DELHI BUS CORRIDOR: AN EVALUATION

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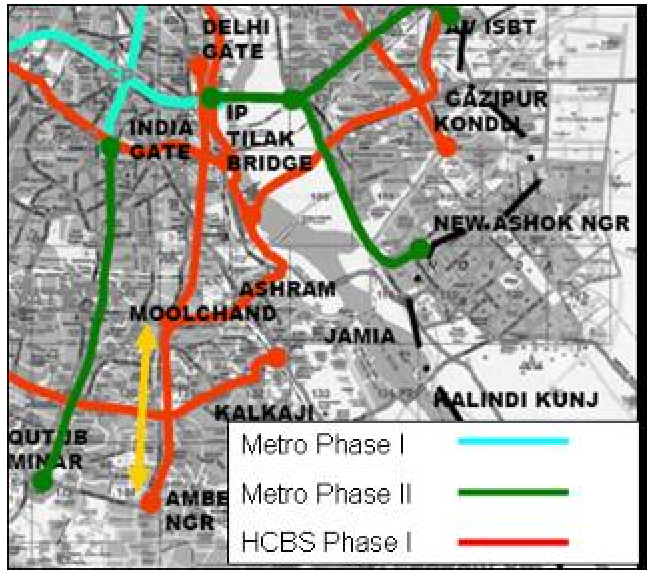
INTRODUCTION



The initial 5.8 Km of the Bus Corridor in Delhi became operational on April 20th 2008. The facility stretches from Moolchand to Ambedkar Nagar along JBT Marg in South Delhi. The corridor infrastructure consist of single median lanes for buses with physical segregation and double platform bus stops located close to the intersections; two lanes for general traffic; and bikeways and sidewalks on the two sides. The general traffic lanes flare at the intersection to provide an additional lane for turning movements.

Bus operations include 57 different routes operated by Delhi Transport Corporation – DTC (a public company owned by the Delhi Government), and private operators (Blue Line Buses) under permit by the Secretary of Transport STC. Company and school buses are required to use the bus lanes[1].

The corridor can be described as an open system, i.e. bus routes enter and leave the corridor along its way. Operations do not have centralized control.

The corridor ran with some difficulties during the first weeks. Some of the main problems observed were[2]:

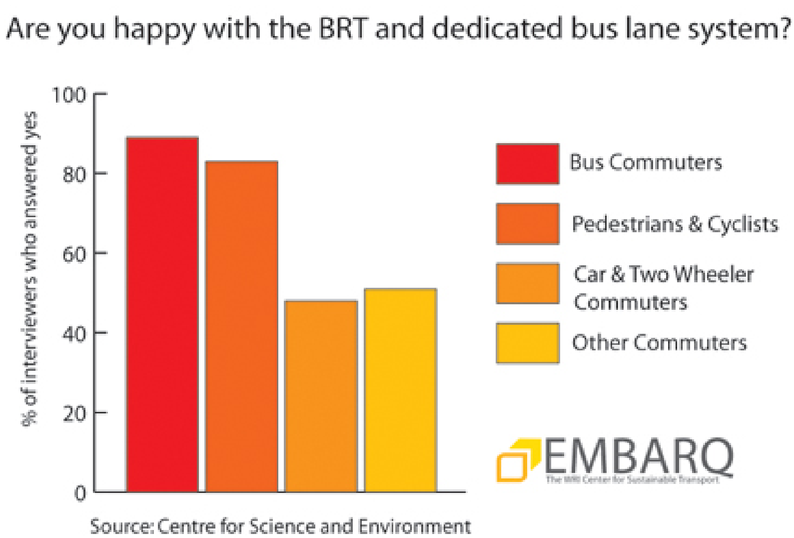
- The traffic signals did not work properly - there were difficulties translating the signal timing plans on paper to the traffic controllers;
- Queuing in the general traffic lanes was extensive;
- A high number of bus breakdowns in the bus lane was observed;
- Drivers lacked adequate training –used wrong platforms, stopped several times;
- There was a lot of encroachment from motor vehicles and two wheelers in bus lanes;
- Users were not adequately informed where to board the buses; and
- Pedestrian crossed the bus and general traffic lanes in unauthorized places (jaywalking).

[1] School buses are allowed to go to the curbside lanes to enter colonies.
[2] Visit to the corridor, April 30th, 2008.

Delhi Integrated Mass Transit Systems – DIMTS-, which is in charge of of the corridor operations, rapidly responded by deploying additional wardens and reviewing the signal plans for the traffic control devices. Having the additional traffic wardens helped providing instructions organizing the traffic flows, and enforcing violations.

The initial difficulties received wide media coverage, specially focused on the problems for motor vehicle users and accidents. As a result, the initial public perception of the project was bad. Moreover, the debate became politicized, with the opposition attacking the government on the grounds of botched implementation of the bus corridor.

Despite the negative perception reflected in mass media outlets, the corridor users had a different opinion. A survey by the Centre for Science and Environment (CSE) in June 2008 reflected a very positive view by bus commuters (88%), pedestrians and cyclists (85%), and a fair perception by car and two wheelers (45%) and other commuters (50%).



The discussion of the benefits and problems of the corridor has been mostly based in perceptions and prejudices, rather than technical evaluations. The debate has not contributed to the improvement of the current operations and the definitions regarding the expansion of the concept to other corridors in Delhi. The negative image of the corridor has affected the development of bus rapid transit (BRT) solutions all over India.

With the purpose to contribute to the bus corridor improvement CSE decided to facilitate an independent evaluation of the bus corridor. *EMBARQ* experts, Dr. Dario Hidalgo and Madhav Pai, were appointed as external reviewers and received support from the ClimateWorks Foundation and EMBARQ Global Strategic Partners, the Shell Foundation and the Caterpillar Foundation to complete this task.

CSE provided support thought the evaluation, including the facilitation of meetings and interviews with relevant stakeholders and site visits; as well as presentations to the Delhi Government and the media. The evaluation was conducted between February 3 and 7, 2009.

The evaluation process was broken into the following steps:

1. Conduct interviews with relevant stakeholders
2. Identify key questions about the corridor
3. Experience the operations on the corridor
4. Provide an analysis to answer the key questions
5. Evaluate current characteristics and performance of the corridor
6. Define areas for potential improvements
7. Provide recommendations for the current corridor.

STAKEHOLDER INTERVIEWS

The review started at a joint meeting with representatives of CSE, Delhi Integrated Multimodal Transport Services (DIMTS) and Traffic and Injury Prevention Program (TRIPP) Indian Institute of Technology (IIT) Delhi. Independent meetings were conducted with all the partners including Delhi Transport Corporation (DTC) and Delhi Traffic Police. The list of individual interviewees is provided in Appendix 1.

The purpose of the meetings was to understand the background of the project from the point of view of the stakeholders, identify the various difficulties/issues encountered and understand the approach chosen to mitigate these difficulties.

People interviewed coincided that the objective of the corridor was to improve mobility and security, through priority measures for public transportation and assignment of dedicated space for bicycles, cycle-rickshaws and pedestrians. It was also clear that Delhi Government has pursued several initiatives to improve the corridor operations:

- There was a reorganization of services, moving several “Blue Line Buses” to other routes and improving the fleet of DTC buses with new low floor and air conditioned vehicles.
- DIMTS has commissioned studies to improve traffic management activities and is measuring travel speeds for buses and general traffic.

- DIMTS has dedicated staff assigned to corridor management, with special focus on mitigating queuing at Chirag Delhi junction.

Planning for corridor expansion to Delhi Gate (9 Km) and for other routes has continued. Main concerns in this effort are the selection of curbside or median bus lanes, the definition of nearside (close to the intersections) or mid-block stations, and the details of the intersections. The team identified the perception that impacts on general traffic should be considered in the design.

Finally, the team identified concerns for special users, such as the students, which might be affected by the operation of school buses on the median lanes.

