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Analyzing Route Segment Performance Based on Multiple Indicators Using DEA: A Case Study on Ahmedabad BRT

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Abstract: It's important to calculate reliability as an index to measure the service level of public transportation. However these service reliability metrics can't account for spatio-temporal dynamics. Further, a comprehensive measure that can isolate inefficient location and temporal zones is necessary to strategize preventive measures. In this paper, authors analyzed the service reliability of Ahmedabad BRT across both space and time by diving the route into stop to stop level segments. Subsequently, a relative performance measure for a particular route which incorporated multiple metrics was obtained using data envelopment analysis (DEA). Measures including average travel time and peak deviation were used in this analysis. Based on the scores for each segment, the underperforming locations were identified and ranked. Finally, the DEA scores were compared against BTI to demonstrate its non-triviality and uniqueness. When the segments were ranked according to DEA and BTI, it that DEA indicated distinct ranks. Such DEA analysis can be used when interaction between factors contributing to reliability is unknown.

Keywords: BRT, Route Performance, DEA, Service reliability, Buffer time

1. INTRODUCTION

To counter increasing private vehicle usage, many developing countries are exploring ways to improve their public transportation. In developing nations, automobile ownership has drastically increased due to economic growth and rising population. Hence the local transport governing agencies are being careful in using suitable technologies and transport systems to smoothen the urban commute and improve sustainability by encouraging public transportation. One of such systems is the Bus Rapid Transit (BRT) which gained considerable attraction and is already being implemented in many developing countries like India due to its less initial investment.

However, some of the cities which operate BRT affected by travel time variability. Fergyant (2015) pointed out that intersections are mainly affecting the performance of BRT in Jakarta. Ankit et al. (2017) revealed 3% early arrival, 41% delay arrival in the operation of Ahmedabad BRT system, India. Though BRT are very efficient in terms of travel time compared to the conventional bus system, they are still bottle necked by intersections where they share the common lane with other traffic. To analyze running performances of a bus, run time adherence can be directly used to validate against a scheduled time table. However, the time tables are generally updated occasionally in spite of traffic conditions changing very dynamically. This effect is profound in developing countries due to increasing motor vehicle usage every year. In such cases, buffer time index is suggested which accounts for the measure of deviation from the mean value. Considering the diurnal variation of BTI, the data was first divided according to time segments and BTI was obtained for each time segment. Further, segment having only low BTI was considered for further inspection.

One needs to identify the locations contributing to the low BTI. To this end, whole route was divided into bus stop to stop level segments and BTI was further evaluated from each segment. Though, the whole route can be evaluated based on BTI, there are scenarios were such evaluation needs multiple variables. More specifically, a single aggregate indicator which takes multiple variables into account is desirable to strategize preventive measures. To develop such an indicator, we adopt data envelopment analysis (DEA) which is conventionally used to calculate relative efficiency of multiple variables. Specifically, we calculate DEA efficiency scores of all stop to stop level segments of a specific route based on multiple attributes. Finally, such scores are compared with BTI values.

2. RELATED WORK

The run-time performance indicators of the buses were very well studied in the past. To calculate service reliability measures from travel time data, buffer index, planning time index, percent variation, percent on-time arrival were suggested (report, 2003, Lomax,2003, Transit capacity and Quality of Service Manual (TCQSM)). The metrics measure the extent of overall travel time variation, one of important indicators of service reliability. Generally, travel time variations are very dynamic in nature varying across both space and time. Additionally, only a few locations at specific times of the day contribute significantly to the overall poor performance. To this end, it is necessary to identify such abnormal locations and time zones to formulate preventive strategies. With the advent of automatic vehicle location (AVL) systems, spatially analyzing the bus performance became possible. MIT, comprehensively laid out the framework for analyzing the GPS data. Many papers, with the help of probe data evaluated reliability measures at different spatial abstractions. For instance, Cristian (2011) systematically monitor average commercial bus speeds at route level and segment level for different time zones. Chen (2009) analyzed the reliability measures at route, stop and network level. Specifically, for BRT, Ehab (2015) considered the effect of various policies on the service reliability.

