WUT Journal of Transportation Engineering

PRACE NAUKOWE - POLITECHNIKA WARSZAWSKA. TRANSPORT

ISSN: 1230-9265
DOI: 10.5604/01.3001.0016.0372

vol. **133**
2021

Evaluation of public transport to develop possible solutions for the implementation of a sustainable transport study on the example of Baghdad

Bashar Al-Janabi, Anna Kwasiborska*

Warsaw University of Technology, Faculty of Transport

Abstract. Sustainable urban transport refers to activities for people mobility that advance economic and social development for current needs by providing efficient, accessible, safe, and affordable transportation with low carbon emissions and less impact on the environment. The paper presents an overview of the sustainable urban transport concept, representing the dimensions of sustainable urban transport. The paper includes a case study for developing urban transport in Baghdad to evaluate public transport and elaborate on possible solutions for implementing sustainable urban transport. The assessment process was conducted according to the Sustainable Urban Transport Index developed by UN ESCAP. The analysis and design process was conducted with the assistance of the PTV-Visum application. The application helped to estimate the demand for public and private vehicles for both scenarios of current public transport and suggested solutions. Both results from the sustainable urban transport index and PTV-Visum have helped to summarize the possible solutions for sustainable urban transport in Iraq.

Keywords: sustainable urban transport, bus rapid transit, walking, cycling, Baghdad, Iraq

1. Introduction

Sustainable Transport definition derives from the sustainable development definition, which refers to *"the provision of services and infrastructure for the mobility of people and goods, which advancing economic and social development to benefit today and future generations in a manner that is safe, affordable, accessible, efficient, and resilient while minimizing carbon and other emissions and environmental impacts"***Błąd! Nie można odnaleźć źródła odwołania.**

Sustainable Transport has become the priority objective in many developed countries. For example, Europe is trying to move closer to more suited and sustainable modes of transport, putting the user first and giving them increasingly accessible, healthier, and cleaner

Article citation information:

Al-Janabi, B., Kwasiborska, A. (2021). Evaluation of public transport to develop possible solutions for the implementation of a sustainable transport study on the example of Baghdad, WUT Journal of Transportation Engineering, 134, 89-112, ISSN: 1230-9265, DOI: 10.5604/01.3001.0016.0372

*Corresponding author
E-mail address: bashar.al-janabi.stud@pw.edu.pl (B. Al-Janabi), mailto:anna.kwasiborska@pw.edu.pl (A. Kwasiborska)*.
ORCID iD: 0000-0003-2727-5197 (B. Al-Janabi), 0000-0002-3285-3337 (A. Kwasiborska)

Received 12 August 2021, Revised 20 November 2021, Accepted 29 November 2021, Available online 11 December 2021

alternatives [4]. This objective is interpreted by the European Green Deal, which aims to reduce 90% of emissions by 2050 and boost clean vehicles and alternative fuels is expected in Europe that by 2025 about 13 million zero-and low-emission vehicles will be operated on European roads [5]. Furthermore, sustainable rail mode has significant development over the last 25 years to be compatible with the general concept of sustainability by improving the interoperability with wide choices of services and punctuality [4].

Consequently, Inland waterway transport for transport goods and passengers is a choice instead of road and rail transport; this mode of transport is an alternative in energy consumption and noise emissions and allocates multimodal measures designed to support multimodal transport involving rail and waterborne transport [4]. Most European cities are ideal models of sustainable urban transport by addressing air quality, emissions, urban congestion, and reducing noise. Indeed, the milestones of developed urban transport are proven to promote active modes of transport, such as clean, energy-efficient vehicles, walking, and cycling, with high information technology, as well as enabling automated mobility and smart traffic management systems with intelligent applications, lead to improving the efficiency across the whole transport systems.

In the last two decades, public transport performance in Iraq has retreated [11]. The number of private motorized vehicles has been increasing year by year, so such a situation leads to dramatically increasing traffic accidents, greenhouse gas emissions, and air pollution.

Therefore, the paper provides an analytical way to evaluate the performance of sustainable transport in Baghdad, based on the Sustainable Urban Transport Index expanded by UN ESCAP and the local statistical data with some basic calculations. The evaluation method can help transport institutions evaluate cities' normalized performance and take suitable measures toward sustainable urban transport in Iraq. The suggested solutions have been designed and analyzed with the assistance of the PTV-Visum application.

The main aim of the research is:

– assessment of the public transport system in Baghdad,
– estimation of the demand for a public transport system in Baghdad,
– elaboration of possible solutions to improve future performance.

The research aims to evaluate public transport in Baghdad based on an analysis of the currently existing road infrastructure, area boundaries, population density, destinations, and travel directions. This evaluation aims to diagnose the problem to suggest a possible solution that can be achievable and affordable.

2. Develop urban transport in Baghdad – Case study

Due to the importance of Baghdad, the growth and development reflected by the rapidly increasing of its population and its continuous need for various services in all fields, such as public transport. Therefore, Baghdad's functions are summarized in a few important points as an important center, which is growing, a prominent religious center, and an administrative, cultural and educational center. It is also the most important center for commercial and professional services and, as a distribution center, a public gateway to enter the tourism movement into Iraq [8].

The population of the city in 2018 was 8126755 people, about 49% were females, 51% were males, 37% for people aged (0-15) years, 59.5% for people aged (15-64) years, 3.5% for people (65+) years. Furthermore, the percentage of the urban population is 87%, and the population of rural is 13% [2]. Baghdad has a network of main highways linking the capital's center with its south, north, east, and west. The most important of these roads is the international road linking Baghdad with the Kingdom of Jordan. Another strategic road links Turkey, extending from the city of Zakho in the north to Basra in the south and passing through the capital Baghdad. There are many important railways linking northern and southern Iraq, and there are two railway lines, towards the north (Baghdad - Mosul) and towards the south (Baghdad - Basra). Furthermore, one of the most important airports in Iraq (Baghdad International Airport) is located in the west of Baghdad, 16 km from the city center. Moreover, a road network connecting the capital Baghdad with international lines such as Saudi Arabia, Kuwait, Iran, and Syria [8].

Usually, the modern transportation system consists of buses, cars, trains, trams, and underground. But since there are prospective projects for elevated trains and underground metro, the case study will discuss the mean of public transport for the buses only in Baghdad and the movement of people across the whole city. The main goal is to connect all parts of the town (living areas, green areas, city center, rural and industrial areas).

2.1. Evaluate the Sustainability of Urban transport in Baghdad

UN ESCAP has developed the Sustainable Urban Transport Index (SUTI) to help evaluate the performance, check and compare the performance of Asian cities on sustainable urban transport [6]. SUTI aims to assess the status of urban transportation in cities as a quantitative tool to match the performance of sustainable urban transport systems and policies. This method helps to spot additional policies and methods required to enhance the urban transportation systems and services; by using ten indicators in system, economic, environmental, and social dimensions, it is possible to assess the progress of transport contribution towards the achievements of sustainable development goals (SDGs), [6]. Therefore, the ten indicators adopted to calculate SUTI are shown in the discretions below (but only chosen indicators are described in this paper):

(1) Planning Transport.
(2) Modal share of active and public transport.
(3) Convenient access to public transport service.
(4) Quality and Reliability of the public transport.
(5) Traffic fatalities per 100.000 inhabitants.
(6) Affordability – travel costs as a share of income.
(7) Operational costs of the public transport system.
(8) Investment in public transport systems.
(9) Air quality (pm10).
(10) Greenhouse gas emissions from transport.

The assessment process was conducted according to the Sustainable Urban Transport Index developed by UN ESCAP. Indicator values are specified in the guideline for using SUTI.

2.2.1. Planning transport

The Indicator "Planning transport" deals with public transport and distinguishes between four aspects, as shown below [6]:

(1) Walking networks.
(2) Cycling networks.
(3) Intermodal transfer facilities.
(4) Expansion of public transport modes by adopting low emission vehicles, in particular electric vehicles, to decarbonize urban mobility.

