1. **INTRODUCTION**

Mobility and transportation are two of the leading indicators of economic growth of a society. Unfortunately, if left unchecked, these indicators show a declining trend with the passage of time (i.e., traffic congestion) because transportation systems are often designed to overcome the present crisis without considering the increasing nature of the population of a country. The situation of urban transport in a developing country like India is, no doubt, very special, because of the combination of rapid demographic and economic growth, enormous increase in travel demand, utterly deficient capacities of the existing transport systems, and turbulence in the land development process during the current era of transition.

The introduction of motorized transportation and especially the automobile has generated social disparities in accessibility. Under Indian conditions, it is becoming difficult for any improvement to be done to restore the equity. The accessibility is deeply biased toward favouring those with access to private automobiles. From the perspective of political science, two points emerge. First, transportation conditions are largely class based. A small percentage of people with access to privately owned vehicles appear to impose serious damages on other road users, particularly pedestrians, non-motorized vehicles, and public transport users. Privately owned vehicles impose serious impacts such as delays, fatal traffic accidents, and air pollution on other modes of transport. It has become a moot point whether or not the costs are charged to the beneficiaries. Second, these damages are in fact neither assigned nor compensated. They remain instead as externalized and unaccredited costs created by the unrestricted use of the automobiles, based on privileged mobility and freedom of access. If this broad approach in equity is acknowledged, it would warrant new approaches to policies for transportation, traffic management, and land use. Such new approaches will have to be considered for the distribution of accessibility and the use of the street by all modes of commuters.

People prefer rail transit to bus transit even thought the mobility is less because of its speed and less delay. There is a splendid transit system called Bus Rapid Transit System with more mobility when compare to heavy rail/ light rail transit. It is an integrated, well defined system with design features similar to light rail rapid transit systems. BRT represents a way to improve mobility at a relatively low cost through incremental investment in a combination of bus infrastructure, operational movements and technology. BRT will utilize Intelligent Transportation System technology, modern land use planning and transportation policies to support new concepts for rapid transit systems based on bus-like vehicles.

1. **BUS RAPID TRANSIT**

**2.1 Introduction**

Bus Rapid Transit is commonly understood as a system that emphasizes priority for and rapid movement of buses by securing segregated bus-ways. BRT is designed to address the sources of delay of traditional bus service and to be an attractive service to passengers. BRT is an incrementally enhanced transit mode, providing faster, passenger-friendly service. This is accomplished in multiple ways including improvement to the infrastructure, vehicle road use and stops/stations; utilizing cleaner, quieter and lighter vehicles; and integrating an amalgam of ITS technologies.

BRT is a new and cost-effective way of providing high-quality transit service with buses. The buses operate primarily in bus-only lanes with light rail-like service characteristics and station spacing. Traffic signals are modified, giving buses priority, helping them to move more quickly and reliably. BRT is much less expensive than light rail to construct and operate and retains the flexibility to operate in conventional traffic lanes. BRT is designed to address the sources of delay of traditional bus service and to be an attractive service to passengers. BRT is an incrementally enhanced transit mode, providing faster, passenger-friendly service. This is accomplished in multiple ways including improvement to the infrastructure, vehicle road use and stops/stations; utilizing cleaner, quieter and lighter vehicles and integrating a blend of ITS technologies. A BRT system is shown in Fig1.



**Fig 1: A Bus Rapid Transit System with buses in dedicated lanes**

**2.2 Background**

***2.2.1. Historical development of BRT in the world***

The first wide-scale development of the BRTs started in Curitiba (Brazil) in 1974 (shown in Fig 2), although there were several smaller-scale projects prior to its development. Since then, Curitiba’s experience has inspired other cities to develop similar systems. In the 1970s, development of BRT systems was limited to the North and South American continent. In the late 1990s, the replication of the BRT concept gained momentum and BRT systems were opened in Quito, Equador (1996), Los Angeles, USA (1999) and Bogota, Columbia (2000). Especially, the TransMilenio project in Bogota started operation in 2000 and its success drew attention from the world community as an example of the state of the art in BRT systems.



**Fig 2: BRTS in Curitiba, Brazil**

***2.2.2. BRT Introduction in Asia***

In Asia, prior to 2000, the experience of BRTs was very limited in number and scope. The systems in Nagoya, Japan and Taipei were regarded as relatively complete systems in the Asian region. The spread of BRT in Asia has become more conspicuous since 2004. In 2004, the TransJakarta busway was started along through the city centre. On 1 July 2004, three BRT corridors totalling about 37 km were installed as a part of Seoul’s reform of its public transport system. On 25 December 2004, the first stage commercial operation of BRT was started in Beijing as a pilot line for 5 km. In Bangkok, the plan for BRT was declared in 2004 by the newly elected governor of Bangkok Metropolitan Administration (BMA) indicating that the first BRT lines would be opened in October 2005. Although there was some confusion in Indonesia and Seoul when those lines were first introduced, the BRTs in Jakarta, Seoul, and Beijing have shown some success and those systems are under the process of expansion and upgrading. In contrast, the plan for BRT in Bangkok has been delayed and has not been introduced yet, although rail and light rail expansion is underway. The number of cities looking into BRT is rapidly increasing. In China, a BRT longer than that in Beijing was officially opened in Hangzou in April 2006. In the present day scenario, many cities in Asia are looking forward to move to BRT system.

