

Evaluation of the Public Transportation System in Kabul by Time of Day User Equilibrium Assignment

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Abstract: Public transportation is a relatively high-capacity and energy-efficient alternative for urban passenger transportation. With the developing of society and economy, demand for public transportation increased dramatically in Kabul city. This paper probed into the public transportation system in Kabul and evaluated its development. Based on current situation and trend in public transportation, the strategy scenarios for public transportation development pointed out. In each scenario discusses the effects of implementing Bus Rapid Transit (BRT) in Kabul city, including how to evaluate the systems and model bus operations with current public transport situation in the study area. For this purpose, the study first considering on traffic demand forecasting based on four steps model, and make a Time of Day User Equilibrium Assignment. Then, predict the future demand to clarify the traffic condition in 2025 and with regard to future traffic conditions that results obtained from Time of Day User Equilibrium Assignment, focused on strategy scenarios to evaluate the system. Finally, in this research focused on Cost-Benefit Analysis for introduction of BRT system in Kabul city. And cost-benefit analysis considered for a relatively long period, 30 years. During the construction of the project, its cost is too high comparing to the benefit, but the benefits during the years of service will dramatic increased. It is intended that the buses should be replaced by every 10 years, therefore the costs for the new vehicle considered during the project years. And also the operation cost considered during the project life.

1. Introduction

In general, two strategies can improve the transportation system and reduce the traffic congestion: the expansion and the improvement of the existing transportation infrastructures. In this research efforts are made to focus more on the second case, because it is suitable to the developing

cities which are unable to pay the high capital cost of new construction. In the process of improving the existing infrastructure it is necessary to improve the public transportation system. Researches in this field show that Bus Rapid Transit (BRT) system is economical at high passenger density which is compared with ordinary bus transit and other automobiles. BRT system introduced based on three scenarios. Therefore, the BRT should be established linking the existing Kabul city, and also the BRT network should cover some part of the existing urban area as well. Feeder services from the BRT stations should cover the entire city area effectively. Terminals for inter-city bus services should be located in the suburbs, and linked to the city center by BRT or feeder services.

2. Objective of the study

Regarding this study, the main objectives of the study are summarized in the following:

- ✓ To forecast traffic demand, 2025 in Kabul city by using Time of Day User Equilibrium Assignment.
- ✓ To find the best public transportation system for Kabul city.

3. Study area and used data

Period planning to forecast will be considered 10 years. Focused area for the study comprises on Kabul the capital of Afghanistan which is 275 square kilometers and around 5 million populations. The data which are used in this research like personal trip survey conducted by JICA, survey questioner which is around 12,000 samples. Preparation of zone base data base so, there are 22 zone in Kabul city, the zonal attributes like zoning area size, population of each zone and employment at workplace. Preparation of network data base therefore route network including number of links, number of nodes, links capacities and link flow. Present and future socioeconomic data, travel time

by mode and fare of each mode, dwell time and waiting time at bus stop.

4. Traffic Demand Forecast

4.1 Trip Generation/Attraction Model

Uses socioeconomic data to determine the number of trips produced by traffic analysis zone, the socioeconomic data normally includes population, employment at workplace. To estimate this step of the model use linear function:

$$y = a_1x_1 + a_2x_2 + a_3x_3 + b \dots \dots (1)$$

Where zoning area size x_1 , x_2 population of each zone, and x_3 is employment at workplace. a_1, a_2 and a_3 Are the parameters and b is constant.

4.2 Trip Distribution Model

Trip distribution model determines where the trips will go. This normally uses a gravity model to estimate the trip distribution model, as follows:

$$T_{ij} = k * \frac{A_i^\alpha * G_j^\beta}{d_{ij}} (2)$$

Where A_i is attracted trip in zone i , G_j generated trip from zone j and "d" is the distance between zones.

4.3 Model Split Model

This step model determines what vehicles trips will utilize when going from one zone to another. Utility function and proportion function are following:

$$V_{ij}^k = \alpha * C_{ij}^k + \beta * (t_{ij}^k + w_{ij}^k + dw_{ij}^k) + \gamma (3)$$

$$P_{ij}^k = \frac{\exp(V_{ij}^k)}{\sum \exp(V_{ij}^k)} (4)$$

Where V_{ij}^k is utility from zone i to j by mode k , C_{ij}^k is cost from zone i to j by mode k , t_{ij}^k travel time from zone i to j by mode k , w_{ij}^k and dw_{ij}^k are the waiting and dwell time.