The National Development Plan for Iraq 2018-2022 is the national development plan for Iraq and addresses public transport. This document focuses on increasing the capacity of the transport network in Baghdad or entire Iraq and on providing intermodal transfer facilities such as Baghdad Underground Metro (BUM) and Baghdad Elevated Train (BET) [9]. In this document, improving the public transport in Baghdad has been addressed by implementing the first stages of the underground metro and the elevated train, further designing and implementing walking and cycling networks in the city center. Of course, the underground metro and the elevated train will provide new intermodal transfer facilities, but these goals are more qualitative goals than to be quantitative. Due to the high cost of implementing railway projects, they do not cover wide areas to provide prospective flexible mobility within a short period. But, there are limited goals to design or budget for improving the walking and cycling network. Therefore, the scoring method has been used to evaluate this indicator (Table 1) [8].

Table 1. Evaluate transportation plan

Score	0 No coverage	1 Limited	2 Middle	3 Extensive	4 Leading
I) Walking networks (x_1)	-	x	-	-	-
II) Cycling networks (x_2)	-	x	-	-	-
III) Intermodal transfer facilities (x_3)	-	-	x	-	-
IV) Public transport (x_4)	-	-	x	-	-

(source: own elaboration based on [6])

The sum of the points obtained is an indicator that assesses the degree of public transport involvement, e.g., intermodal facilities and infrastructure, as shown in the formula below:

$$Planning\ Indicator = x_1 + x_2 + x_3 + x_4 = 1 + 1 + 2 + 2 = 6 \quad (1)$$

where:

x_1, x_2, x_3, x_4 - scored row values of planning aspects

The obtained score is unsuitable due to some walking and cycling network designation.

2.1.2. The modal share of active and public transport

Percentages of commuters use public transport rather than personal motorized vehicles **Błąd! Nie można odnaleźć źródła odwołania.**. The number of total commuters carried by the regional and local public buses managed by the State Company for Travelers and Delegates Transportation SCTDT was 13,272,000 in 2019 (Fig.1) based on the number of sold tickets [12].

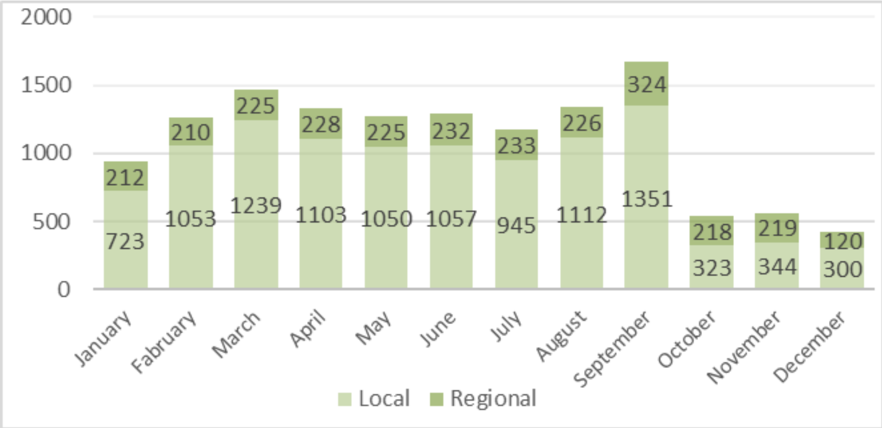

Fig. 1. The number of total commuters carried by the regional and local public buses (1000 passengers) (source: own elaboration based on [12])

It is necessary to have a value of the number of inhabitants between 15 to 65 years old (over 4,8 million) and the total number of local commuters in Baghdad (over 10 million) to estimate the percentage of public transport activity. Therefore, the estimated maximum percentage of commuters in 2019 is shown in the formula below:

$$The\ activity\ of\ public\ transport = \frac{Av}{N_{15-65}} x\ 100 = \frac{10{,}600{,}000/12}{4{,}838{,}746} x100 = 18\% \quad (2)$$

where:
Av - Average number of commuters per year
N_{15-65} - Number of inhabitants between 15-65 years old
The value for this index is 18%. The range should be between 10% and 90% [6].

2.1.3. Access to public transport service

The percentage of people using public transport is defined as 500 meters from a bus stop and a trip lasting at least 20 minutes [6]. The 20 minutes means the interval of the bus frequency at each bus stop. Based on the operator's website, 13 routes are working in Baghdad [10]. Still, most bus stops become out of service, and inhabitants are looking for alternative approaches such as private vehicles and informal transport to reach their destination. Therefore, estimating the accessibility is based on the following formula:

$$A = CA \times n \times \text{Population}/\ km^2$$
$$Access\ to\ public\ transport = \frac{\sum_{i=1}^{48} A_i}{Total\ inhabitants} \times 100 = \frac{1{,}008{,}911}{8{,}126{,}755} \times 100 = 12.5\% \quad (3)$$

where:
A - inhabitants can access public transport in each main zone,
CA- stop catchment area, which is equal to 0.78 Km^2,
n - number of stop catchment areas in each zone,
i – main zone number.

The value equals 12,5% and is calculated depending on zone divisions, which are 48 with different areas and populations. (Fig. 2) presented 20 zones with access to public transport more than 0. The range of this indicator should be between 20% and 100% [6]. Therefore, there is no adequate access to the public transport services presented in (Fig. 2).

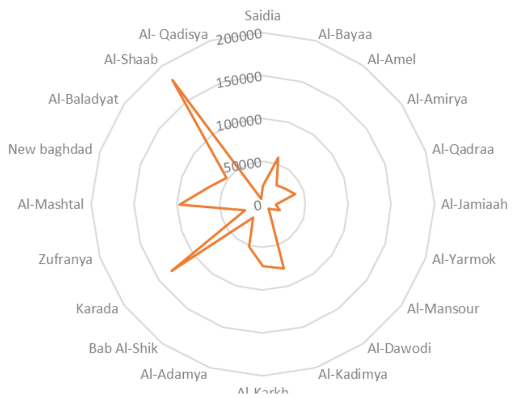

Fig. 2. Inhabitants can Access public transport

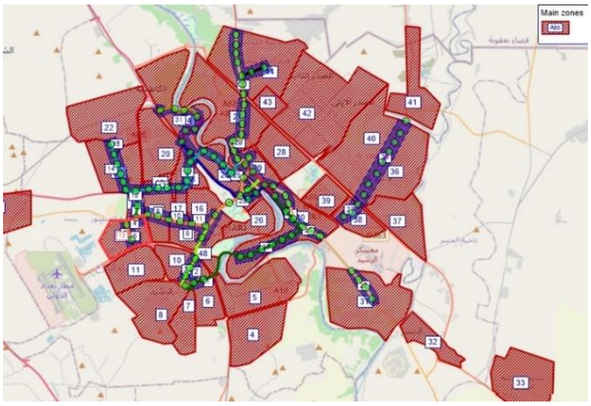

Fig. 3. Current Accessibility To public transport

(source: own elaboration in PTV-Visum)

As shown in Fig. 3, the existing routes are not meeting sustainable transport requirements. The estimated accessibility percentage, which is 12,5%, is lower than the minimum required value of convenient access to public transport services. Furthermore, the current routes do not access rural areas.

2.1.4. Traffic fatalities per 100,000 inhabitants

The indicator "Traffic fatalities" is defined as the number of fatalities per 100,000 inhabitants due to traffic accidents [6]. Due to inconvenient public transport in Baghdad, people tend to use private vehicles further to share taxis. This trend increases the number of traffic accidents (Fig. 4) due to many reasons such as speedy driving, lack of road maintenance, lack of traffic equipment, and lack of traffic management.

Fig. 4. Statistic of traffic accidents in Baghdad
(source: [12])

The official reports classified traffic accidents as deadly, deadly with injuries, Injuries only, and no death and no injuries. Fig 4 summarizes the total number of accidents, injuries, and fatalities to give an overview of the result of all traffic accidents in Baghdad.

As shown in Fig. 4, the last statistic for the number of fatalities in 2019 is 258. To calculate the number of fatalities per 100,000, that by applying the formula below:

$$\frac{Number\ of\ fatalities}{Population} \times 100{,}000 = \frac{258}{8{,}126{,}755} \times 100{,}000 = 4\ fatilities/100{,}000\ inhabitants \quad (4)$$

The range of Indicator should be between values equal to 0 and 35 [6]**Błąd! Nie można odnaleźć źródła odwołania.**.