***2.2.3 Inception of BRT in India***

BRTS was first introduced in India in Ahmedabad with a stretch of 25 km. It was open to public on 14th October 2009 with 25 buses. This is the first full fledged BRTS project in the country and later it is planned in many cities like Hyderabad, Vijayawada, Visakhapatnam, Bangalore, Chennai, Indore, Madurai, Mumbai, Pimprichnchwad, Pune, Rajkot, Surat, Coimbatoor. But BRT is presently running only in Ahmedabad (shown in Fig 3) and Delhi in India.

**Fig 3: BRTS in Ahmedabad, India**

**2.3 Benefits of BRTS**

1. **Improved Travel Time**

Travel times would be reduced up to 25% for bus passengers in the corridor.

1. **Improved Transit Reliability**

The ability to operate in bus-only lanes with signal priority reduces the unpredictability caused by city traffic.

1. **Easy-to-use, Comfortable, Secure Transit Service**

BRT increases mobility throughout the region, provides better accessibility for riders with special needs, and supports easy connections between other modes of travel (bicycling, walking, other bus lines, BART, etc.)

1. **Increased Transit Usage**

Projections show that weekday ridership would increase 50–75% with the implementation of BRT.

1. **Bus and Station Amenities**

Larger capacity buses can accommodate more passengers comfortably. The new BRT stations feature shelters, benches, landscaping, and better lighting as well as electronic signs to notify riders when the next bus is arriving.

1. **Improved Quality of Life**

Studies have shown that improved transit service leads to increased opportunities for redevelopment and increased local tax revenues.

## 2.4 Major elements of BRT

1. Running ways
2. Stations
3. Vehicles
4. Service
5. Fare Collection
6. ITS (Intelligent Transportation System)
7. Cost
8. **Running Ways**

BRT vehicles operate primarily in fast and easily identifiable exclusive at-grade transit-ways, grade separated transitways, managed lanes, tunnels and in dedicated bus lanes. Vehicles may also operate in general traffic. Some running ways are shown in Fig4.



**Fig 4: Bus running ways**

1. **Stations**

BRT stations, ranging from enhanced shelters to large transit centers, are attractive and easily accessible. They are also conveniently located and integrated into the community they serve. They provide amenities such as ligting, shelters, benches, ticketing security etc., as shown in Fig 5.



**Fig 5: Bus Stations**

1. **Vehicles**

Stylized and specialised buses can operate along BRT corridors, with emphasis on comfort, aesthatic enhancements, easy access, passenger circulations and environmentally friendly propulsion. Buses uses rubber tired vehicles that are easy and comfortable to ride.

1. **Service**

BRT systems generally include rapid transit features such as all-day service spans, less waiting time, greater spacing between stations, and more frequent service than local bus service. The flexibility and lower-cost of BRT allow it to provide greater network coverage.

1. **Fare Collection**

Simple BRT fare collection system make it fast and easy to pay often before you even get on the bus. They allow multiple door boarding, reducing time in stations. Electronic fare cards, off-board fare collection, or proof of payment options allow for shorter dwell times and shorter overall travel times.

1. **ITS (Intelligent Transportation System)**

BRT incorporates ITS applications such as transit signal priority, advanced communication systems, automated scheduling and dispatch systems, and real time traveler information at stations and on vehicles for faster and more convenient trips.

1. **Cost**

Operating costs reflects the ridership, type of running way and operating environment. Capital and operating cost data indicate that Bus Rapid Transit applications are significantly less expensive to construct than LRT.

## 2.5 Major feature of BRT

These bus systems can come in a variety of forms, from dedicated bus ways that have their own rights-of-way (e.g., the Ottawa Transitway or the Pittsburgh MLK East Busway) to bus services that utilize High Occupancy Vehicles  lanes and dedicated freeway lanes (e.g., Honolulu's CityExpress) to limited stop buses on pre-existing routes.

An ideal bus rapid transit service would be expected to include most of the following features:

1. **Bus only, grade-separated (or at-grade exclusive) right-of-way**:

The main feature of a BRT system is having dedicated bus lanes which operate separate from all other traffic modes. This allows buses to operate at a very high level of reliability since only professional motorists are allowed on the busway. A side benefit of this are lower construction costs since busways can be engineered to tighter standards and still remain safe compared to a roadway open to non-professional drivers, although buses need space and have problems with too tight roads.

1. Such a right of way may be elevated; on rare occasions, the right of way may be a modified rail right of way.
2. A bus street or transit mall can be created in an urban center by dedicating all lanes of a city street to the exclusive use of buses.
3. **Comprehensive coverage** :

In addition to using dedicated busways, BRT's can also take advantage of existing roadways in cities that already have a comprehensive road network for private automobiles. Service can be made more time efficient and reliable than a standard bus system by taking advantage of bus priority methods.

1. **Serves a diverse market with high-frequency all day service**:

A BRT network with comprehensive coverage can serve a diverse market (all income ranges) by moving people from their current location to their destination with high frequency and reliability while maintaining a high level of customer experience. As with any transit system, if any of these benefits are taken out of the equation, or do not provide better service than other modes of transit, the network will not be able to serve as diverse a market or offer high-frequency service without heavy subsidy.

1. [**Bus priority**](http://en.wikipedia.org/wiki/Bus_priority)**/ bus lanes** :

Preferential treatment of buses at intersections can involve the extension of green time or actuation of the green light at signalized intersections upon detection of an approaching bus. Intersection priority can be particularly helpful when implemented in conjunction with bus lanes or streets, because general-purpose traffic does not intervene between buses and traffic signals.

