Sustainable Public Transportation: Environmentally Friendly Mobility

DETAILS

20 pages | | PAPERBACK
ISBN 978-0-309-21372-1 | DOI 10.17226/14608

AUTHORS

December 2011

TRANSIT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Transit Administration

Responsible Senior Program Officer: Gwen Chisholm-Smith

Research Results Digest 103

International Transit Studies Program
Report on the Spring 2011 Mission

SUSTAINABLE PUBLIC TRANSPORTATION: ENVIRONMENTALLY FRIENDLY MOBILITY

This TCRP digest summarizes the results of mission performed from April 1 through April 16, 2011, under TCRP Project J-03, "International Transit Studies Program." This digest includes transportation information on the organizations and facilities visited. It was prepared by Harrington-Hughes & Associates, Inc., and is based on reports filed by the mission participants.

CONTENTS

INTERNATIONAL TRANSIT STUDIES PROGRAM

The International Transit Studies Program (ITSP) is a part of the Transit Cooperative Research Program (TCRP), authorized by the Intermodal Surface Transportation Efficiency Act of 1991 and reauthorized, in 2005, by the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users. TCRP is managed by the Transportation Research Board (TRB) of the National Academies and is funded annually by a grant from the FTA. ITSP is managed by Harrington-Hughes & Associates, Inc., under a contract with the National Academies.

The TCRP has sponsored the ITSP since 1994. The primary purpose of the program is to broaden the professional development of U.S. transit managers by providing them with opportunities to visit transit systems abroad; the managers return with insights and knowledge useful to their organizations, the transit industry, and their own transit careers. ITSP carries out its mandate by offering transportation professionals practical insight into global public transportation operations. The program affords the opportunity for them to visit and study exemplary transit operations outside the United States.

Two ITSP study missions are conducted each year, usually in the spring and fall, and are composed of up to 17 participants, including a senior official designated as the group spokesperson, a representative of the FTA, and a mission coordinator. Transit organizations across the nation are contacted directly and asked to nominate candidates for participation in the program. Nominees are screened by committee, and the TCRP Project J-03 Oversight Panel endorses all selections. Members are appointed to the study team based on their depth of knowledge and experience in transit operations, as well as for their demonstrated advancement potential to executive levels of the public transportation industry. Participation on a mission team is designed to complement and enhance professional development, helping to produce managers and leaders capable of dealing with a variety of problems inherent in managing transit activities in a complex environment. Travel expenses for ITSP participants are underwritten by TCRP Project J-03 funding.

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

Each mission abroad focuses on a theme that encompasses a topic of concern in public transportation. Cities are selected according to their ability to demonstrate leading-edge strategies and approaches to public transportation issues and challenges as reflected in the study mission's overarching theme.

The members of each study team are fully briefed prior to departure. The intensive, professionally challenging, 2-week mission has three objectives: to afford team members the opportunity to expand their network of domestic and international public transportation peers, to provide a forum for discussion of global initiatives and lessons learned in public transportation, and to facilitate idea-sharing and the possible import of strategies for application to transportation communities in the United States. Mission participants return home with ideas for possible application in their own communities. Participants are encouraged to share their international experience and findings with peers in the public transit community throughout the United States.

For additional information about the International Transit Studies Program, please contact Gwen Chisholm-Smith at TCRP (202-334-3246; gsmith@nas.edu) or Kathryn Harrington-Hughes at 443-385-0300 (khh@tcrpstudymissions.com).

ABOUT THIS DIGEST

The following digest is an overview of a mission that explored how public transportation systems in India and China have implemented plans, policies, technologies, and strategies for creating more livable communities through bus, metro, bus rapid transit, rail, and light rail systems. These innovative systems are designed to reduce energy consumption and carbon emissions, lower operating costs, and provide safe and accessible transportation services. The digest is based on individual reports provided by the mission team members, and it reflects the observations of the team members, who are responsible for the facts and accuracy of the data presented. The digest does not necessarily reflect the views of TCRP, TRB, the National Academies, the American Public Transportation Association (APTA), FTA, or Harrington-Hughes & Associates.

A list of the study team members is included in Appendix A. A list of the public transportation agencies and organizations with whom the team met is included in Appendix B.

