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Providing a Decision-Making Method for Evaluation of Exclusive BRT lanes Implementation Using Benefit-Cost Analysis – Case Study: Tehran BRT line 4

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ABSTRACT

Recently, the rapid growth of urbanization, in conjunction with a lack of proper transportation infrastructures, has raised traffic congestion in a great number of developing cities. The growing concern about traffic congestion persuades governments to promote public transit services which mostly need a substantial amount of money to implement. Budget limitations entice decision-makers to choose Bus Rapid Transit (BRT) systems as a less expensive solution. The implementation of BRT lines always comes with advantages and disadvantages. Furthermore decision-makers need a tool to evaluate the effects of converting a mixed-flow lane to a BRT lane. The main aim of this paper is to provide a decision-making criterion for the problem of lane conversion for BRT. To do so, Benefit-Cost Analysis (BCA) is applied, and finally, we assess Tehran BRT line 4, as a case study, in order to evaluate the impact of dedication of one lane to BRT on Chamran highway.

Key words: Traffic Congestion, Bus Rapid Transit, BRT, Benefit-Cost Analysis, BCA, Benefit/Cost Ratio.

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1. INTRODUCTION

Recently in developing countries, rapid growth in urbanization has raised numerous traffic issues, the main reason of which is a lack of sufficient and efficient transportation infrastructures (1). The suburbs of many new urbanized areas have no appropriate access to transit networks. Thus, the dependency of their dwellers on private vehicles rises due to long travel distances, and consequently, traffic congestion increases in such urban areas (2). Although the growing concern over traffic congestion incites policy-makers to develop mass transit systems, they always face limited budgets in the implementation of well-equipped transport systems (3). Constrains on local expenditures on public transit developments prompt decision-makers to invest in low-budget transportation systems. Therefore, Bus Rapid Transit (BRT) system has recently been proposed to

address the issues of traffic congestion (4). BRT systems, in comparison to other mass transit services, need less money and time to implement. One of the main reasons that BRT is prospering across developing cities, is the possibility of BRT to cover its costs by fare revenues (5). A great number of researches and experiments have shown that such systems not only promote the performance of public transit services, but also are more compatible with the financial restraints of developing cities (6). BRT has proven its efficiency to attract more non-captive users in both U.S. and other cities all around the world. Operating in an exclusive lane provides BRT with high speed and gives it a rail-like performance (7). Generally, compared with other mass transit systems, BRT has slight advantages namely: acceptable operational speed and reliability, greater patronage, lower costs, higher capacity, operational flexibility (8), less waiting time, and more user safety and security (9). Apart from this, it has been scientifically

proven that long distances between stops can reduce bus emissions (10). Moreover, the major achievement of BRT systems is their sustainability over more conventional bus systems (6). Dedicated bus lanes grant the highest level of service. However, implementation and development of such services are always faced with public arguments. Converting a lane to BRT lane decreases the capacity of mixed-flow traffic lanes (11). Hence, such lane conversions are not usually possible and must be deliberate. In order to overcome these challenges, policy-makers require a tool to evaluate the impacts of converting a mixed-flow lane to a bus lane. To do so, a benefit-cost analysis can readily help decision-makers to assess proposed BRT projects (12). The main objective of the present study is to provide a decision-making methodology in order to evaluate the lane conversion of BRT projects. In this paper, after defining the importance of such problem, a comprehensive review is conducted to find an appropriate method – that is – Benefits-Cost Analysis. In what follows, the proposed methodology is described, and eventually, it is applied to Tehran BRT line 4, and the results are presented.