KEY QUESTIONS ABOUT THE CORRIDOR

Based on the meetings and interviews the evaluation team selected a set of key questions (common concerns) about the bus corridor:

1. Has the project improved the mobility in the corridor?
2. Are the strategies to mitigate delays to motor vehicles effective?
3. Would curbside bus lanes work better than median bus lanes?
4. Has the corridor reduced or increased accidents?
5. Should school buses travel in the median lane?

It was decided to answers these questions in an analytical framework. Data collected on the corridor by DIMTS and TRIPP-IIT Delhi was used as the basis for the analysis.

EXPERIENCE THE OPERATIONS OF THE CORRIDOR

The team visited the corridor three times to experience the operations at different times of the day and days of the week. Aspects of special attention were the operation of each of the components of the corridor: pedestrian and bicycle facilities, bus lanes and stations, motor vehicle lanes. Some of the interviews were conducted on the facility itself (operational personnel of DIMTS and Delhi Police).

The main observations resulting from these visits are:

- Long traffic signal cycles (4 minutes in the peak hour)
- Long queues in the general traffic lanes
- Bus queuing at stations – spillovers
- Bus breakdowns in the bus lane
- Pedestrian jaywalking
- Motor vehicles encroachment of bus lanes

- High bus occupancy levels (peak hour)
- Unreliable Bus Operation (High variability in intervals and commercial speeds)
- High number of bicycles in the designated tracks
- Encroachment of the bicycle tracks by two wheelers
- Reduction of space for bicycles to create an additional turning lane for general traffic

Chirag Delhi Junction, South to North, Feb 5 2009, 9 am

Chirag Delhi Junction, South to North, Feb 5 2009, 8:45 am

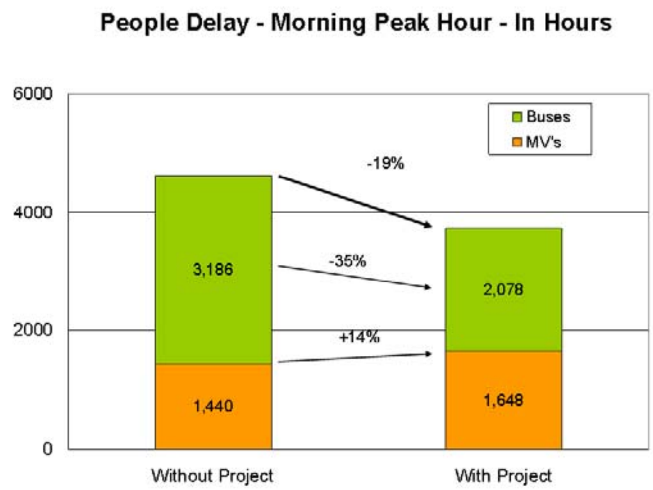
Chirag Delhi Junction, North to South, Feb 4 2009, 11:00 am

KEY QUESTIONS ABOUT THE BUS CORRIDOR – ANALYSIS AND RECOMMENDATIONS

1. Has the project improved mobility in the corridor?

From the data collected it is evident that the pilot corridor has improved mobility on the corridor. The average travel time for motorized travel along the corridor has reduced 19% (Figure I). This is the combined effect of a 35% reduction in travel time for bus users and a 14% increase in travel time for personal motor vehicles users.

Figure I: Travel time savings in the without and with project



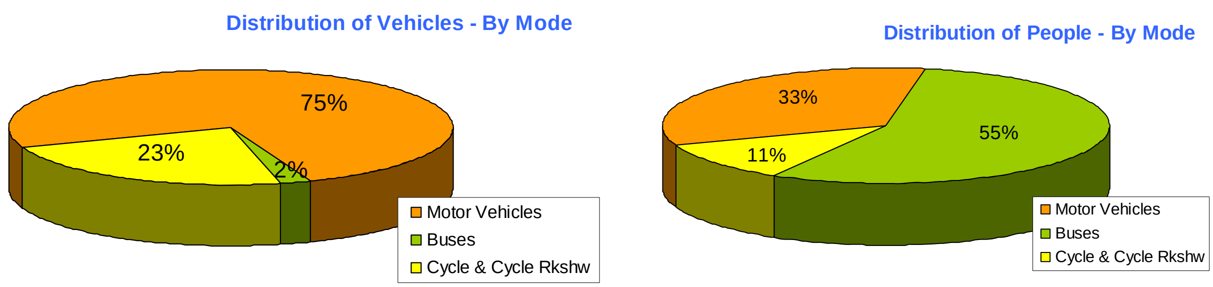
This comparison was made with the traffic counts and vehicle occupancies reported after the corridor was implemented: 3,675 motor vehicles per hour, with 3,841 people (1.045 persons per vehicle), and 112 buses per hour with 6,371 people (57 passengers per bus), as reported to the team by DIMTS.

The situation without project, which cannot be observed, assumes the same volumes and vehicle occupancies; only changes in speed: from 16 km/h to 14 km/h in motor vehicles, and from 12 km/hr to 18 km/hr in buses (as reported by DIMTS using probe vehicles and GPS data from the buses in the corridor and outside the corridor).

As most of the users of the corridor are in buses the decrease in travel time for bus users offsets the increased travel time for cars.

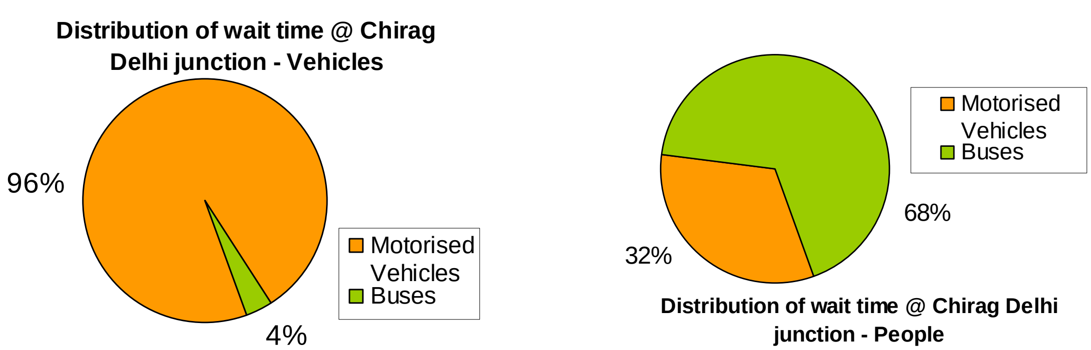
The review shows that buses are just 2 per cent of all vehicles at the Chirag Delhi Junction during the morning peak hour, but they move 55 per cent of the people (Figure II). Cars and two-wheelers make up 75 per cent of the vehicles, but move 33 per cent of the people. Source data for these computations is provided in Appendix 4.

Figure II: Compares mode shares at the Chirag Delhi junction in the peak hour, in terms of vehicles and people



In terms of wait time at Chirag Delhi Junction, vehicle wait time for buses is 4 per cent of the total vehicle wait time, but 68 per cent than the total people wait time (Figure II). Wait time for vehicles is 96 percent of the total vehicle wait time, but 32 per cent of the total people wait time. These calculations are based on Webster's delay formula for signalized intersections (see Appendix 3) and the data provided by DIMTS.

Figure III: Compares wait times (average delay) at the Chirag Delhi junction in the peak hour, in terms of vehicle and people



The team recommends focusing the evaluation of the corridor and the management measures, as well as the design of the extensions and new corridors, in terms of people delay, not vehicle delay.