Ankit (2017) evaluated the route performance of Ahmedabad BRT, both spatially and temporally. They also gave spatial analysis of a route by dividing it into segments and analyzing TTV, coefficient of variation for each of the segments. Though, most of these papers spatially evaluate multiple reliability measures, very limited effort has been made in giving an measure which considers deviation of peak hour characteristics for each segment. On the other hand, DEA has been successfully used as a relative performance measure in different fields (Liu, 2013). It has also been used to compare and identify inefficient routes (Lin, 2009). However, limited research exists on identifying badly performing location of a single route that affect the reliability. To this end, authors adopt DEA to evaluate efficiency of each segment in terms of the above median velocity and its deviation along with deviation of peak hour characteristics and identify poorly performing segments. Additionally, we also examine the choice of indicators to give better DEA scores.

Table 1. Operation trajectory data

Provider	Ahmedabad Municipal Corporation
Data attributes	Time, bus number, latitude, longitude and speed
Duration	October 1st to 31st 2016 (1 month)

3. CASE STUDY: AHMEDABAD BRT

Ahmedabad is the seventh largest metropolis in India and is projected to have 1.7 million population by 2050. Its motor vehicle ownership is increasing by 40% every year. Its BRT is operating at coverage 97 km (see in Figure.1) with 250 buses and about 1.35 lakhs average passengers per day. It is a semi-closed BRT system having the routes characteristics tabulated in Table 1. Further, most of the BRT tracks have a dedicated bus zones with bus stations and busways being located on the median. It also has an implementation of pre-board fare collection system. Each bus station maintains the recommended 40 meters from the intersection and has a high-level platform minimizing the boarding time. It was one of the successful BRT service in the world handling 1.35 lakh population per day. The route map of Ahmedabad BRT is showing Figure 1. However, a decline in the utilization ratio was recently reported which probably is due to poor reliability (Times of India). To improve the services, it is important to robustly identify the locations that are causing the problem.

4. MATERIAL AND METHODS

4.1 Data Collection

The data set consisting of GPS logs from October 1st to 31st in 2016 covering all the routes provided by Ahmedabad Municipal Corporation is shown Table 1. The data included time, bus number, latitude, longitude and speed for all the operating routes. However, data was not complete with number of missing trips. Only routes with considerable amount of data was used for further analysis. All the codes were written in MATLAB while QGIS, google earth and Microsoft EXCEL were used for data visualization assistance.

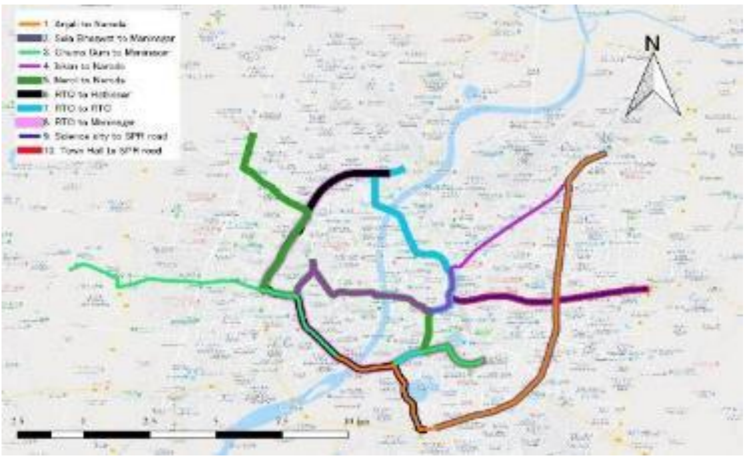

Figure 1. Ahmedabad route map

Table 2. Route characteristics of Ahmedabad BRTS

No.	Origine to Destination	Route length	Number of bus stop	Number of mix traffic lane	Trips extracted
1	Anjali to Naroda	21.2	34	30	981
2	Sola Bhagwat to Maninagar	21.9	35	42	447
3	Ghuma Gum to Maninagar	21.5	30	38	1867
4	Iskon to Naroda	20.9	34	44	537
5	Narol to Naroda	15	24	19	1565
6	RTO to Hatkesar	21.8	30	29	777
7	RTO-Anjali-RTO	24.1	38	31	334
8	RTO to Maninagar	18	26	44	503
9	Science city to SPR road	20.8	30	38	374
10	Town Hall to SPR road	10.9	18	28	325