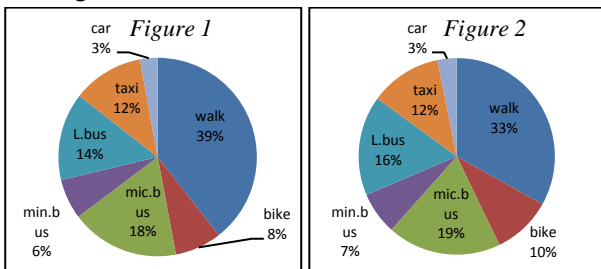


Figure 1 Actual proportion in 2008
Figure 2 Estimated proportions, 2088

4.4 Time of Day User Equilibrium Assignment

The model assumes the following two hypotheses:

- 1) The time duration is less than the maximum travel time.
- 2) The traffic is uniformly generated and distributed within each time durations

The presence of residual traffic that is left over to the next time duration is handled by the OD traffic adjustment for the next time duration. The main functions which are used in time of day user equilibrium assignment as follows;

5.4.1 Residual Traffic

Suppose that u_k^{nrs} stands for the traffic that is statically distributed onto the route k for the OD pair rs during the n^{th} time duration. Suppose also that T_w stands for the length of time duration and $t_k^{nrs}(j)$ for the travel time needed to reach the ending node of the j^{th} link from the origin node of the route k . of the traffic u_k^{nrs} generated on the route k during the time duration, $Yl_k^{nrs}(j)$ is its residual traffic that fails to pass the starting node of the link j within that time duration. This residual traffic is obtained by the following equation:

$$Yl_k^{nrs}(j) = \left(\frac{u_k^{nrs}}{T_w} \right) * t_k^{nrs}(j - 1) = \frac{u_k^{nrs} t_k^{nrs}(j - 1)}{T_w} (5)$$

Where u_k^{nrs} is the traffic that is statically distributed onto route k for OD pair rs , during the n^{th} . And T_w stands for the length of time duration, $t_k^{nrs}(j)$ is travel time the ending of node of the j^{th} link from origin node of the route k .

5.4.2 Adjustment traffic

The adjusted traffic includes the residual traffic from the previous time duration can be obtained from the following equation;

$$v_k^{nrs} = u_k^{nrs} * t_k^{nrs} (m_k^{nrs}) / 2T_k^{nrs} (6)$$

The model assumes the uniform traffic generation and distribution per time duration for assignment. Therefore, the time needed to reach the destination on a given route is equal to the travel time on the minimum path searched per OD pair. Supposing that stands for the total traffic per OD pair per time duration, the aggregate total of residual traffic

on all available routes is defined by the following equation.

$$q_{rs}^n = \sum v_k^{nrs} = Q_k^{nrs} * c_k^{rs} / 2T_w \quad (7)$$

Where Q_k^{nrs} is for the total traffic OD pair per time duration route network k zone r to s and c_k^{rs} is the travel time on the minimum path searched per OD pair. And also the traffic after residual traffic adjustment can be obtained by the following equation;

$$q_{rs}^n = \sum q_{rs}^{n-1} + Q_{rs}^n - q_{rs}^n \quad (8)$$

Furthermore, the OD traffic after residual traffic adjustment can be expressed in the following equation, by using the minimum path travel time.

$$q_{rs}^n = q_{rs}^{n-1} + Q_{rs}^n - \frac{c_k^{rs}}{2T_w} * Q_{rs}^n \quad (9)$$

5.4.3 Link Cost Function

To calculate the velocity of travel relative to traffic congestion, can select one of three alternative link cost functions (QV, BPR and DAVIDSON) formulas, and define parameters for up to 99 QV types from these formulas. Therefore in case of time of day user equilibrium assignment considered on BBR formula as follows;

$$t_a(x_a) = t_{a0} \left\{ 1 + \alpha \left(\frac{x_a}{C_a} \right)^\beta \right\} \quad (10)$$

By using STRADA program. Therefore, the required input data as follow;

- OD Matrix by time of day (from 5am to 9pm), so the time duration is every two hours and the number of time durations is eight.

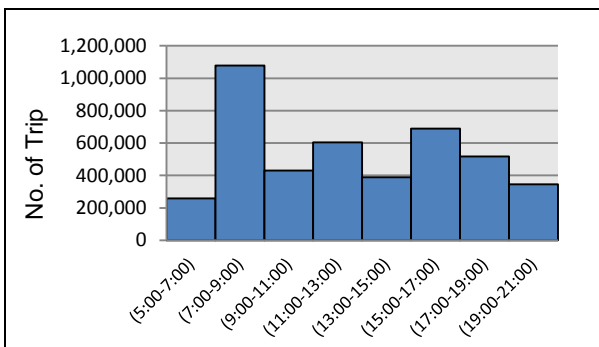


Figure 3 Distribution of Trip

- Network data & assignment parameter. The number of links are 670, number of nodes are 464, number of zones are 74 and number of modes are seven.

