An Evaluation of Cost Optimization Strategies for BRT Projects in Pakistan

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Abstract-In developing countries like Pakistan, economic instability, improper planning, non-optimal design, delays in construction, and unsustainability during the operations of transportation megaprojects cause an unnecessary burden on the national exchequer. Recently, several Bus Rapid Transit (BRT) projects have been initiated in Pakistan. The detailed evaluation of the cost and capacity of BRT projects in Pakistan revealed that their cost could have been optimized. This research evaluated the first BRT project in Karachi for potential cost optimization through proper alignment of the BRT. One of the major segments of the Green-Line BRT from Surjani to Nagan was evaluated, which is presently designed as an elevated section. Other possible options such as curb-side, two-way side, and median alignments were explored in detail. The study showed that the cost of this section could have been reduced from the existing USD 75 million to USD 61 million by providing a two-way side aligned or curb-side aligned BRT infrastructure without affecting existing capacity. This case study shows that it is necessary to critically evaluate all the possible options while planning and designing transportation megaprojects.

Keywords-public transport; mass transit; transportation economics; sustainable transport; BRT Capacity

I. INTRODUCTION

According to the World Bank, more than 50% of the world's population lives in urban areas, and it is predicted that it would increase to 68% by 2050 [1]. Rapid urbanization has become one of the major global challenges, resulting in population influx and urban sprawl. Urban sprawl and population growth cause an increase in travel demand and urban mobility [2, 3]. The major problems associated with the high demand for mobility are: traffic congestion, economic loss, travel time increase, fuel consumption, and air pollution [4-6]. Short-term solutions to these problems include increasing the existing capacity of the road network by introducing new infrastructure facilities such as flyovers, underpasses, more lanes, and improving traffic controls. Long-term solutions include changes in land-use patterns, introducing new modes into the transportation network, and increasing the share of public mass transit systems [7]. Among the existing solutions, mass transport is considered one of the key solutions for the provision of high mobility and for the resolution of traffic problems by providing reliable, affordable, and sustainable means of transportation [8]. The selection of an appropriate mass transport system depends on the demands and characteristics of the city [9].

Bus Rapid Transit (BRT) is considered one of the optimal solutions due to its ability to deal with high demand at a relatively low cost compared to other mass transit solutions, such as rail transport [10]. BRT was first introduced in Curitiba, Brazil with a 9Km long corridor in 1972 [11], and is now spread at approximately 74Km serving around 721,500 passengers per day [12, 13]. The TransMilenio Bogota BRT is considered one of the most efficient systems in the world with a capacity of 49,000 passengers per hour per direction (pphpd) through 117 trunk corridors and is accessible by 107 feeder routes that serve more than 2.2 million passengers per day [12, 14-15]. The efficient BRT experience in Latin America has been introduced to many other countries. Transport planning in megacities of many developing countries focuses on facilitating the use of private vehicles by increasing road network capacity [16]. Therefore, the incorporation of transit systems causes various land-use problems. The need for extensive planning for BRT systems was discussed in [15], as BRTs may fail due to fewer passengers and higher operating costs.

Pakistan is the fifth most populous country, having approximately 39.5% of the total 212 million population living in urban areas [17]. The inadequate and poor provision of public transportation in megacities of Pakistan urges each

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individual to own a private vehicle to meet his travel needs, causing an increase in private vehicle ownership [18-19]. One of the main reasons for the degradation of public transport in most developing countries is the continued investment in road infrastructure while ignoring the improvement in the mass transport systems [20]. Only commuters from low-income groups depend on public transport to fulfill their travel needs. Therefore, there is a need to improve the existing public transport system in Pakistan and other developing countries [18, 21]. In 2013, Pakistan initiated the first BRT project in Lahore, followed by many other similar projects in other cities, including the Islamabad-Rawalpindi Metrobus, Multan Metro, Karachi Metrobus, and Peshawar Metro. Many BRT projects started without considering their future impacts on the economic conditions of the country [17, 22-23]. In 2020, the Orange-Line transit project built in Lahore consumed Rs 1.9 billion in electricity to remain operational, which is a huge investment for a developing country [24].