INTRODUCTION

China and India now represent one-third of the world's population. In the past 20 years, both countries have experienced rapid economic growth and urbanization. The Chinese economy has become the second-largest economy in the world and India the fourth-largest.

This rapid expansion, however, presents new and significant challenges to India, China, the global economy, and the environment. India's population was approximately 30% urbanized in 2006, but this share is expected to grow to 60% before stabilizing.[1] Similarly, China's urban population has reached nearly 50%.[2] The transportation sectors in both economies are rapidly expanding their share of energy use. If these countries follow the typical model of economic growth that involves high energy use and high consumption, their continued growth will have a significant, and potentially dangerous, effect on the global environment. Air quality and traffic safety have declined precipitously in many urban areas as street congestion has worsened, and China is already displacing the United States as the world's largest producer of greenhouse gas (GHG) emissions.

The ITSP team visited two cities in India (Ahmedabad and Delhi) and three cities in China (Guangzhou, Hangzhou, and Shanghai) to evaluate how these two countries are responding to the challenges of urbanization and sustainable public transit systems.

Two of the cities recently were honored with the Sustainable Transport Award, which is given annually by the Institute for Transportation Development and Policy (ITDP) in recognition of progress in increasing mobility for all residents while reducing transportation greenhouse and air pollution emissions and improving safety and access for cyclists and pedestrians. Ahmedabad received the award in 2010 and Guangzhou in 2011. Both cities were recognized for their bus rapid transit (BRT) systems and high-quality pedestrian and bicycle facilities.

Ahmedabad

Ahmedabad, with a population of approximately 5 million, is the largest city in the state of Gujarat

[1]Ministry of Urban Development. National Urban Transport Policy (NUTP). Government of India, April 2006, p. 1.
[2]NUTP, p. 3.

and serves as its commercial and cultural capital. For decades, Ahmedabad's economic vitality was based on its manufacturing industry, primarily textiles, which led to its ranking in 2001 as the fourth most-polluted city in India. At the same time, the city faced transportation challenges caused by increased auto ownership, population growth, and longer commuting distances. In response, the Ahmedabad Municipal Corporation (AMC) in 2007 committed to the development of India's first citywide BRT system. A substantial portion of the funding for design, engineering, and construction was provided by the Jawaharlal Nehru National Urban Renewal Mission (JNNURM), a discretionary program administered by the federal Ministry of Urban Development.

AMC was well prepared to compete for JNNURM funds because of the master planning process carried out every 10 years by the Ahmedabad Urban Development Authority (AUDA). The latest version of the plan was completed in 2002. Both AMC and AUDA benefit substantially from technical expertise provided by academic partners at the Center for Environmental Planning and Technology (CEPT) University. A leading institution for urban planning in India, CEPT University is planning support activities for other BRT systems under development in India and is one of four universities that have been designated by India's Ministry of Urban Development as centers of excellence for technical and institutional support.

Delhi

The population of Delhi's metropolitan area is expected to exceed 20 million in the next 10 years. Given that the metropolitan area extends beyond the boundaries of the Delhi National Capital Territory, in 1985 the Indian Parliament created the National Capital Region Planning Board to coordinate transportation planning for the Delhi National Capital Territory and portions of Haryana, Rajasthan, and Uttar Pradesh states in the Delhi metropolitan area.

As in Ahmedabad and other urban areas in India, the primary causes of acute congestion are the rapid growth in automobile ownership and steadily rising incomes, which allow residents to live farther from work. Unlike many other metropolitan areas in India, however, Delhi's potential for redevelopment in the urban core is limited by the presence of the federal government and its associated buildings, institutions, and services. Delhi's more advanced highway infrastructure and higher rates of automobile ownership have generated substantially more sprawl than in many other Indian cities.

Guangzhou

Guangzhou (formerly Canton) is experiencing massive booms in both infrastructure development and population. Long an industrial powerhouse in southern China, Guangzhou is the administrative capital, and the cultural and commercial center, of Guangdong Province. Guangzhou's current population stands at approximately 12 million.

