EVALUATION OF LAHORE BUS RAPID TRANSIT BASED ON KEY PERFORMANCE INDICATORS

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ABSTRACT: The study analysed the bus rapid transit (BRT) system in Lahore based on operational key performance indicators (KPI)compiled into an evaluation framework with reference to international guidelines and standard practices of countries with successful experiences of BRT. The study relied on data obtained from automated data collection system of Punjab Metrobus Authority (PMA). This enabled the research to include complete population and lead to concrete results instead of conducting only sample studies. The raw data was converted into useful information through computer programmes specifically developed for this research. The performance of bus services was measured and compared according to different operational parameters such as Travel Time Savings, Service Reliability, Capacity and Comfort, Safety and Security. Detailed investigations and results were included in the manuscript. The study concluded that the overall situation of bus operations was quite satisfactory, however there are minor weaknesses observed in certain areas such as Schedule Adherence, Headway Regularity and Capacity.

Key words: Bus rapid transit system,key performance indicators, Safety, comfort, schedule adherence.

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INTRODUCTION

Bus Rapid Transit (BRT) is a recent concept which started to evolve, a decade ago and currently in a mature and operational state in developed as well as developing countries of the world. The main concept of BRT was derived from Rail Transit with the difference of roadway in place of railway and buses (normal and articulated buses) in place of train-set. Due to dynamic, flexible and cost effective nature of BRT, many countries gave it preference over Rail Transit. The most successful examples are seen in South America especially Brazil and Colombia where capacity of BRTs are observed as equivalent to Metro Rail.(Hidalgo,2010).

Lahore BRT was built as an inspiration from Istanbul BRT, Turkey. This is first of this kind of Urban Mass Transit project in Pakistan which proved to be a bumper success and is remarkably accepted and appreciated by habitants of the city. The project is built with latest design standards and technology opened a new door for the solution of existing urban transport problems. Lahore BRT, constructed in a record time of 11 months, has served more than 4.6 millions of people since in its first year of operations starting from February 10, 20132014 (PMA, 2014).

The Lahore BRT is not an end rather start of the resolution of urban transport issues. The need of the hour is to expand such facilities into other major cities of Pakistan. Evaluation of Bus Operations of Lahore BRT is required in order to assess its planning, design and operations based on standard international practices, find gaps and lessons learned.

Lahore BRT corridor consists of a 27 Kilometer stretch starting from Gajjumatta in the South to Shahdara in the North. The corridor is segregated, aligned in the middle of the road and dedicated to Metrobuses only. From Canal to Bhaati, 8.3 kilometer of the section is elevated. There are eight intersections equipped with transit signal priority. The system comprises of 27 stations with curb aligned platforms and with average one kilometer of inter station distance.18 meter long articulated buses are used to run the operations. Each bus has a normal capacity of 160 passengers and crush capacity of 239 passengers. The buses operate at a frequency of 2.25 to 2.5 minutes in the peak hours and 4 to 6 minutes in the off peak hours serving an average daily ridership of 125,000 to 150,000 passengers. (PMA, 2014)

MATERIALS AND METHODS

Bus Rapid Transit was evaluated based on various performance measures or Key Performance Indicators (KPI) accepted and practiced internationally. Several organizations formulated and specified KPIs keeping in view the leading BRTs of the world. Federal Transit Administration USA (FTA, 2004) compiled detailed guidelines for evaluation and important characteristics of BRT for decision making. American Public Transportation Association also made BRT

Service Design Guidelines based on certain performance measures (APTA, 2010). World Bank developed a toolkit comprising mainly of benchmarks and indicators, and was designed to help government officials and policy makers evaluate existing and alternative urban bus systems in developing and transitional countries (World Bank Group, 2006). It offered practical advice to enact fundamental system reforms. A significant work was done by Asian Development Bank in form of Tool Kit for Public Private Partnership Projects in Urban Bus Transport in India (ADB, 2006). The toolkits developed by World Bank and Asian Development Bank were concerned more with Urban Bus Transit and not BRT specifically, but could be used for BRT evaluation also.

A lot of useful information in form of research papers and case studies were made available on internet and were used for development of framework for evaluation using automated data collection systems. (Laura, 2006)

PMA in its Service Level Agreements with the Bus Operator has also specified certain performance indicators for evaluation of the operations. These indicators helped the organization in monitoring and maintaining operational quality (PMA, 2014).