1. Are the strategies to reduce MV lane queue length effective?

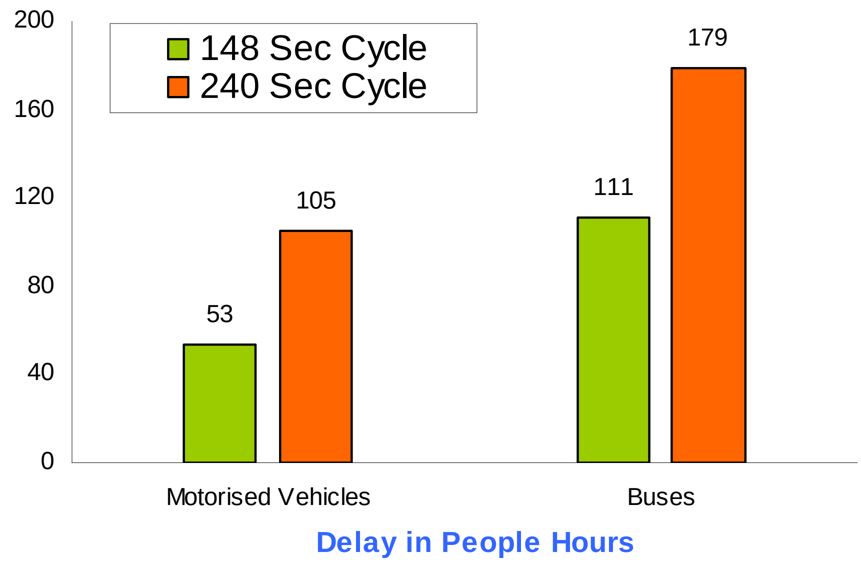
DIMTS had introduced traffic management strategies to reduce the queue length at Chirag Delhi Junction based on increasing the cycle time of the signal when the queue length in the motor vehicle lanes exceed a given threshold (about 700-750 meters).

The analysis of this strategy shows that increasing the signal cycle increases the waiting time for *all users*; hence the strategy is not effective. Moreover, the biggest negative impact is accrued by the majority of the people traveling in buses (55%).

Figure IV compares the wait times at the Chirag Delhi junction in the peak hour/ peak leg for two signal cycle settings. The cumulative delay (wait at the junction) is computed in terms of people hours. Computations using Webster's delay formula for signalised intersections show increasing signal cycle increases wait time for all users.

The automatic cycle of 148 seconds (2 minutes 28 seconds) results in delays of 53 hours for users of motorised vehicles and 111 hours for bus commuters during the peak hour and in the peak direction. The manual cycle of 240 seconds increases the delay to 105 hours for motorised vehicles (98 per cent increase) and 179 hours for bus commuters (61 per cent increase).

Figure IV: People Wait times at the Chirag Delhi junction in the peak hour peak leg in terms (in people hours).



Moreover, longer signal cycles result in longer wait times for pedestrians at the signalized intersections. The international literature in traffic operations and safety indicates that wait times longer than 60 seconds greatly increase the likelihood of jaywalking.

In addition to the queue reduction strategy through cycle time expansion, there is an effort to create additional capacity for motor vehicles. For instance, a left turn lane has been created by encroaching into the bicycle lane at the Chirag Delhi Junction. This temporary solution for motor vehicle congestion relief is compromising the concept of segregated facilities for bicycles and pedestrians not only at the current location, but across the whole corridor, with negative impacts in safety and performance.

The team recommends using short cycle times and avoiding manual operation of the traffic controllers. Queue length might be only a concern when it spills over the preceding intersection. Critical traffic conditions at Chirag Delhi Junction should also be addressed in a conjunction with other intersections using area wide traffic management measures. The team also recommends not using the bicycle and pedestrian facilities to relief motor vehicle congestion

2. Would curbside bus lanes work better than median bus lanes?

The discussion of curbside lanes and median lanes has not been settled in Delhi. International experiences with bus priority measures indicate that curbside lanes result in lower travel speed for buses and, hence, longer travel times for bus commuters). The main reasons are:

- Left turns are usually higher than right turns (left turns along the entire stretch whereas right turns only at the junction)
- Encroachment: hawkers, taxis, auto-rickshaws
- Punctures or openings along the corridor[3]
- Breakdown vehicles are left in curbside lanes
- Continuous enforcement is more difficult

In addition, the type of segregation is also important. Physical segregation, as opposed to horizontal and vertical signage significantly reduces encroachment.

[3] For example on the extension of the pilot corridor to Delhi Gate, where curbside lanes are proposed, the average distance between openings is 114 m on the left hand side and 134 m on right hand side

Delhi has already implemented curbside lanes with painted lanes throughout the city. Implementing this type of arrangement for the bus corridor expansion is not expected to change the current operation for buses.

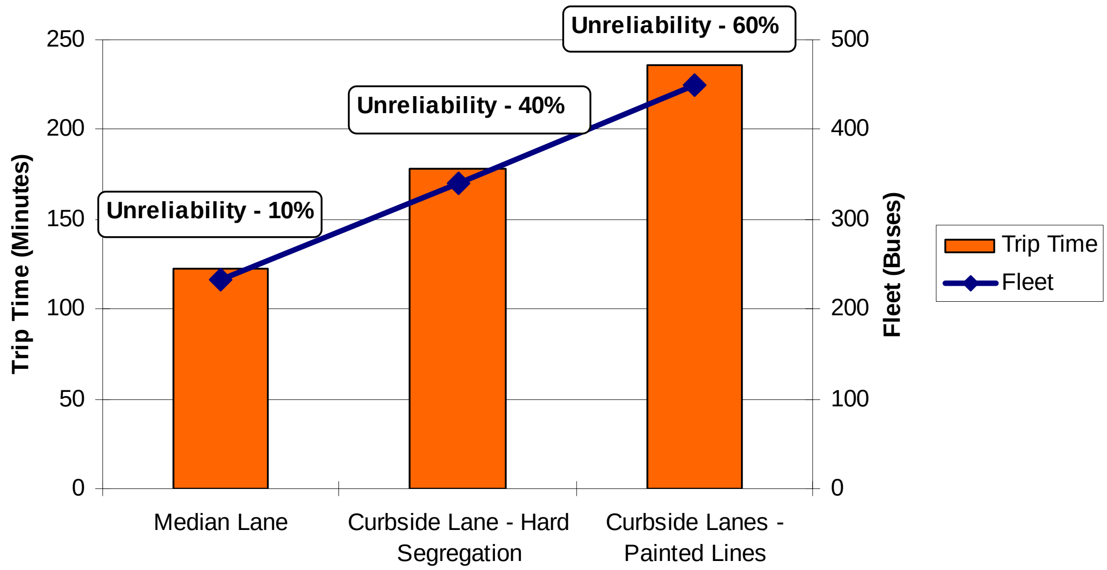
As an illustration of current bus corridors with curbside lines, we can also observe experiences in other world cities. Images from Santiago, Chile illustrate the difficulties of enforcing curbside lanes even at low traffic volumes. The image to the left show bus lanes encroached by cars. The image to the right shows a low floor, low emission articulated bus weaving around a parked taxi and a hawker.

Images: Curbside Bus Lanes, Santiago Chile, April 2008.

This type of effects is also present in Brazil, where the reported differences in bus speeds between curbside and median lanes are between 5-7 km/h, in favor of median lanes.

With these concepts in mind, the team analyzed the quantitative impact of the location of the bus lane in terms of travel time and fleet requirements for the expansion of the bus corridor to Delhi Gate (Figure V). The assumptions for the calculations are provided in Appendix 5. According to this analysis the required fleet size doubles as you move away from segregated median lanes to painted curbside lanes. The reliability of the service drops as a result of higher friction with other vehicles, pedestrians, and even hawkers, making it more difficult to scheduled service and impacts the quality of the service provided.

Figure V: Comparison of cycle times, buses/hr and fleet requirement for each scenario, assuming frequency remains unaffected.



The team recommends using median bus lanes with strong segregation as the preferred option for bus priority, as it reduces the time for most users and reduces the bus fleet required. Assuming that painted curbside lanes will perform at the same speeds, and with the same reliability, than median segregated lanes is not supported by evidence in other bus corridors around the world.