By 2005, gridlock conditions on Zhongshan Avenue, the city's primary east-west arterial through the urban core, had become a major impediment to the success of a number of adjacent commercial and residential developments. Zhongshan Avenue crosses several "new town" urban development districts, such as the landmark Zhujiang financial district where new skyscrapers reach above 100 stories. This corridor also serves the Huangcun district near the Guangdong Olympic Sports Center, a large sports stadium used extensively in the 2010 Asian Games.

As in Ahmedabad, officials in Guangzhou decided to leverage expertise from a public research institution to help develop sustainable solutions to acute traffic congestion problems. The Guangzhou Municipal Engineering Design and Research Institute (GMEDRI) was tapped in early 2005 to investigate improvements to the Zhongshan Avenue corridor.

Congestion was being caused not only by automobile traffic, but also by the hundreds of buses hourly serving core segments. Especially at bus stops near major intersections, buses queuing behind or passing one another often caused gridlock. The Guangzhou Metro was also rapidly developing in 2005, with four of its railway lines crossing the corridor at various points and generating additional pedestrian traffic. Because of these traffic volumes on all modes, GMEDRI determined that full reconstruction of the Tianhe Road/Zhongshan Avenue/Huangpu East Road corridor was necessary, and that physically separated facilities should be provided for buses, automobiles, pedestrians, and bicycles. GMEDRI proposed the implementation of a BRT system along Tianhe Road and Zhongshan Avenue and continuing along Huangpu East Road to the Huangpu district of the city.

Hangzhou

Hangzhou, a city of nearly 7 million people, lies in the shadow of its much larger neighbor Shanghai, which is approximately 90 miles to the northeast. This proximity to one of the world's largest cities allows Hangzhou to capitalize on its reputation as one of the most picturesque urban destinations in all of China. The growing disposable income available to many people in Shanghai, coupled with the new high-speed rail link between the two cities, allows Hangzhou's tourism market to thrive. Its major attraction, West Lake, lies in the heart of the city. To the east of the lake are Hangzhou's historic districts, including the popular Shangcheng Old Town. To the northeast is the modern business center of the city.

Before April 2006, Hangzhou's public transportation options consisted only of local buses and taxis, with no common fare collection media. At that time, the city opened the first of 11 planned BRT lines, quickly followed by three additional lines. In 2008, the first bicycle-share stations were opened, and the network has since expanded to more than 2,400 stations throughout the city. Between 10 and 70 bicycles are accommodated at each facility, with a total of 60,000 bicycles available throughout the system. During 2010, the municipality reported 70 million individual uses of the bicycles. Growth of the network remains strong, with between 300 and 500 new bicycle-share stations expected during 2011.

Shanghai

Shanghai is home to approximately 20 million people in a land area of just under 4,000 square miles. The city is located on the Pacific coast of east-central China near the mouth of the Yangtze River, within the most-developed delta in China. Even with its well-documented highway congestion, Shanghai's auto ownership rates remain relatively low. Of the 2.5 million motor vehicles registered in the city, only 1.6 million are private automobiles. This figure is expected to grow by 100,000 each year, however, and to limit this auto ownership growth rate, vehicle license plates may now be purchased only through auctions conducted by the city. As a result, recent prices for license plates have exceeded the average vehicle purchase price.

Shanghai is committed to providing a robust transit network that serves every neighborhood of the city. In particular, a goal has been set of locating a bus or metro rail stop within one-third mile (less than a 10-minute walk) of any point within the outer ring road. Within the inner ring road, transit options are planned to be available no farther than one-fifth mile from any point (less than a five-minute walk).

According to municipal planning officials, improving air quality is a key element of Shanghai's drive toward sustainability. Emissions reduction targets were set at 45% for the 15-year period starting in 2005. As part of that effort, a goal of 50% transit mode share for all trips made in Shanghai also has been defined, up from its current 42%. Like Hangzhou, Shanghai's municipal officials consider taxis to be an integral part of the transit network and thus a part of the suite of transportation options that encourage residents to limit acquisition of private automobiles.