After establishing an evaluation framework in the light of aforementioned standards and guidelines, data was collected from PMA archives having time period from April 2013 to December 2013 to measure each KPI as per the established benchmarks. The data consisted of various reports generated by successfully established and globally proven Automated, Bus Scheduling System and Vehicle Location System in PMA. The enormity of the data made the analysis difficult through conventional techniques available. Software modules were made for extraction, compilation and summarization of the raw data to overcome this difficulty. The software modules were utilized after they passed through testing and validation process. The summarized data was then converted into meaningful tables and graphs for presentation. The software modules were developed in Microsoft Excel Visual Basic for Applications (VBA) environment. The selection of this environment gave the added advantages of utilizing various useful feature of Microsoft Excel.

Table- 1: Framework for Evaluation of Lahore BRT,

Sr. No	KPI	DESCRIPTION	MEASUREMENT CRITERIA	BENCH MARK
1	Travel Time Savings	Travel Time Saved by using BRT as compared to previous Transit Service	$TTS = \frac{TTB - TTP}{TTP} x\ 100$ Where:- TTS = Travel Time Savings TTB = Travel Time on BRT TTP = Travel Time on Previous Transit Service	15% – 25 %
2	Service Reliability			
A	Trip Realization	Number of trips completed in comparison to the total trips assigned in a given time period	$\frac{Total\ Trips\ Executed}{Total\ Trips\ Planned} x\ 100$	98%
B	Punctuality	Number of trips started on scheduled time compared with total trips executed in a given period.	$\frac{Trips\ Started\ on\ Time}{Total\ Trips\ Executed} x\ 100$	95%
C	Travel Time Reliability	Number of Trips Completed on Scheduled Time (63 Minutes) compared with total trips executed in a given period	$\frac{Trips\ Completed\ on\ Time}{Total\ Trips\ Executed} x\ 100$	95%
D	Schedule Adherence / On time performance	Number of Bus Arrivals / Departures observed on predefined locations called time points within a specified margin, compared with total observations. The specified margin taken is ± 30% of scheduled headway which works out to be one minute in this study	$\frac{A}{Total\ Observations} x\ 100$ Where:- A = Number of Bus Arrivals / Departures observed within the specified margin at Time Points	85%
E	Headway Regularity	Headway is the Arrival / Departure time difference between two consecutive buses moving in same direction at a specific point Headway regularity is Number of headways observed within specified margin at all stations	$\frac{B}{Total\ Observations} x\ 100$ Where:- B = Number of Headways observed within specified	85%

		compared with total observations The specified margin taken is ± 30% of scheduled headway which works out to be one minute in this study	margin at all stations	
F	Wait Time Reliability	Passenger Wait Time observed within 5 minutes compared with total observations	$\frac{Wait\ Time\ within\ 5\ min.}{Total\ Observations} x\ 100$	85%
G	Fleet Maintenance	Number of breakdowns observed against plied kilometers	$\frac{Total\ Plied\ Kilometers}{Total\ Breakdowns} x\ 100$	>= 20,000
3	Safety	Number of accidents observed against plied kilometers	$\frac{Total\ Plied\ Kilometers}{Total\ Accidents} x\ 100$	>= (10,000 – 60,000)
4	Capacity and Comfort	No of observations at all stations with Load per bus less than 85% of bus capacity (136 passengers) compared with total observations.	$\frac{C}{Total\ Observations} x\ 100$ Where:- C = Number of Observations with load per bus less than 85% of bus capacity at all stations	> 85%

RESULTS AND DISCUSSION

This section presents results and discussion of each KPI, measured and evaluated in the light of established framework, as afore mentioned in Table 1

1. ***KPI No. 1: TRAVEL TIME SAVINGS:*** Travel time saving for Lahore BRT was evaluated by comparison with bus service that existed before the project along Ferozpur Road with a common section starting from Qartaba Chowk to Gajjumatta called route no 9. The bus service had an average peak hour travel time of 62 minutes (JICA, 2010) as compared to Lahore BRT which was found to be 37 minutes only (PMA, 2014). This indicated a travel time savings of 45%. The travel time savings observed in other BRTs of the world ranged from 15% to 25% (FTA, 2004). Compared with international experiences, Lahore BRT demonstrated an extra ordinary high level equivalent to highertravel time and cost savings and reduction in multiple economic costs.

2. ***KPI No. 2A: SERVICE RELIABILITY - TRIP REALIZATION:*** The overall trip realization as per the measurement criteria of the established frame work was worked out to be 98.17% for the study period. A monthly analysis shown in Figure-1 indicated a lower performance level in the start followed by a gradual improvement and then sustenanceat higher level. The benchmark for trip realization mentioned in international guidelines ranged from 95% to 98.5% (ADB, 2011 and WBG, 2013). The adopted benchmark was 98% which was also mentioned in service level agreement between PMA and the Bus Operator. A lower value of Trip Realization in the starting months was linked with reasons such as frequent breakdowns, traffic congestions and organizational weaknesses. However the values in July 2013 and onwards, attained by Lahore BRT, indicated an appreciable come back, well maintained buses, operational efficiency and organizational strength.