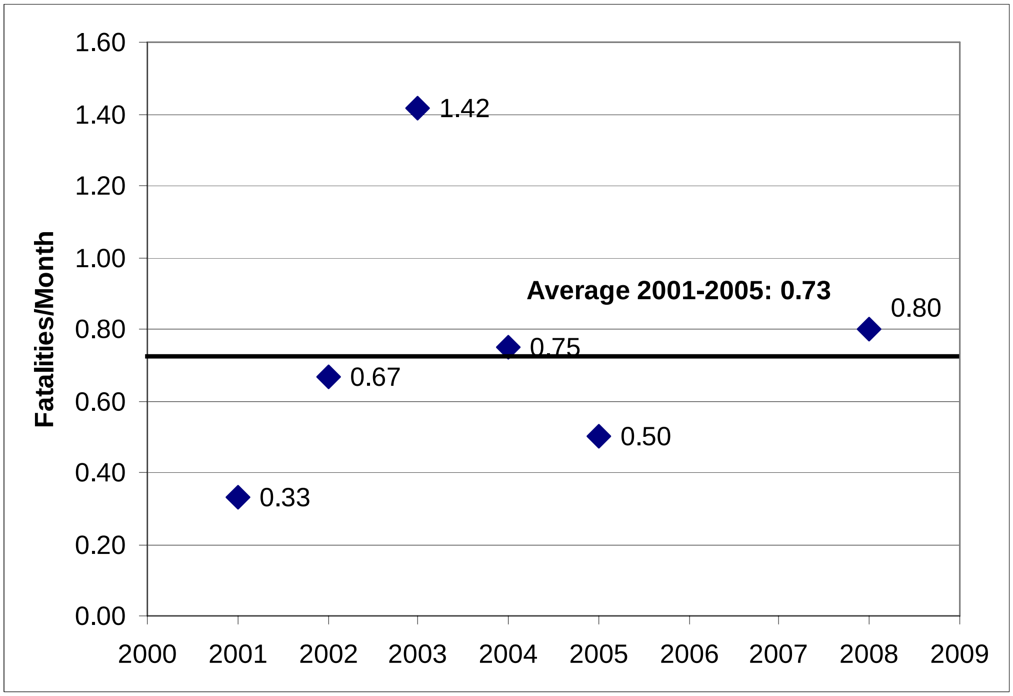
3. Has the corridor reduced/increased accidents?

The most important indicator of traffic safety is the number of fatalities. According to the reports received from the Delhi Police, there have been 8 fatalities in 10 months since the corridor started operations.

The comparison of this figure with data before the corridor started construction does not suggest any statistically significant change in the fatalities per month (Figure VI). Data from 2001 to 2005 shows an average of 0.73 fatalities per month, but a very high variation from one year to another[4].

[4] One of the reasons for the very high variation is that the corridor is very short. In addition, comparing one point with a short series may not result in meaningful evidence.

Figure VI. Comparison of Monthly Fatality Rates Before and After Corridor Implementation



Data: Poilce FIR's compiled by TRIPP - IIT Delhi

Representatives from DIMTS indicated that the number of fatalities per month has been decreasing since the start of operations. This is important and needs to be part of the standard reporting the agency collects and publish. The reported decrease may be a natural effect of the commuters getting used to the characteristics of the corridor, the strong presence of wardens, and the speed reduction devices implemented in the bus lanes, and better driver and pedestrian behavior, among other causes.

Nonetheless, the team still observed a significant number of pedestrians crossing at non-designated places due to bus queues spilling beyond the platforms at the stations, lack of safe access/exit in the back of the station, long pedestrian waiting times at the zebra crossings, and lack of education and enforcement.

The team recommends addressing the outstanding traffic safety needs of the corridor through a combination of measures such as: safe crossings at the other end of the stations (preferably at grade); better management of the bus operations to reduce spill-over at the stations; review of the infrastructure devices *that prevent jaywalking; and increased education and enforcement[5]. The goal should be to reduce fatalities to zero.*

5. Should school buses travel in median lane?

The team was informed of the school age parent's discontent with the operation of school buses in the median lanes. According to the complaints, this resulted in unsafe travel conditions for children, as they need to cross traffic lanes to get to the curbside. The team was also informed that the initial provision that required all the buses to travel in the bus lanes was relaxed, as to allow school buses to operate in general traffic lanes and gain access to the curbside and the colonies.

It is important to note that the school bus numbers are small. Only 6.5% of the buses traveling on the bus lanes are school buses, and only 0.13% of the total number of vehicles crossing at Chirag Delhi Junction at the peak hour[6]. Management of school buses can be specially targeted to provide special operations for them to address the parent's concerns, without compromising the overall performance of the bus corridor.

The team recommends implementing a special management program for school buses beyond the general provisions already in place. This could be done by studying the specific bus routes and defining the points of departure from the bus lanes to gain access to the curbside and the colonies, in consultation with the parents and the schools. This should not be a major issue regarding the location of the bus lanes.

[5] Enforcement may require passing new legislation to be able to penalize users; similar to the Delhi Metro Railways -Operation and Maintenance- Act, 2002, which includes penalties for inadequate user behavior.
[6] Traffic count data provided by DIMTS, November 2008, Appendix IV.

QUALITATIVE EVALUATION OF THE BUS CORRIDOR

The main descriptors of the bus corridor are[7]:

• Initial Operation:	May 2008
• Length:	5.6 kms
• Stations:	9
• Total Ridership:	n/a
• Peak Load:	6,500 passenger/hr/direction
• Frequency:	120 buses/hr
• Commercial Speed	In corridor: 16-19 km/hr (peak hour) Off corridor: 7-11 km/hr (peak hour)
• Operational Productivity:	n/a (4.8 passengers/bus-km citywide DTC)
• Capital Productivity:	n/a (848 passengers/bus/day citywide DTC)
• Infrastructure Investment:	Rs. 14 crores/km (3 million/km)[8]
• Cost per Passenger:	n/a
• Average User Fare:	Rs. ~ 1/km[9] - Rs. 3.87 per passenger citywide DTC (USD 0.08)

The team used a dual framework to evaluate the bus corridor in Delhi in relation the BRT concepts, commonly shared by the international transit community. In the first place the team evaluated the bus corridor from the supply side, and then in terms of its performance. The evaluation is qualitative in nature, but provides a structure for systematic comparison across projects, cities and countries.

[7] Data provided by DIMTS, February 2009
[8] Figure includes all the investment in the corridor: bus lanes, stations, general traffic lanes, bicycle tracks, and pedestrian facilities.
[9] Ordinary service: 1-4 Kms; Rs. 2; 4-8 Kms. Rs. 5; 8-12 Kms. Rs. 7; 12-onwards, Rs.10; DTC.

Supply Side Evaluation

As per TCRP Report 90 – Bus Rapid Transit – Volume 2: Implementation Guidelines 2003, Bus Rapid Transit "*is a flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways and ITS elements into an integrated system with strong identity*".

A BRT system can mix different components according to the service needs and the local constraints. The team used the common understanding of the high end characteristics of each of the components, to compare with the current characteristics of the bus corridor in Delhi.

The "High End" BRT characteristics are presented in the following table:

Component	"High End" BRT
Running Ways	• Longitudinal Segregation
Traffic Engineering	• Geometric Adjustments • Left and Right Turn Controls • Traffic Signal Priorities for Buses • Modern Traffic Signal Technology
Stations	• Enclosed Facilities • Level Boarding and Prepayment • Passing Lanes (when required)
Vehicles	• Multiple doors • Easy Boarding/Alighting • Low Emissions
Services	• Mixed services (local, accelerated, express; short loops) • Design according to the service needs
ITS	• Automatic Vehicle Location/Centralized Control • Traffic Signal Priority • Electronic Fare Collection/Fare Integration

With these concepts in mind, the team classified the components of the Delhi Bus Corridor.