1. **Vehicles with tram-like characteristics**

Recent technological developments such as bi-articulated buses and [guided buses](http://en.wikipedia.org/wiki/Guided_bus) have benefited the set up of BRT systems. The main developments are:

1. Improved riding quality ([guided bus](http://en.wikipedia.org/wiki/Guided_bus), [electronic drive train control](http://en.wikipedia.org/w/index.php?title=Electronic_drivetrain_control&action=edit&redlink=1) smoothing the operation),
2. Increased capacity ([bi-articulated](http://en.wikipedia.org/wiki/Bi-articulated_bus) or [double decker](http://en.wikipedia.org/wiki/Double_decker_bus)),
3. Reduced operating costs (hybrid electric power train).
4. **Off-bus fare collection** :

Conventional on board fare collection slows the boarding process, particularly when a variety of fares are collected for different destinations and/or classes of passengers. An alternative would be the collection of fares upon entering an enclosed bus station or shelter area prior to bus arrivals (similar to fare collection at a kiosk prior to entering a subway system). This system would allow passengers to board through all doors of a stopped bus.

1. **Level boarding** :

Many BRT systems also use low floor buses (or high level platforms with high floor buses) to speed up passenger boarding and enhance accessibility.

1. **Stations** :

High quality BRT systems often feature significant investment in enclosed stations which may incorporate attractive sliding glass doors, staffed ticket booths & information booths, and other more standard features listed above. These styles of station is seen in [Bogota](http://en.wikipedia.org/wiki/Bogota)'s [TransMilenio](http://en.wikipedia.org/wiki/TransMilenio) and in some other cities in Latin America that have adopted BRT systems, while most North American systems tend to use open platform stops, or shelter-style platform stops.

1. **INTEGRATION OF ITS WITH BUS RAPIT TRANSIT**

Currently, there are many ITS technologies, which can be integrated into BRT systems that have been defined. Other technologies will emerge over time. For the purpose of this paper, the technologies have been categorized in the following six groups in order to organize future recommendations and actions

**3.1.** **ITS Technologies**

**1) Vehicle Prioritization**

This technology group includes methods to provide preference or priority to the BRT vehicles. Signal Timing / Phasing and Signal Priority help BRT vehicles minimize delay caused by having to stop for traffic at intersections. Access Control provides the BRT vehicles with unencumbered entrance to and exit from their facilities. All prioritization for BRT vehicles reduces travel delay and increases reliability of the BRT operation.

**2) IVI Technology**

This technology group includes Intelligent Vehicle Initiatives which provide automated controls for a BRT vehicle. Use of the Collision Warning function assists a driver to operate a BRT vehicle safely. Use of Collision Avoidance, Lane Assist, and Precision Docking functions provides for direct control of the BRT vehicle when making avoidance, guidance or docking maneuvers. All IVI functions help to reduce frequency and severity of crashes and collisions and provide reduced travel or boarding times.

**3) Fare Collection**

This technology group includes some method of electronic fare collection which provides a fast, cashless interface for the passenger. Use of magnetic stripe and smart card technologies are proven and the benefits of electronic payment systems are known. Use of either station-based or vehicle-based fare collection helps to reduced dwell times and increase passenger convenience.

**4) Operations Management**

This technology group includes automation methods which provide for enhanced operations management for a BRT fleet. Use of an Advanced Communication System can be the backbone to support various functions of fleet operational management. Use of Automated Scheduling Dispatch System and a Vehicle Tracking method assists BRT management to best utilize the BRT vehicles. Use of Vehicle Mechanical Monitoring and Maintenance assists in minimizing downtime of the BRT vehicles. All Operations Management functions improve operating efficiencies which supports a reliable service and reduced travel times.

**5) Passenger Information**

This technology group includes various methods of providing information to passengers so they can make the best use of their time. Information about the vehicle schedule can be provided at the station / stop and / or on the vehicle. Providing schedule information to travelers via PDA, cell phone or similar device and supporting trip planning are other functions that can be provided, if there is sufficient need by travelers. All the Passenger Information functions improve passenger satisfaction, help to reduced wait times, and can increase ridership.

**6) Other Technology**

This technology group includes functions which provide some unique enhancements for a BRT system. Use of Archived Data and automatic Passenger Counters can support operations and planning efforts for operating a BRT fleet. Use of Silent Alarms and Monitoring systems can increase the security of the operation. All of these functions can help to support passenger satisfaction.

**3.2. Technology benefits**

ITS technologies have been proven to help transit agencies increase safety and operational efficiencies. Remote monitoring of transit vehicle status and passenger activity helps to provide additional safety and security to passengers. ITS technologies also assist operations in maintaining vehicle fleets. Vehicle self-diagnostics can alert mechanics of impending mechanical problems as well as routine maintenance needs. AVL that utilizes Automated

Scheduling and Dispatch Service (ASDS) can improve scheduling activities and schedule adherence. All of these technologies have demonstrated that they are capable of reducing travel time both by improving the operation of the vehicle and the overall operation of the transportation network.

BRT is designed to overcome weaknesses of traditional service and sources of delay. Individual ITS technologies provide the basic features key to many of BRT’s benefits. Combinations of ITS technologies can work together to provide synergies to increase improvements in service. Separately, all of these ITS technologies would provide no unique benefit to BRT systems. Collectively they help to define BRT. What makes BRT unique is that it requires a combination, or set, of technologies to help meet system requirements. A transit bus system that does not include AVL or EFP is still a transit bus system. However, a BRT system that does not include AVL or EFP is only a transit bus system. Therefore, it is important to articulate those ITS technologies, either requisite or optional, that provide some amount of benefit to: 1) further define BRT system characteristics, 2) meet BRT goals, and 3) contribute to BRT user benefits.