2. LITERATURE REVIEW

Until now, a great number of researches and studies have conducted on the subject of the impact of dedicated bus lanes. For example, Taotao Deng et al (2013) conducted a survey on BRT services in Beijing, and presented that, after the construction of BRT line 1, the operational speed of bus services rose from 16 Km/h to 22 Km/h in peak hours, and to 26 Km/h in nonpeak hours (5). Aside from this, travel time decreased by 38.3 % (3). Bel and Holst (2015) used econometric based methods to quantify the environmental effects of BRT (13). Their analysis showed that, except for SO₂, the concentrations of all pollutants increased. Specifically, CO concentrations were reduced by 16.6-20.4%, NOX by 12.9- 18.1%, PM2.5 by 20.8-39.0% and PM10 by 9.6-24.4% (13). Beigi et al (2015) in their survey performed a SWOT analysis to provide strategies to improve BRT system of Tehran (9). There is also another group of studies applying economic analysis in their assessments. Blonn (2006) in his research, in order to carry out a benefit-cost analysis, considered the following benefit categories: 1) reduced travel time for current bus users, 2) reduced vehicle user costs for new bus users, 3) reduced air emissions and 4) reduced vehicle accident costs (14). He also categorized costs into three classes include 1) the capital costs of BRT implementation, 2) operations and maintenance costs of BRT, 3) the cost of boosting local revenue. The research group under Karen Savage's direction (2009) conducted an extensive review of BRT projects implemented all around the world in general and in U.S. in particular (12). In this study, they presented quantifying costs and benefits of converting a mixed-flow lane to an exclusive BRT lane, as one of the main requirements of evaluation of such projects. Ang-Olson and Mahendra (2011) applied a benefit-cost analysis

on a hypothetical 8-mile long corridor with a BRT lane, using assumptions for the peak hours and peak direction of traffic. They also, conducted a sensitivity analysis to show how the net benefits, costs, and final cost/benefit ratio of the project vary when the assumed values are altered (11). Hidalgo et al (2013) evaluated TransMilenio BRT system in Bogota, using an ex-post cost-benefit analysis. They involved impacts on travel time and travel cost as direct impacts; and improved road safety and air quality, impacts on crime, land values, employment, and tax revenue, as indirect impacts. Their results presented a positive BCR for TransMilenio; however, some requirements must be imposed to increase its demand (15). Wang et al (2013) surveyed modal shifts to BRT in Chinese cities, and proved that if BRT services are able to reduce travel time by 10 minutes, the modal shifts to BRT will rise by 15% (16). Vermeiren et al (2015) claimed that BRT projects reduce passengers travel time, but on the other hand, they might deprive the lowest income dwellers of such services since not all residents can afford to pay BRT system (2). Satiennam et al (2015) assessed the BRT system of Khon Kaen City, in Thailand, to show its potential to attract private car users to BRT. The results of their study suggested that motorcycle riders have often changed their travel mode to BRT, but on the contrary, almost all personal car users have preferred to choose their private cars rather than BRT and other public transit systems (17). Myung-Jin Jun (2012) proved that Seoul's BRT plays a significant role as a centripetal force to attract firms from the suburbs into CBD, and to increase development density in urban centers. Additionally, increasing demand for central areas leads to raising the price of properties in the urban cores, and consequently, to reducing property values in suburbs (18).

3. METHODOLOGY

Transportation plans and projects mostly cost a fortune to implement. For instance, the construction of a grade-separated junction leading to reduce traffic delays always forces municipalities to spend a substantial amount of money. Indeed, the most important effect of planning costly projects is the provision of high-level social welfare by improving supply systems. The implementation of BRT with a dedicated bus lane comes with pros and cons depending on how the system influences the travel speed, delays, as well as vehicle kilometers traveled, for its either users or nonusers (11). With this in mind, the subject at issue here is when the costs and benefits – especially social benefits – of a project are equal in value, and what decision-making criterion must be used. An economic analysis is seeking to address such issues, and furthermore, policy-makers can employ this method to measure the earnings and profits of a plan against its expenditures. In this paper, the benefit-cost analysis, which is a noted methodology in economic analysis, is applied in order to evaluate lane conversion. To do so, its concept is defined clearly, and the specific steps of such methodology are

presented.

3.1. Economic analysis

Transportation services have a variety of impacts (either benefits or "disbenefits") felt by both their users and residents – nonusers – in a direct or indirect manner. Some costs relate to the implementation of services, some relate to a reduction in private car users, and others result from land-use developments (19). Benefit/Cost Analysis (BCA) is a systematic approach for estimating the benefits and costs of each alternative experienced by anyone in anywhere. The definition of BCA is acceptable for decision-makers; however, they have not reached a consensus about how to estimate or calculate these benefits and costs (20).