It has been observed that various mass transit projects are executed without considering the cost optimization aspect. This study briefly analyzes the Global BRT data to evaluate the performance of BRTs in Pakistan. Furthermore, a detailed evaluation of a selected elevated segment of the first BRT project constructed in Karachi, Pakistan, was performed. This study also examines other possible alignments of the selected segment, including median, curb-side, and two-way side alignments. The cost and capacity of each of the proposed alignments were estimated to show that the total infrastructure cost of the BRT project could be significantly reduced by considering other alternatives without compromising the capacity of the corridor.

II. GLOBAL DATA AND BRT IN PAKISTAN

Global BRT data is a public platform developed by BRT+CoE and EMBARQ WRI Brazil, in collaboration with ITDP [12]. The database consists of more than 300 data points from different cities. However, data from only 50 BRT corridors are considered for analysis in this study due to the unavailability of the BRT cost or peak load parameters. The Global BRT data provide information on peak load, which is the maximum number of passengers traveling in buses per hour along the most loaded segment, and therefore can be considered as the transport capacity of the BRT [12, 25]. Based on this data, about 62% of the BRT corridors around the world are median-aligned while only 7% have a grade-separated row.

Figure 1 relates the peak load served (capacity) with the infrastructure cost incurred in the construction of BRT corridors around the world. The most used BRT alignment is median, achieving 49,000 pphpd capacity in Bogota, Colombia, and constructed with USD 12.7 million per Km. Around USD 46 million per Km was invested for the grade-separated corridor in Nagoya, Japan, serving a peak load of 750 pphpd. Figure 1 shows the data points of the BRT projects around the world, including Pakistan. The 27 Km route of the Lahore Metrobus was constructed with an infrastructural cost of USD 11.5 million per Km and serves 10,000 pphpd. This BRT model was based on Istanbul Metrobus, serving around 30,000 pphpd and constructed with USD 9 million per Km. A 23 Km long BRT corridor was constructed to connect the twin cities of Islamabad and Rawalpindi (Islamabad-Rawalpindi Metrobus), being grade-separated, and median busways constructed with an infrastructure cost of USD 20 million per Km and serving only 2,100 pphpd.

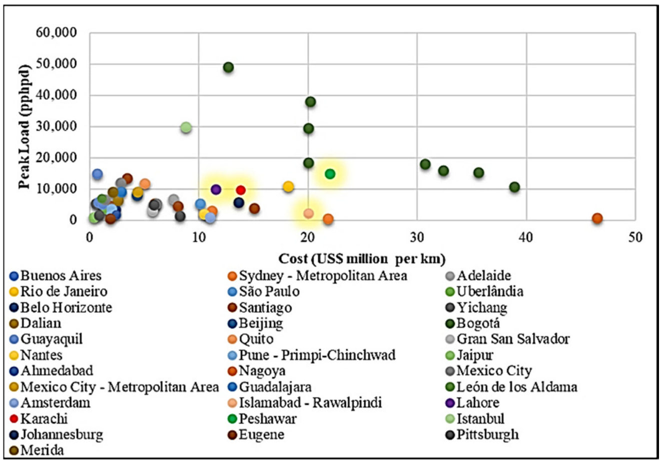

Fig. 1. Comparison of cost and capacity of corridors around the globe.

The third operational BRT project in Pakistan was constructed in Peshawar for USD 22 million per Km and serves 15000 pphpd [26-27]. The Green-Line project in Karachi costs US $13.8 million per Km and has a capacity of 9708 pphpd. The detailed estimation of the Green-Line BRT capacity and its cost are examined below. The higher capital investment for the construction of BRT corridors in Pakistan shows less efficient planning, which is reflected in the higher construction cost to serve comparatively fewer commuters. This is a critical concern, especially for the developing countries where the limited budget must be efficiently utilized in development and construction. Most of these projects were built by acquiring loans from various funding agencies. The higher project cost increases the debt burden and reduces the resources that could have been used in human development. Furthermore, a significant amount is also consumed for BRT operations and providing subsidized fares to commuters [12, 22, 28].