**3.3. Scheduling forms of BRT**

Scheduling combination is the special characteristics of BRT. According to vehicle operation form and stops number, the scheduling is divided into normal scheduling, zone scheduling, and express scheduling, and so on.

1. Normal scheduling: Vehicles run along the routes and stop at every station from the initial stop to the end. The vehicle must run at fixed stations and complete the whole routes, as shown in Fig. 6(a).
2. Zone scheduling is defined as vehicles only run on high-traffic volume section or zone, as shown Fig. 6(b).
3. Express scheduling, that is, vehicles only stop at certain station with large passenger volume, as shown in Fig. 6(c).

In traditional bus scheduling, the normal scheduling is the most popular form. Whereas in BRT operation, there are scheduling combinations, which are more in accordance with the trips needed on the corridor than traditional bus.

Traditional bus scheduling is a kind of fixed scheduling, which is checked on the terminals. Because of the congestion in urban city, public transport vehicles often arrive at station unevenly, which leads to instable quality and low attraction. BRT is constructed by exclusive lanes and intelligent transportation systems. Moreover, BRT can provide scheduling combination to meet passengers travel demand well and reduce vehicles operation costs. Therefore, it is necessary to study the scheduling combination of BRT.

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**Fig.6 (a): Normal Scheduling**

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**Fig.6 (b): Zone Scheduling**

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**Fig.6 (c): Express Scheduling**

Real world transit scheduling is very complicated. The large numbers of trips, links, and paths to be considered rapidly increase the number of variables and constraints in any model developed. The transit scheduling problem belongs to the general class of vehicle scheduling problems. The general vehicle scheduling problems are problems in which a number of vehicles starting from one or more depot have to collectively visit a number of demand points and then return to the depot from which they start. Each demand point has a definitive time of service. In any scheduling problem, the following conditions should be satisfied:

1. An objective function given in advance is optimized.
2. Each trip is run by exactly one vehicle.
3. Each block of trips starts and ends at the same depot.
4. Each depot has a given maximum number of vehicles (capacity).
5. All operational constraints, including any restriction on the total time a vehicle spends away from the depot, are satisfied.
6. **CASE STUDY**

In Indian cities, the traffic on the roads is highly heterogeneous comprising vehicles of wide ranging static and dynamic characteristics. The vehicles occupy any lateral position on the road, depending on the availability of road space, at a given instant of time without any lane discipline and it is nearly impossible to impose lane discipline under such conditions. Under the said heterogeneous traffic flow conditions, the buses, being relatively larger vehicles, find it difficult to manoeuvre through the mixed traffic and are subjected to frequent acceleration and deceleration leading to lower speed and discomfort to both the driver and passengers.

This also results in enormous delay and uncertainty to bus passengers and consequently, the level of service of buses gets reduced considerably making the bus, a less attractive mode of transport. Indian cities desperately need improved and expanded public transport service and not personal vehicles. This requires both an increase in quantity as well as quality of bus transport service and effective application of demand as well as supply-side management measures. This goal can be attained by encouraging bus transport by assigning priority to it. One of the common bus preferential treatments is provision of reserved bus lanes on major urban roads to facilitate faster movement of buses, which will make the mode more attractive. Provision of exclusive road space, thus, will enhance the level of service of buses and this may also result in shift of some of the personal vehicle users to buses. The motorized personal vehicles available for travel, in Indian cities are, Car, Auto-rickshaw—three-wheeled motorized transit vehicle and motorized two-wheelers. As the possible shift of travellers from these personal modes to bus is independent of one another, the probability of shift has been studied through three separate binary choice models. This paper is concerned with the study of the possible shift of car users to bus because of increased level of service of bus, after provision of exclusive bus lanes.

The Delhi Bus Rapid Transit System is a newly introduced concept of transport in Delhi in which the buses cater to sixty percent of the city's transportation needs. Together with [Delhi Metro](http://en.wikipedia.org/wiki/Delhi_Metro) and soon to be introduced [Monorail](http://en.wikipedia.org/wiki/Monorail) and [Light Rail](http://en.wikipedia.org/wiki/Light_Rail), it will be part of integrated multi-modal transport systems operational in [Delhi](http://en.wikipedia.org/wiki/Delhi). The Government of National Capital Territory of Delhi is undertaking major reforms to make the transport in the capital city better. This includes introducing the multi-modal transport system that will interact with each other at common bays as well as other measures, like the AC buses, privatizing [Delhi Transport Corporation](http://en.wikipedia.org/wiki/Delhi_Transport_Corporation) etc. Like other bus-rapid transit systems across the world, Delhi BRT aims to make public transport a more convenient option for its people. Delhi BRT is not [grade-separated](http://en.wikipedia.org/wiki/Grade-separated), i.e., the buses do not run at a different level or height than the normal traffic and shares the same traffic signals.

## 4.1. Traffic Scenario in Delhi

***4.1.1 General***

The transportation network in Delhi is predominantly road based with 1,284 km of road per 100 km2. The number of vehicles on Delhi’s road has increased by 212% in the last 18 years from 19.23 lakh in 1991 to over 60 lakh by 2008. Road space in Delhi is 21% of the total space available, thus there is little scope of future expansion of road length. The road length in Delhi has increased from 22,487 km in 1991 to 31,183 km in 2008, a modest increase of 17% in the same period. To accommodate the increasing vehicular population, additional space is increasingly sought to be created either over or beneath the road, i.e. Flyovers and underpasses.