Delhi Bus Corridor – Supply Side Qualitative Evaluation

BRT Component	Advances	Elements to Improve
Running Ways	• Strong Longitudinal Segregation • Median Busways	• Extend Longitudinal Segregation to Delhi Gate, preferably using median lanes (expected)
Traffic Engineering	• Adequate Changes in Roadway Geometry	• Timing plan of traffic signals at intersections to maximize people throughput and minimize variability (use short cycles, eliminate manual operation) • Manage Left and Right Turn movements for buses away from the intersection to reduce the number of phases • Improve the traffic signal technology (expected)
Stations	• Protected Bus Shelters • Level Boarding for a fraction of the fleet	• Enhance the stations to provide better protection to the users • Expand the fleet with level access (expected) • Introduce pre-payment at the stations to reduce bus dwell time and increase bus commercial speeds
Vehicles	• Easy Boarding/Alighting Low Floor Buses (13% of the fleet) • Low Emissions CNG Buses	• Replace the conventional one-door buses with stairs (expected) • Introduce emissions post-treatment to reduce air pollutants beyond the current levels
Services	• Relocation of some “Blue Line” bus routes	• Introduce special service plans to increase quality of service and reduce fleet and operational costs (short cycle routes, express services) • Provide and adequate match between demand and supply
ITS	• Automatic Vehicle Location (GPS in a fraction of the fleet) • Real time user information systems (Variable message signs at stations)	• Replace manual operations with real time control and dispatch • Introduce automatic fare collection systems, preferably integrated

As an evolving project the Delhi bus corridor still requires several adjustments on the supply side to become a high-end BRT. A systematic effort to integrate these components is required if Delhi wants to upgrade the bus corridor and enhance its service and performance.

Performance Side Evaluation

Regarding performance, a system can be evaluated according to the way the service is delivered to the users. As per the BRT Planning Guide – ITDP GTZ, 2007, *"Bus Rapid Transit is a high quality public transport system, oriented to the user that offers fast, comfortable and low cost urban mobility"*. It is possible then to determine measures of performance for the level of achievement of each component of the above definition.

The team used the following classification and definition of targets:

Component	"High End" BRT
Quality of Service	• High User Acceptance
Travel Time	• Easily Accessible • Low waiting time • High commercial speed
Reliability	• Low variability (intervals, speeds) • Low breakdowns, incidents
Comfort	• Low Occupancy Levels (buses, platforms) • Good user information • Seamless integration with other transport modes • Perception of safety and security
Cost	• Relative low capital and operational costs • High capital and operational productivity
Externalities	• Low level of accidents (fatalities, injuries) • Low emissions • Congestion relief (attraction of personalized vehicle users) • Increased land values

The team also included a category of "externalities" to see the level of achievement of impacts beyond those perceived by the bus commuters.

Delhi Bus Corridor – Performance Qualitative Evaluation

Component	Advances	Elements to Improve
User Acceptance	• High Bus User Acceptance (88% (CSE, Jun 08; weighted average: 68%)	• Continuous monitoring of user perception
Travel Time	• Good accessibility through at-grade pedestrian crossings at signalized intersections; • Acceptable waiting time for bus services: 3 routes along the corridor with 5 minute interval during peak hour • Good Commercial speed: 16-19 Km/h (DIMTS, Jan 09); improved by 128%-27% (from 7-15 Km/h without the bus corridor)	• Reduce pedestrian wait time at pedestrian crossings, currently higher than 60 seconds at the signal. • Introduce non-grade intersections where warranted (expected) • Further increase the commercial speed for buses (beyond threshold of 20 km/hr) through improved infrastructure
Reliability	• Automatic vehicle location (GPS) for a fraction of the bus fleet may provide information to monitor this variable	• Reduce the high variability observed in bus intervals and speeds (dispatch, control, signal management) • Reduce the observed bunching of buses and wide time intervals • Reduce and manage high level of breakdowns, incidents and encroachment
Comfort	• Bus shelters provide better protection than former bus stops • Presence of guards increase the perception of safety and security • A fraction of the fleet has advanced characteristics • Variable message signs provide information on the expected interval • Integration with three wheelers provided by design	• Reduce the high occupancy of buses and platforms (match supply and demand) • Increase and maintain in adequate condition the user information systems (scarce or vandalized maps & signs) • Variable message signs need to be connected with the real information from the buses • Improve connectivity to other transport modes and introduce single payment media (Metro, Buses, Regional Buses, Trains)
Cost	• Low Costs: capital investment (Infrastructure 14 Crores/km)	• Collect data on capital and operational productivity (expected to improve as corridor is expanded)

Component	Advances	Elements to Improve
Externalities	• Reduced emissions (particulate matter, CNG engines; 13% New Fleet	• Monitor and report fatality rates (currently high 0.8/month) • Expand corridor and improve bus service to attract personal motor vehicle commuters and generate land development opportunities

As observed, the corridor has achieved some advances in performance, but several elements need to be improved, especially reliability and comfort.

Reliability refers to the capability of a given system to be relied on, to be dependable[10]. A bus system is reliable if it provides consistent waiting and travel times. This is achieved through low variability of the bus intervals (consistent frequency) and low variability of the bus commercial speeds.

Reliability is fundamental in attracting passengers to the bus system, and can be improved through:

- physical measures (segregation of the bus lanes, reduce interference with the rest of the traffic),
- the traffic operations (consistent signal cycle times at intersections), and
- the transit operations (consistent dwell times and driving practices, regular dispatch, control of the bus intervals along the route). Fleet management systems, using automatic vehicle location and on-line supervision, are able to monitor and help bus operations achieve reliable operations.

Comfort is the capacity to give physical ease and well-being[11]. In a transit system comfort refers to several attributes of the passenger experience such as the occupancy levels in buses and station platforms, the availability of user information, the integration with other transport modes (including walking to and from stations), and the perception of safety and security, among other factors.

Comfort is probably the most important concept in making a transit system attractive for motor vehicle users. Comfort can be improved by increasing:

- the capacity and reliability of the bus system (more frequent buses, consistent arriving times and speeds, wider platforms)

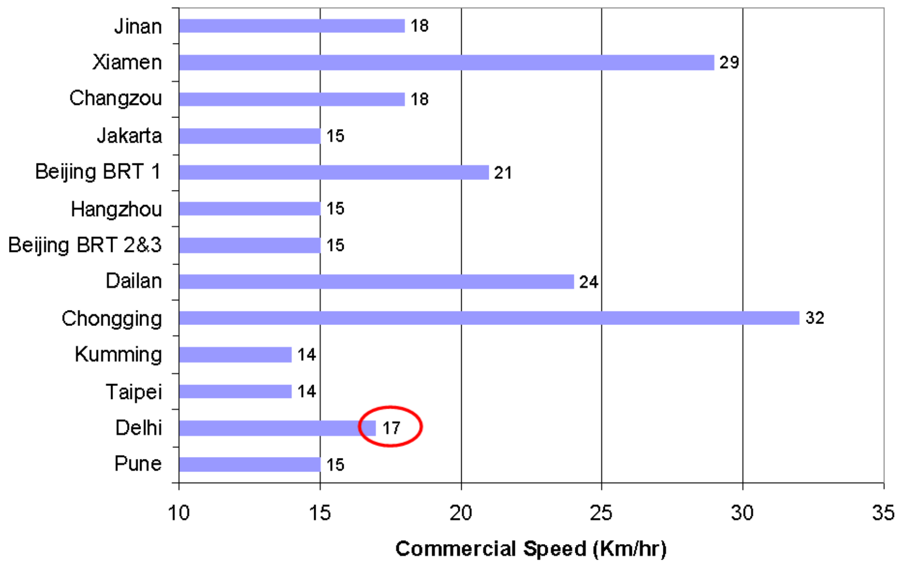
[10] http://www.thefreedictionary.com/reliability
[11] http://www.thefreedictionary.com/comfort

- the quality, adequacy and quantity of user information elements (fixed signs, maps, variable message signs)
- the connections and systems to integrate the bus corridor with other transport systems, including seamless pedestrian crossings and integrated fare collection systems, and
- the design features of the stations and buses, illumination, tidiness and presence of security personnel and personal protection systems (closed circuit TV, alarm and communication elements).