III. TRANSPORT INFRASTRUCTURE IN KARACHI

Karachi is a commercial and economic hub having a population of more than 20 million and generates up to 25% of Pakistan's GDP [29-30]. The increase in population and the expansion of the city without sustainable means of transportation have increased traffic congestion [30]. The traffic count on four main arterials conducted in Karachi shows that only 15% of commuters travel in public transport, while the remaining 85% of commuters travel using private vehicles [31]. The poor condition of the public transport systems has led commuters to use private vehicles. This causes a significant increase in traffic on the main arterials, leading to congestion, accidents, and pollution [32]. The Japan International Cooperation Agency (JICA) proposed five rapid transit lines (Green, Yellow, Orange, Blue, and Red) and the rehabilitation of the Karachi Circular Railway to improve transportation [33]. The construction of the Green-Line BRT corridor started in February 2016 with estimated completion by December 2017.

However, due to various reasons, the BRT started its operations in January 2022.

IV. EVALUATION OF GREEN-LINE BRT CORRIDOR

A detailed survey was conducted to examine the layout and infrastructural characteristics of the existing Green-Line BRT. This section describes the evaluation based on the route survey, capacity, and cost estimate of the existing Green-Line BRT corridor.

A. Route Survey and Layout

The Green-Line BRT route extends from Surjani to the Municipal Park. The Green Line will travel from Surjani passing famous landmarks including Nagan, AO Clock Tower, Lasbela Chowk, Gurumandir, and Numaish. The route is approximately 17.8 Km, about 58% of the corridor is grade-separated, and the remaining 42% has physically separated median aligned bus lanes. It consists of 21 stations, out of which 12 are grade-separated (2 stopping bays), and 9 at-grade (3 stopping bays). A fleet of 80 buses was obtained, each with a capacity of 160 passengers per vehicle [34]. Figure 2 shows the details of the alignment of the route and the locations of the bus stations on a GIS map.

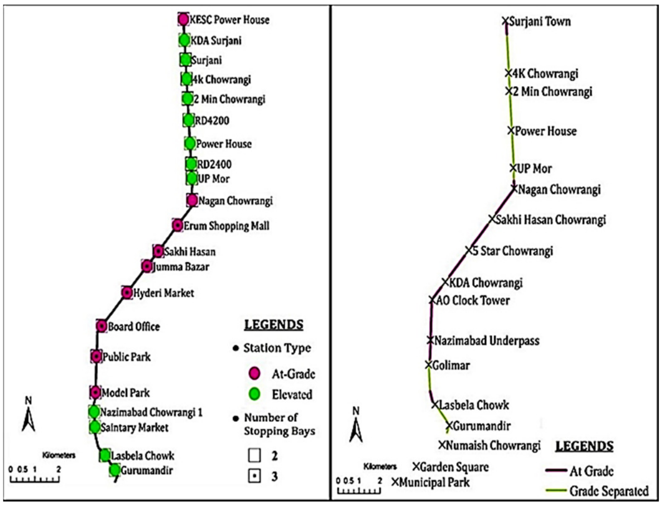

Fig. 2. Green Line route map with stations (left) and intersections (right).

B. Capacity Estimation

Capacity is the maximum number of passengers that can be carried past a point in a direction, during a given period along the critical section of the BRT under specific operating conditions [35]. This research uses the BRT Planning Guide for the estimation of the corridor capacity along with the saturation level for the Green-Line BRT route [36]. Equation (1) was used to calculate the capacity in pphpd, containing the main attributes that affect the capacity of BRT systems including the capacity of the vehicle, load factor, frequency, and the number of stopping bays provided. The load factor of 0.9 is used considering the peak period conditions. The cycle time for a complete round trip is calculated by estimating the journey time from the origin to the destination. Equation (2) was used to determine the headway in minutes between two consecutive buses. Using headway, the service frequency for operations is calculated by (3). Equation (4) is used to determine the saturation level of the Green-Line BRT corridor from the estimated frequency.

$$Cc = Cb * LF * SF * Nsp \quad (1)$$

$$H = \frac{T_c}{F_o} \quad (2)$$

$$SF = \frac{60}{H} \quad (3)$$

$$X = \frac{SF * T_d}{3600} \quad (4)$$

Table I shows the estimation of possible capacities that can be achieved in the infrastructure constructed for Green-Line with two and three stopping bays along with the corresponding saturation levels. The optimum saturation level is considered between 0.3 to 0.6 for BRT systems. A saturation level greater than 0.6 creates a risk of congestion and may lead to crowding of buses at stations [36]. The maximum possible crushing capacity for the Green-Line can be 24270 pphpd with a fleet size of 200 buses, while the optimal capacity achieved for its operations with smooth flows is 14562 pphpd.