2.1.5. Affordability – travel costs as part of the income

In this indicator, affordability means the cost of a monthly use of public transport tickets covering transport modes compared to the personal monthly income [6]. Generally, in Baghdad, public transport's monthly cost is affordable compared with other transport modes such as taxis or even private vehicles. For example, there are two categories of tickets priced as 5,000 IQD for 12 rides and 10,000 IQD for 25 rides. The maximum individual needs for monthly public transport cost is 30,000 IQD a month. On the other hand, the average monthly wage is about 683,900 IQD. Therefore, the percentage of affordability could be calculated by the formula below:

$$\text{Affordability}\ \% = \frac{Monthly\ Public\ transport\ cost}{Avarage\ monthly\ income} \times 100 = \frac{30{,}000}{683{,}900} \times 100 = 4.4\% \quad (5)$$

The range of indicator should be between 20% (minimum) and 3,5% (maximum).

2.1.6. Investment in public transportation systems

The indicator represents the ratio of all transport investment spending as the average of five years made by the city directed to public transport to provide access to safe, affordable, accessible, and sustainable transport systems for all [6]. Public transport is mainly in Baghdad, and it is limited to operating buses and paying wages (Fig. 5) [12].

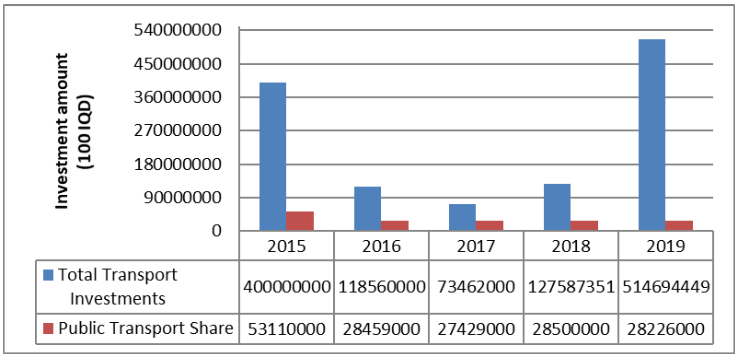

Fig. 5. Investment in public transport systems in Baghdad (source: [3, 12])

The percentage of Investments in Public Transport Systems (IPTS) is determined by applying this formula:

$$IPTS\ \% = \frac{\sum_{j=1}^{n=5} x_{jn}}{n} = \frac{13+24+37+22+5.4}{5} = 20\ \% \quad (6)$$

where:
x_j - percent of annual public transport investment,
n - number of years, which are 5.
The Indicator of minimum value is 10%, and the maximum value is 50%.

2.1.7. Greenhouse gas emissions (CO_2eq tons/year)

Transport contributes around 25% of the global CO_2 emissions, and a significant proportion is emitted in cities (Guideline 2019). The indicator "Greenhouse gas emissions" has been defined as CO_2 equivalent emissions from transport by urban residents per year per capita [6]. There is no direct data for this indicator in the official statistics. Therefore, to determine this indicator, the way which is used in the calculation depends on the number of vehicles in the city. A typical passenger vehicle emits about 4.6 metric tons of CO_2 per year. Assuming that the average consuming gasoline on the road is approximately 35.4 kilometers per gallon and drives around 18,507.456 kilometers per year, every gallon of gasoline burned creates about 8,887 grams of CO_2 [13].

The number of total vehicles in Baghdad is 2,409,390 vehicles (car, bus, minibus, light truck, and heavy-duty truck), whereas the number of passengers vehicles number is 2,043,270 [12]. Therefore, CO_2 emission can be estimated by using the formula below:

$$\frac{total\ passengers\ vehicles\ number \times 4.6}{Population} = \frac{2{,}043{,}270 \times 4.6}{8{,}126{,}755} = 1.2 \quad (7)$$

The Indicator of minimum value is 2,75, and the maximum value is 0.

3. Sustainable Urban Transport Index (SUTI)

The ten indicators are presented to exemplify the potential results of SUTI (Tables 2 and 3). Calculated data from each indicator to allow for applying them in the formula below [6]: **Błąd! Nie można odnaleźć źródła odwołania.**

$$Z_i = \frac{(X_i) - (X_{min,i})}{(X_{max,i}) - (X_{min,i})} \times 100 \quad (8)$$

where:

X_i - the value of the indicator of the topic *I,*

Z_i - normalized indicator *X* of the topic *I,*

Xmin - the lowest value of the indicator in actual units,

Xmax - the highest value of the indicator in actual units.

$$SUTI = \sqrt[10]{Zi_1 \times Zi_2 \times Zi_3 \ldots .. \times Zi_{10}} \quad (9)$$

where:
SUTI - overall index composed of ten indicators $i_1 - i_{10}$.

Table 2. Indicators, units, and normalization

No.	Indicators	Natural units	Weights	Normalization MIN	Normalization MAX	Data Calculated	Normalization of Baghdad
1	The extent to which transport plans cover facilities for active modes and public transport	0 - 16 scale	0.1	0	16	6	37.50
2	Modal share of active and public transport in commuting	Trips	0.1	10	90	18	10.00
3	Convenient access to public transport service	Number of people	0.1	20	100	12.5	-9.38
4	User satisfaction with public transport service	% satisfied	0.1	30	95	30	0.00
5	Traffic fatalities per 100,000 inhabitants	No. of fatalities	0.1	35	0	4	88.57
6	Affordability – travel costs as part of the income	% of income	0.1	35	3.5	4.4	97.14
7	Operational costs of the public transport system	Cost recovery ratio	0.1	22	175	88	43.14
8	Investment in public transportation systems	Share of total investment	0.1	0	50	20	40.00
9	Air quality (pm10)	μg/m^3	0.1	150	10	160	-7.14
10	Greenhouse gas emissions from transport	Tons	0.1	2.75	0	1.2	56.55
	MUST SUM TO 1		1.0				

Table 3. Sustainable Urban Transport Index SUTI

INDEX	Arithmetic	35.77
INDEX	Arithmetic using weights	35.77
INDEX	**Geometric**	**22.44**

Table 3 shows the results of the Arithmetic Index, which is the average of obtained normalization performance [6]. The results of arithmetic using weights means the summation of all indicators results after multiplying each indicator result by its weight, as shown in the formula below:

$$Arithmetic\ using\ weights = \sum_{i=1}^{10}(x_i \times w_{i,x}) \tag{10}$$

where:

w - is the weight of ten indicators $i_1 - i_{10}$.

The Geometric MEAN is the overall index, composed of the results of the ten indicators $i_1 - i_{10}$, after applying the formula of the normalized indicator (Z_i). If the maximum SUTI is 100, all indicators scored the maximum. The collected data, taking into account the 10 SUTI indicators, is presented in Fig. 6. The estimated SUTI is 22.44 of 100.

In this case study, Baghdad scores highest in indicator 5, "Traffic fatalities per 100,000 inhabitants," and indicator 6, "Affordability – travel costs as part of income". The city also scores lower than medium in indicator 1, "Planning public transport", indicator 7, "Operational costs of the public transport system", indicator 8, "Investment in public transportation," and indicator 10, "Greenhouse gas emissions". Baghdad scores lowest in indicator 2, "Modal share of active and public transport", indicator 3, "convenient access to public transport service", indicator 4, "User satisfaction with public transport service", and indicator 9, "Air quality (PM_{10})". Therefore, it is important to apply some measures to improve Baghdad's SUTI.