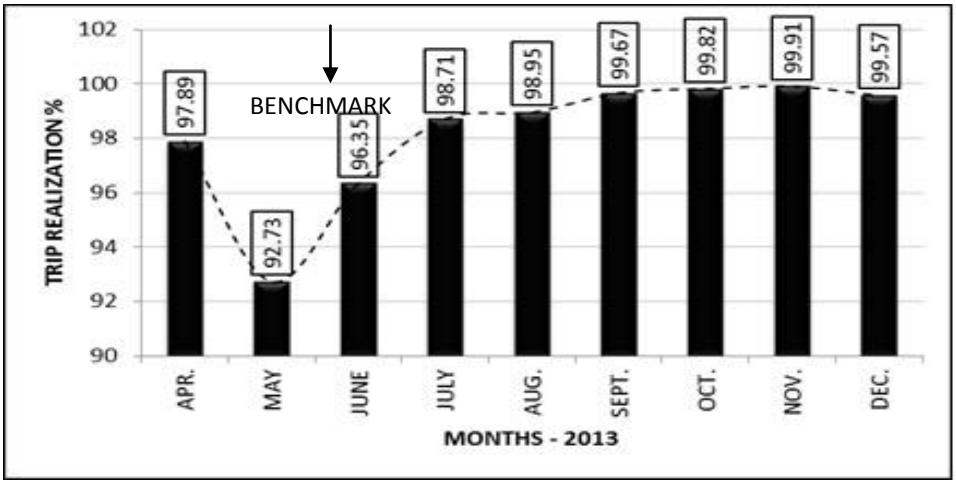

Figure-1: Showing Trip Realization

3. ***KPI NO 2B: SERVICE RELIABILITY - TRIP PUNCTUALITY:*** The overall Trip Punctuality as per the measurement criteria of the established framework was worked out to be 86.59% for the analysis period. The benchmark for trip punctuality mentioned in international guidelines and adopted in the evaluation framework was 95% (ADB, 2011). A monthly analysis is presented in Figure-2. It was noticed that in the starting months till July 2013Trip Punctuality was quit below the benchmark, however August 2013 showed a remarkable improvement followed by achievement of benchmark in the later months. This improvement increased the probability of on time completion of trips and reduced the probability of driver over speeding as a consequence of late trip start. Despite of a lower punctuality in the starting months, the value attained by Lahore BRT in the last five months was 96.6%, indicative of how well the requirement of number of buses was met on the terminals.