The pace of transportation capital development in the Shanghai region is astounding. Twenty-five years ago, Shanghai had no metro lines and no express highways. At that time, the first comprehensive traffic surveys were being conducted by the municipal planning office. Two years later, in 1988, China's first expressway opened in Shanghai, after which approval was granted to begin construction of the city's first metro line. This first line opened in 1995, and 39 miles of metro rail lines were in service a scant 5 years later. The rail network grew to more than 90 miles by 2005, and the Shanghai Metro is now the world's largest at nearly 300 miles. Close to 250 more miles of lines are projected to be in service by 2020. A fleet of 17,000 buses currently complements this rail network.

OVERVIEW

For purposes of this digest, "sustainability" is defined as meeting today's needs without compromising the ability of future generations to meet their needs. With regard to sustainable transportation programs/projects, three critical factors, or pillars, should be considered when making decisions.

1. **Environmental aspects.** Consideration should be given to methods that minimize or mitigate any negative aspects and maximize benefits to the environment of any transportation program/project decision.
2. **Economic aspects.** Consideration should be given to funding a transportation program/project in a way that maximizes the economic vitality of those affected by the decision over the long term.
3. **Social issues.** Consideration should be given to how the program/project will affect society

in general, as well as individuals who might be affected directly by the decision.

When meeting with transportation and government officials, throughout the mission, team members used this definition of sustainability and the three related pillars as a lens through which to examine the transportation systems in each city.

Officials in India and China recognize that population growth is far outpacing the ability of federal, regional, and local governments to provide needed infrastructure and housing. Public transportation plays a key role not only in moving people but also in sustaining economic activity. In every city visited, dramatic growth in automobile ownership and use is causing severe congestion, and building new highway capacity is not viewed as a sustainable option. These cities face environmental quality issues caused by air pollution from traffic congestion coupled with emissions from industrial sites.

Federal, regional, and local governments in India and China have responded to these challenges through a wide variety of policies and programs. The team received presentations on various modes of public transportation, including traditional fixed-route bus service, BRT, metro (subway), bicycle share, and a pedestrian greenway. The public transportation systems studied receive subsidies from local and state governments for operating assistance, with some level of public-private partnerships playing a role in service delivery. Each transit system strives to make service convenient and affordable. Advancements in technology, ranging from fare collection to real time information systems, are critical to the success of the services.

PUBLIC POLICY FRAMEWORK

In both India and China, responses to the challenges of urbanization and rapid economic growth are being made within a supportive national policy framework. The central governments in both countries recognize the importance of public transportation to their national growth strategies and have taken steps to provide strong policy guidance to the local jurisdictions responsible for building and operating the public transit systems.

India's National Urban Transport Policy, adopted in 2006, includes the following policy objectives:

- Encourage greater use of public transport and non-motorized modes by offering central financing assistance for this purpose.
- Incorporate urban transportation as an important parameter at the urban planning stage . . .
- Encourage integrated land use and transport planning in all cities so that travel distances are minimized . . .
- Bring about a more equitable allocation of road space with people, rather than vehicles, as its main focus.[3]

India's central government has backed this commitment with resources. Its national policy states that it will provide 50% of the costs of preparing comprehensive city transport plans and detailed project reports. It will also offer equity participation and/or viability gap funding to the extent of 20% of the capital costs of public transportation systems. Finally, the policy commits the central government to provide 50% of the cost of project development to projects that conform to national planning standards.[4] National policy also supports investment in appropriate technologies, integrated modal systems, strong paratransit service, use of clean technologies, and stronger public outreach and awareness. Although the federal government sets a strong policy framework, the "primary responsibility for urban transport infrastructure and service delivery rests with state governments and local bodies."[5]

Since the early 1990s, public transportation in China has benefited from an improved policy framework and increased investment, which have resulted in rising ridership levels. During the first phase of this reform, the focus was on reducing costs and improving efficiencies of operations for existing systems and organizations and instituting fare increases. During the second phase, focus shifted to changes in the underlying organizational structure, with moves to privatization or spin-off of independent transit agencies, use of joint ventures and bus or rail line franchises, and subcontracts with private companies.