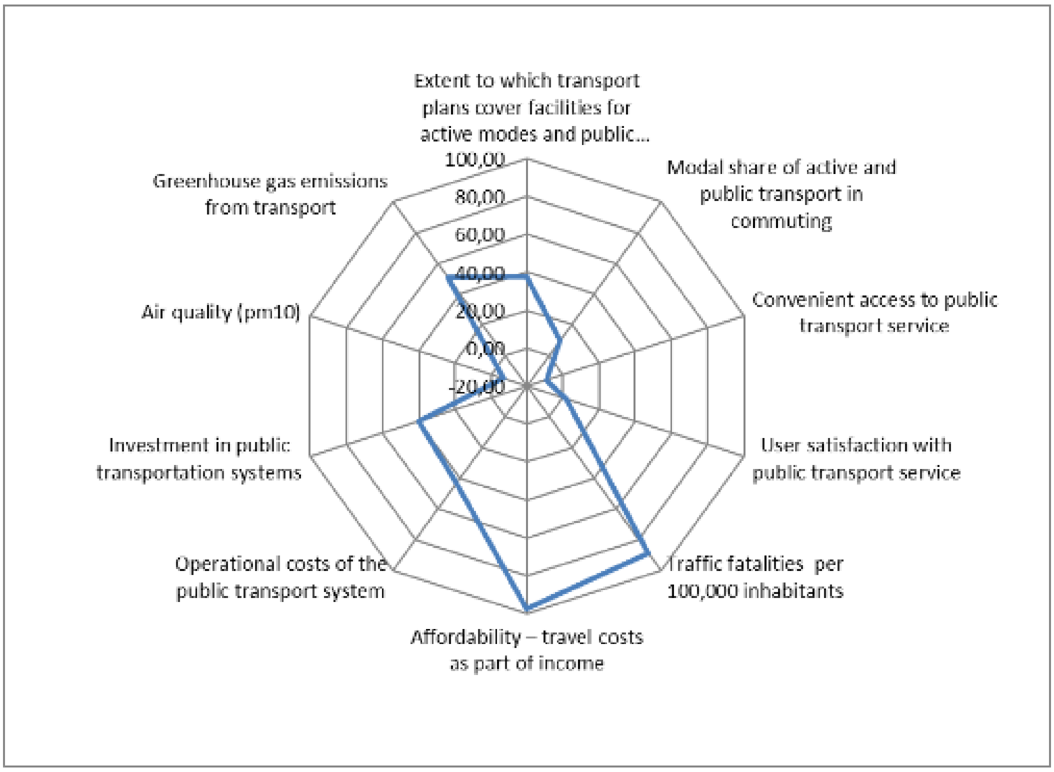

Fig. 6. Baghdad Normalized Performance
(source: data collected is own elaboration calculation based on [6])

4. Possible Solutions for the city

Solutions measures towards sustainability in urban transport should be simulated the SUTI. These indicators could be improved by elaborating the current resources efficiently. As obvious, there are big zones with a high population, such as Al-Sadir city. Therefore, the proper solution is to provide a mass public transport network to connect these zones with the main lines of the public transport system, depending on the existing infrastructure in the city. Therefore, using the land is the key factor in providing convenient public transport by using the medians of the road and the shoulders to apply the idea of Bus Rapid Transit (BRT) [1].

The BRT system could be applied on highways and inside some districts in each zone. Moreover, BRT is cheaper than rail projects and can be delivered in the short term for infrastructure projects. This system can be a reliable and highly effective tool to achieve the goal of organizing public transport for Baghdad. Providing equal access and mobility for residents who need high-quality public transport, especially in the suburbs, is a major challenge.

Another solution is applying the modal shift concept by determining some zones to be specified for non-motorized modes such as electric minibusses, bicycles, and pedestrians.

4.1. Construct BRT system

BRT has proved itself a vital means for providing mass transit, with easy scalability, low costs, and operational and implementation advantages [1]. BRT technology can help by shortening travel time, minimizing personal transport expenses, and increasing commuting comfort. In addition, BRT will affect government finances and economic efficiency further to the cost of constructing and operating BRT is reasonable, such as the stations, vehicles, rights-of-way, and other factors [1]. Some utilities are easy to expand in small parts, while different modes such as underground metro or elevated train make financial sense in larger segments. Another benefit is the expansion of existing modes as services and infrastructure can be combined into a more efficient one. In addition, BRT millstones can be realized more quickly than other railway modes. BRT has main elements put the technical term "rapid" in bus rapid transit [1]:

- separated bus lanes make buses avoid congestion,
- bus lanes and stations and can be located in the center of the street to avoid being delayed by turning vehicles, as well as vehicles dropping off passengers or goods,
- fares can be collected off the bus to avoid delays caused by passengers paying on board,
- fast boarding from a platform level with the bus floor, and so that people in wheelchairs can roll into the bus directly without extra effort,
- bus priority at intersections contributes to reducing delay at intersections from red signals.

The objective of public transport systems is to encourage transit-oriented development (TOD). With the BRT system, TOD refers to the dense, walkable, bikeable urban development along corridors [15]. If the BRT project is implemented successfully in Baghdad, creating dense around the BRT network can help increase property values and shop sales levels. It can be useful for creating new job opportunities, whether during construction or operation.

4.2. Facts about nominated roads

Using the land in Baghdad is not convenient to cover the number of vehicles, especially during peak hours. Most main roads are congested, particularly those which lead to the city center. Most main roads with wide medians are used to be green areas. Despite these green areas being important for the environment, they do not have enough ability to decrease CO2 emissions due to the dramatically increasing use of private vehicles in transport. The reason for expanding the private modes is that public transport is not performed efficiently. If people find sufficient alternatives to be fast, comfortable, and affordable, they will be more attracted to use these alternatives than private vehicles or other informal transport means. At this point, sacrificing some green areas to provide active public transport will decrease the number of motorize-modes on the roads and decrease the CO_2 emissions from transport means.

For example, along the Army Canal Highway is a wide area designed to be a park. This highway is usually congested at the intersections of Al-Sadir city. The width of one side of this park is about 51m along the highway. This area is a proper location to construct the BRT line due to its design as a park.

Inside Al-Sadir city, there are also the wide sidewalk and roads medians that could be used properly to construct a BRT network inside this district to be also connected or provide a possibility to transit to other BRT routes. The main streets in Al-Sadir city have about 18 meters used as medians and shoulders. Therefore, it is possible to make a balance while distributing the dimensions of BRT lanes and roads to provide efficient public transport mobility.

Another example from another part of Baghdad is the median area in Damascus Street, which is around 10 m in width along 3.2 km of the street. This place is considered an essential street in Baghdad because it includes many main destinations, such as the Baghdad mall, Baghdad's international exhibition, Al-Zwraa park, courts, schools, and a housing complex. The endpoint of this street is the international railway station and Al-Alawi terminal, which are considered the main destination for most commuters who transit to reach the old city or other destinations connected with this point, whether ministries or markets.

The Airport Highway has a very wide median, around 57 m width along 7.5 km. Although this street is not congested, it passes through many bridged intersections. If the BRT line passes through this street, it will make a direct transit from at least three connections to ease reaching the airport and Al-Alawi terminal. Furthermore, this wide green area will be BRT station's most attractive walkable and bikeable corridors.

4.3. Suggested BRT network

In the beginning, the BRT network could be applied in Baghdad as an open system to make buses enter and leave the BRT system easily. It expects many obstacles to creating a close BRT system in Baghdad. However, it is possible to give the BRT system priority in maneuvers in some intersections which cannot be qualified to be a part of the BRT system as well as some highways are not congested, such as Airport Highway, but it is so important to construct only BRT station to integrate the BRT network. Generally, the majority of the suggested BRT system in Baghdad is isolated from traffic (Fig. 6). In this proposed BRT system, the suburbs of Baghdad are connected with the city center by one or two rides.

Therefore, 29 BRT line routes have been suggested to be a possible solution to implement sustainable urban transport measures in Baghdad. Such a solution was prepared for 50,2% of inhabitants could access this system by 500 m walk (Fig. 6) and (Fig. 7). This ratio was calculated depending on each stop catchment area in each main zones based on the formula:

$$\text{A}= CA \times n \times \text{Population}/\ km^2$$

$$Access\ to\ public\ transport = \frac{\sum_{i=1}^{48} A_i}{Total\ inhabitants} \times 100 = \frac{4{,}080{,}428}{8{,}126{,}755} \times 100 = 52.2\% \quad (11)$$

where:

A - inhabitants can access public transport in each main zone,

CA - stop catchment area, which equals 0.78 Km^2,

n - number of stop catchment areas in each zone,

i - main zone number.