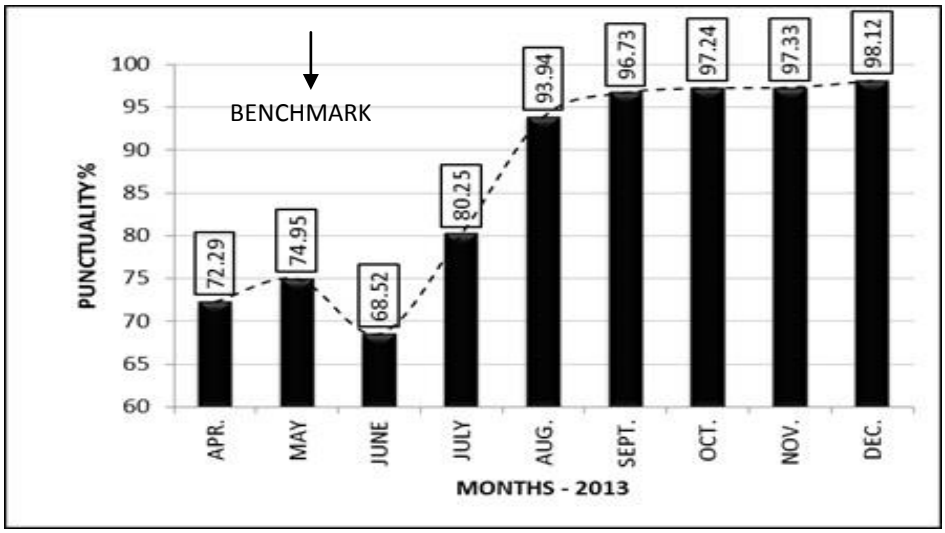

Figure-2: Showing Trip Punctuality

4. ***KPI No.2C: SERVICE RELIABILITY - TRAVEL TIME RELIABILITY:*** The overall Travel Time Reliabilityas per the measurement criteria of the established framework was worked out to be 92.39% for the study period. The benchmark mentioned in international guidelines, PMA Operational Policies and consequently adopted in the evaluation framework was 95% (ADB, 2011). The mean trip time was 59.01 minutes against the schedule time of 63 minutes while standard deviation was 2.65 minutes. This translated to an average travel time of 2.26 minutes per kilometre as compared to other BRT studies which was1.24 to 2.17 minutes per kilometer (FTA, 2004). The total 7.41% late trips were found mainly because of usual traffic congestions faced by Metrobuses on the mixed traffic portion from Niazi chowk station to Shahdara Station through Ravi Bridge. A monthly analysis presented in Figure-3 showed same pattern of lower performance level in the start followed by revival and attainment of the benchmark in later months was noticed in the monthly analysis, as noticed in Trip Realization and Trip Punctuality. The value observed in the last five months was 98.13%, which was quite higher than the Benchmark. The higher values indicated consistency in running time (time consumed by bus in motion only), controlled stay at stations, efficient performance of Signal Priority Systems installed on intersections and good maintenance of buses.

5. ***KPI No. 2D: SERVICE RELIABILITY - SCHEDULED ADHERENCE / ON TIME PERFORMANCE:*** The overall Schedule Adherence as per the measurement criteria of the established framework was worked out to be 38.5% for the study period (Figure-4). Schedule adherence was observed at specific locations called time points as per international guidelines (TRB, 2002). The margin adopted was -1 to 1 minute. Three time points were selected for measurement of schedule adherence namely Chungi Amer Sidhu, Qaddafi and Civil Secretariat Stations. The benchmark consulted and adopted from international guidelines was 85% (APTA, 2010). As compared to the benchmark, schedule adherence was found quit low i.e. 38.5% only. Out of total trips, 49.7% were found ahead of the schedule or early while only 11.8% were found late. There were several reasons for such large percentage of early trips. These included drivers intention for an early completion of the trip to get more layover time at terminals, absence of possible traffic delays on mixed flow portions incorporated in the scheduled trip time, lack of driver's training and optimization of station to station schedule time. The 85th percentile was found within the time difference window of -4.2 to 0.2 minutes indicative of driver's tendency of departing early from the time points. This tendency was found dominant in

southwards direction as compared to northwards direction. This was primarily due to early encounter of mixed flow traffic portion from Shahdara to Niazi chowk Station during traffic off-peak hours which drivers completed earlier than the schedule time and then continuation of trip as it was without attempting to adhere to schedule through established strategies such as decreased running speed or increased stay time at stations called holding. A monthly analysis of schedule adherence revealed no significant improvement with passage of time, unlike other KPIs as discussed earlier. The schedule adherence computed represented lack of driver's training, weak control, organizational inefficiency, increased probability of irregular headways/frequency of buses and resulting excess passenger wait times at stations.