A 2005 combined policy statement by five key central government ministries in China states the following:

> Urban public transportation provides important and fundamental infrastructure which is closely related to productivity and quality of life of the people. . . . Giving priority to the development

[3]NUTP, p. 3.
[4]NUTP, p. 7.
[5]Urban Transport Wing, Ministry of Urban Development, Government of India. PowerPoint Presentation, April 2011.

of urban public transit is an important tool to improve transportation efficiency, resource utilization and to ease traffic congestion. . . . We should fully utilize public transportation's high capacity, low cost advantage, and guide people to choose public transport as the main way to travel.[6]

SUSTAINABLE PUBLIC TRANSIT SYSTEMS

Bus Rapid Transit

In Ahmedabad, the Janmarg BRT system was developed by the Gujarat Infrastructure Development Board (GIDB) with planning and implementation assistance from the Ahmedabad Urban Development Authority (AUDA) and the Ahmedabad Municipal Corporation (AMC). Operation on the first corridor of the Janmarg BRT system began in October 2009 and required approximately US$100 million in capital funding, consisting of 35% federal, 15% state, and 50% municipal funds. The first corridor initially covered 12 kilometers, with 58 kilometers approved for five corridors.

Janmarg BRT's operations is contracted to a private operator who is compensated based on the service level provided. Janmarg uses Tata-built, BRT-specific, front-engine, nonarticulated buses. The BRT buses feature a distinctive front and rear fascia and a unique paint scheme to make them easily identifiable to riders. The BRT buses are fueled with modern diesel engines that meet Euro III emission standards. The driver is physically separated from the riders by an engine housing situated to the left of the driver's seat, as well as by vertical and horizontal railings. All buses are manually shifted, and air conditioning is provided on the newest buses, which are designated with a sign, "A/C BUS," to inform riders. A global positioning system (GPS) provides real-time vehicle location to dispatchers, as well as real-time next-stop information to bus riders.

Janmarg BRT buses are essentially flat-floor/high-floor buses, and the BRT stations are configured to permit same-level boarding/alighting. The raised-floor specification is critical to the elevated BRT station design. No automatic docking procedures are utilized. The driver controls the single mid-bus passenger entry/exit door and also remotely controls the sliding passenger gates of the BRT station platforms after manually docking at the station. The gap between the platform and the bus depends on the skill of the driver. No provisions are apparent that would allow a rider in a wheelchair to easily or independently board the buses, but tactile strips are embedded in the platforms to guide limited-vision ambulatory riders to the boarding gates. The station platforms are modest and typically are made of concrete, stainless steel, glass, and/or metal gating. Platforms appear to have been designed to maximize airflow, as no platforms are enclosed or climate-controlled. Signage consists of a mix of printed signs, light-emitting diode (LED) signs, and system maps.

Fare collection is handled through person-to-person transactions at the entrances to stations. Fare-collection staff currently sell only single-journey tickets, but use networked computers and ticket dispensers to aid in revenue control and accounting. Ahmedabad residents generally prefer this type of personal cash transaction, and it allows for universal accessibility; however, heavy ridership at some stations has resulted in long queues to purchase tickets, sometimes exceeding scheduled headways. In response, CEPT University and the operations contractor have accelerated efforts to institute a smartcard fare payment. While the loading of value will likely remain a person-to-person transaction, those with existing balances on their cards will be able to skip queues and proceed directly to electronic fare gates.

Responsibility for maintaining a state of good repair is assigned to contractors who receive payment from AMC based on the number of trips operated. AMC retains some fare revenue, along with proceeds from the sale of developable parcels of excess land in mixed-mode corridors where BRT is built, for an Urban Transport Fund. A primary purpose of the Urban Transport Fund is to provide for vehicle replacement and capital improvements as they become necessary on existing lines. For construction of new lines and procurement of new vehicles, the funding responsibility is distributed between the federal government, Gujarat state government, and the AMC.

Janmarg BRT stations typically are located mid-block, approximately 500 to 700 meters apart (Figure 1). No transit signal priority is provided at intersections, although agency staff members indicated that they are considering it at intersections that exhibit poor performance. The entire first corridor has been constructed within the existing public right-of-

[6]Circular of the National Council, Ministry of Construction and other departments, People's Republic of China: Views on the development priority of urban public transport; SCS 2005-26.