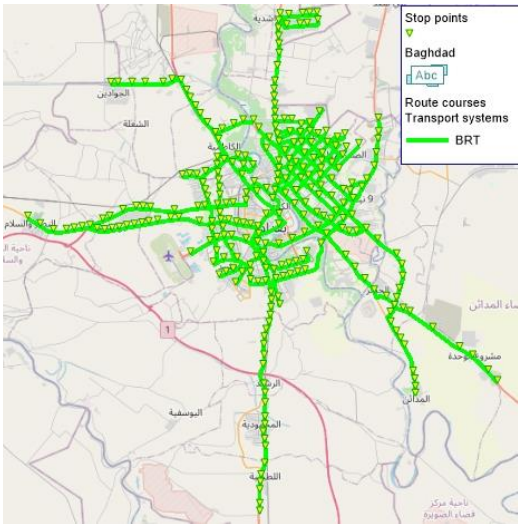

Fig. 7. Suggested BRT system in Baghdad

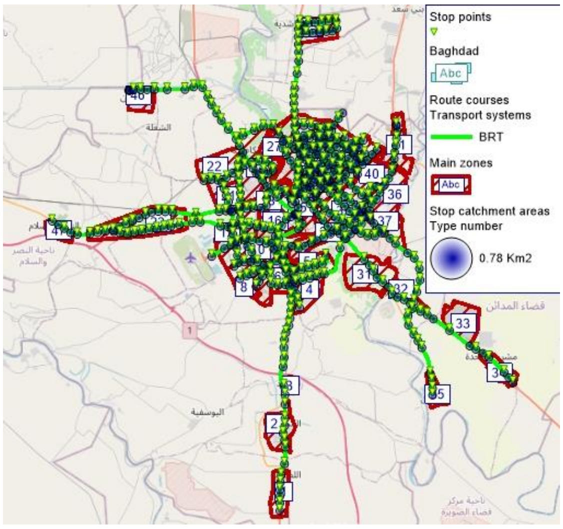

Fig. 8. Accessibility to suggested BRT system in Baghdad

(source: own elaboration in PTV-Visum)

Applying the isochrones analysis in PTV-Visum on the suggested BRT network is presented in Fig. 9. The result shows that the transfer distance between stops is 180 – 540 m at transfer areas. This feature will ease the transit between line routes. On the other hand, it shows the majority of accessibility to the BRT system from residential areas is between 180 – 1200 m by walk.

Fig. 9. Passenger transfer distance measured in PTV-Visum
(source: own elaboration)

As accessibility to public transport is one of the ten indicators used in this case study, therefore, by constructing this system, the indicator of accessibility will increase and will enhance the normalized performance in general. Furthermore, this suggested BRT system will also be an extensive quantitative goal for future planning, with many designations across Baghdad. This project has enough budget then implement and operate efficiently, and a lot of people will be attracted to use it to reach their destinations instead of using private vehicles. That will lead to enhancing more than six indicators used in the case study. For example, the indicators of planning public transport, modal share of active and public transport, Investment in public transport systems, air quality, and greenhouse gas emissions (CO_2eq tons/year).

Within the sustainability concept, the BRT system can prove the main three dimensions of sustainable transport:

1) Economically, BRT is an investment project. If the related institution is working on a concrete plan and clear objectives for implementing this system, firms will be competing to invest their assets in this project. Furthermore, new job opportunities will be provided. For example, informal transport operators could be involved to have careers in this project. Moreover, suppose the operator is an owned-sate company. In that case, the direct profit will diversify the state economy and attract the private sector to operate this system according to the private-public-partnership concept. Therefore, the BRT system is economically sustainable.
2) Environmentally, wide commuters will use fewer private vehicles, leading to greater environmental benefits. The BRT project does not a complicated construction project because, during the construction process, there is no wide of heavy vehicles that will be used for a long period. Despite the BRT system using diesel buses during the operation phase, it is possible to convert it to work on electrified buses as future alternative approaches. Generally, with using BRT, air quality and greenhouse gas will be reduced during the construction and operating process.
3) Socially, the BRT system easily provides connections between all city zones to provide targeted social equity, which can be interpreted during the design and implementation of BRT utilities. BRT system gives an opportunity to redesign streets to be more urbanization, safe and sociable. By aggregating the streets to provide safe corridors for buses, private cars, bikes, and pedestrians. Hiring employees to be involved in this project has a positive social impact on the community.

4.4. Estimate the demand

It is necessary to estimate the demand to measure the feasibility of the BRT system in Baghdad. Estimating the demand is the key factor for proving how this mode will improve the normalized performance of Baghdad. Therefore, this process is an experimental way to examine the current bus routes and prospective BRT routes.

In this case study, it is ideal for explaining the following purposes of conducting demand analysis:

– to comprise the estimated demand of the current routes with the suggested BRT system,
– to summarize results and estimate future performance.

Estimating the demand depends on calculating the demand matrix for both current bus routes and the suggested BRT system. The gathered data are examined in PTV-Visum. The results represent the estimated demand at peak hours. Therefore, the following procedure is applied in both scenarios [7]:

– dividing each main zone into sub-zones, 176 sub-zones have been examined,
– estimating the population in each sub-zone base on the number of voters in the 2018 elections,

- calculate the proportional matrix to estimate the number of travelers between zones by applying the bellows formula in each zone,
- calculate, for example, the number of travelers From Zone A to Zone B,

$$Propotional\ travalers_{Zone\ A\_B} = P_{Zone\ B} \times \frac{P_{Zone\ A}}{total\ population} \quad (12)$$

where:
$P_{zone\ A}$ - population of zone A,
$P_{zone\ B}$ - population of zone B,

- calculate the matrix of the distance between zones. This matrix is calculated in PTV-Visum for public and private transport,
- calculate the share of pedestrians matrix by applying the formula below in each zone:

$$U_p = a.e^{(b.L_{ij})} \quad (13)$$

where:
U_p - share of pedestrians,
L_{ij} - the distance between reigns,
a,b - model parameters,
a= 1,2; b= -1,25

- calculate the pedestrian travel matrix by multiplying the share of the pedestrian by the number of travelers between zones,
- calculate the matrix of vehicles, including public and private transport, by applying the bellows formula:

$$Matrix\ of\ Vehicles = Proportional\ Matrix - Pedestrian\ Travel\ Matrix$$

- calculate matrix time of private transport in PTV-Visum,
- calculate matrix time of public transport in PTV-Visum,
- calculate the QUOTIENT matrix of travel time between individual and public transport, which is the result of the formula:

$$\text{QUOTIENT Matrix} = \frac{TTC}{JRT} \quad (14)$$

where:
TTC - matrix time of private transport,
JRT - matrix time of public transport,
Calculate the travel matrix share of private transport by applying the formula below:

$$U_{ki} = a.e^{(b.l_{ki/kz})} \quad (15)$$

where:
U_{ki} - share of individual transport,
$l_{ki/kz}$ - QUOTIENT matrix of travel time between individual and public transport,
a,b - model parameters,
a= 1; b= -1,1

- calculate the travel matrix of individual transport, which is the result of multiplying the travel matrix share of private transport by the matrix of vehicles, including public and private transport,

– calculate the travel matrix of public transport, which is the result of the subtraction matrix of individual transport from the matrix of vehicles, including public and private transport,
– then transferring the obtaining data of matrix of private transport and matrix of public transport to the PTV-Visum to estimate the demand for both scenarios.

In the first scenario, the obtained result of estimating the demand at peak hours for private vehicles reached '433,986' (Fig. 10), where the demand for public transport reached to'6,266' commuters.