The success of policy initiatives aimed at public transport is palpable. Delhi Metro has proved to be a tremendous success story in Delhi. The idea was approved in 1998, with an aim to improve the traffic condition and mobility of commuters. Delhi Metro is operating around 90 trains and carrying approx. 8 lakhs passenger per day. The bus system, however, has its own importance. Delhi Metro can not completely replace the bus-based system on all routes. Due to higher capital cost, low capital returns and large gestation period, it is not feasible to build Metro line on all stretches. The logic of this argument is seen from the situation in other cities with well developed metro networks like London and Paris, where buses still cater to a much larger number of passenger trips than metro.

The reason is that the bus system is more flexible compared to other transportation system. There is, thus, a need to strengthen the bus-based system. In Delhi, buses are generally considered unreliable and time consuming, to reach the destination. Thus, there is need to develop a system to give priority and dedicated road space to buses in order to make them reliable and faster. BRT system is part of the Multi Modal Transport Policy of GNCTD, a total of 7 BRT corridors are proposed to be built in the first phase.

### *4.1.2. Traffic Volume*

Traffic volume on the BRT corridor is very high. The corridor is situated along some of the prime colonies in South Delhi and is the main connecting road to the large commercial development in Gurgaon. On the stretch from Dr. Ambedkar Nagar to Moolchand, there are 6 key intersections, of which Chirag Delhi and Moolchand are the busiest ones. According to a DIMTS Survey, Chirag Delhi is one of the busiest junctions in Delhi. More than 1.35 lakhs vehicles cross the junction in a day (16 hours). Motorised vehicles consisting of cars, two wheelers and auto rickshaws constitute more than 90% of the vehicle traffic, of which the number of cars/Jeeps constitute around 35-40% of total motorized vehicles. These, however, carry only 15-20% of the total commuters. On the other hand, buses account only for 2.0-2.5% of total vehicles, but carry around 55-60% of the total commuters, thus using road space more democratically.

Approximately 200-250 buses move on Chirag Delhi Junction (the busiest section) during peak hour, catering to passenger load of about 11,000 - 12,000 on an average day. It has been observed that net throughput of all kinds of vehicles have significantly improved after the implementation of the BRT and bus and cycle transit time through the corridor has reduced.

**4.2. Methodology**

The broad guidelines based on traffic planning and simulation modelling in improving the performance of the pilot corridor in implementing dedicated lanes for BRT is mentioned in the following. In India, traffic moves on the left-hand side of the road.

1. The total pavement approach width of the earlier corridor is 11.00 m. This approach lane for BRT is divided into three different size lanes. An exclusive left-most lane is assigned for NMVs, an exclusive right-most lane is assigned for public transport and middle lanes are assigned for motorized vehicles (MVs). Total pavement approach width of the BRT will be 12.45 m. Therefore, BRT total pavement approach width is more than the earlier total lane width as shown in Fig.7 and Fig 8.

2. The width of the NMV lane is taken as 2.5 m throughout the corridor. A 0.4 m wide physical concrete divider on either side separates the NMV lane.

3. The width of the MV lane is taken as 6.75 m throughout the corridor. To improve the performance of the MV section near the intersections, the width of the MV lane is gradually increased from 6.75 to 9.75 m near the intersections for a length of 54.0 m.

4. The width of the bus lane is taken as 3.2 m throughout the corridor except near intersections. Near an intersection, two bus lanes are provided and separated by a 0.4 m wide divider on either side until it reaches 54.0 m. A bus shelter of 3.7 m in width and 54 m in length is provided on each side of the segregated lane.



**Fig.7: Junction Diagram for earlier corridor and BRT Systems**



**Fig 8: Dedicated lanes for different modes of vehicles**

5. The location of the bus shelter is a very important factor to improve the mobility of commuters. In the earlier situation, for certain stretches the bus shelters were situated more than 1 km apart. However, in the BRT system an average distance between two signalized intersections is kept at 650 m. Midblock bus shelter is proposed between two intersections, which are more than 1 km apart to increase commuter accessibility to the BRT. The bus shelters are located just before the intersection. The upstream side bus fleet can utilize the red phase of signal for boarding and alighting the passengers.

6. Although developing a signal plan for the BRT corridor, the speed and flow in the bus lane, safe and efficient signal cycle for pedestrian movement have been given the highest priority. TRANSYT-12 and aaSIDRA2.1 are used for signal optimization and progression. Based on experimental verification of TRANSYT-12 and aaSIDRA2.1 results for existing traffic signal phasing and timing at Chirag Delhi intersection, six signal phase intervals for a four-arm intersection and four-signal phase interval for a three-arm intersection are proposed in one signal cycle for BRT corridor. The coordinated and optimized signal cycle for four arms and three arms in oversaturated and saturated corridor were found to be 180±20 and 120±15 s, respectively. Midblock optimized signal cycle time was recommended as 75 s (green=55 s, red=20 s). Bus priority signal phase interval of 20 s is provided in each signal cycle. Optimum signal cycle length using TRANSYT-12 and aaSIDRA2.1 was implemented with some modification at Chirag Delhi intersection. At present, optimized signal cycle length was working well at Chirag Delhi intersection for mixed traffic. Detailed analysis of signal cycle study for existing and proposed BRT has been studied .