4.2 Methodology

To improve service reliability, data was preprocessed to separate different routes. Routes were divided into 25 m grids and grid numbers of all the bus stations were extracted. Further, all the GPS logs were mapped with the corresponding grid number. Based on the grid number, arrival time of all trips of buses at each station were extracted. Now, time was divided into multiple time segments respecting the diurnal travel characteristics observed in a day. Once they were divided, BTI was calculated according to

$$Buffer\ time\ index\ n = \frac{T_{95} - T_{ave}}{T_{ave}} \tag{1}$$

Where,

n : Time /spatial segment,

T_{95} : 95th percentile of travel time of route n and,

T_{ave} : Average travel time.

It was evaluated to measure the extent of fluctuation from the average travel time in each time zone. Now, the whole route was further divided into stop to stop level segments and median

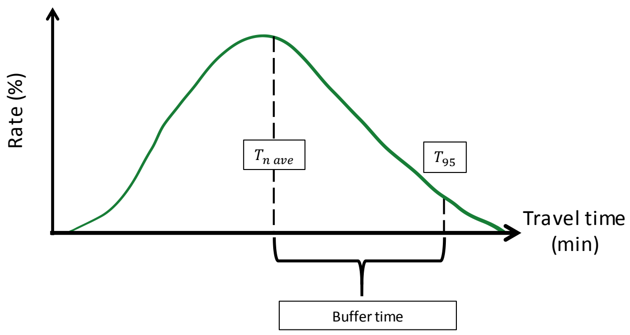

Figure 2. BTI visual representation

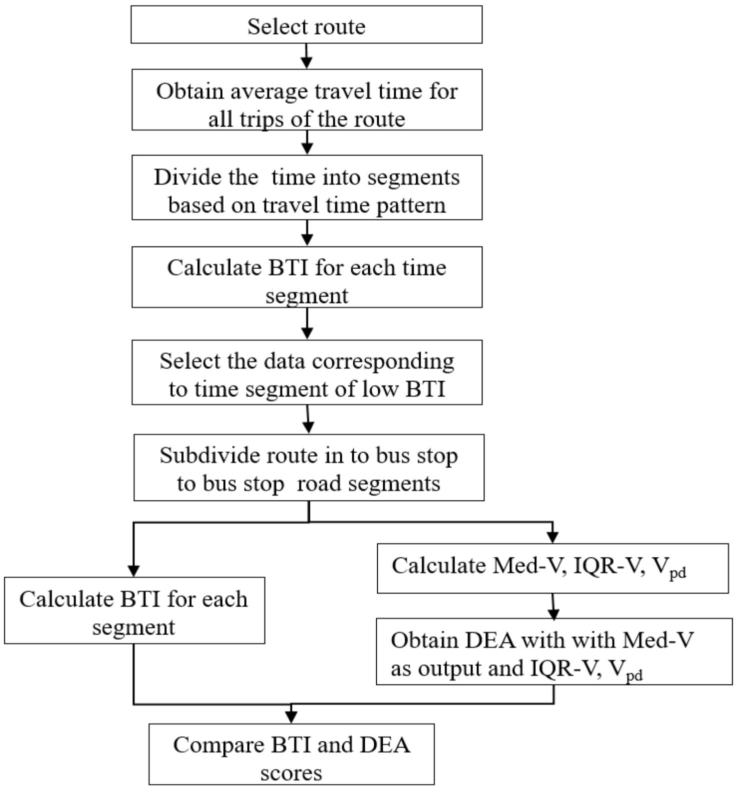

Figure 3. Flowchart of the methodology

velocity (Med-V_i), IQR, and average velocity peak deviation (V_{pd}) were calculated for each segment according to:

$$Med-V_{(i,j)} = \frac{Med-T_{(i,j)}}{d_i} \tag{2}$$

$$Med-T_{(i,j)} = Median\left\{T_{i,j,k} - T_{i-1,j,k}\right\}_{k=1}^{N} \tag{3}$$

$$V_{pd} = V_{i4} - \left[\frac{v_{i1} + v_{i2} + v_{i3} + v_{i5}}{4}\right] \tag{4}$$

$$IQR = Q3 - Q1 \tag{5}$$

Where,

$$Segment\ number(i) = 1, 2, \ldots, 3,$$

$$Bus\ trip\ number(k) = 1, 2, \ldots, 3,$$

$$Time\ zone(j) = 1, 2, 3.$$

Each of these metrics capture unique information and depending on the type of analysis, data can be validated against them. However, in a relative performance measure which includes multiple such indicators is more efficient in certain cases. To this end, we us DEA to obtain the relative performance measure described in the next section.

4.2.1 DEA analysis

DEA calculates relative performance of each individual efficiency among the groups of interest. It has been successful applied in domains such as the medical field, agriculture and transportation industry, etc. Each individual segment whose performance is to be measured is labelled as decision making unit (DMU). The DMU unit which uses lesser inputs and generates larger outputs is more efficient. In other words, the task is to find the set of coefficients (u's and v's) that will give the highest possible efficiency ratio of outputs to inputs for the DMU being evaluated which are optimized based on linear programming. To make for relative ratio of virtual input and output to be less than or equal to one, CCR variant of DEA was used. The mathematical formulation for DEA is as follows:

$$\text{Objective function:}\quad \max\theta = u_1 y_{1o} + \cdots + u_s y_{so}$$

$$\begin{aligned} \text{Constraint expression:}\quad & u_1 x_{1o} + \cdots + u_m x_{mo} = 1 \\ & u_1 y_{1j} + \cdots + u_s y_{sj} \le v_1 x_{1j} + \cdots + v x_{mj} \\ & \qquad\qquad (j = 1, \cdots n) \\ & u_1, u_2, \cdots u_m \ge 0 \\ & v_1, v_2, \cdots v_s \ge 0 \end{aligned} \tag{6}$$

Where,

$v_1, v_2, \cdots v_s$	: Weight of output items
$u_1, u_2, \cdots u_m$	: Weight of input items.
θ	: Considered as DEA efficient scores

DEA framework needs the appropriate choice of input and output variables which shall be described now.

4.2.2 Choice of input and output for DEA

Three main indicators Med-V, IQR-V, V_{pd} were considered for obtaining an aggregate indicator while the information captured by individual indicators being mutually exclusive. V_{pd} especially incorporates the temporal dynamics of bus operation, while Med-V IQR, capture the magnitude and the deviation. On the other hand, DEA assumes increasing outputs are desirable and increasing inputs are undesirable (Lin, 2009). Since IQR and V_{pd} are undesirable, they were set as inputs and Med-V being desirable was set as output.

4.3 Comparison

Validating DEA efficiency scores with respect to indicators not included is not appropriate. To this end, scores were compared with individual indicators to justify their non-triviality. Specifically, the DEA scores were compared with BTI. The performance rankings were evaluated against each other.

5. RESULT AND DISCUSSION

In Figure 4, travel times of all trips were extracted and mapped on to a single day. Subsequently, a moving average with a window of 3 hours was calculated and superimposed on the figure. Route number 3 (up) was selected for critical analysis due to availability of sufficient data. Initially, to the analyse the temporal trends, the diurnal travel time was plotted as shown in Figure 4. Specifically, the travel times of all trips were extracted and mapped on to a single day. Subsequently, a moving average with a window of 3 hours was calculated and superimposed on the figure. We can clearly see 5 groups with different patterns which were divided by horizontal lines. The resulting groups were as follows: 6:00 to 8:30 (morning off-peak), 8:30 to 12:30 (morning peak), 12:30 to 17:00 (inter-peak), 17:00 to 20:30 (evening off-peak), 20:30 to 23:00 (evening peak).