Figure 1 BRT station in Ahmedabad.

way. BRT construction has provided significant improvements at intersections and at choke points along the corridor, including very large roundabouts at several high-traffic intersections and flyovers for automobiles to ensure center-lane BRT operations in narrow rights-of-way. These improvements have resulted in enhanced travel for other modes. High-density development has begun along the corridor, and additional development is planned.

In the initial corridor, other public transportation vehicles, including both public and private buses, have been allowed to use exclusive BRT lane segments that are interspersed with segments of mixed traffic. The exclusive lane segments also can be used by emergency vehicles.

The Janmarg BRT travel surface and BRT station bus berths were constructed using hot-mix asphalt (HMA) concrete. Considerable shoving of the pavement has occurred, both in the queue areas at signalized intersections and at several BRT station bus-berth areas. Staff is evaluating retrofitting those areas with a higher strength HMA concrete or with portland cement concrete, and the latter will likely be incorporated into the design of future BRT corridors.

The driver-operated remote-controlled gate system provides a safe, simple-to-implement, and cost-effective system for boarding/alighting passengers. However, the opening/closing mechanism on some gates seems to struggle during normal operation. The design life and maintenance requirements of any gate system incorporated into a BRT program would appear to be important design parameters given that the gates must withstand a great number of duty cycles throughout a service day.

In Ahmedabad, drivers often must steer around temples and shrines situated in the middle of what would be considered the BRT right-of-way. In addition, cows—considered sacred animals—are free to meander onto roadways, including those shared by BRT buses, which can delay service. In the United States, transit agencies commit considerable resources to identify and mitigate potential impacts to historical or cultural resources, including either relocating the protected resource or realigning the corridor to avoid disturbing the important resource.

The bus system in Delhi is operated by the Delhi Transport Corporation (DTC), a separate entity from the metro system. With 5,700 buses on the road each day (out of a total fleet of nearly 6,200 buses), the DTC carries 4.2 million passengers daily, operates 100 bus terminals and services 4,800 bus stops throughout the city. With the exception of the head-sign designations, the buses on the BRT routes are indistinguishable from the conventional, fixed-route buses (Figure 2).

Fares on DTC buses are distance-based, although higher fares are charged on red (climate-controlled) buses than on green (non-climate-controlled) buses. The service is subsidized by the government, with 25% of the city's budget going toward public transportation. The government sets the salaries for the unionized bus drivers, and wages compose 67% of their operating costs.

Through a public-private partnership, the Indian bus manufacturer Tata maintains the low-floor fleet on site for the DTC. DTC recently purchased 3,775 new low-floor buses, of which 1,200 buses are climate

Figure 2 New CNG buses line up at the DTC depot in Delhi.

controlled. The buses operate on compressed natural gas (CNG) and are designed for 12 years or 750,000 kilometers. A maintenance contract equating to 4 rupees (US$0.09) per kilometer traveled was negotiated as part of the purchase contract. The purchase-maintenance agreement requires the bus manufacturer to focus on the long-term viability of the bus design rather than merely the 1- or 2-year warranty period that is typical for buses purchased in the United States. The high-floor buses are maintained directly by DTC employees.

Delhi's BRT system is relatively new, currently operating only a 5.8 kilometer corridor from the Munchen Hospital to the Mool Chand Flyover. At buildout, the BRT system will serve 14 corridors on more than 100 kilometers of BRT lanes. Each BRT station currently includes six to seven passenger shelters.

No exclusive BRT lanes are provided. Lane marking is used instead of physical barriers, and BRT buses operate in middle lanes. Three routes on the BRT corridor are shared with local fixed routes. Service frequency is 5 minutes for the BRT routes. Transit signal priority is provided using loops in the queue area at intersections within the BRT corridor.

Because the stations are used by various public and private transit providers, stations have no entry barriers and fare collection is handled on board the buses. This system does not necessarily result in increased dwell times, largely thanks to the presence of conductors on the buses; however, it does limit the BRT service's ability to distinguish itself from other local bus services.