7. The junction structure of BRT system and existing system is shown in Fig. 7. The main characteristic of BRT junction structure over existing junction structures are bus way and NMV phase protection. Bus way signal phase are controlled by only one bus priority signal of 20 s including 5 s of yellow time. Within the corridor, the dwell times at the bus stops were fixed to 20 s for BRT, whereas for existing ones it varies from 15 to 25 s. This additional green time for through buses on the dedicated bus way will increase the capacity of the bus lane. This will enhance the mobility of public transport and commuters. In order to protect bicyclist movements, especially right turns, some signal phases were split. This split signal phase provides enough time for bicyclists to complete their movement while reducing the green time for the movement of minor motorized vehicles in this phase. The green time allotted to the major, motorized vehicles remains the same.

8. The minimum green time required for pedestrians to cross over the intersections in the chosen corridor was studied by TRIPP, and safe pedestrian crossing time in Indian conditions was estimated. On site study of existing intersection for mixed traffic reveals that pedestrian waiting time varies from 50 to 160 s and is one of the major causes for injury and fatal accidents at intersections. A pedestrian behaviour study shows that less than 60 s waiting time will provide safe and efficient movement of pedestrians at the intersection. In the BRT system, an IIT Delhi analysis shows that pedestrians are not waiting for more than 55 s at any intersection (IIT 2000).

**4.3. AIMSUN Simulation Model**

AIMSUN, v4.2, a microscopic traffic simulator is used to realistically emulate the flow of vehicles on an arterial network. It provides a detailed modelling of the traffic network, distinguishing between different types of vehicles, modelling incidents, and conflicting manoeuvres. To assist in the validation of the microscopic traffic model for existing and BRT, experimental measurements were taken at all the intersections. Data is collected at 5 min intervals for all modes of vehicles during peak hours. The morning peak hour \_from 9:15 a.m to 10:15 a.m\_ traffic composition on this corridor is about 39.33% cars, 31.23% two wheelers, 9.67% three wheelers, 3.73% buses, and 10.04% goods and slow moving vehicles. AIMSUN models were run with an hour measured data with a calibration of the original geometry of the road and existing signal timing. The simulation was run with a fixed demand level for the entire period and a few detectors were placed to detect actual traffic characteristics. After calibrating and validating the existing corridor traffic model, the BRT corridor was modelled. To get the actual conditions of BRT, all the side lanes were also segregated near the intersection to stop any level of traffic mixing. In the existing traffic model calibration and validation study, the model assessment was carried out by comparing measured traffic characteristics at selected sampling intersections.

**4.4. Comparison between BRT and Earlier Corridors**

A broader comparison between the earlier and BRT systems will follow in the following sections. The dedicated lanes and bus priority signal system closely influences the efficiency of bus trip service. On the contrary, in the earlier system motorized vehicles other than public transport dominate the vehicular flow rate. Increase in bus volume will correspondingly increase commuter mobility.

Fig. 9 illustrates the typical speed variation of public transport in the earlier and the BRT corridors. The BRT corridor is showing overall improvement in speed by more than 100% over the earlier system in both directions. Also in Fig. 8, the curve shows the kink in the speed curve, which is indicating the presence of a bus shelter. These results clearly show the benefits of dedicated lane versus mixed lane for public transport. Commuter mobility will increase due to the increased speed of the public transport, and will encourage people in large numbers to choose public transport.

** Earlier  BRT**



**Fig 9. Bus Speed in BRT and earlier corridor**

** Earlier  BRT**



**Fig 10. Bus Travel Time comparison**

To make a decisive option about public transport, we will be stronger by observing travel time analysis as shown in Fig. 10. In the present situation a typical study was conducted by RITES about commuter satisfaction on this corridor. RITES report analysis reveals that commuters have to travel for 10–15 min on average to cross 3,000 m distance during peak hours. This can also be seen from the typical travel time. Fig 10 shows that average travel time in the earlier system is 7–8 min per kilometer whereas in the BRT corridor, average travel time is about 1 to 2 min per kilometer. In the proposed corridor, the increased travel time actually shows the bus shelter on the corridor. The travel time of bus is decreased very significantly in all corridors. A high volume of MVs near Sadiq Nagar caused increased travel time at 2000m. Therefore, a decrease in travel time will put positive impacts on commuter mobility. This impact will also be felt in fuel consumption. A typical delay time is shown in Fig. 11, which is one of the important mobility indicators to psychologically convince the commuter to choose public transport over privately owned vehicles. Delays for buses in the earlier system are much more pronounced than in the proposed BRT corridor. The impact of mixed traffic on the public transport system can be seen as waiting time to cross the 6 km long corridor. From the analysis of the result data, the average delay time for the BRT proposed corridor was found about 60 s /km as compared to earlier conditions of about 360 s /km.

** Earlier  BRT**



**Fig.11. Delay Time Comparison Fig.12. Stop Time Comparison**

Finally, Fig. 12 shows the typical stop time of traffic flow over the corridor due to geometrical, signal, and congestion situations. As it is seen from Fig. 12, in the earlier corridor buses are stopped even in between two intersections and before the Chirag Delhi intersection the stop time is about 8 min. However, in the proposed BRT system, stop time was calculated in the range of 45–60 s. In the BRT proposed corridor, buses are stopping at the intersection only, but this is not the case in the earlier condition. Experimental and environmental modelling results show that in

the earlier condition, the average speed of the buses is 16.5 km/h and the fuel consumption was noted to be about 3.05 km/L. However, in the BRT corridor the average speed is 25.4 km/h and the fuel efficiency is 6.06 km/L. Consequently, vehicle emission will also be decreased due to a decreasing percentage of acceleration, deceleration, and idling duration in the driving cycle of vehicles on this corridor. Public commuter transit in the BRT system is increased by approximately 45% against the earlier condition. Analysis shows that traffic flow is increased by more than 100%. By comparing the magnitude of the traffic quality values, it is possible to reveal the relative benefits of the BRT system against the existing system.