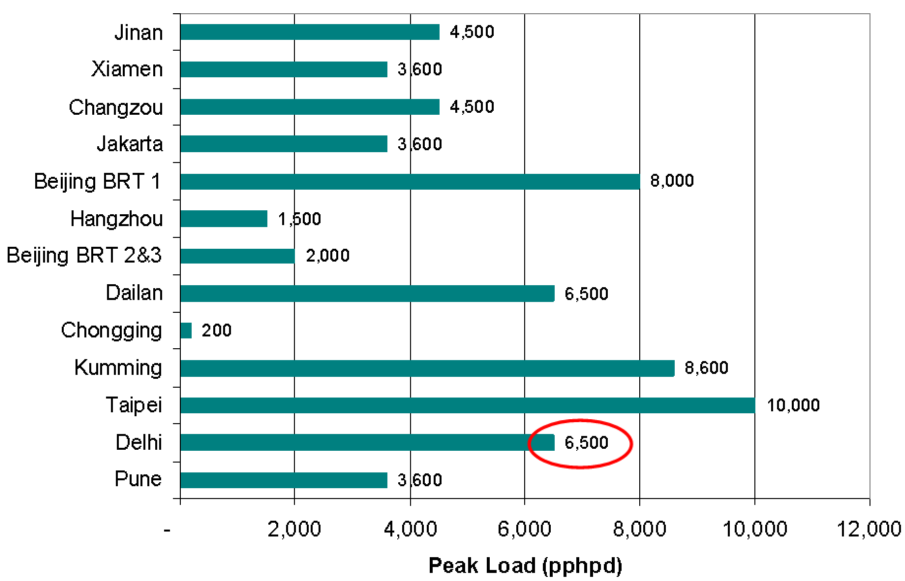
COMPARISON OF THE DELHI BUS CORRIDOR WITH OTHER SYSTEMS IN ASIA

PERFORMANCE MEASURES

Commercial Speed



Peak Load Peak Hour Peak Direction (PPHPD)



CONCLUSIONS AND RECOMMENDATIONS

The Delhi bus corridor has improved the mobility of the people along the initial pilot stretch. Bus travel speeds are around 18 km per hour, 150% faster than buses outside the corridor (12 km per hour). As more people use the buses than motor vehicles, the overall reduction in travel time along the corridor for all the users is estimated in 19%. The corridor has also received high ratings from the users: 88% of the bus commuters expressed they were happy with the corridor in a CSE survey in June 2008. In addition, the segregation of bicycles and pedestrians has improved the travel experience and the perception of safety for these important users of the corridor.

The conclusions and recommendations are divided in common concerns and overall evaluation of the corridor.

Common concerns (key questions)

Most of the attention of the media and the authorities is currently given to the queues in the motor vehicle lanes. While this is a visible difficulty, focusing on this problem misses the goal of improving mobility to the overall population.

The data provided to the team shows that cars and two-wheelers make up 75 per cent of the vehicles, but move only 33 per cent of the people, while buses are just 2 per cent of all vehicles but they move 55 per cent of the people at the Chirag Delhi Junction during the morning peak hour. If special attention is given to the vehicles, any improvement measure will result in benefiting a fraction of the people.

The team recommends focusing the management measures to improve the performance of the corridor in terms of people delay, not vehicle delay. This is also applicable to the design of extensions and new corridors.

As a consequence of the special media attention to the difficulties in the motor vehicle lanes, DIMTS and the Traffic Police had introduced traffic management strategies to reduce the queue length at Chirag Delhi Junction. These strategies are based on increasing the cycle time of the signal when the queue length exceeds a given threshold (about 700-750 meters).

The analysis of this strategy shows that increasing the signal cycle increases the waiting time for *all users*; hence the strategy is not effective. This strategy not only results in greater delays to the majority of users of the bus corridor (the bus commuters), but also in longer wait times for pedestrians at the signalized intersections. This greatly increases the likelihood of traffic accidents, as has been extensively reported in the traffic safety literature.

The team recommends using short cycle times and avoiding manual operation of the traffic controllers. Queue length might be only a concern when it spills over the preceding intersection. Introducing area wide traffic management measures to address traffic concerns is also advised.

In addition, additional capacity for motor vehicles is being created by encroaching into the bicycle lanes. This temporary solution for motor vehicle congestion relief is compromising the concept of segregated facilities for bicycles and pedestrians across the whole corridor, with negative impacts in safety and performance.

The team recommends protecting the bicycle and pedestrian facilities by not using them to relief motor vehicle congestion.

The initial difficulties, especially for motor vehicles, had sparked a discussion on whether the bus lanes should be located in the median or the curbside.

International experiences with bus priority measures indicate that curbside lanes result in 5-7 km/h travel speed reductions for buses. In addition physical segregation, as opposed to horizontal and vertical signage, significantly reduces encroachment.

Delhi has already implemented curbside lanes with painted lanes throughout the city. Implementing this type of arrangement for the bus corridors planned for Delhi is not expected to change the current operation for buses.

An analysis of the expansion of the corridor to Delhi Gate shows that the required fleet size doubles as you move away from segregated median lanes to painted curbside lanes. The reliability of the service drops as a result of higher friction with other vehicles, pedestrians, and hawkers, impacting the quality of the service provided.

The team recommends using median bus lanes with strong segregation as the preferred option for bus priority in Delhi. It reduces the time for most users and reduces the bus fleet required. Assuming that painted curbside lanes will perform at the same speeds, and with the same reliability, than median segregated lanes is not supported by evidence in other bus corridors around the world.

The bus corridor has been also portrayed as a very dangerous facility. Data available to the team indicates that there have been 8 traffic related fatalities in 10 months of operation. The comparison of this figure with data before the corridor started construction does not suggest any statistically significant change in the fatalities per month.

The team observed a significant number of pedestrians crossing at non-designated places due to bus queues spilling beyond the platforms at the stations, lack of safe access/exit in the back of the station, long pedestrian waiting times at the zebra crossings, and lack of education and enforcement.

The team recommends addressing the outstanding traffic safety needs of the corridor through a combination of measures such as: safe crossings at the other end of the stations (preferably at grade); better management of the bus operations to reduce spill-over at the stations; review of the infrastructure devices that prevent jaywalking; and increased education and enforcement . The goal should be to reduce fatalities to zero.

An additional concern has been the attention of the school population. Only 6.5% of the buses traveling on the bus lanes are school buses, and only 0.13% of the total number of vehicles crossing at Chirag Delhi Junction at the peak hour. Management of school buses can be specially targeted to provide special operations for them to address the student population needs, without compromising the overall performance of the bus corridor.

The team recommends implementing a special management program for school buses beyond the general provisions already in place. This could be done by studying the specific bus routes and defining the points of departure from the bus lanes to gain access to the curbside and the colonies, in consultation with the parents and the schools. This should not be a major issue regarding the location of the bus lanes.

Delhi Bus Corridor Evaluation

The Delhi bus corridor is a project in evolution. It has been a step in the right direction to improve mobility to the majority of the population, and can be improved gradually.

The team observed several difficulties associated with the bus operations and the interaction of pedestrians and general motor vehicles with the facilities. The Delhi government, through DIMTS, indicated that several actions are underway to improve the project: DTC bus fleet is being replaced, new contracts for private providers are under preparation, traffic signals will be replaced by advanced technologies, and the corridor will be expanded 9 km to reach Delhi Gate. These actions are expected to improve the overall corridor performance, and should be complemented with other activities to achieve higher levels of quality.

The team observed issues that can and should be solved. No corridor has been implemented without initial difficulties, and most of these difficulties have been solved gradually as the projects progress. A practical mechanism to assure gradual improvement is to establish a quality improvement program in which the performance is measured periodically and specific actions are taken to address the identified concerns.

The team observed that the initial implementation incorporates some elements of a "High End" Bus Rapid Transit paradigm, but several components can be incorporated gradually, such as improved vehicles, fleet management and user information systems, but very specially, enhanced service plans.