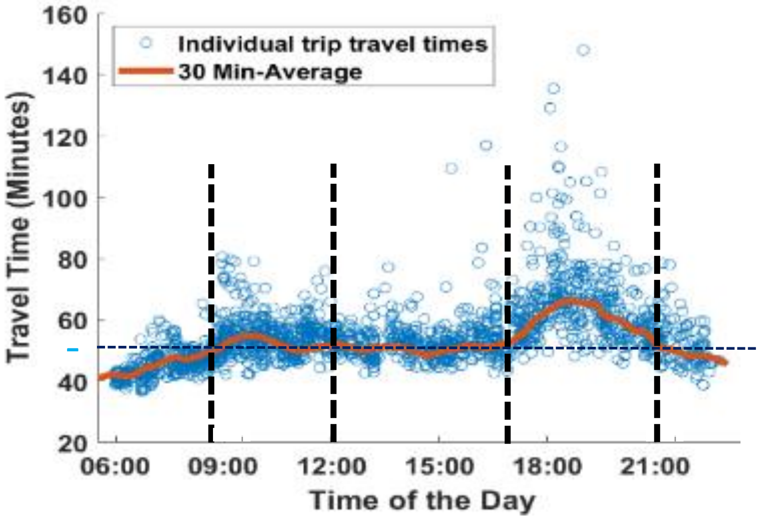

Figure 4. Estimated travel time along route 3 throughout the day.

Further, route wsa divided into 26 stop to stop segments for spatial analysis as shown in Figure 5. Now, buffer time index was calculated for each segment and time zone and visually represented as image contour in Figure 6. It clearly indicates that BTI for time zone 4 is consistently high for most of the segments. This is due to the reason the BRT service reliability as mainly affected by interference with the non-BRT traffic at intersections. To quantify and characterize high BTI values, the performance metrics, Med-V, IQR-V and V_{pd} were calculated according to Equation. (3, 4, and 5).

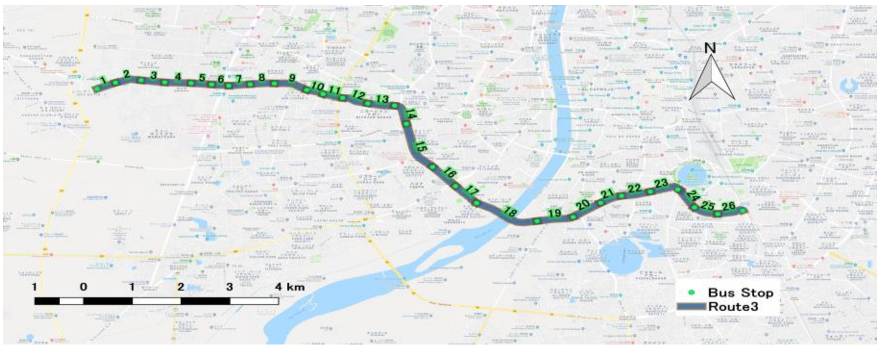

Figure 5. Stop level segmentation of route number 3.

Consequently, DEA was used to understand the relative performance of each segment with respect to these three measures. V_{pd} and IQR-V were used as input and Med-V was used as output as shown in Table 3. Values of DEA scores and BTI of each segment are shown Figure 7. Segment 6, 11 and 10 are poorly performing compared to other segments. Ideally, higher median velocity is associated with small variation while lower velocity corresponds to higher variation. A DMU with the former property will have a good DEA score and latter gets a bad score. In other words, segment 6 with median velocity of 10 km/hr, IQR of 151 seconds and peak deviation of 39 min is underperforming compared to segment 3 with median velocity of of 10 km/hr, IQR of 151 seconds and peak deviation of 39 min is underperforming compared to segment 3 with median velocity of 24 km/hr, IQR of 19 seconds and peak deviation of 3 min. To validate the uniqueness of the obtained DEA scores, they were compared to BTI which also considers multiple variables namely the average value and its deviation. All the segments were ranked based on both DEA scores and BTI values. Further, top 10 segments in terms of best and worst performances were compared in Table 5. DEA indicates that segment 10 is underperforming compared to segment 14 while BTI indicates otherwise. This is probably because of BTI not considering peak deviation. Furthermore, DEA scores were verified with the corresponding traffic conditions and it was observed that segment 6, 10, 11 handle larger traffic volume and resulted in bad scores.