Generally, BCA fundamental principles are as follows (20):

- Involving all important impacts of scenarios
- Drawing a comparison between alternatives based on the relative difference between them, rather than total costs or benefits of each scenario.
- The distribution of impacts is more important than the summation of them.
- Benefits and costs in the future have less monetary value in comparison to the present (the effect of the annual inflation)

BCA is not analogous to financial analyses. The financial analyses tend to find how budgets should be assigned to a project, for increasing its revenue and meeting both operational and maintenance costs of it. However, being an economical project is not related to the way its overall expenditure is provided, rather it is BCA which defines whether the project is economically practical or not. The process of BCA used in this study has 6 major steps which are described below.

3.2. Step 1: Costs and Benefits definition

The key objective of BCA is to compare benefits and costs of alternatives in order to choose the scenario, in which more benefits are provided (12). To do so, the monetary value of such benefits and costs should be calculated in each scenario. In this study, unlike many studies, we analyze the problem with a multi-modal approach. Thus all benefit and cost items are defined for three transportation modes of Bus, Taxi, and Personal Car. The significant subject that should be considered in the evaluation of BRT systems is that passengers' characteristics and their priorities differ from one person to another one, based on travel mode, travel demand, socioeconomic status, and the importance of travel time and travel cost reduction. This issue presents heterogeneous nature of ridership and travel preferences which must be considered in planning and development of public transit systems. However, several types of research have proven that travel time is still the most important parameters among all group of people.

Especially, personal car users, for whom travel cost is less important than travel time, and thus, they are not willing to shift to BRT systems. Hence, the consideration of travelers' features in policies and plane is a crucial factor policy-maker should pay attention to in their assessments (16). Generally speaking, benefits and costs of a scenario are classified into two main levels described below (20):

3.2.1. Direct Impacts (Benefits and Costs)

Direct impacts are, also, categorized into three groups: first, primary impacts which directly influence users of a system, second, secondary impacts which are the result of the primary impacts and have an effect on both users and nonusers, and third, direct costs of transportation systems which governments and municipalities afford.

3.2.1.1. Primary impacts (impacts on users)

These impacts directly have an influence on users of transportation systems. The primary impacts are considered in this study are as follows:

The Value of Travel Time: It refers to the amount of time a traveler spends on his or her trip inside or outside of a vehicle. The value of travel time is quantified based on the average of users' income-per-hour.

- 1) Fare: Such costs are paid only by the user of Bus and Taxi modes.
- 2) Parking Fee (personal car users)
- 3) Ownership Costs (personal car users)
- 4) Operational Costs (personal car users)

3.2.1.2. Secondary impacts (impacts on both users and nonusers)

Secondary impacts are the sequel of primary impacts. Unlike primary impacts, such impacts affect all residents of a city (whether users or nonusers) and are itemized below:

- 1) Air Pollution Costs
- 2) Accident Costs
- 3) Traffic Delays Costs: This affects the users of mixed-flow lanes.

3.2.1.3. Direct costs of transportation systems (impacts on urban planners)

These costs which are related to financial requirements of transportation systems implementation and operation are paid by governments and municipalities. They are categorized in two main classes.

- 1) **Capital Costs:** The capital costs are related to the implementation of a new BRT line, and they are paid once during the project lifetime.
- 2) **Operation and Maintenance Costs:** Such costs, despite the capital costs, must be afforded during the lifetime of the project, and are related to not only the new BRT line but also to conventional Bus and Taxi systems.

3.2.2. Indirect Benefits/Costs

Primarily, indirect benefits and costs have an influence on other systems, except for transportation systems. Such impacts are not felt in the short term, but rather, they influence gradually. For instance, the construction of new roads improves accessibility in some areas, thereby raising properties value. It is crystal clear that transportation experts in proposing transit plans are not seeking to take the control over land use and properties value. Such proposed projects, however, have an influence on land use in the long term. A great number of studies have proven that the development of transportation systems has direct impacts on the increase in properties value, as well as the revival of land use in urban areas. In the other words, transportation infrastructures provide accessibilities, thereby, preparing capability to develop urbanization leading to raising properties price in both urban and suburban areas. Nevertheless, such change in land use may occur gradually due to the managerial incompetence of other governmental organizations (21). The indirect impacts bring about changes in land use and economic developments, and almost, it is difficult to estimate the monetary value of them. Being hard to quantify is the first reason that many studies have eliminated such impacts from their analysis (12). Furthermore, in this survey, due to lack of data, the indirect impact are not considered. According to previous studies and the classification of benefits and costs mentioned above, a BRT line impacts on users, society and governments are summarized in Table 1.