There are also some advances in performance, as the corridor greatly improved the travel experience for the bus commuters. Nevertheless, key elements of reliability, comfort and safety need to be addressed and adjusted.

Delhi bus corridor has the opportunity of evolving into a high performance bus system, if the bus operations are monitored and enhanced. Along with the recommendations regarding common concerns outlined above, the team encourages the local authorities to:

1. *Establish a Quality Improvement Program with the participation of external stakeholders in measurement and oversight*
    - *Define Indicators: User Acceptance, Travel Time, Reliability, Comfort, Productivity, Externalities (see for example Appendix II)*
    - *Define Goals and time based milestones*
    - *Set up a monitoring mechanism: plan, perform, report, including periodic user surveys to define commuter's acceptance and specific studies for the other categories (e.g. every 4-6 months)*
    - *Take improvement actions, evaluate the impact in the set of indicators*

2. *Focus on Improving Reliability and Comfort which are key components in making the system attractive and currently are not receiving enough attention.*
    - *Reliability refers to consistent arrivals of the buses at the stations, to minimize waiting time uncertainty, and consistent travel speeds.*
    - *Reliability can be improved through steady signal cycle times at intersections and improved transit operations, to achieve regular dwell times and driving practices, steady dispatch and control of the bus intervals along the route. Fleet management systems, using automatic vehicle location and on-line supervision, are able to monitor and help bus operations achieve reliable operations.*

- *Comfort refers to several aspects of the passenger experience such as the occupancy levels in buses and station platforms, the availability of user information, the integration with other transport modes, and the perception of safety and security.*
- *Comfort can be mainly achieved by increasing :the capacity and reliability of the bus system (more frequent buses, consistent arriving times and speeds, wider platforms), and by enhancing other user convenience elements, such as the user information systems, the integration with other transport systems, the maintenance and illumination of the stations and buses and presence of security personnel.*

3. *Reevaluate the service plan to provide a better match of the supply and demand, while minimizing the fleet and the bus-km, through mechanisms like:*

   - *Introducing flexible route planning (e.g. short loop routes as opposed to routes from terminal to terminal only)*
   - *Route planning follows detailed data collection on the load profile, occupancy at peak location, and variation along the day for each route; then definition of the required supply (buses/hour, fleet)*

4. *Evaluate the implementation of car use disincentives and restraint policies along the implementation of better transit systems, including parking restrictions and pricing, congestion and pollution charges, fuel taxes and administrative restrictions to vehicle use in certain areas of the city and times of the day, for example using the plate numbers.*

Improving the supply and quality of public transportation is not enough to bring environmental sustainability to the rapidly growing cities in India. Only comprehensive policies that promote active transport -biking and walking- and transit, coupled with car use disincentives and restraint policies have proven effective in curbing motorization and pollution worldwide. Places like Singapore, Beijing, London, Paris, New York City, Bogotá, and Sao Paulo provide good examples of such effective and comprehensive approaches, while retaining economic vitality. Adaptation of the world class examples to the particular conditions and culture of Indian cities is possible.

APPENDIX I – INTERVIEWS IN DELHI

Shri Rakesh Mehta, Chief Secretary of Delhi

Center for Science and Environment (CSE)

1. Ms. Anumita Roy Chowdhary
2. Ms. Jayeeta Mukherjee
3. Ms. Sunita Narain

Traffic and Injury Prevention Program (TRIPP) at Indian Institute of Technology (IIT) - Delhi

1. Dr. Dinesh Mohan
2. Dr. Geetam Tiwari
3. Mr. Sandeep Gandhi

Delhi Integrated Multimodal Transport Systems (DIMTS)

1. Mr. Manoj Agarwal
2. Colonel Ashok Singh
3. Mr. Amichand Srivastav
4. Mr. Sharad Mohindru
5. Mr. Anuj Sinha

Delhi Transport Corportation

1. Mr. Sehgal

Delhi Traffic Police

1. Mr. Harinder Singh

APPENDIX II

QUALITY IMPROVEMENT PROGRAM

A practical mechanism to assure a successful initiative is to establish a Quality Improvement Program in which the performance is measured periodically and specific actions are taken to address the identified concerns.

A quality monitoring program consists of three components

a) Define Indicators
b) Set up a monitoring mechanism
c) Measurement and actions

This report provides a framework for monitoring buses procured and actions of the entire process.

INDICATORS

Indicators can be divided into three categories:

1. System characteristics to understand the basic supply and performance of the system.
2. Indicators to measure performance of routes
3. Surveys to understand user perception. All passengers on the bus systems should be treated as customers. The system should be designed to achieve the operational characteristics desired by the customer.

System Characteristics

Every state transport corporation, city bus company or company (SPV) should provide aggregate system wide information. System characteristics listed below should be reported.

1. Routes
2. Route-Kms (total length of the routes)
3. Fleet (total number of buses)
4. Fleet/Route (average number of buses in each route)
5. Vehicle-Kms per month (average distance logged)
6. Bus Stops (number of bus stops)
7. Total Passengers per month (average number of passenger boardings)
8. Total revenue per month (average income from user fares per month)

9. Other revenue per day (average income from sources different than fares per month)
10. Average User Fare
11. Operational Cost per month
12. Annual Revenues
13. Fuel Consumption (liters per year)
14. Fatalities from traffic accidents involving buses per year

Operational Indicators by Route

Operational indicator data should be gathered on every route. The operational indicators are listed in the table below.

Table I: Operational Indicators for individual routes, and recommended performance thresholds

Sr. No	Indicator	Recommended Threshold
1	Passengers per bus per day	> 800
	BRT	> 1000
2	Frequency (Buses per hour)	> 2 Buses/Hour
	BRT	> 12 Buses/Hour
3	Commercial Speed Peak Period	> 12 km/hour
	BRT	> 18 km/hour
4	Operational Productivity	> 4 passengers/bus-km
	BRT	> 5 passengers/bus-km
5	Fleet Utilization	> 95%
	(actual trips/planned trips)	
6	Peak Load - Passengers Peak/Capacity Peak	< 95%
	peak Section, peak hour, peak direction	
7	Reliability (0.9 I < # Trips < 1.1 I)/Total Trips	> 90%
	Where I is the planned interval (frequency/60)	

BRT – Denotes, part or entire route is on segregated infrastructure. Thresholds recommended for BRT operations are higher. Higher speeds allow buses to make additional trips and increases both operational and capital productivity.

Route design should always be for peak period, peak direction. As a first step it is necessary to identify the peak period. Once peak period, peak direction has been identified; to determine indicator 3 speed data can be computed by processing data from GPS devices on board the buses or through a person physically riding on the bus from origin to destination. To compute operational indicators 6 and 7 it is first necessary to identify the peak section in the peak period, peak direction for each route. This is done through an on-board survey, observing the load profile for the route. Once the peak location has been established, peak load information should be collected for the whole hour. Reliability should be measured by noting the difference between scheduled arrival and actual arrivals of buses for the whole hour.

User Survey

The system should be designed to achieve the operational characteristics desired by the customer. We recommend conducting at least one user perception survey per year. Appendix I has a questionnaire for the user perception survey.

SETUP FOR MONITORING

It is recommended to hire a third party consultant to collect the data necessary for monitoring. A single consultant selected for collection of data will ensure timely collection of data in standardized formats. Consultant with expertise in transport planning should be given preference to lead the data collection effort. Standardization is very important to allow comparison of the indicators across routes. It will create competition and foster an excellent environment for peer to peer learning. The project timelines and monitoring activities are provided in Figure 1.