5.4.4 Outputs of Route Related Data

The STRADA Time of Day User Equilibrium Assignment is calculate to output unique link

flows, but this does not necessarily mean that it offers similarly unique route-related data outputs. The assignment does perform the minimum route search for loading as indicated in the algorithms already explained above. This can be put to use to obtain the approximate route-related data. Three route-related data outputs, namely, link OD details, directional link flows and route information are saved up during the iterated loadings. The result shown in the following figure;

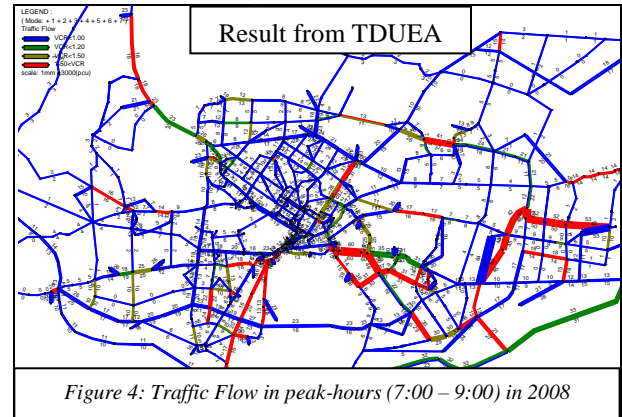


Figure 4: Traffic Flow in peak-hours (7:00 – 9:00) in 2008

Thus according to the result it is clear that area under the study (Kabul city) there is traffic congestion and this problem is different at during time of the day. Given the current state of the Kabul city, the congestion caused by rapid population growth, lack of public transport services, increasing the number of passenger cars and blocking roads because of the security problems, and other researches that have been done already shows that the main problems, namely in the public transportation services are low. Therefore, the strengthening of the public transportation can reduces the congestion and travel time from origin to destination. To reduce this problem (traffic congestion), the solutions ways must be addressed, which is satisfaction of the people, be efficient and useful. Thus, the policies that meet the expectations of a number of scenarios were considered to be closer to the target. The obtained results from Time of Day User Equilibrium Assignment (TDUEA) are shows in Figures 2. The results show that there is traffic congestion in Kabul city and it is clear that the congestion is different during the time of the day especially at peak hours and off-hours (5-7am and 7-9 pm). The color in the figures displays the link congestion levels. The congestion is expressed by the total traffic volume divided by the link capacity. For example, the red colors means that

the $VCR > 1.5$, the blue colors shows that the $VCR < 1$ and the green color shows that the $VCR < 1.2$.

5. Accuracy of Traffic Volume in 2008

(1) According to the survey, the largest traffic volume was observed on the Jadayi Sehi Aqrab road (S2) with 49,800 vehicles for both ways in 12 hours, followed by the Baghbala road (S1) and the Gozarga road (S3) with 41,200 and 14,400 vehicles.

Table 1 Traffic Volume on Screen Line
(Source, JICA in 2008. Unit: vehicles)

Time	S1	S2	S3
	Traffic Volume	Traffic Volume	Traffic Volume
7:00-9:00	8,904	12,562	3,569
9:00-11:00	7,320	9,849	2,139
11:00-13:00	5,572	4,043	1,949
13:00-15:00	5,288	4,812	1,574
15:00-17:00	6,347	10,428	2,387
17:00-19:00	7,758	8,142	2,792
Total	41,189	49,836	14,410

