.08	11.024	43.74	3.1	11.02	43.74	3.2
4	2.91	10.405	54.15	2.9	10.40	54.15	2.5
5	1.98	7.099	61.25	1.9	7.09	61.25	2.5
6	1.66	5.927	67.17	1.6	5.92	67.17	3.3
7	1.47	5.270	72.44	1.5	5.27	72.44	2.2
8	1.29	4.628	77.07	1.3	4.62	77.07	2.05
9	1.10	3.961	81.03	1.2	3.96	81.03	1.5

Table 5 Table of classification of variables into three groups according to the variable's variances

Factor 1 indicators	Factor 2 indicators	Factor 3 indicators
Reliability	Safety from crime\station	Safety from crime\trains
Accident	Safety from crime on trains	Distances between stations
Safety from crime at stations/stops	Length of system/km	Area of the city
Population	Number of lines	Frequency
Total annual income per capita	Number of stations	Age of infrastructure
Safety from crime on trains	Pollution and noise	Pet friendly
Trip time between two consecutive stops	Frequency	
Integration		
Number of stations		

transport systems in general and the metro system in particular ([21], https://www.piercetransit.org/PT-Key-Performance-Indicators/مصادر الارقام [22, 23]). They are concerned with accomplishing daily trips of passengers efficiently, quickly, and safely, without neglecting the right of the disabled and the elderly to ride the metro. All safety and quality standards were taken into account in the design and implementation. So, the main goal of these cities is to achieve the satisfaction and well-being of passengers of all ages and conditions, taking into account the environment and preserving it, and thus combine all standards (Table 6).

Below, a multiple regression analysis will be done for each set of variables dependent on each of the three factors separately. Multiple linear regression is one of the statistical methods and generally explains the relationship between multiple independent or predictive variables and one dependent variable or criterion in order to improve results by improving the use of data to establish causal relationships between the phenomena under study. The dependent variable is modeled as a function of several independent variables with corresponding coefficients, along with the constant term. Multiple linear regression requires two or more predictor variables. That is why it is called multiple regression. The multiple regression equation explained above takes this form:

$$y = b_1x_1 + b_2x_2 + \cdots + b_nx_n + c.$$

Here, b_i's ($i = 1,2...n$) are the regression coefficients, which represent the value at which the criterion variable changes when the predictor variable changes (Table 7).

By conducting a multiple regression analysis on the variables resulting from the PCA analysis, it resulted in three main factors affecting the improvement of the performance of the metro system, but in varying ratios. Accordingly, three main equations were deduced, each of which includes a set of variables that explain the impact of these variables on

Table 6 Country classification according to factor scores

Factor scores 1	Factor scores 2	Factor scores 3
Countries with a high level		
Beijing	Montreal	Paris
New York	Osaka	New York
Seoul	Bucharest	Stockholm
Shanghai	Dubai	Berlin
London	Hong Kong	London
	Seoul	
Countries with a medium level		
Moscow	Tokyo	Nagoya
Paris	Shanghai	Montreal
Madrid	Singapore	Athens
Tokyo	Athens	Madrid
Delhi	Nagoya	Osaka
Berlin	Mexico City	Rome
	Madrid	Cairo
Countries with a low level		
Mexico City	Stockholm	Copenhagen
Hong Kong	Istanbul	Istanbul
Singapore	Berlin	Singapore
Osaka	Moscow	Seoul
Cairo	Paris	Dubai
Istanbul	Jakarta	Beijing
Stockholm	Sao Paulo	Jakarta
Athens	Copenhagen	Moscow
Montreal	New York	Brasilia

Table 7 Analysis of variance (ANOVA) for factor 1 variables

Model		Sum of squares	df	Mean square	*F*	Sig.
1	Regression	1673841636.101	9	185982404.011	0.374	.934[b]
	Residual	9459484754.106	19	497867618.637		
	Total	11133326390.207	28			

Table 8 Regression results for factor 1 variables

	Unstandardized coefficients		Standardized coefficients	*t*	Sig.
	3.1.1. *B*	Std. error	Beta		
1	−291888.47	368707		−0.792	0.43
V2	103.383	145.5	0.19	0.710	0.48
V3	−0.110	0.2	−0.11	−0.417	0.68
V4	1.216	29.8	0.01	0.041	0.96
V8	−8715.659	14471.8	−0.18	−0.602	0.55
V13	699.919	566.29	0.33	1.236	0.232
V17	2.864	668.17	0.00	0.004	0.997
V18	2722.975	4110.70	3.13	0.662	0.516
V8	−213.416	601.95	−0.27	−0.355	0.727
V20	2302.845	3663.26	2.64	0.629	0.537

evaluating the performance of the metro system in metropolitan cities. Tables 8, 10, and 12, respectively, show the values of the coefficients of the variables based on which the three regression equations for each factor were generated separately.