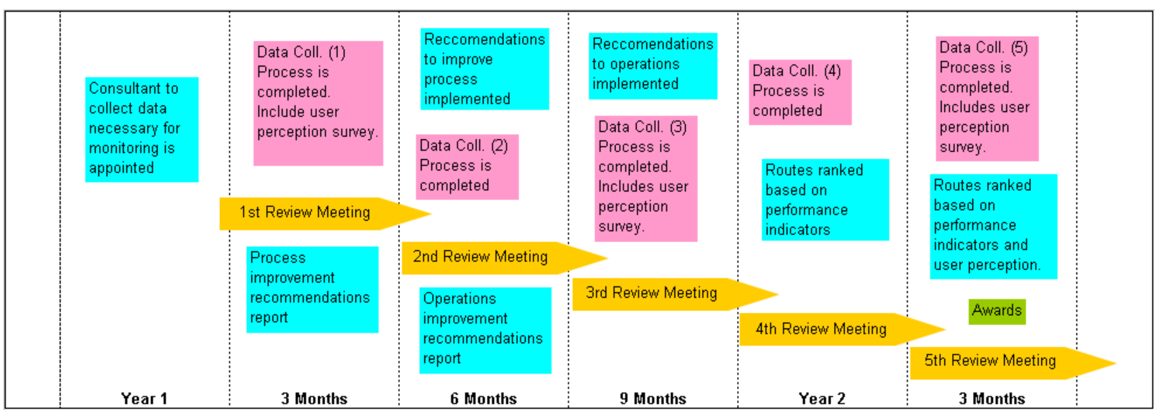


Figure 1: Project Timeline & Activities

MEASUREMENTS AND ACTIONS

Consultant to collect indicator data should be selected in the first three months of the program. The consultant will review the indicator list provided, interact with the City bus agencies and make recommendations to add or change the list of indicators. The consultant will then create a set-up to conduct five quarterly data collection efforts. The details of the activities for the review meetings are provided in Table II.

Table II: Activities proposed for the review meetings

Meetings	Activities
Review 1	1. Review the data collection process along with the city bus agencies. 2. Evaluate responses, concerns from data collection consultant and city bus agencies 3. Develop a set of recommendations to improve the process. 4. Review operations indicators for routes
Review 2	1. Review the data collection process along with the City bus agencies. 2. Evaluate responses, concerns from data collection consultant and city bus agencies 3. Develop a set of recommendations to improve the process. 4. Review operations indicators for routes
Review 3	1. Review operations indicators for routes. 2. Develop a set of recommendations to improve operations monitoring process.
Review 4	1. Review operations indicators for routes. 2. Rank routes based on the performance indicators 3. Develop a set of recommendations to improve operations.
Review 5	1. Review operations indicators for routes. 2. Rank routes based on the performance indicators 3. Awards will be given to best performing routes

Passenger User Survey

Sample characterization

- Female, male
- Age
- What is your principal activity? (Employee, student, independent worker, home)
- What is the educational level (primary incomplete, primary complete, secondary incomplete, secondary complete, technical or university incomplete, technical or university complete)

Characterization of trips

- What transport mode do you use with more frequency for your typical trips? (only bus, only metro, bus and metro, transfer between buses, bicycle, car, taxi, auto-rickshaw, cycle-rickshaw, combination: which___)
- How many times in a week do you make the typical trips?
- What is the main purpose of your typical trips? (study, work, errands, other)
- Average trip time (walk, waiting, trip)
- What alternative transport mode do you have available? (car, carpooling, bus, metro, walk, taxi, walk, bicycle, etc.)
- How much to do you spend daily in transport?

Opinion about the service

Please classify the following aspects of your trip (from 1-Appaling to 7 - Excellent)

- Time waiting for transport at station

- Quality of access to stations (distance from where you live, how easy it is to reach the station, distance from station to your destination, safety of access)
- Driving safety
- Comfort level of trip
- Number of transfers
- Quality of buses
- Personal security in bus stops and inside mode of transport
- Price of transport
- Payment system

Which of these aspects have improved since the implementation of the bus system (Improved, maintained, got worse)?

- Time waiting for transport at station
- Quality of access to stations (distance from where you live, how easy it is to reach the station, distance from station to your destination, safety of access)
- Driving safety
- Comfort level of trip
- Number of transfers
- Quality of buses
- Personal security in bus stops and inside mode of transport
- Price of transport
- Payment system

APPENDIX III

Webster's delay formula for signalized intersections:

$$d = \frac{c(1-g/c)^2}{2[1-(g/c)x]} + \frac{x^2}{2q(1-x)} - 0.65\left(\frac{c}{q^2}\right)^{\frac{1}{3}} x^{2+5(g/c)} \qquad (9.17)$$

where,

d = average delay per vehicle (sec),
c = cycle length (sec),
g = effective green time (sec),
x = degree of saturation (flow to capacity ratio),
q = arrival rate (veh/sec).

APPENDIX IV

Morning peak hour traffic counts at Chirag Delhi junction (December 2008)

Towards Ambedkar Nagar			**1332**			
		641	251	440		
	220				349	
3675	1425		**Chirag Delhi**		1991	**2620**
	2030				280	
		1654	76	755		
			2485		Towards Moolchand	

Source: Figure 5.1, Page 31, intelligent signaling system, Ambedkar Nagar to Delhi Gate - Bus Rapid Transit Corridor, prepared by Capita Symonds for DIMTS.

Bus Occupancy Survey at Chirag Delhi junction – Ambedkar Nagar to Moolchand (July 2008)

	Occupants					
Time	**LHS**	**No of Buses**	**RHS**	**No of Buses**	**Total**	**Total No of Buses**
8 -9 AM	3238	59	3118	64	6356	123
9 - 10 AM	2931	51	3440	61	6371	112
10 -11 AM	2559	39	1809	40	4368	79
13 - 14 PM	1400	49	1624	52	3024	101
14 - 15 PM	1658	33	1793	65	3451	98
15 - 16 PM	978	39	1511	55	2489	94
17 - 18 PM	855	38	1235	40	2090	78
18 - 19 PM	1147	31	1758	47	2905	78
19 - 21 PM	1205	34	1135	35	2340	69
20 - 20 PM	883	37	1020	38	1903	75
Total	**16854**	**410**	**18443**	**497**	**35297**	**907**

Source: Table 19, Page 37, Preliminary Monitoring Report, Prepared by TRIPP – IIT Delhi.

Distribution of Buses by Bus Type at Chirag Delhi Junction – Ambedkar Nagar to Moolchand

Low Floor	Blue Line	DTC Old	School	RTV	Tourist/ Chartered	Ambulanc e	Other s	Total
122	315	85	59	156	146	5	19	**907**
13.5%	**34.7%**	**9.4%**	**6.5%**	**17.2 %**	**16.1%**	**0.6%**	**2.1%**	**100.0 %**

Source: Table 20, Page 37, Preliminary Monitoring Report, Prepared by TRIPP – IIT Delhi.

APPENDIX V

Choice of bus lane location
Assumptions & Calculations for illustrative example

Demand = 8,000 Passengers Peak Hour Peak Direction
Passengers per Bus= 70

Scenario 1 (s1): Median Lanes to Delhi Gate

	leg 1	leg 2	total
distance	6	9	15
speed	18	18	18
time	20	30	
unreliabilty	10%	10%	
average	20.92	31.41	
85th percentile	21.39	32.13	54

Scenario 2 (s2): Curbside lanes with hard segregation to Delhi Gate

	leg 1	leg 2	total
distance	6	9	15
speed	18	12	14
time	20	45	
unreliabilty	10%	40%	
average	20.92	53.32	
85th percentile	21.39	60.15	82

Scenario 3 (s3): Curbside lanes with painted lanes to Delhi gate

	leg 1	leg 2	total
distance	6	9	15
speed	18	9	13
time	20	60	
unreliabilty	10%	60%	
average	20.92	77.82	
85th percentile	21.39	89.01	110

Comparison of cycle times, buses/hr and fleet requirement for each scenario, assuming frequency remains unaffected.

APPENDIX VI:

Photos documenting anecdotal experiences onthe bus corridor.

Photo 1: Heavily used bicycle facility at Chirag Delhi Junction towards Moolchand.

December 3rd, 2008 – Madhav Pai

Photo 2: Bus breakdown on the corridor

February 6th, 2009 – Madhav Pai

Photo 3: Buses queued beyond the bus stop