Table 3. Input and outputs of all the segments for DEA

Space	Input		Output	Space	Input		Output
	IQR-V	V_{pd}	Med-V		IQR-V	V_{pd}	Med-V
1	19.095	3.496	24.518	14	53.849	26.311	15.363
2	24.248	4.213	29.012	15	58.578	37.842	22.438
3	13.803	4.107	28.249	16	51.552	17.801	18.219
4	21.853	6.464	28.324	17	37.807	14.847	19.808
5	22.401	4.692	25.514	18	33.922	10.785	30.311
6	151.478	39.350	10.015	19	26.442	11.174	23.005
7	54.000	24.686	13.411	20	36.626	15.200	17.540
8	23.054	5.981	20.795	21	26.916	12.164	17.298
9	40.352	13.066	22.756	22	35.900	16.597	19.173
10	87.746	23.114	12.950	23	42.063	17.857	17.153
11	75.333	25.973	12.516	24	28.777	10.270	15.184
12	31.638	10.183	20.918	25	30.951	16.823	20.013
13	23.830	6.024	22.762	26	25.895	14.980	14.823

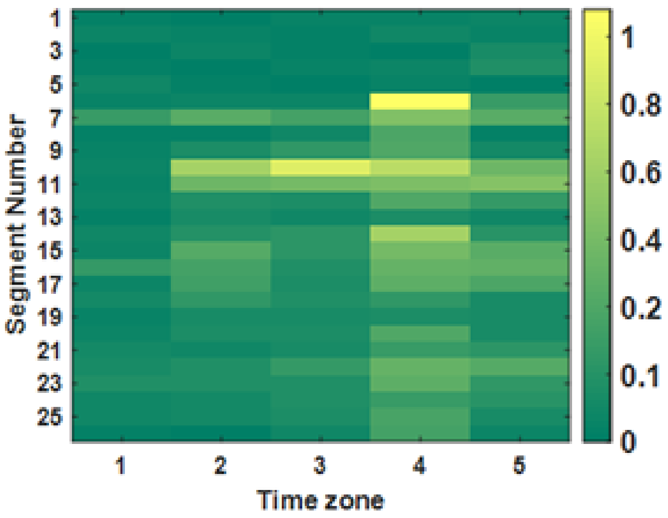

Figure 6. BTI across both space and time

Table 4. Comparing performance ranks according to DEA and BTI

Rank	Top 10 segments according to DEA	Top 10 segments according to BTI	Rank	Worst 10 segments according to DEA	Worst 10 segments according to BTI
1	1	3	1	6	6
2	3	18	2	11	14
3	2	19	3	10	7
4	5	1	4	7	11
5	4	4	5	14	10
6	13	5	6	16	8
7	8	2	7	15	12
8	18	13	8	23	22
9	19	15	9	20	17
10	12	20	10	17	9

6. CONCLUSION

Service reliability is one of the key factors of improving public transportation. However analyzing the inherent metrics is complicated due to the spatio-temporal dynamics of bus diurnal variation. To this end, the authors first selected a route, extracted the data, and identified the peak hour to be 17:30 hrs to 20:30 hrs and that congestion occurred at the busy intersections like shivranjani. Further, the whole route was divided into 26 bus stop to stop level segments and obtained median velocity, its inter-quartile range and peak hour deviation for each segment. Consequently, with suitable selection of input and output choices, DEA was applied to obtain relative performance scores of each segment. Busiest intersections (segments 6, 10,11) had the lowest DEA scores. This was possibly due to larger variation and peak hour deviation of travel time. To demonstrate the significance and make the distinction with the conventional individual metrics, the scores were compared with BTI. As the former involves multiple metrics like the peak hour deviation, it showed a different ranking especially rank number 2 of both worst and best performances of segments. Therefore, it is concluded that the DEA helps to extract and reveal potential factors such as the time and road segment although conventional method was not possible. However, this study did not consider the temporal dynamics of travel time which shall be focused in the future.

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