TABLE I. VARIOUS POSSIBLE OPERATIONS FOR THE GREEN-LINE BRT CORRIDOR

Fleet Size	Headway (min)	Frequency (bph)	Saturation level	Corridor capacity (pphpd)
80	0.89	67.4	0.37	9708
100	0.71	84.3	0.47	12135
120	0.59	101.1	0.56	14562
140	0.51	118.0	0.66	16989
160	0.45	134.8	0.75	19416
180	0.40	151.7	0.84	21843
200	0.36	168.5	0.94	24270

C. Existing Infrastructural Cost

The critical elements that increase the infrastructural cost for BRTs are the design type of running ways and stations. The cost per unit of elements in the Green-Line BRT corridor was obtained from the Sindh Infrastructural Development Corporation Limited (SIDCL), which was the authority responsible for the execution of this project. The total cost for the existing alignment was estimated based on the cost per unit in PKR million per Km at 552 and 203 for elevated and at-grade busways respectively. For one elevated and at-grade station, the cost was PKR 288 and 141 million respectively.

TABLE II. COST ESTIMATION OF EXISTING ALIGNMENT

Section	Surjani to Nagan		Nagan to Golimar		Golimar to Gurumandir	
Type	Elevated	At-grade	Elevated	At-grade	Elevated	At-grade
Length (Km)	5.86	0.51	1.66	6.6	2.8	0.4
Cost PKR million per Km	3235	104	916	1340	1546	81
Stations	8	2	-	7	4	-
Cost PKR million (each station)	2304	282	-	987	1152	-
Cost PKR million per Km	930		393		868	
Cost USD million per Km	5.85		2.47		5.46	

Table II shows the complete cost estimation for the Green-Line BRT corridor. The segment between Surjani and Nagan was the most expensive segment, constructed for USD 5.85 million per Km. The grade-separated segment is 5.86Km long, having 10 stations along the segment. The per Km cost of the Nagan-Golimar corridor was estimated at approximately USD 2.47 million, which is 2.3 times lesser than the unit cost of the elevated segment. The unit cost of the Golimar-Gurumandir segment was USD 5.46 million per Km.

V. Optimization of Green-Line BRT Route

The cost estimation and the evaluation of various BRT segments shown in Table II indicate that there is a potential to reduce infrastructure costs without compromising capacity. The various options to reduce the cost of the Green BRT line infrastructure are explored below.

A. Gurumandir- Golimar

The existing route length of this segment is 3.2 Km with 2.8 Km elevated and 0.4 Km as an at-grade median corridor. The cross-section of the existing alignment of the Green BRT line for the Gurumandir-Golimar segment is shown in Figure 3. Around 90% of the width of the segment is less than 40 m while 10% of the width is more than 40 m, showing the possible difficulty of constructing an at-grade alignment for this segment. Figure 3 shows the median aligned corridor as evaluated for this segment. The segment may become more congested for general traffic if the BRT is constructed in a median alignment. An at-grade busway along this corridor would significantly reduce the width of the carriageway for general traffic from 11 to 7.3m. The reduction in the right-of-way can truncate the number of lanes for general traffic, causing traffic pressure with a greater possibility of traffic congestion.

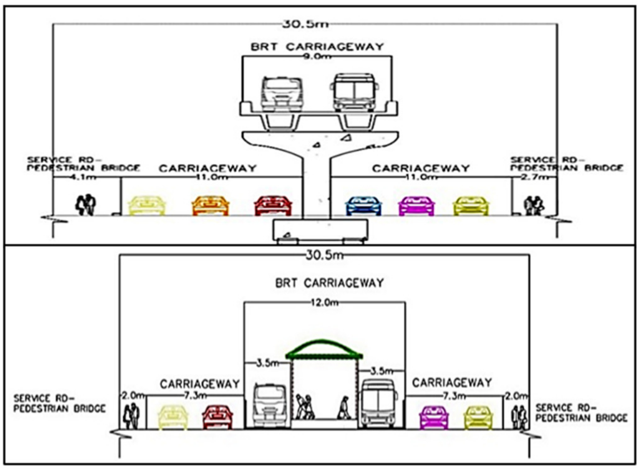

Fig. 3. Gurumandir-Golimar cross-section with existing elevated (top) and proposed median (bottom) alignment.