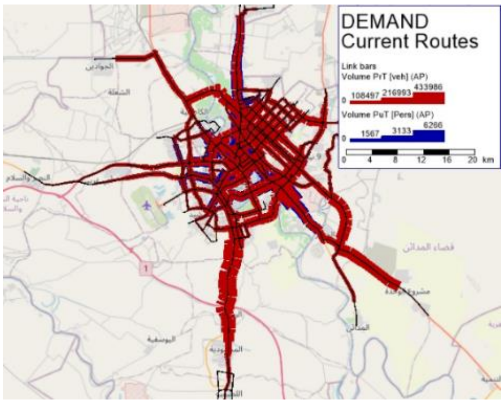

Fig. 10. Estimate the demand for public and private transport for current routes in Baghdad (source: own elaboration in PTV-Visum)

In the second scenario applied to the suggested BRT system, the obtained result of estimating the demand at peak hours for private vehicles reached '207,153' vehicles (Fig. 11), where the number of commuters is '17,509' persons.

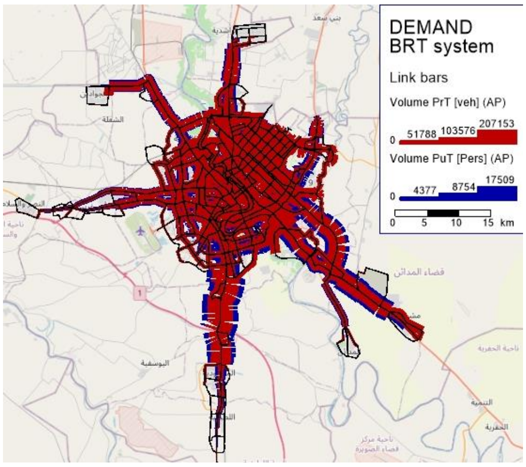

Fig. 11. Estimate the demand for public and private transport for the BRT system in Baghdad
(source: own elaboration in PTV-Visum)

When applying the isochrones analysis in PTV-Visum on the suggested BRT system, to estimate how much time is needed to reach the main destination, such as the Al-Alawi terminal with an operating speed of 50 km/h. The results showed (Fig. 12) that the estimated travel time within the urban area is between 3 minutes to 20 minutes. Furthermore, travel time from rural areas is estimated between 15 minutes to 50 minutes.

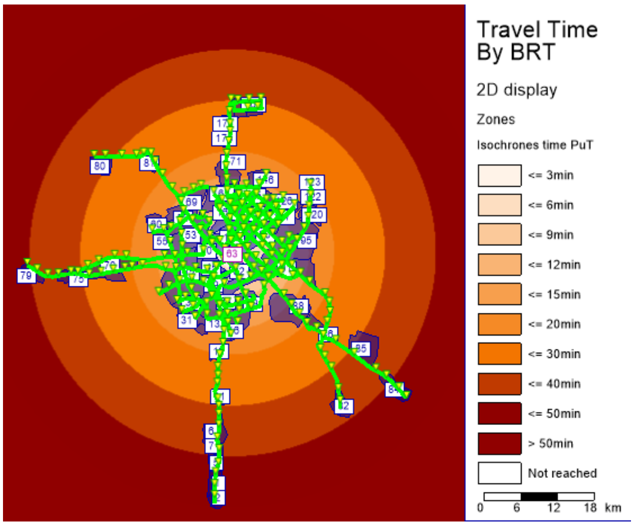

Fig. 12. Estimate travel time for a BRT system in Baghdad
(source: own elaboration in PTV-Visum)

On the other hand, when the travel time of current routes has been tested, estimate the time needed to reach the Al-Alawi terminal with an operating speed of 20 km/h to consider the congestion associated with current bus routes. The results showed (Fig. 12) that the estimated travel time within the urban area is between 3 and 40 minutes. Furthermore, travel time from rural areas is estimated between 40 minutes to more than 50 minutes.

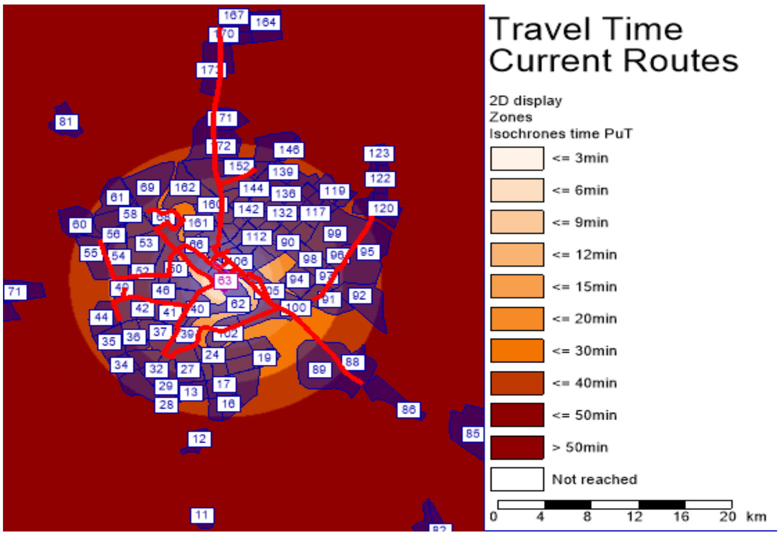

Fig. 13. Estimate travel time for current routes in Baghdad
(source: own elaboration in PTV-Visum)

Therefore, the results show that the expected demand for using private vehicles could be reduced to half of the current demand (Fig. 13). From this instance, it is possible to estimate the future performance of the BRT scenario has been applied in order to predict the improvements of SUTI. The prediction can be assumed theoretically by applying several assumptions:

1. The length of the suggested BRT is 560 km. Let's assume this project can be implemented via national efforts by about 1 million dollars per km. Hence, the implementation process can pass through five stages to cover 20% at each stage with a realistic budget of 50% of total transportation investments.
2. In parallel to implementing the BRT scenario, regular buses can cover about 20 million commuters a year, and BRT can add about 6 million passengers each implementation year. This implementation will lead to a rapidly improving the modal of active and public transport in commuting. Therefore, the prospective improvement of activity can be calculated using the formula below:

$$(P_A)_n = \frac{(RB_A + \sum_{n-1}^{n} BRT_A)/12}{N_{n-1} + (N_{n-1} \times G)} \tag{16}$$

where:
P_A - prospective improvement of public transport activity,
RB_A - Regular buses activity, which equals 20 million passengers,
BRT_A - BRT activity for implemented stage,
N - inhabitants between 15 and 65 years old,
G - population growth equal to %2.5,
n - implementation year.

3. The improvement of the accessibility can come from increasing regular buses activity further to the prospective implementation stages of the BRT scenario, the prospective improvement of accessibility can be calculated using the formula below:

$$(P_{Ac})_n = RB_{Ac_{n-1}} + \sum_{n-1}^{n} BRT_{Ac} \tag{17}$$

where:
P_{Ac} - prospective accessibility for a year n,
RB_{Ac} - regular buses accessibility,
BRT_{Ac} - BRT accessibility for implemented stage,
n - implementation year.

4. The improvement of operation cost indicator can be figured by reviewing the BRT service evaluation in some countries. For example, in the United States, the operation cost of the BRT system is about half the operating cost of regular buses [**Błąd! Nie można odnaleźć źródła odwołania.**]. However, we can consider the differences in the management model. Therefore, let's assume the improvement of operation cost with implementing the BRT scenario is increasing 10% per each operation stage, and we can apply the formula below to calculate the improvement of the operation cost indicator:

$$(\mathrm{P_{Oc}}) = \mathrm{RB_{Oc_{n-1}}} + \sum_{\mathrm{n-1}}^{\mathrm{n}} \mathrm{BRT_{Oc}} \tag{18}$$

where:
$\mathrm{P_{Oc}}$ - prospective operation cost for a year,
$\mathrm{RB_{Oc}}$ - regular buses operation cost,
$\mathrm{BRT_{Oc}}$ - the BRT operation cost for the implemented stage,
n - implementation year.