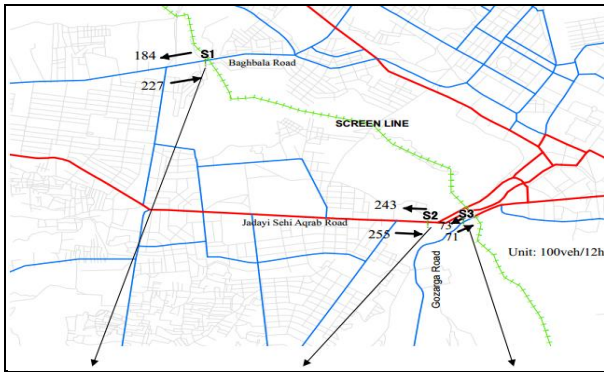
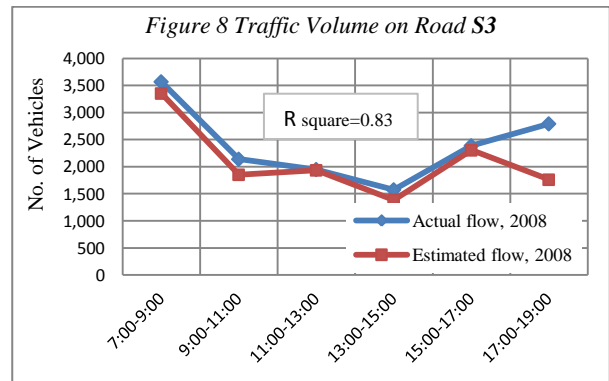
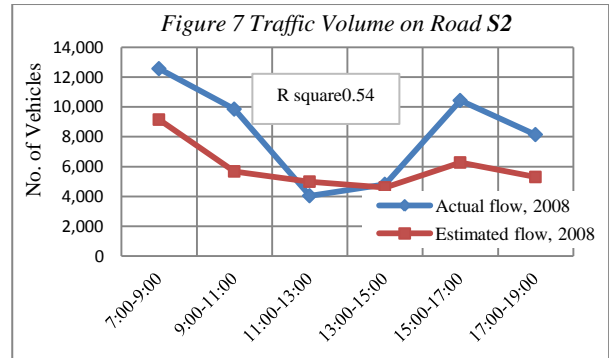
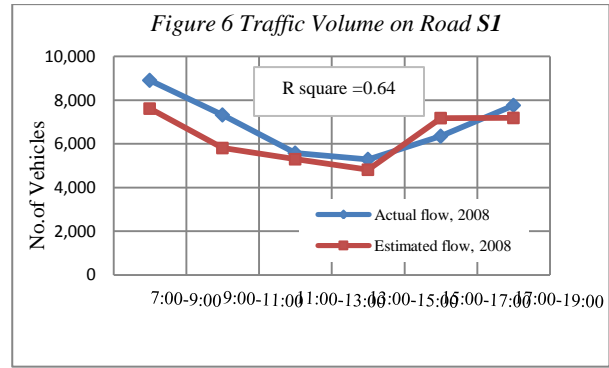


Figure 5 Outline of the Traffic Volume on the Screen line

(2) According to the result from time of day user equilibrium assignment the traffic volume also observed on the Jadayi Sehi Aqrab road (S2) with 35986 vehicles for both ways in 12 hours, followed by the Baghbala road (S1) and the Gozarga road (S3) with 37874 and 12,589 vehicles.

Table 2 Estimated traffic volume in 2008(unit: vehicle)

Time	S1	S2	S3
	Traffic volume	Traffic volume	Traffic volume
7:00-9:00	7,610	9,149	3,353
9:00-11:00	5,805	5,675	1,852
11:00-13:00	5,292	4,989	1,934
13:00-15:00	4,810	4,600	1,386
15:00-17:00	7,175	6,273	2,304
17:00-19:00	7,182	5,301	1,760
Total	37,874	35,986	12,589



6. Evaluation of the System

The main purpose of this chapter will be to evaluate the system according to traffic condition in 2025. First, the future (2025) traffic demand will be calculated based on four step models, by using the parameters in 2008 and after that make a time of day user equilibrium assignment to get the traffic flow in 2025. Second, in case of traffic congestion (high traffic flow) in the study area, therefore the solution ways to reduce this problem will be considered through several scenarios. And finally focuses on cost-benefit analysis for the introduction of BRT system in each scenario.

6.1 Strategy Scenarios

Scenarios are used in evaluation of the probable effects of one or more variables. The overall purpose of considering the scenarios is to reduction

of traffic congestion in the Kabul city. Therefore in this research by considered on three scenarios with introduction of Bus Rapid Transit instead of large bus to the public transportation system and their impact on traffic congestion, these scenarios are discussed separately and by applied Time of Day User Equilibrium Assignment (TDUEA) to get the result and evaluate the scenarios and after that the best scenario have been selected of among them. Thus the scenarios as follows:

- ✓ **Scenario Zero**; according to this scenario nothing changes in case of public transportation system in the future for Kabul city.
- ✓ **Scenario A**: This scenario, the public transport services considered on the two conditions like Feeder Buses services and Bus Rapid Transit service (BRTs). According to This scenario the corridors are designed only for BRT service. Therefore the other vehicles (feeder buses, private car and passenger car and etc.) cannot use or enter to the bus rapid transit (BRT) corridors. But feeder bus transferred passengers to the BRT.
- ✓ **Scenario B**: in this scenario the public transport services in Kabul city also considered on feeder buses and Bus Rapid Transit service (BRTs) whit a different case compared with scenario A, that the feeder buses also can use or inter to the BRTs corridors.
- ✓ **Scenario C**: in case, all the public transport services performed by feeder buses and BRTs too, and also feeder buses can use or enter to BRT corridors. But the different between scenario B and scenario C is the number of bus stops (different bus stop). For further clarification:

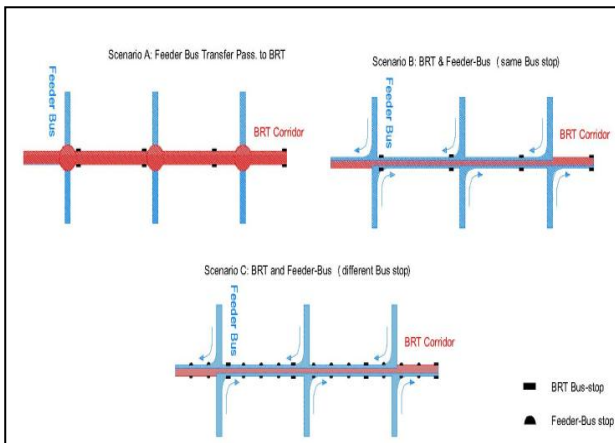


Figure 9 Network for three Scenarios

7. Traffic Demand Forecast in 2025

8.1 Trip Generation and Attraction in 2025

To estimate trip generation and attraction uses future socioeconomic data for Kabul city and calculated by linear function as described above.

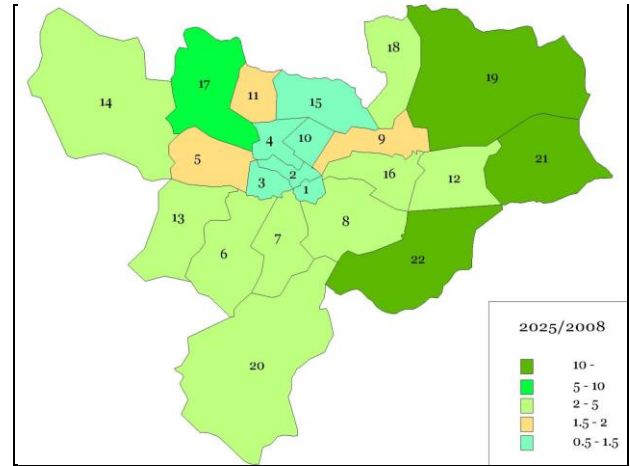


Figure 10 Classification of Kabul Districts by increase Rate of Trip Generation and Attraction

8.2 Trip Distribution in 2025

The future trip distribution model is developed by applying the gravity model. Therefore the gravity model is formulated in before section.

8.3 Modal Split Model in 2025

In this step of model determines which vehicles trips will utilized when the people going from one zone to another. Therefore, at first by using the utility function which the variables are cost, travel time, dwell time and waiting time at bus stop to get the utility of each mode and after that by using the proportion function to estimate proportion of each mode in 2025 for all scenarios. The results are shown in the following table:

Table 3: Mode share of each Scenario in 2025

Mode	Scenario Zero	Scenario A	Scenario B	Scenario C
	Percentage (%)	Percentage (%)	Percentage (%)	Percentage (%)
Walk	32.0	31.0	29.0	32.0
Bike	9.0	8.0	9.0	8.0
Feeder -bus	26.0	19.0	22.0	20.0
Large Bus	16.0			
BRT		25.0	24.0	23.0
Taxi	13.0	13.0	12.0	13.0
Car	4.0	4.0	4.0	4.0
Total	100.0	100.0	100.0	100.0

8.4 Time of Day User Equilibrium Assignment

As mentioned above that the model assumes the following two hypotheses like: (1) the time duration is less than the maximum travel time; (2) the traffic is uniformly generated and distributed within duration of time. The OD matrix data must be prepared per time duration, each file name numbered serially from 1 for the first time duration through the last. After analyzing the results achieved for all scenarios.

8.4.1 Result from Time of Day User Equilibrium Assignment:

The STRADA Time of Day User Equilibrium Assignment is calculating to output unique link flows shown in figure 5.10. The assignment does perform the minimum route search for loading as indicated in the algorithms already explained above. This can be put to use to obtain the approximate route-related data.