B. Golimar-Nagan

The existing route length for this segment is 8.26 Km, with 6.6 Km median aligned and 1.66 Km elevated section. All the intersections in this segment are grade-separated and the remaining segment is at-grade median aligned. Hence, the existing design of this section was evaluated as a cost-optimal design and no further optimization was possible without compromising capacity.

C. Nagan-Surjani

The existing Nagan-Surjani segment has a route length of 6.37 Km, with 5.86 Km elevated and 0.51 Km median aligned. Around 84% of the segment width is between 81-100m, 12% is less than 80m, and 4% is more than 100m, showing a clear possibility of construction for an at-grade alignment along the segment. Figure 4 shows the cross-section of the existing alignment. The median alignment was considered difficult to be constructed by authorities because of the 5-8 m pylons (electric poles) on the median of the roadway. The two-way side and curb-side alignment possibilities were studied for this segment. The available right-of-way for the Nagan-Surjani segment is approximately 63 m. The available space provides an opportunity for its utilization as a BRT corridor. Therefore, it is possible to construct two-way and curb-side aligned corridors for this segment. The two-way side aligned right-of-way for BRT would be a feasible option to deal with the pylons and would not reduce the width of lanes for general traffic. One major benefit of this alignment could be that it would increase accessibility for one side of commuters. The possibility of providing a curb-side alignment is also shown in Figure 4.

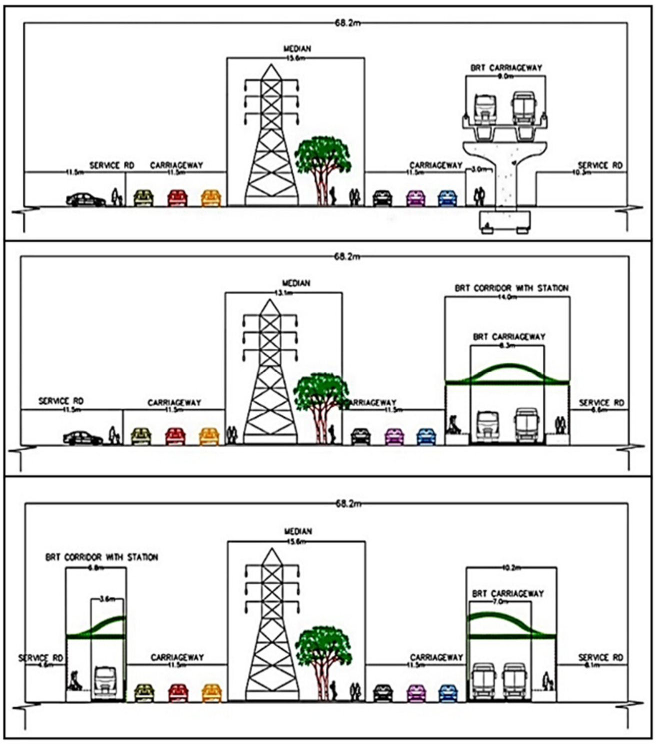

Fig. 4. Nagan-Surjani cross-section with existing elevated alignment (top), proposed two-way side alignment (middle), and curb-side (bottom).

D. Existing and Proposed Intersections

The existing infrastructure of BRT has grade separation at intersections. The intersection on the BRT route must be treated so that its capacity is not affected at the intersections. The two possible ways to deal with intersections, while maintaining sufficient capacity of the corridor, could be signalized intersections with bus priority and grade separation. Signalized intersections may cause delays to the general traffic as well as the BRT. Therefore, it is proposed that all major intersections should be grade-separated along the corridor, leaving its capacity unaffected.