3.3. Step 2: Quantification of the Monetary Value of Benefits and Costs Items (cost per unit)

In order to compare and contrast different transportation modes, monetary items of a BCA are typically quantified as unit benefits and costs (i.e. \$/vehicle-km or \$/passenger-km) (22). The direct impacts of a scenario, in comparison to its indirect impacts, are less difficult to calculate. However, there are a lot of arguments about how the monetary value of such impacts is estimated.

3.4. Step 3: Defining scenarios

BCA usually draws a comparison between alternatives of a plan with do-nothing scenario assuming no plan is

implemented. To do so, the standardization of the monetary items and the calculation methodology of them must be considered (11). In this paper, the direct impacts of BRT on its users, conventional bus users, taxi users, and private car users, are estimated to compare them before and after the implementation of BRT line 4. It is worth mentioning that, the reduction in costs are described as benefits in this survey.

3.5. Steps 4 & 5: Calculation of the Units of the Items and Total Benefits and Costs

In previous steps the benefit and cost items in all scenarios are estimated as benefit or cost per unit, in this step, in order to calculate the total benefits and costs of the scenarios, the unit of each item should be calculated. By so doing, the total benefits and costs would be equal to the product of their benefit or cost per unit and their units. It is worth mentioning that BCA is generally conducted for the critical status of a project. The critical status of transportation systems always occurs in peak-hour traffic. Hence, in this survey, the project of BRT line is evaluated in a.m. peak-hour traffic.

3.6. Step 6: Analyzing the Calculated Benefits and Cost

When the total benefits and costs of the project are calculated, such benefits and costs should be analyzed to present meaningful results, based on which we are able to discuss if the project is economical. There are several methods to carry out such analysis, the most prominent of which are Net Present Value (NPV), Equivalent Uniform Annual Value (EUAV), Rate or Return (ROR), and Benefit-Cost Ratio (BCR). In this survey, we apply BCR and NPV in order to analyze the total benefits and costs. The other point to consider is that the benefits and costs of a project may occur at various times over its lifetime since, generally, major costs (capital costs) are met in primary stages of a plan, while, benefits and revenues are generated through the lifespan of the project. As many studies suggested, to solve the problem, these benefits and costs should be adjusted to a base year, in which the analysis is being conducted (11).

Table 1. The benefits and costs of BRT projects

Classes		Main Impact On...	Items (IRR* per unit)		Units
Direct Impacts	Primary Impacts	Users	The Value Of Travel Time	On-Vehicle Travel Time	Passenger Hour Traveled inside of a vehicle
				Off-Vehicle Travel Time	Passenger Hour Traveled outside of a vehicle
			Fare	Bus Or Taxi	Passenger Traveled
			Parking Fee	Personal Car	Passenger Traveled
			Ownership Costs	Taxes And Insurance	Vehicle Kilometer Traveled
				Depreciation	Vehicle Kilometer Traveled
			Operational Costs (Personal Car)	Fuel	Vehicle Kilometer Traveled
				Lubricant	Vehicle Kilometer Traveled
				Tires	Vehicle Kilometer Traveled
				Maintenance	Vehicle Kilometer Traveled
	Second any Impacts	Society	Traffic Accidents Costs		Vehicle Kilometer Traveled
			Air Pollution Costs		Vehicle Kilometer Traveled
			Traffic Congestion Costs	Travel Time In Mixed Flow Lanes	On-Vehicle Passenger Hour Traveled
	Direct Costs Of Transportation Systems	Governments	Capital Costs	Construction Costs	
				Researching Costs	
				Provision Of Equipment	
			Operational Costs (Bus Services)	Fuel	Vehicle Kilometer Traveled
				Maintenance	Vehicle Kilometer Traveled
				Carwash	Vehicle Kilometer Traveled
				Insurance	Vehicle Kilometer Traveled
Depreciation				Vehicle Kilometer Traveled	
Driver's Salary				Vehicle Kilometer Traveled	
Others				Vehicle Kilometer Traveled	
Operational Costs (Taxi Services)				Insurance	Vehicle Kilometer Traveled
			Depreciation	Vehicle Kilometer Traveled	
			Fuel	Vehicle Kilometer Traveled	
			Lubricant	Vehicle Kilometer Traveled	
			Tires	Vehicle Kilometer Traveled	
			Maintenance	Vehicle Kilometer Traveled	
			Driver's Salary	Vehicle Kilometer Traveled	
Monthly Charge	Vehicle Kilometer Traveled				
Indirect Impacts	Other Impacts	Society	Land Use	Almost All Researches Have Assessed Such Impacts In a Qualitative Study	
			Economic		