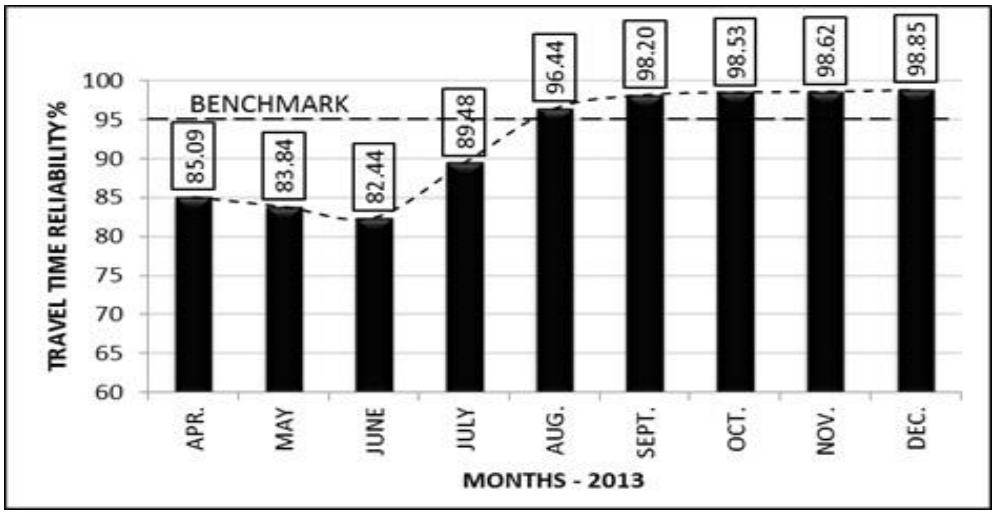

Figure-3: Showing Travel Time Reliability

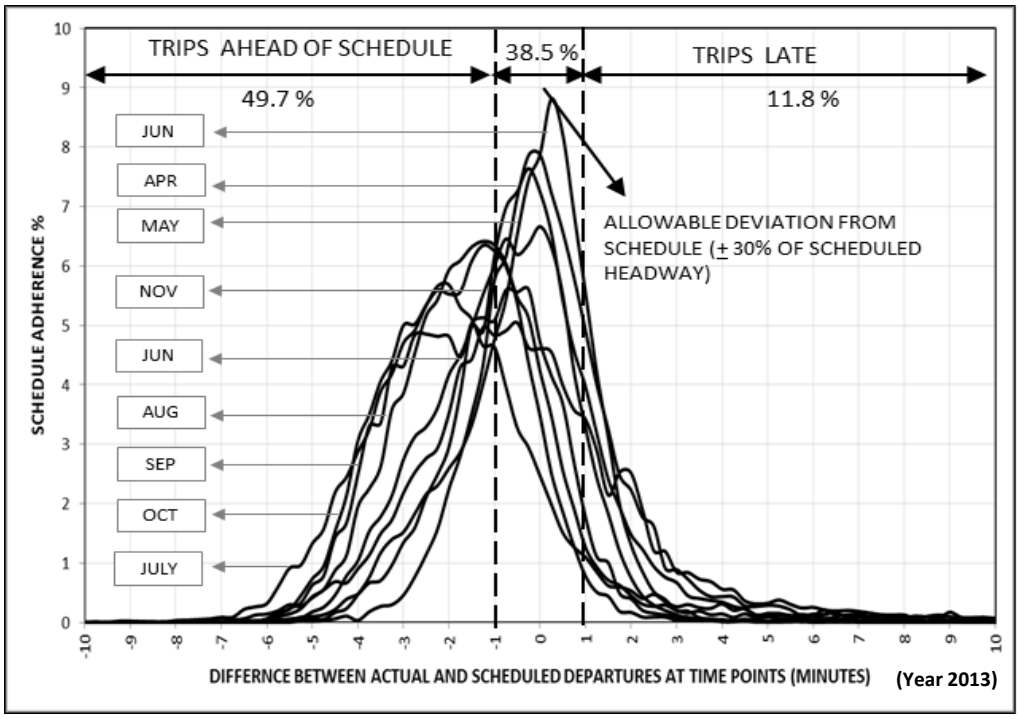

Figure-4: Showing Schedule Adherence

6. **KPI No. 2E: SERVICE RELIABILITY - HEADWAY REGULARITY:** The overall Headway Regularity as per the measurement criteria of the established framework was worked out to be 57.4% for the study period as shown in Figure-5.The benchmark consulted and adopted from international guidelines was

85% (APTA, 2010). As compared to the benchmark, Headway Regularity was found low. 22.1% of trips observed at all stations were found with headway lower, while 20.5% of the trips were found with headway higher than the scheduled headway i.e. 3 minutes. The major reason could be attributed to lower schedule adherence resulting in uneven headways. Headway being a function of schedule adherence did not show value as low as observed for schedule adherence. This was primarily because all drivers showed more or less same trip time pattern resulting in lesser deviations in headways between them as compared to scheduled times. The mean headway was found to be 3.13 minutes with standard deviation as 1.68 minutes. As these observations were not very far from the scheduled headway, resulting operational disturbances were not substantial. During a monthly analysis of headway, it was noticed that headway regularity remained almost same throughout the months and no significant improvement or directional variation was observed. A lower value of headway than the established benchmark indicated uneven arrival of buses at stations which represented operational non-control, inefficiency, lack of driver's awareness, and underutilized available technology including Bus Scheduling System (BSS) and Intelligent Transportation System (ITS).