Therefore, a mobility indicator such as volume is showing positive signs for public transport and commuter mobility. The choice of opting for public transport among other modes of transportation depends upon speed, travel time, delay time, and stop time of public transport. In the BRT corridor, public transportation is running at its optimum speed (as defined in the simulation parameters) as compared to the earlier system.

**5. APPLICATION EFFECT OF BRT AT BEIJING**

**5.1. General**

The BRT system at Beijing South-Centre Corridor is the first large-capacity rapid bus line based on the needs of developing public transportation, which is designed using foreign advanced ideas and technology as reference.

The BRT system at Beijing South-Centre Corridor is divided into the road-reconstruction project, the stations, and Intelligent Transportation System (ITS). The investment of the road reconstruction project is about 321.31 million yuan while the investment of the station and the intelligent transportation system (stations, parking lots, vehicles, ITS) is approximately 288.19 million yuan, and the total of these two parts reaches 609.5 million yuan while the construction cost per kilometer is about 38.1 million yuan. The special lane of lines is a physically isolated central two-way lane, and the designed transportation capacity is 20,000 passengers/hour/direction; currently, there are 87 vehicles in the system, each vehicle is 18 m long, 2.55 m wide, and 3.25 m high, with the passenger capacity of 180 persons, and the doors are at the left side of the bus body. The buses are mounted with GPS satellite positioning terminal equipments, and they meet the Euro- emission standard. The average speed of buses on the special line reaches about 25 km/h. The central island-type platform is 60−80 m long and 5 m wide, the height of which is as high as that of the bus floor, and the height to road is 0.3 m. The buses will enter and leave the stations in order. At present, the tickets are sold at the platform, and electronic-ticket is also acceptable. At the intersection, the active signal priority system is also adopted. Electronic information service plates have been set up in all stations; the content includes the time of the first and last bus, the location of station, the trend of lines, and other information. The construction of the intelligent system is an important component of the BRT system at South-Center Corridor, including the fiber network information transmission system, the bus-mounted electronic system, the intelligent platform system, the parking management system, the public transit signal priority system, the closed-circuit television monitoring system, the intelligent integration system, the operation scheduling system, and the enterprise MIS system. The construction of the intelligent system has created good conditions for the successful operation of the BRT system at South-Center Corridor and the intelligence of integration bring into effect the BRT supporting scheduling and the high level of service.

**5.2 The Improvement of Transit Environment**

To coordinate with the opening of BRT lines, the regular bus lines at south-centre corridor are adjusted by stages. The purpose of combining lines falls on: reduce the line overlapping, enhance the linking between regular lines and BRT lines, provide and evacuate passengers for BRT lines, optimize and improve the bus-line net in south city, and improve the service level of public transit. Prior to integration, there were 22 regular bus lines at south-centre corridor, in which 10 lines accept monthly-ticket while 12 lines reject monthly-ticket. The total daily passenger volume at the Qianmen–Demaozhuang section for regular bus lines is about 260,000.

As seven lines are cancelled, shortened, or course-changed after integration, the volume of buses reduces about 400 sets and the transit time reduces about 7000 times. The volume of motor vehicles at south- enter corridor is greatly increased as well as the speeds of vehicles are greatly improved. According to a survey result, the speed of social vehicles can reach 26.7 km/h at the noon peak-hour, and at the morning and evening peak-hours, it can reach 25 km/h. Both are improved when compared to those before BRT opening. Meanwhile, the volume of motor vehicles is improved at all sections, with the largest proportion being 95%.

Both the bus-taking order and the transit order of social vehicles are improved greatly, and as a result, the traffic jam is relaxed. It also makes it convenient for passers-by to run across the line or transfer bus.

**5.3 The Improvement of Service Level**

For the purpose of service level, the successful operation of BRT of South-Center Corridor has brought evident benefit to passengers, enterprises, and line transit system. It mainly includes:

1. **Saving the travel time**

Since the priority has been given to special lines, selling and checking tickets and intersection signals after the opening of BRT, the travel time from Demaozhuang to Qianmen is shortened by 30 min, that is, from 70 min to 40 min. The advantage is outstanding especially during the morning and evening peak hours, the advantage is outstanding.

1. **Speed improvement**

After the opening of special lines for buses, the transit environment has been greatly ameliorated, and the vehicle speed has been improved with the reduction of disturbance. According to a survey result, the vehicle speed on the whole course of BRT at peak hours can reach 23.5 km/h. It is faster than the speed of regular public transit buses (16 km/h) before the opening, though it is slightly slower than the current speed of social vehicles. At the Sanyingmen−Tiantan section, the speed of BRT vehicles reaches 30 km/h with steady transit status and slight influence of time and direction (to south or north). It indicates that the transit status on special lines for buses for BRT is similar to that on railways.

1. **Decrease in delay**

The total delay time of BRT vehicles mainly consists of the intersection delay time and the station parking time. The survey results show that the total delay time of BRT vehicles accounts for 23% of the total travel time while the intersection delay time accounts for 80%. Meanwhile, the station parking time occupies 20% of the total travel time. For the purpose of intersection delay, as a series of signal priority measures have been taken and the lines are for special purpose. Thus, it ensures that the BRT vehicles can pass an intersection in one signal cycle. For the purpose of the station parking time, according to the survey results, the average delay time per station is 12 s while the average delay time for regular public buses is about 13 s; at any time and direction, the average delay time per station for BRT vehicles is shorter than that before the opening, and the largest difference reaches 15.5 s. It shows that the efficiency of regular public buses has been greatly improved than that before the opening of BRT.