5. The air quality improvement can also be estimated via the reduction of CO_2 emissions from private vehicles. The correlation between CO_2 emissions and $PM_{2.5}$ is defined as 1 million tons of motorized vehicle CO_2 emission increase per km^2 is related to a 0.646 μg/m^3 concentration [16], where the coefficient factor from typical passenger vehicles is 4.6 metric tons of CO_2 per year [13] as the evaluation is conducted base on PM_{10}. Hence, $PM_{2.5}$ can be converted to PM_{10} by dividing $PM_{2.5}$ by 0.71 [17]. Consequently, with the BRT scenario, the simulation results illustrated that the demand for using private vehicles reached half. Therefore, if the BRT scenario is implemented via five stages, each stage can reduce about 10% of CO_2 emissions from private transport, and prospective improvements in CO_2 emissions and PM_{10} can be calculated using the formulas below:

$$(CO_2)_p = \frac{V \times 4.6}{Nt_{n-1} + (Nt_{n-1} \times G)} \quad (19)$$

$$(\mathrm{PM}_{10})_p = (\mathrm{PM}_{10})_{n-1} - \left(\frac{(CO_2)_p \times 0.646}{0.71 \times 10^6}\right) \quad (20)$$

where:
$(CO_2)_p$ - carbon dioxide equivalent emissions from transport by urban residents per year per capita,
V - number of prospective private vehicles used in transportation,
Nt - total population,
G - population growth,
$(PM_{10})_p$ - prospective air quality μg/m^3,
n - implementation year.

Table 3. Normalized performance values of Baghdad

No.	Indicator	Value
1	Planning transport	37.50
2	Modal share of active and public transport in commuting	10.00
3	Convenient access to public transport service	-9.38
4	User satisfaction with public transport service	1.54
5	Traffic fatalities per 100,000 inhabitants	88.57
6	Affordability – travel costs as part of the income	97.14
7	Operational costs of the public transport system	43.14
8	Investment in public transportation systems	40.00
9	Air quality (pm10)	-7.14
10	Greenhouse gas emissions from transport	56.55
INDEX	**Geometric MEAN**	22.44

Improvements scenarios of SUTI:

1- The first scenario is an assumption that the proposed BRT has been addressed in the plan. That means the plan is included quantitative goals with many designations across the city to improve public transport, further qualitative goals for walking and cycling corridors, and quantitative goals for intermodal transfer facilities that may also be connected with the BET and BUT projects. Therefore, the planning indicator improvement is shown in the formula bellows:

$$Planning\ Indicator = x_1 + x_2 + x_3 + x_4 = 2 + 2 + 3 + 3 = 10$$

2- The second scenario can be presented as 20% of the BRT construction process has been implemented with a realistic budget of 50% of total transportation investments. The transportation plan includes many quantitative goals and designations of walking and cycling networks. Therefore, the planning indicator will reach a scale of 12, and the indicator of investment in public transportation systems can reach the maximum value.
3- The third scenario represents keeping the scale of planning transport as a value of 12. And operating the first stage of the BRT scenario further to construct its second stage. The outcome of this scenario is improving both indicators of the activity and accessibility of public transport further to begin gaining the environmental benefits of reducing CO_2 emissions from private transport and improving the air quality.
4- From the fourth to the sixth scenario, the improvements in SUTI will rapidly increase with a parallel progressing construction and operation activities of BRT.
5- In the seventh scenario, as a result of implementing a comprehensive public transport plan, planned BRT has been implemented and operated 100%. Here the milestone of sustainable transport appears practically what will lead to facilitate attracting the assets and gain loans to implement more sustainable urban transport facilities.

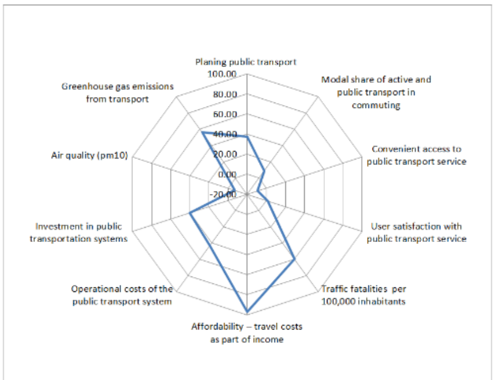

Fig. 14. Baghdad Normalized Performance
(source: data collected is own elaboration calculation based on [6])

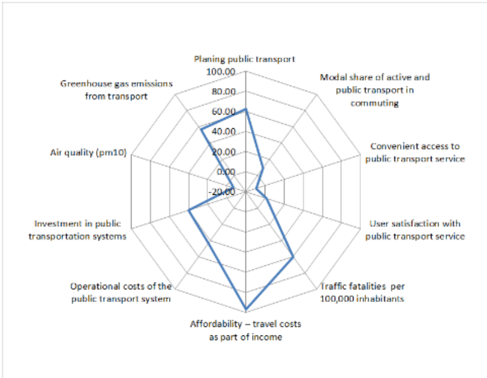

Fig. 15. 1st scenario of SUTI, BRT system has included the in the plan
(source: data collected is own elaboration calculation based on [6])

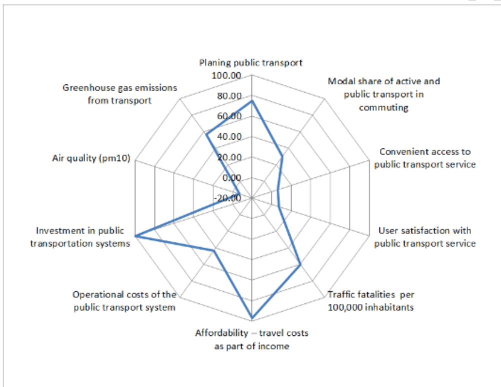

Fig. 16. 2nd scenario of SUTI, construct %20 of the BRT system
(source: data collected is own elaboration calculation based on [6])

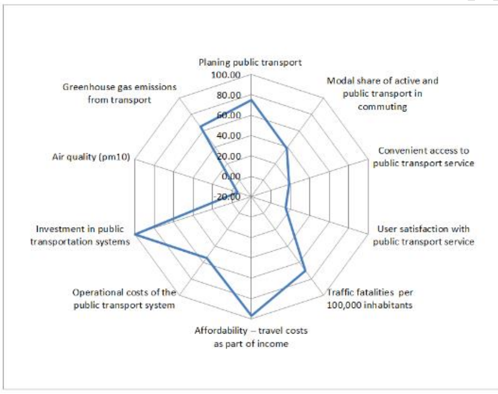

Fig. 17. 3rd scenario of SUTI, construct %40 and operate %20 of the BRT system
(source: data collected is own elaboration calculation based on [6])

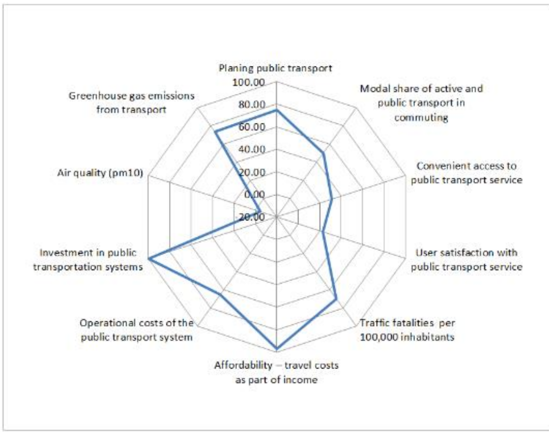

Fig. 18. 5th scenario of SUTI, construct %60 and operate %40 of the BRT system (source: data collected is own elaboration calculation based on [6])

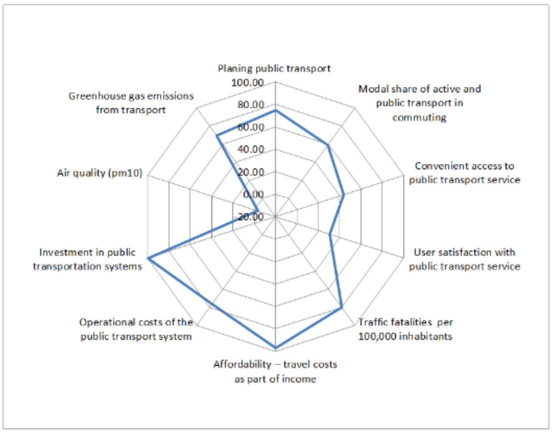

Fig. 19. 6th scenario of SUTI, construct %80 and operate %60 of the BRT system (source: data collected is own elaboration calculation based on [6])