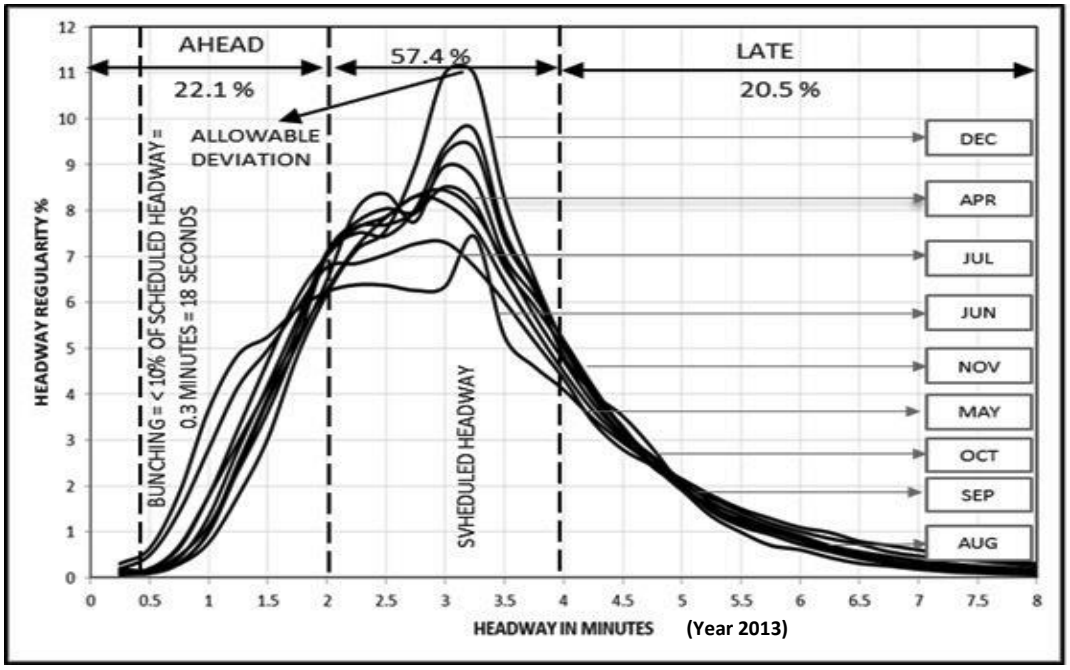

Figure-5: Showing Headway Regularity

7. KPI No.2F: SERVICE RELIABILITY - WAIT TIME RELIABILITY: The overall Wait Time Reliability as per the measurement criteria of the established framework was worked out to be 90.2% for the study period as shown in Figure-6. According to the guidelines, high frequency BRT systems i.e. less than 5 minutes had given passengers an impression of service availability at any station without delay (FTA, 2004). This resulted into a maximum wait time of 5 minutes in order to ensure a reliable service and was used as measurement criteria with a minimum percentile of 85. As compared to the benchmark, Wait Time Reliability was found to be quite satisfactory. Only 9.8% of the passengers were found who had to wait for the bus service for more than 5 minutes. The mean time computed was 1.4 minutes with a standard deviation of 1.8 minutes. The directional variability was found to be insignificant. The performance was observed to be matching when analysed on monthly basis. As discussed earlier, Headway Regularity was found quit less than the benchmark. However still, Wait Time achieved the required compliance mainly due to the reason that overall deviations in headway were not far from the scheduled headway. The distribution in Figure-6 showed wait times ranging up to 15 minutes. Larger wait times were due to operational disturbances by factors including traffic blocks at mixed flow portions, strikes, bus breakdowns, unusual and temporary increase in daily ridership demand and bus overloading. Wait Time Reliability as 90.2% indicated service reliability and passenger satisfaction. This outcome of Lahore BRT was found unmatchable with any other bus service of the city and played a pivotal role in earning a reputation of highly reliable service.