Three route-related data outputs, namely,

- ✓ Link OD details,
- ✓ Directional link flows
- ✓ Route information

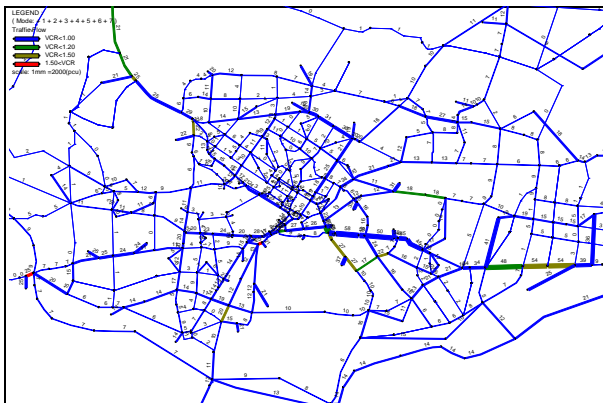


Figure 11 Traffic flow in off peak hours (5:00 to 7:00) in 2025

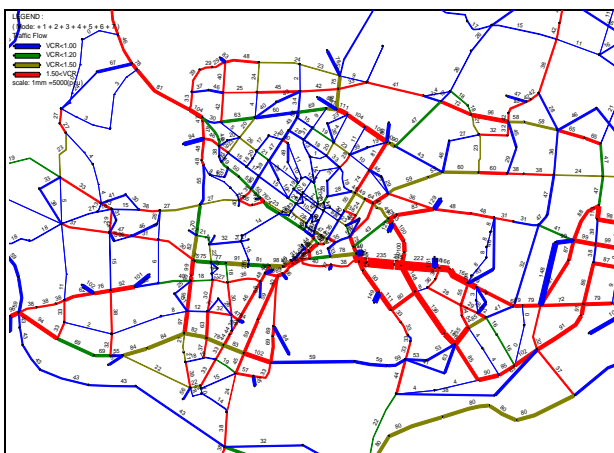


Figure 12 Traffic flow in peak-hours (7:00 to 9:00) in 2025

Figure 7 shows there is traffic congestion in Kabul city and it is clear that the congestion is different during the time of the day especially at peak hours and off-hours (5-7am and 7-9 pm). The colors displayed the level links congestion. The congestion is expressed by the total traffic volume divided by the link capacity. For example, the red colors means that the $VCR > 1.5$, the blue colors shows that the $VCR < 1$ and the green color shows that the $VCR < 1.2$.

Table 4 Results from TDUEA for Scenarios

Evaluation Indices	Mode	Scenario Zero	Scenario A	Scenario B	Scenario C
		Large-Bus & Feeder-Bus	BRT & Feeder Bus (Transfer pass. to BRT)	BRT & Feeder Bus (same Bus stop)	BRT & Feeder Bus (different Bus-stop)
PCU-Km	Large-Bus	69,787			
	BRT		76,943	96,796	82,956
	Feeder-Bus	142,962	178,902	196,792	183,336
PCU-hour	Large-Bus	2,972			
	BRT		1,843	1,708	1,612
	Feeder-Bus	12,177	4,815	3,671	3,114
Total length	Large-Bus	190			
	BRT		190	190	190
	Feeder-Bus	190	190	190	190
Average VCR	Large-Bus	0.43			
	BRT		0.13	0.12	0.12
	Feeder-Bus	0.68	0.32	0.23	0.22
Average speed	Large-Bus	30.4			
	BRT		39.0	38.5	37
	Feeder-Bus	34.6	37.0	38.5	36.4

9. Measure of Cost-Benefit Analysis: To evaluation the CBA there is several measures to compare benefits to cost in a cost benefit analysis. Therefore, all benefits and costs over the project's lifecycle are discounted to present values and the costs are subtracted from the benefits to obtain the NPV, which must be a positive number for the project to be justified. When multiple project alternatives exist, the alternative with the largest NPV of net benefits is typically the preferred alternative, though sometimes, other factors including project risks and funding availability may play a role in the selection of an alternative with a lower, positive NPV as follows:

$$NPV = \sum_{t=1}^n \frac{(b-c)_t}{(1+r)^t} \quad (11)$$

And also the other measure to evaluate CBA benefit cost ratio (BCR) which is a ratio where the present value of benefits is divided by the present value of the initial agency investment cost. When benefits exceed costs, the ratio is greater than 1 and

implies that the project is worth pursuing. The BCA function as follows:

$$\sum_{t=1}^n \frac{c_t}{(1+i)^t} = \sum_{t=1}^n \frac{(b-c)_t}{(1+i)^t} \quad (12)$$

$$BCR = \frac{\sum_{t=1}^n \frac{(b-c)_t}{(1+r)^t}}{\sum_{t=1}^n \frac{c_t}{(1+r)^t}} \quad (13)$$