The mathematical equation for measuring performance of metro systems using factor 1 indicators:

$$Y = 2723\,\mathrm{V18}+2303\,\mathrm{V20}+670\,\mathrm{V13}+103\,\mathrm{V2}+3\,\mathrm{V17}+\mathrm{V4}-0.1\mathrm{V3}-213\,\mathrm{V19}-8716\,\mathrm{V8}-291889 \tag{1}$$

Based on the analysis of Eq. 1, it was found that variables given in Eq. 1 which have the most relation with improving the performance of the metro are technical criteria (number of metro stations, journey time between successive stations, length of the metro route) and some of them are planning criteria (integration with other mass transit systems, reliability or dependency, and the population of the city). This is in addition to the safety standards, whether from train accidents or crimes of theft and kidnapping, all of which really aim to achieve an efficient public transport system that integrates with the rest of public transport systems and meets the needs of individuals to move from one place to another easily, quickly, and safely and in the least time and at the lowest cost. Thus, it is relied upon for daily trips and activities. The metro system in Paris, London, Beijing, Osaka, Shanghai, and Brazil is the most obvious example in this regard (Tables 9, 10, 11, and 12).

The mathematical equation for measuring performance of metro systems using factor 2 indicators:

$$Y = \mathbf{2958\,V12 + 1365\,V7 + 216\,V18 + 50\,V19 + 17\,V6 - 10\,V15 - 43\,V4 - 35416} \tag{2}$$

Table 9 Analysis of variance (ANOVA) for factor 2 variables

Model		Sum of squares	df	Mean square	*F*	Sig.
1	3.1.2. Regression	3.1.3. 2015775155.859	3.1.4. 7	3.1.5. 287967879.408	3.1.6. 0.663	3.1.7. .700[b]
	3.1.8. Residual	3.1.9. 9117551234.348	3.1.10. 21	3.1.11. 434169106.398		
	3.1.12. Total	3.1.13. 11133326390.207	3.1.14. 28			

Table 10 Regression results for factor 2 variables

	Unstandardized coefficients		Standardized coefficients	*t*	Sig.
	3.1.15. *B*	**Std. error**	**Beta**		
	−35416.228	25969.88		−1.364	0.187
V4	−42.861	68.414	−0.361	−0.626	0.538
V6	16.963	40.174	0.154	0.422	0.677
V7	1365.196	1696.680	0.486	0.805	0.430
V12	2957.951	1977.657	0.377	1.496	0.150
V15	−9.603	198.756	−0.015	−0.048	0.962
V18	215.484	424.799	0.248	0.507	0.617
V19	49.77	399.81	0.06	0.12	0.90

Table 11 Analysis of variance (ANOVA) for factor 3 variables

Model		Sum of squares	df	Mean square	*F*	Sig.
1	Regression	1887247748.533	6	314541291.422	0.748	.617[b]
	Residual	9246078641.674	22	420276301.894		
	Total	11133326390.207	28			

Table 12 Regression results for factor 3 variables

	Unstandardized coefficients		Standardized coefficients	*t*	Sig.
	3.1.16. *B*	**Std. error**	**Beta**		
	−13536.44	27554.5		−0.49	0.628
V12	−20.30	41.04	−0.121	−0.495	0.626
V26	−1731.17	10962.9	−0.039	−0.158	0.876
V19	1969.99	1859.18	0.251	1.06	0.301
V1	123.05	174.83	0.159	0.704	0.489
V24	−100.58	111.76	−0.209	−0.90	0.378
V5	153.08	127.46	0.295	1.201	0.24

Based on the analysis of Eq. 2, we find that the set of security variables have a moderate relation with improving the performance of the metro system anywhere, as the individual's feeling of reassurance about himself and his family members is one of the most important requirements that must be met in the public transport system in general and in the metro system in particular, due to the longtime of its trips and because most of its stations are underground or in the outskirts of the city, such as Mexico City, New York, etc., where the crime rate in the stations increases in particular [24].

Therefore, there must be an element of security and safety along its route, whether in the train or stations, so that the system as a whole can perform the service and conduct the trips efficiently, easily, and safely, in order to be able to achieve the ultimate goal of urban public transport, which is to attract individuals for public transport and encourage them to not use their private cars to address the public transport issues of congestion and bottlenecks and the high rate of pollution, noise, and accidents [25].