VI. PROPOSED OPTIMAL ALIGNMENTS

The Surjani-Nagan segment was identified as one of the most expensive segments of the Green BRT line. The detailed evaluation of the corridor also showed that this is the segment with the highest potential for cost optimization. Table III shows that providing an at-grade carriageway for this segment could reduce its cost by USD 14.36 million. The possible cost saving by providing a median-aligned busway in the section of Gurumandir to Golimar could be USD 6.69 million. However, reducing the right-of-way for general traffic could adversely affect the travel time and speed of other vehicles.

TABLE III. ALTERNATIVE BRT BUSWAYS

Parameters	Nagan to Surjani		Gurumandir to Golimar	
	Existing	Curb-side/ Two-way side	Existing	Median
Length elevated (km)	5.86	2.3	2.8	1.02
Length at-grade (km)	0.51	4.01	0.4	2.17
No of elevated stations	8	1	4	1
No of at-grade Stations	2	9	-	3
Intersections	Elevated	Elevated	Elevated	Elevated
Accessibility	Low	Medium	Low	Low
Effect on general traffic carriageway	-	-	-	Reduction in ROW
Effect on capacity	-	-	-	-
Cost (USD Million)	37.26	22.9	17.47	10.78

TABLE IV. COMPARISON OF EXISTING WITH OPTIMAL ALIGNMENTS

	Existing Green-Line	Alternative 1/2 Green-Line	Alternative 3 Green-Line
Surjani-Nagan	Elevated	Curbside/Two-way side aligned Green-Line	Curbside/Two-way side aligned Green-Line
Nagan-Golimar	Median	Median	Median
Golimar-Gurumandir	Elevated	Elevated	Median
Percent elevated	58	38	28
Percent at-grade	42	62	72
Cost (USD million)	75.12	61.02	54.33

The two-way side-aligned busways from Surjani to Nagan were the most suitable and feasible. They can significantly decrease cost without affecting capacity along with making BRT stations more accessible to users. Although the curbside alignment has an almost similar cost, it may not be feasible, as the transition from the curbside alignment (Surjani-Nagan) to the median aligned segments (Nagan-Golimar) may increase cost. Two elevated flyovers are required to join both sides of the curb-aligned to the median, but for the two-way side alignment, it could be possible to use a one-sided elevated flyover. Table IV shows the difference in cost between the existing and proposed alignments. Increasing the proportion of elevated segments in the corridor causes a significant increase in cost. As the existing corridor is 58% elevated, it increased the total cost by USD 14.1 million in comparison with the proposed two-way side alignment.

VII. CONCLUSIONS AND RECOMMENDATIONS

Several BRT projects have been initiated in Pakistan during the past decade. The evaluation of the cost of BRT projects in Pakistan and its comparison with BRT systems around the world reveal that those constructed in Pakistan offer comparatively lower capacity and utilization. Due to high construction and operational cost and unjustified delays, the economic impact of the BRT projects has increased. Uneven city planning and local conditions often cause delays in the construction of these megaprojects. Due to the high demand for sustainable and affordable means of transport, the need for mass transit projects is also increasing in a developing country like Pakistan.

Green-Line was the first BRT project started in Karachi. Construction of the infrastructure for the Green-Line BRT was delayed and caused a significant increase in its initial estimated cost of PKR 25 billion. This research investigated this project in detail to evaluate the potential for cost optimization. The proposed Green-Line BRT alignment consists of 58% of elevated sections, which have the highest cost among all possible alignments. Detailed field surveys were conducted to examine the feasibility of other possible alignments, such as curb-side, median-aligned, and two-way side aligned BRT infrastructure. The capacity of each of the proposed alignments was also evaluated, and it was concluded that by designing the Nagan-Surjani segment using a two-way side aligned option, the existing cost of this section could have been reduced from USD 75 million to USD 61 million, which is a 20% saving on the original cost without compromising the system's capacity. Planners and policymakers should investigate the alternatives in detail to optimize the cost. The efficient at-grade BRT with the same capacity is still an option for developing countries where the primary need is to invest resources most optimally. This solution could also benefit the government to consider various strategies to alleviate the huge investments in the construction of mega transportation projects.

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