* IRR (Islamic Republic Rial): The local currency of Iran

4. CASE STUDY

Nowadays, the city of Tehran has faced considerable challenges in meeting the transportation demands of its dwellers due to an increase in its population (23). According to the Traffic Data of Tehran in 2013, the large majority of travelers (43.9 %) use their personal cars. Meanwhile, the bus mode share is 20 % (24). As already mentioned, in this part, the presented methodology is applied to assess the impacts of Tehran BRT line 4.

4.1. BRT Line 4 Characteristics

In August 2010, the first phase of BRT line 4 of Tehran

city was implemented from Afshar Terminal to Jomhori Square. BRT line 4, the length of which is 13.7 km, has 11 stations on both sides and daily carried over 98,000 passengers in the first year of its operation (24). According to the report published by Tehran department of transportation, the primary proposed bus way of BRT line 4 has overlapped with 25 lines of the conventional bus, 9 of which have been merged with BRT line 4. This report, also, presented that the travel speed of mixed-flow traffic lanes users has been reduced by 5 % after the implementation of BRT line 4 (23). Table 2 presents a summary of features and operational characteristics of BRT line 4.

Table 2. Tehran BRT line 4 information (15, 26)

Item	Amount	Unit
BRT Length	13.75	Kilometers
Separated Lane Length	8.5	Kilometers
Average of Operational Speed	20.1	Kilometers Per Hour
Number of Stations	16	
Number of Fleets	60	
Total Passengers	30478000	Traveled In a Year Passenger

4.2. Capital costs of BRT line 4

According to Table 1 and Table 2, the capital costs of BRT line 4 are calculated based on the financial year of 2010 in which the project was implemented, and their summation

is 248,069,610,000 IRR. In order to standardize the total capital cost in the base year (2010), its equivalent uniform annual cost (EUAC) should be estimated. To do so, equation 1 is used.

$$A = \frac{P(1+i)^n}{n} \tag{1}$$

Where

A : Equivalent uniform annual cost

P : Present worth

i : Interest rate

n : Number of interest period

It is worth mentioning that, BCA is generally conducted for the critical status of a project. The critical status of transportation systems always occurs in peak-hour traffic. Hence, in this survey, the project of BRT line 4 is evaluated in a.m. peak-hour traffic. As mentioned in many

types of research, 10 to 15 percent of daily traffic volume are equal to peak-hour traffic volume. With this in mind, the EUAC of capital costs in peak-hour traffic would nearly be equal to 15 % of EUAC of total capital costs. Thus, BRT line 4 capital costs in a.m. peak-hour traffic and in its first year is calculated in equation 2.

$$A = \frac{248069610000(1+0.15)^{10}}{10} \times 0.15 = 15053698946 \text{ IRR} \tag{2}$$

4.3. Benefits and Disbenefits of BRT line 4

Previously, all the impacts of implementation of BRT line 4 for four transportation modes (BRT, conventional bus, taxi, and personal car) were presented in Table 1. In order to calculate the monetary value of each item, in the first step, the cost per unit of the items is estimated, and then

their units in a.m. peak-hour traffic are quantified in the next step. Eventually, the monetary value of BRT line 4 impacts in a.m. peak-hour is calculated for each year of its operation. Table 3 presents the total costs of each transit mode for each scenario – before and after BRT line 4.