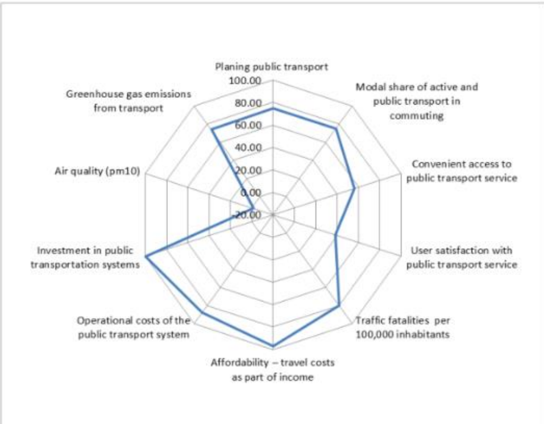

Fig. 20. 7th scenario of SUTI, construct 100% and operate 80% of the BRT system (source: data collected is own elaboration calculation based on [6])

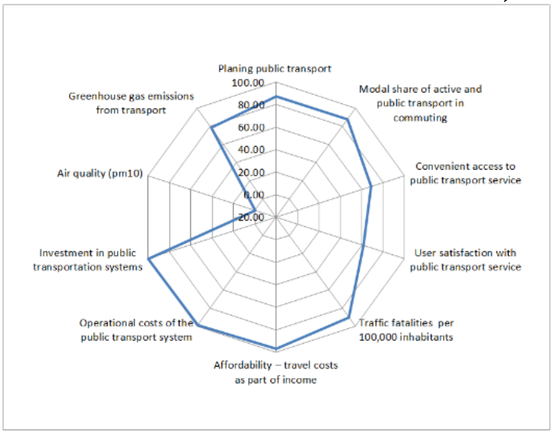

Fig. 21. 8th scenario of SUTI, operate 100% of the BRT system (source: data collected is own elaboration calculation based on [6])

Table 3. Normalized performance values of Baghdad

No	Indicator	Current value	1st scenario	2nd scenario	3rd scenario	4th scenario	5th scenario	6th scenario	7th scenario
1	Planning transport	37.50	62.50	75.00	75.00	75.00	75.00	75.00	87.50
2	Modal share of active and public transport in commuting	9.00	9.00	30.00	38.75	50.00	58.75	75.00	87.50
3	Convenient access to public transport service	-9.38	-9.38	6.25	18.75	31.25	43.75	56.25	68.75
4	User satisfaction with public transport service	1.54	1.54	7.69	15.38	23.08	30.77	38.46	61.54
5	Traffic fatalities per 100,000 inhabitants	60.00	60.00	60.00	70.00	70.00	80.00	80.00	90.00
6	Affordability – travel costs as part of the income	97.14	97.14	97.14	97.14	97.14	97.14	97.14	97.14

7	Operational costs of the public transport system	43.14	43.14	43.14	54.25	65.36	76.47	87.58	98.69
8	Investment in public transportation systems	40.00	40.00	100	100	100	100	100	100
9	Air quality (PM_{10})	-7.14	-7.14	-7.14	-5.93	-4.71	-3.50	-1.64	-0.43
10	Greenhouse gas emissions from transport	56.36	56.36	56.36	60.73	65.09	69.45	73.82	78.18
Index	**Geometric MEAN**	**21.35**	**22.47**	**31.91**	**40.24**	**45.36**	**49.35**	**50.14**	**51.23**

5. Summary and conclusions

Predicting future performance can be interpreted by evaluating the current situation (Table 3) and adopting comprehensive plans to reach the prospective objectives of sustainable urban transport. The overall result of Baghdad's normalized performance is 22.44 of 100. This result proves that the public transport in Baghdad is not sustainable.

The obtained value of the indicator "planning transport" is 37.50 because the authors did not find sufficient goals for designing or budgeting for improving the walking and cycling network. That means this project will include qualitative goals for walking and cycling corridors. Furthermore, quantitative goals for intermodal transfer facilities will also connect with the BET and BUT projects. Moreover, adopting decarbonize emissions modes such as electric vehicles in public transport with a realistic budget will increase the scoring level of planning transport to be close to the maximum value.

The obtained value of evaluating the indicator "Modal share of active and public transport in commuting" is 10, which is very low. Based on the estimated demand for the BRT system, the percentage of commuters using public transport than private vehicles will increase. As the estimated number of commuters at peak hours is 17509, the demand for the current routes is 6266.

For the third indicator, "Convenient access to public transport service", the estimation of current accessibility to public transport is about 12.5%, where the normalized performance value reached -9.38, which is below the norm. When elaborating the BRT solution, the calculation shows that 50.2% of inhabitants will access public transport by 500m walk. This measure will also increase about four times the normalized performance of accessibility to public transportation. Hence, the improvement of this indicator is associated with providing at least a 500 m walk of accessibility to stop areas, taken into account when planning public transport.

The fourth indicator of "Quality and Reliability for the public transport" is expected to increase dramatically with improving the accessibility to public transportation. Hence, it is important to secure the reliability in time of scheduled services. With the BRT system arriving or departing will not be influenced by road congestion. Therefore, the percentage of people's satisfaction will increase, but it is essential to conduct periodic surveys by the public transport operator to update the data on the satisfaction percentage. Therefore, the satisfaction percentage improvement could depend on the accessibility improvement. It maybe reaches high levels if the operation plans are periodically reviewed to meet people's requirements.

With mass public transport, the expected demand for private transport reaches half. The fifth indicator of 'Traffic fatalities per 100,000 inhabitants' will also be influenced positively. It may also reach half, as the calculated number of fatalities is 4 per 100,000 inhabitants, which means Baghdad scored a high-performance value of 88.57. Therefore, these fatalities may be reduced if mass public transport is applied efficiently.

Regarding the sixth indicator of "Affordability of travel costs as a share of income", it is important to maintain the current percentage of affordability, which is 4.4%, because it raised the affordability evaluation to 97.14, which is a very good performance. If this percentage is kept, it will attract inhabitants to use public transport rather than private mode and increase the normalized performance in general.

The seventh indicator, "Operational costs of the public transport system", is on the level of 88%, calculated as the ratio of fare revenue to operating costs for current public transport. Therefore, this indicator's performance value reached 43.14 because the revenues are less than the expenditures. The expected reason could be that buses are in a traffic jam, as this problem leads to increased fuel consumption and maintenance costs. Hence, when buses have separated lanes, the operation cost will be reduced, and revenues will increase with the demand expansion due to the journey time reduction.

The eighth indicator, "Investment in public transport system", is related to implementing investments spending as an average of five years made by the city directed to public transport to provide access to safe, affordable, accessible, and sustainable transport systems for all. The percentage of investment is 20%, and the normalized performance of this indicator is 40. Therefore, the BRT system will provide the required aspects of sustainable transport and can be implemented within several stages to cover a wide area. Thus, increasing annual public transport investments positively affects social life and diversifies the economy, further contributing to improving the city's performance towards sustainable urban transport.

The scenario of the BRT system shows that the estimated demand for private vehicles decreased to half. Therefore, the indicator of greenhouse gas emissions from transport will gradually reduce with the less demand for using private vehicles. This reduction will also improve the air quality indicator, as its performance value is -7.14 because the air quality level in Baghdad is 160 (µg/m3), which is over the norm.

To make these improvements achievable, it is essential to identify the objectives of sustainable urban transport, which represent diversity economy, social equity, and protection of the environment. To achieve these objectives, a coherent transport policy should be adopted according to the up-to-date legal framework that covers all aspects of sustainable transport. Furthermore, Public transport institutions should be decentralized. In other words, each province should have its institution to manage public transport. The previous prosperity of the public transport in Baghdad was obvious when the public transport was reporting to the mayoralty of Baghdad, which had the authority to use the land as well.

Providing sufficient funds is a crucial factor in implementing sustainable transport through establishing an independent fund to invest transport revenues with continuous support from the public budget until visualizing the milestones of sustainable urban transport. Finally, urban transport should be periodically evaluated to meet people's requirements of providing an integrated transport system. The appraisal process should base on appropriate international indicators such as SUTI and associated with simulated solutions.

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