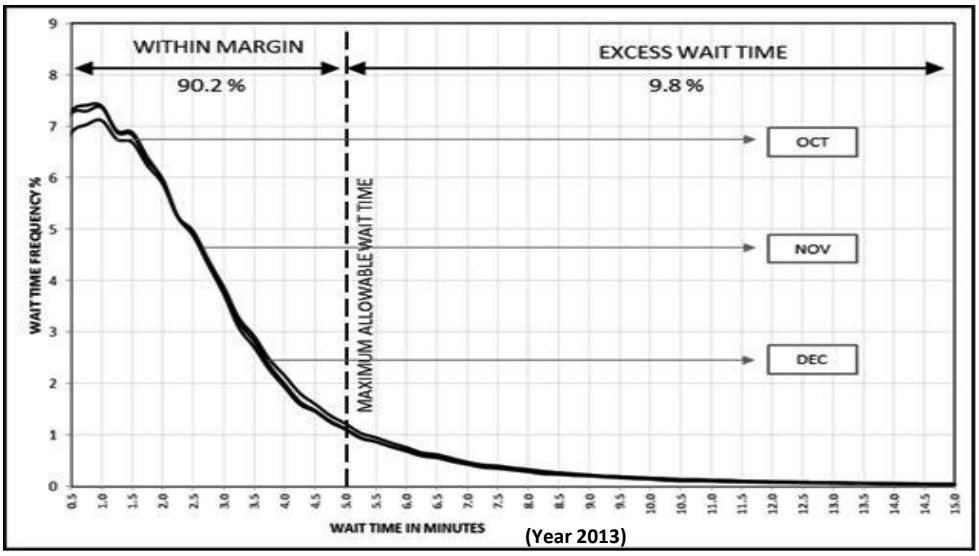

Figure-6: Showing Wait Time Reliability

8. **KPI No.2G: SERVICE RELIABILITY - MAINTENANCE:** The overall Maintenance performance in terms of kilometres per breakdown as per the measurement criteria of the established framework was worked out to be 45,229 Kilometres per breakdown for the study period. The benchmark established for this KPI was 20,000 Kilometres per breakdown (WBG, 2013). Values lower than the benchmark indicated poor maintenance of buses resulting in increased number of breakdowns and hence lesser kilometres plied by buses per breakdown. The performance level of Lahore BRT against the benchmark was evidently quite high. This indicated very good routine checking and maintenance of buses, timely repair and replacement of spare parts, efficient maintenance schedules, adequate technical strength, timely investments on buses and well-designed bus specifications. A monthly analysis performed and shown in Figure-7 revealed that maintenance achieved the required benchmarks except in months of June and July where kilometres per breakdown were only 7,007 and 11,450 respectively. These were the months of peak summer season where buses experienced continuous engine heat-up issues and frequent breakdowns. The implications could also be observed in lower performance of Trip Realization and Punctuality in the same months presented earlier as shown in Figure-1 and Figure-2. The issue was taken immediately and resolved on war footing basis. The retrieval of the performance level in the next months was an evidence of organizational commitment and efficiency which was highly appreciable.

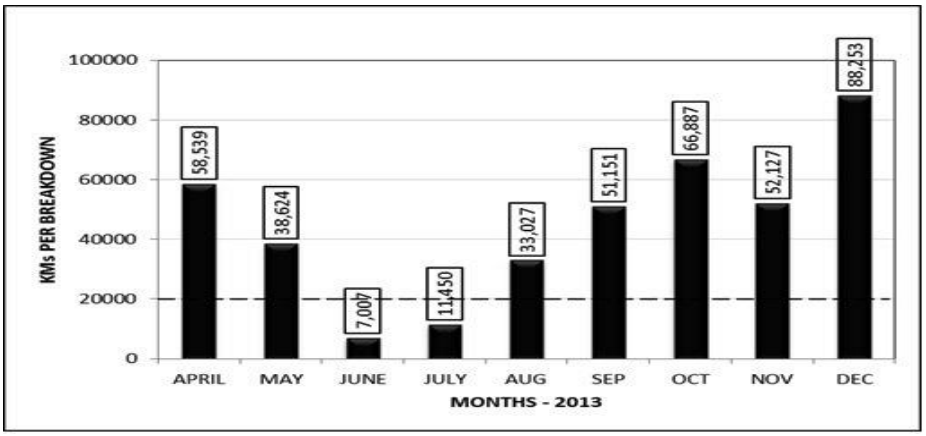

Figure-7: Showing Maintenance of Buses

9. **KPI No.3:SAFETY:** The overall Safety performance in terms of kilometres per accident as per the measurement criteria of the established framework was worked out to be 390,567 Kilometres per accident for the study period. The benchmark established for this KPI was 10,000 –60,000 Kilometres per accident (WBG, 2013). Values lower than the benchmark indicated poor and unsafe driving, over speeding, lack of driver's

training, and unattended safety measures. The performance level of Lahore BRT against the benchmark was extra ordinarily high. This indicated organizational awareness and commitments regarding passenger safety, proper safety procedures adopted for routine maintenance of buses, efficient and experienced drivers, increased passenger satisfaction and service reliability. A monthly analysis performed and shown in Figure-8 revealed that performance level achieved the required benchmark in all months with no accidents observed in the months of April, August and September. Moreover more than 98% of the accidents had no passenger injury and were found to be of minor nature.