The public company responsible for the development of BRT throughout Delhi is the Delhi Integrated Multimodal Transit System (DIMTS), which is a joint venture, equal-equity company set up between the Government of the National Capital Territory of Delhi (GNCTD) and the Infrastructure Development Finance Company. Established to tackle the problem of ineffective public transportation delivery and to provide expert services in the field of urban transport, DIMTS's mission ranges from identifying problems and opportunities in urban transport infrastructure to providing policy-level support for the government and government agencies, transportation planning and operations, and public outreach and advocacy to promote public transport. With regard to BRT, DIMTS is examining whether additional amenities and alternative operating characteristics should be applied to future lines. Within India, the gradual introduction of a new transit mode and taking an incremental approach to incorporating characteristics that distinguish BRT from traditional bus service are identified as best practices.

The BRT system in Guangzhou is robust and well-utilized. Officials at the Guangzhou BRT agency described BRT as incorporating the best features of both metro rail transit and traditional bus transit, including operating in dedicated lanes at high speeds and utilizing high technology solutions, while requiring less capital funding and less overall time to implement. The system operates along a corridor with very high density development and currently serves 26 stations, providing up to 350 buses per hour (almost a 10-second frequency) during peak periods. Daily ridership on the corridor is approximately 800,000 people. The system uses a direct service model, incorporating the principal BRT route (designated as "B1") and 40 local bus routes that simultaneously provide direct feeder service onto the corridor and service along the corridor. (Following a traditional trunk model, feeder buses would bring passengers from their points of origin to the corridor, where they would then transfer to the BRT trunk line and possibly transfer again to get to their final destinations.)

Particularly in the urban core, the BRT stations typically are located mid-block, with pedestrian flyovers using stairways or escalators in the busier stations (Figure 3). This configuration is not wheelchair accessible. At the joint BRT/Guangzhou Metro station that was being constructed, wheelchair accessibility

Figure 3 BRT station in Guangzhou.

will require the use of cumbersome, handrail-mounted fold-out platforms to travel from one level to another.

No automated docking is used in Guangzhou, so bus drivers must skillfully minimize the gap between the station platform and the bus entry/exit floor. The platforms are separated from the bus lanes by glass partitions and elevator-door-style gates that align with the front and rear doors of the buses. This separation between the platform and travel lanes serves as a safety measure for customers when platforms are crowded and allows buses to dock at each station at speeds that maximize vehicle throughput. This arrangement also ensures that three vehicles may use each platform simultaneously. Sliding-glass doors are used to orient passengers to the correct boarding areas, and each bus berth is marked with both printed and colored LED signs in both English and Chinese. Three-dimensional (3-D) maps used at the metro rail stations and at larger BRT stations show where the pedestrian exits are located in relation to nearby streets and landmarks (Figure 4). Other amenities on the BRT platforms include next-bus digital arrival information. This service is particularly useful to customers who can choose among multiple routes to a destination or who may be willing to take the next arriving bus to the farthest station it serves on the corridor.

To gain entry to the BRT station, riders can use smartcards or purchase tokens from staffed kiosks. The same smartcards can be used to ride metro rail, travel in taxicabs, or rent bicycles that are available at each BRT station. Fares had been reduced from between 2 yuan and 6 yuan (depending on distance) to a flat fare of 2 yuan.

The buses operate on exclusive lanes located in the middle of the BRT right-of-way, and each station along the corridor has adequate passing lanes. GPS is used to provide both real-time dispatching information and real-time passenger vehicle arrival prediction information.

Besides handling other traffic issues, the Guangzhou traffic control headquarters provides real-time assistance to BRT and local buses along the BRT corridor. Throughout Guangzhou, an additional 15 branch locations control intersections off the BRT corridor. A total of 713 signalized intersections are controlled at these 16 centers. On-bus transit signal priority is not provided, but intersection signal phasing can be changed by the control center staff if buses begin to bunch or are delayed because of long signal queues. All newly licensed drivers of private auto-

Figure 4 Three-dimensional maps in Guangzhou make it easy to locate pedestrian exits in relation to nearby streets and landmarks.

mobiles are required to attend training at the traffic control headquarters to learn how traffic is monitored and controlled. In addition, two state-run radio stations are located in the traffic control headquarters so that real-time traffic information can be broadcast during peak travel periods.