Where NPV is net present value, BCR is benefit-cost ratio, b is benefit & c is cost, t is the period of project life, r is discount rate and i is internal rate of return (IRR)

9.1 Cost-Benefit Analysis for introduction of BRTs: category of cost considered on capital cost, operation and maintenance cost. And also category of benefits considered on benefit to change in travel time, benefit to change in vehicle operation cost for driver and fare transit user, benefit to change in emission of criteria pollutants and benefit to change in crash costs.

Table 5 Scenarios Characteristic

	Scenario zero	Scenario A	Scenario B	Scenario C
Total No. of passengers	2,463,872	2,594,402	2,774,298	2,524,392
Total corridors (km)		92	92	92
No. of station		92	92	153
No. vehicles		931	750	690
On-board fare collection		931	750	690
Traffic signal		41	41	41
Passenger on board Information		931	750	690

Cost-benefit analysis consider for a relatively long period, 30 years. The results show that during the construction of the project, its cost is too high comparing the benefit, but the benefits during the years of service will dramatic increased. It is also intended that the buses should be replaced by every 10 years, therefore the costs for the new vehicle also considered during the project years. And the operation cost in each year considered. For further clarification of these issues, the following tables are displayed.

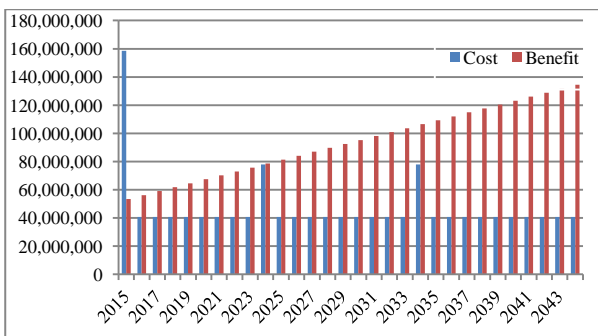


Figure 13 Costs-benefits during project life, Scenario A

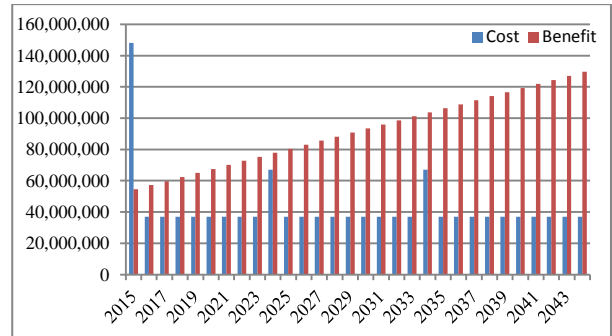


Figure 14 Costs-benefits during project life, Scenario B

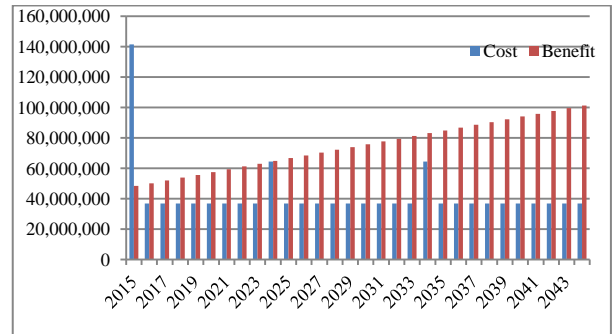


Figure 15 Costs-benefits during project life, Scenario C

9.2 Evaluation of Scenarios:

- ✓ **Scenario A:** in this scenario the pcu-km is 255,845, pcu-hour is 6,658 and average speed is 39 kilometer per hour, therefore this scenario will provide a better service and more appropriate compare to Scenario zero and other scenarios, but according to the economic indicators (cost-benefit analysis) this scenario is much costly compare to the scenarios.
- ✓ **Scenario B:** the pcu-km in this scenario is 293,588, pcu-hour is 5,379 and average speed is 38 kilometer per hour. Therefore this scenario also will provide better services than scenario zero and scenario C. And also according to economic indicators (cost-benefit analysis) **Scenario B** has low cost compared to scenario A, and is the best choice.
- ✓ **Scenario C:** the pcu-km is 286,292, pcu-hour is 4,726 and average speed is 36,4 kilometer per hour. Therefore base on these indicators this scenario cannot provide better service and more appropriate than scenarios A&B. But, according to the economic indicators (cost-benefit analysis) the cost is low compared to other scenarios like scenario A&B.