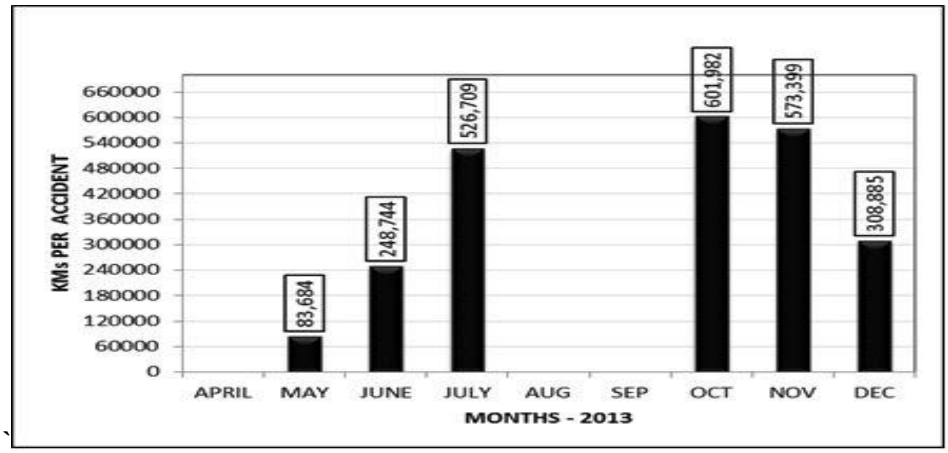

Figure-8: Showing Safety

10. **KPI No.4: PASSENGER COMFORT:** The overall Passenger Comfort as per the measurement criteria of the established framework was worked out to be 85.16%as shown in Figure-9 for the study period. The bus capacity was 160 passengers and passengers per bus were evaluated at each station. Buses found with passenger count up to 85% of the bus capacity or 136 passengers were considered to have passenger comfort and the benchmark established was 85th percentile of buses that established this criterion (ITDP, 2004). Values lower than the bench mark indicated discomfort, bus overloading, increased travel times, reduced reliability, passenger dissatisfaction and ridership loss. Lahore BRT showed full compliance with the required benchmark. Only 14.84% buses were found to have non-compliance or passenger discomfort. Overloading (passenger count more than 160) was found to be 4.25% which was insignificant. Moreover overloading was not observed throughout the study period except in certain corridor sections and hours. A lower percentage of overloaded buses represented maintenance cost saving and improved vehicle life. The KPI value attained by Lahore BRT indicated comfortable trip journey, adequate number of operational buses, demand compliant operational capacity, passenger acceptance and satisfaction with the facility and good operational planning. A monthly analysis revealed persistent results throughout the study period showing maintained service quality and reliability.

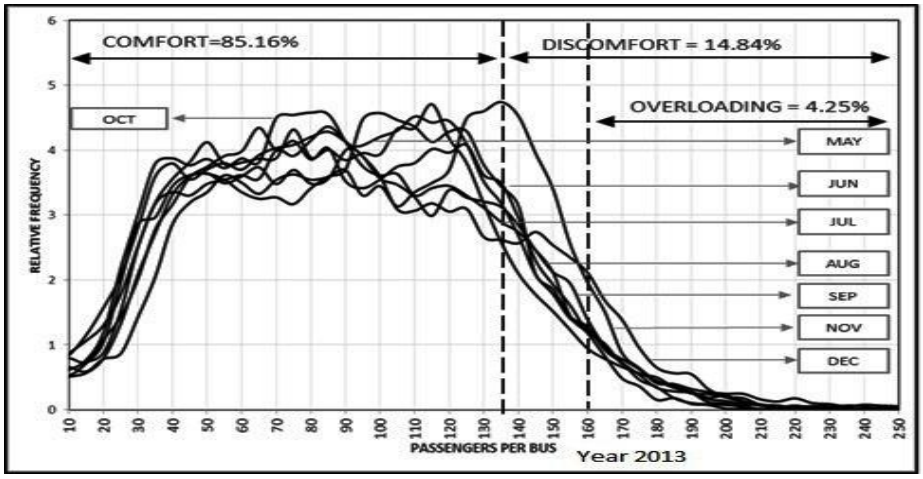

Figure-9: Showing Comfort

Conclusions: Lahore BRT is the first BRT in Pakistan and has not only revolutionized the transport sector but has also opened new dimensions for the resolution of travel demand issues. Lahore BRT is one of its own kinds of project having hi-tech and modern technology comparable to any best BRT of the world. The evaluation processhas revealed certain weaknesses in certain aspects, however weaknesses should be treated as lessons learned and efforts should be made to overcome these problems and build next BRTs with the aim of achieving higher quality standards.

Recommendations: Major weaknesses highlighted in operations are Schedule Adherence and Headway Regularity. Despite of this, the resulting increase in passenger wait times were not large enough to cause passenger dissatisfaction. The weakness can be overcome by special drivers training and enforcements, new operational strategies such as "Holding" in which drivers stay at time points without causing disturbance to passengers in case they are ahead of the schedule and re-evaluation of time schedules.

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