Table 3. Total costs in a.m. peak-hour before and after the implementation of BRT line 4 in 2010

Total Costs	Before BRT (IRR)	After BRT (IRR)
Capital Costs of BRT	-	15,053,698,946
Total Costs of BRT System	-	43,368,407,091
Total Costs of Conventional Bus System	43,181,627,949	-
Total Costs of Taxi System	53,839,548,540	49,074,584,516
Total Costs of Private Car System	101,652,650,533	92,652,531,025

4.4. Economic Analysis

The general equation for BCR as well as the general

equation for NPV are defined as below:

$$B/C = \frac{B_i}{C_i} = \frac{\text{Benefit} - \text{Disbenefit}}{\text{Cost}} \tag{3}$$

$$NPV = B_i - C_i \tag{4}$$

Where

B_i : net benefits

C_i : net costs

Accordingly, net benefits and net costs of BRT line 4 are

calculated as presented in equations 5 and 6 respectively.

$$B_t = 43181627949 + 53839548540 + 101652650533 - 43368407091 - 49074584516 - 92652531025 = 13578304390 \quad \text{IRR} \quad \text{Equation 5}$$

$$C_t = 15053698946 \quad \text{IRR} \quad \text{Equation 6}$$

Furthermore, BRT line 4 BCR and NPV are estimated as below:

$$BCR = \frac{13578304390}{15053698946} = 0.90 \quad \text{Equation 7}$$

$$\text{IRR NPV} = 13578304390 - 15053698946 = -1475394556 \quad \text{Equation 8}$$

5. CONCLUSIONS

Based on the result presented above, for the lifetime of BRT line 4 operation, the BCR of the project is less than 1, and also, its NPV has a negative value, which illustrates that the project of BRT line 4 is not a successful plan from an economic point of view. Such results cannot be convincing since we have many limitations on collecting the data of BRT line 4, and therefore, we make some assumption to make up missing data. It is worth mentioning that this study is conducted to present a decision-making method for BRT lane conversion rather than the economic analysis of a case study. The first point is that including more monetary items (either benefits or costs) in the BCA of a project is a crucial factor. Since there are always items of benefits and costs which are hard to quantify due to restrictions in our calculation, we cannot draw a conclusion confidently based on results. The other aspect of such method is its multi-modal approach which provides decision makers with a tool to carry out a comprehensive evaluation of impacts of BRT projects in such a way that they not only are able to compare a new BRT system with previous conventional bus services, but also can assess the effect of modal shifts between BRT system and both Taxi and Personal Car modes. It is vitally important especially when we are going to evaluate the whole corridor on which a BRT line is implemented. Last but not least, BCA method is highly recommended for analyzing a project before its implementation. In doing so, it is necessary to estimate demand changes after the project operation in an elaborated manner.

6. SUGGESTIONS FOR FURTHER RESEARCH

In this section, some suggestions are proposed in order to improve this methodology in future studies. These suggestion are itemized below:

a). One of the most important parameters in being economical for project is the value of travel time. In this paper, we assume that the value of travel time is the same among all travelers and is equal to the average of citizens' gross incomes. While, in a.m. peak hour, BRT users are mostly employees going to their workplaces. Thus, the average income of users varies from the average of all citizens' income. Additionally, public transit users are

mainly from classes with low or moderate income levels. Therefore, the income level of users of BRT may differ from those of Taxi users or Personal car users. Consequently, we future studies are recommended to estimate the value of travel time based on detailed information about the number of employed and unemployed users as well as their income levels.

b). BRT lines always operate in a network, and as a result, they affect the demand of each other. Thus, BCA can be effective if we analyze the whole network of BRT lines rather than a single line.

c). The implementation of BRT line undoubtedly brings a change in land use as provided accessibilities lead to the development of both residential and commercial areas. Therefore, if we take such impacts under our consideration in BCA, our results will be much realistic. However, definition and quantification of these parameters are not simple and need more studies in this field.

d). Analyzing a BRT project during its lifespan increases its chance of being close to real conditions because each BRT project needs a substantial amount of money to implement at the beginning. Nevertheless, the project benefits are gained not in the early stage of its operation but in upcoming years. Thus, such benefits will be considered in the project assessment if a life-cycle-evaluation is conducted.

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