The mathematical equation for measuring the performance of metro systems using factor 3 indicators:

$$Y = 1970\ \mathrm{V12} + 153\ \mathrm{V26} + 123\ \mathrm{V19} - -20\ \mathrm{V1} - -101\ \mathrm{V24} - -1731\ \mathrm{V5} - -13536 \tag{3}$$

Based on the analysis of Eq. 3, it was found that these criteria have the weakest relation with improving the performance of the metro system, because they are not included within the interests or requirements of many segments of society that depend on the public transport in their daily trips. Not all individuals have the luxury of owning and raising pets. Moreover, the area of the cities served by the metro does not constitute an obstacle to its implementation. The most important thing is the number of residents and the number of daily trips and whether the same requires the implementation of a metro system or not. In addition, in the oldness or modernity of the metro networks, they may not negatively affect the performance of the system as long as there is continuous maintenance, follow-up, and evaluation [26]. Therefore, we find that these standards come in third place in terms of the importance of taking them into account for transport planners and decision-makers.

The rest of the indicators showed a slight impact on the performance improvement of the metro system, as their importance might differ from one country to another according to their priorities. For example, passengers may need means of transport to the nearest metro station, and this is not considered as a failure in the performance of the metro, especially because trips can be long, so the passenger prefers the metro in order to save cost and time, rather than riding one of the expensive means of transportation [27]. Some transport and land-use planners consider that the presence of stations next to places of residence is not the optimal or most efficient planning approach, as a result of noise and congestion at the stations. In addition, the factor of having pets is considered a luxury by some passengers, thus an influencing factor measuring the quality of public transport service and the completion of daily trips, especially that not all individuals have the luxury of acquiring and raising pets, and so on. Thus, these factors are considered to have no impact on the performance of the metro system as a whole and may not be taken into account by transport planners and decision-makers [28].

Statistical results will show that some of these factors may contribute to improving the performance of the metro system while others may not. The reason behind this is that there is no specific set of unified factors that only affect the evaluation of metro system efficiency, but rather the factors vary between security, environmental, technical, etc. [29], according to environmental nature, economic, social, and urban conditions of each state, as each country has its own nature and set of priorities.

By comparing the results of this study, we find that the previous studies were limited to compiling some administrative, economic, social, and technical standards, and neglected some other standards concerned with urban, demographic, and security aspects. Hence, the importance of this research derived from its attempts to bridge this gap. Moreover, further standards that may contribute to improving the performance of the metro system and evaluate its efficiency do exist in all aspects.

Conclusions

Efficient public transport systems are the backbone of development in cities and the main driver of activities and trips within them. Their networks and routes are the main arteries for urban expansion inside cities. Hence, the importance of this research emerges from the urgent need to reconsider current public transport systems in cities, which itself is considered important to derive success criteria that allow for continuous evaluation and follow-up ensuring sustainability and performance of such systems. In light of the current trends towards environmentally friendly public transport systems that meet the requirements of passengers, new factors have emerged that contribute to the success of the public transport system and activate its role in development. Public transport planners have agreed that the metro system is the optimal choice in many cities, especially overpopulated cities. Therefore, the study tried to find the factors affecting the improvement of the performance of the metro system, as it is the most important and efficient public transport system long time ago until now, which is successfully existing in large cities such as Beijing, Paris, Osaka, London, Seoul, New York, etc. Thus, the research began to study these cities, beside others, as a benchmark and concluded the success factors of metro systems and what are the reasons behind their higher performance. The research also concluded 28 variables that have been statistically examined in 29 cities to determine the most influential in assessing metro performance. By performing a principal component statistical analysis, results revealed three main factors that might affect the performance assessment of the metro system, with different percentages. Accordingly, three equations were deduced, each of which includes a set of variables that explain the impact of these variables on improving the performance of the metro system in metropolitan cities. Eventually, the research concluded that it is not possible to limit all the influencing factors to one fixed group, because there are no unified criteria for evaluation in all cities, but the importance is distributed among all factors. Indeed, when classifying these factors, it was found that some of them are planning, environmental and technical, security, and safety factors in addition to social and economic ones. This means that the factors are complementary to each other, and therefore, decision-makers cannot rely on a certain set of factors and ignore the others. It is safer and more accurate to take all factors into consideration when deciding to implement a metro system.

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T.A. design of the work, made substantial contributions to the conception, and approved the submitted version. S.B. design of the work, data analysis, and interpretation of the data. All authors have read and approved the final manuscript.

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Declarations

Competing interests
The authors declare that they have no competing interests.

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