In detail according to CBA indices, Scenario B represented a positive NPV with a highest net benefits compare to scenario A and scenario C. Similarly, scenario A and scenario C also has a

positive NPV with low net benefits than scenario B, respectively get the second and third position. Therefore, according to the concept of NPV, a positive NPV indicates that estimated total benefits exceed total costs. Therefore scenario B is the best scenario among them. Also other closely related evaluation criteria often used in project appraisal that is the benefit-cost ratio (CBR), so, a project with a BCR greater than one has a positive NPV. In this study according to the evaluation criteria (BCR) scenario B has a greater BCR compare to two other scenarios. Therefore scenario B is the best choice for Kabul city. For further clarification:

Table 6 Evaluation Indices

Indices	Mode	Scenario zero	Scenario A	Scenario B	Scenario C
Average speed	Large-Bus	30.4			
	BRT		39.0	38.5	37.0
	Feeder-Bus	34.6	37.0	38.5	36.4
NPV			208,610,930	247,883,411	140,483,235
BCR			1.41	1.53	1.31

10. Conclusions:

Scientific research aims to solve problems and increase the welfare for human societies. The research on urban traffic congestion in Kabul City aims to contribute to this target. Kabul city as a post war city started the reconstruction of its transportation system from scratch and faces a lot of challenges. The goal of this research is to identify the problems, the origin where the problem emanates from as well as to use geographic knowledge and experience and certain other scientific approaches for solving the problems and improving the transportation system of Kabul City. The steps which have been taken during the research process are based on a scientific strategy for developing cities. The strategy starts with studying the characteristics of the city (urban structure and functions), its population (social integration and economical status) and the current transportation system. The strategy studies the characteristics of Kabul City regarding the establishment and development factors shaped by history. The second step analyzes the transportation system which has been the demand analysis the future condition of Kabul city. Moreover efforts are made to search for scenarios and approaches which are appropriate for the structure of Kabul City. Of course the research process faced some problems as each scientific approach does. The lack of data and sources are the main difficulties. Referring to

the population number different sources issued a variety of numbers which make the analyzing process difficult. Security challenges (terrorist attacks against governmental employees) and the sensitivity of the people during the field work did not give the opportunity to perform a comprehensive survey to find the transportation demand. Thus to estimate the transportation demand the survey has been done only in the city center. All the factors that are mentioned about the Kabul City structure illustrate that a radial transportation network is functioning best rather than the raster and the parallel system. Improving mass transit (BRT operation) is used worldwide especially in developing cities to reduce traffic congestion and improve urban mobility and economy. In this study to improve public transit focused on introduction of BRT system. Bus rapid transit is implemented in three scenarios. Therefore, after analyzing and evaluating each scenario, the most appropriate scenario is selected (scenario B).

11. Recommendation

The results of this study should be implemented in the real situations of Kabul city. The introduced of BRT system should be reduced the traffic congestions when the conflicting traffic flow is high. Thus, to improve public transit there are some approaches that mentioned as follows:

1) Technical infrastructure improvement

- ✓ Bus way and lane construction (direct and feeder lines): This strategy increases the operational capacity of a bus. Moreover the catchment area of feeder lines should be defined based on honeycomb model to make the transportation services accessible to BRT corridors for each region.
- ✓ Bus terminals and stops: It avoids using roads as parking place. Also Kabul City has no a central main bus station it would be better to build a central bus station or the existing bus stations which are not connected by any bus line should be connected by a bus line.
- ✓ Increasing transportation modes capacity (big capacity buses): It avoids increasing the number of vehicles on road.
- ✓ Fulfilling the city road network master plan: This increases the capacity of the road network.

2) Administrative infrastructure improvements

✓ Improvement of revenue collection process: it supports the quality of operation and maintenance, especially the fleet operation which is performed by governmental public transportation.

✓ Commercialization of bus lines: the roads in the city as the realms of the city can be profitable. The bus lines should be leased to the private sector but under the control and supervision of the government. The government should control the quality and accessibility of the private companies which are operating on the bus line and defined the link between transportation and economic opportunities for the private sector.

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