1. **Punctuality rate improvement**

The setting of special lines for public buses, and the efficient intersection priority measures taken substantially reduce the delay caused by external factors of the BRT system. To ensure the stable speed of BRT vehicles on the line, limited delay at intersection shall be borne. According to the survey results, the punctuality rate of BRT vehicles is considerably higher than that of regular bus lines. Especially at the Sanyingmen– uxiyuanqiao section and the Muxiyuanqiao–Tianqiao section, the punctuality rate reaches 60%.

1. **Transit efficiency Improvement**

After the opening of BRT at south-center corridor, the daily passenger volume of individual BRT bus ( for standard buses) reaches 1037 persons and the daily journey reaches 273.9 km. Meanwhile, the daily passenger volume of individual regular public bus is 267 persons (for standard buses) and the daily journey is 145 km (according to statistics in 2005). The daily passenger volume of individual BRT is 3.9 times that of regular public buses and the daily journey of individual BRT is two times that of regular public buses. It shows the rapid turnover and the high transit efficiency of BRT vehicles.

1. **The Evident priority of intersection signals**

The phase of signal for south-north direct running at the investigated intersection and appointed time (16:00–19:00) accounts for 39% of the total cycle; the observed cycle of intersection signal is 150–160 s, with the time for south-north direct running representing 47%–50%, the south-north left turning representing 29%–31%, and the east-west direct running representing 20%–22%. Viewing from the probability theory, the passing rate of BRT vehicles at the intersection shall be the rate of green light time to the direction of the total cycle, which is 47%–50%. According to the actual survey, the passing rate of BRT in both directions is 54% and 55.4%, respectively, which is higher than the percentage of green light to the total cycle at appointed time (39%), and it is also higher than the percentage of actually observed green light to the total cycle (47%–50%). Thus, the priority equipment for the intersection signal has played its role, and it improves the passing rate of BRT at the intersection for 4%–6%. Furthermore, according to the scene observance, if the BRT vehicle arrives at the intersection when the green light is on, the time of green light will be extended to allow the BRT vehicles to pass through, and the effect is obvious. If the BRT vehicle arrives when the red light is on, the time of red light ought to be shortened, but actually this effect is not obvious. The phase of red light at this intersection is not obviously shortened owing to the security consideration for pedestrians to cross the street. The west Dahongmen intersection is considerably wider, but for some reasons, the street-crossing island for pedestrians has not been set up (to facilitate the second time of street-crossing for pedestrians), and therefore, the effect of shortening the red light phase is switched off. To better implement the strategy of intersection signal priority, we suggest that islands can be constructed at intersections conforming to construction requirements. The survey also found that the departure frequency of BRT is too high, and these BRT vehicles can easily catch up with each other especially in the intersections. Therefore, it is difficult to achieve fully priority for BRT vehicles in intersections. It is proposed that BRT vehicles stop only in major stations, grouping the vehicles, adding some interval vehicles, and adopting vehicles with large passenger volume to decrease the departure frequencies.

1. **Improvement of passenger satisfaction rate**

A survey is conducted from the time savings, quality of service (waiting time on or off the bus), passenger information, convenience of crossing the street, etc, and passengers on the whole affirmed that the superiority of BRT falls on the convenience and high-speed. The passengers contributing the main advantage to high-speed account for about 54%, and 20% contribute the advantage to convenience as well as 14% think that it is both convenient and faster, and the total is 88%. Viewing from the survey of time-saving index, the passengers’ satisfaction rate is very high, and the very satisfied or satisfied passengers account for 90% or above. Viewing from the traveling time index, the passengers satisfaction rate can reach up to 80%; from the aspect of information providing, the rate is 90% or above; from the congestion level, the passengers are lenient to crowding at working days relatively, but those who feel very congested and crowded account for 75%. Passengers have slightly higher requirements to congestion at weekends and 84% of passengers feel BRT very crowded and congested. As there are overpasses or subways at each station, which directly connected to the platform, BRT passengers are quite satisfied with the convenience and the security of crossing street.

In short, owing to the opening of BRT at South-Center Corridor, the allocation and use of scarce traffic space resources has become more rational and fair, and the Optimization of line-grid and integration of bus lines ease the traffic jams at South Central corridor. The transport efficiency and service level have significantly increased, the traveling time for passengers has been saved, and the public satisfaction level has been enhanced. While enhancing the population mobility and the city’s vitality, the traffic environment and the urban landscape have been improved.

**SUMMARY**

1. Bus Rapid Transit is an emerging approach to using buses as an improved high speed transit system.
2. By employing innovative technologies such as signal prioritization, better stations or shelters, fewer stops, and faster service on more attractive vehicles, Bus Rapid Transit shows promise in meeting a variety of transit needs.
3. Bus Rapid Transit systems can have lower capital costs than Light Rail systems yet can often provide similar performance
4. By using different traffic qualities in a corridor, BRT was found to be positive impact on the traffic and commuter mobility
5. The average bus speed and flow rate in the BRT corridor was more than 100% against the previous condition
6. Delay time, and stop time has also significantly decreased in the BRT system with respect to the present situation.
7. The transport efficiency and service level have significantly increased
8. The travelling time for passengers has been saved, and the public satisfaction level has been enhanced
9. Motorized Vehicles (car) flow and speed is also increased in the BRT corridor with respect to the existing mixed system

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