The Guangzhou BRT was constructed and is operated by a company created specifically for those purposes. This company is wholly owned by the Guangzhou municipality and seeks financing for expansion and capital improvements in private markets. Domestic banks within China have provided a substantial portion of the financing. Even so, the network of buses serving the BRT line requires a subsidy from the municipal government. Direct support to cover ongoing debt service is also necessary. Accordingly, design of bus routes and vehicle specifications—including required emissions profiles—are handled directly by the municipality.

Hangzhou's BRT system opened in 2006 and currently comprises 160 diesel-powered buses operating on four routes, of which the third and fourth routes opened in January and February 2011. The BRT system is part of the extensive Hangzhou Public Transportation Group bus system that operates 9,000 buses on 500 routes. All BRT buses are color-coded to indicate the route (B1 = red, B2 = blue, B3 = green, and B4 = dark blue). The Hangzhou BRT stations incorporate more ornate metalwork and more intricate floor treatments (involving interlocking pavers with demarcations for loading zones) as compared with BRT systems observed in other cities. Because the Hangzhou BRT system is more mature than that in other cities, the landscaping is also fuller and more expansive. The station platforms are essentially at curb level, which provides near-level boarding of the BRT low-floor buses. GPS is used to provide real-time dispatching information and real-time passenger vehicle arrival predictions.

The Hangzhou BRT uses an outside-lane configuration, which increases conflicts with drivers of private automobiles as the drivers maneuver across the BRT lane to access the automobile travel lane in the center of the road. Such outside-lane BRT services can, however, minimize conflict between pedestrians and automobiles, as passengers cross directly from the BRT station to the adjacent sidewalk. Complicating the situation in Hangzhou, a scooter/bicycle lane separates the BRT lane from the sidewalk. No BRT station passing lanes were observed, nor were the exclusive bus lanes wide enough to permit passing.

Metro

The team visited metro systems in Delhi, Guangzhou, and Shanghai. All three cities have excellent metro systems with very high ridership and aggressive expansion plans. Hangzhou is beginning construction of a metro system, and Ahmedabad is in the planning stages for a system.

The centerpiece of Delhi's urban transit network is its metro rail system (Figure 5). Although the capital cost of the system is substantial, so is the payoff: savings of 492 metric tons of emissions per day, 217 metric tons of fuel per day, and 28 minutes per trip, according to a study conducted by the Central Road Research Institute.[7]

Figure 5 Delhi's Metro is the centerpiece of its urban transit network.

The Delhi Metro is being constructed in phases. Phase 1, which opened in 2005, consisted of 65 kilometers built at a cost of US$2.1 billion, of which approximately 60% was financed by a soft loan (i.e., with a below-market interest rate) from the Japanese government. Phase 2 consisted of 125 kilometers that were completed in 2011. Phase 2 was financed primarily by the federal and state governments. The system now has six lines, operating with up to 4-minute headways. Phase 3 will add another 115 kilometers, and Phase 4 will add 108 kilometers. Delhi Metro Rail Corporation (DMRC) is currently preparing to accept proposals from the private sector to build elements of Phase 3.

To achieve an integrated public transportation network throughout Delhi, local buses have been rerouted to feed metro rail stations rather than compete against the operationally self-sustaining DMRC. To bring the benefits of metro rail to neighborhoods not scheduled for service until Phases 3 or 4 become operational, DMRC operates its own feeder bus network to locations where substantial demand already exists. A joint ticketing system is being planned to serve metro rail, BRT, and local buses.

Approximately 65% of capital costs have been financed through loans, primarily from the Japan International Cooperation Agency. DMRC generally achieves operational profitability through a combination of metro rail and feeder bus fares, the develop-

[7]Presentation on Delhi Metro by Dr. E. Sreedharan, Delhi Metro Rail Corporation, April 7, 2011.

ment of air rights and land along rights-of-way, and consultation services to assist in the development of six other metro systems throughout India. Given this combination of funding sources, DMRC's incentive to operate according to the state-of-the-practices is not just a matter of local pride but also a matter of corporate competitiveness.

About 20% of DMRC's annual revenue is unrelated to fares. DMRC attempts to preserve between one-quarter and one-third of the rights-of-way purchased for metro rail construction for commercial and residential development. Substantial concession opportunities also are available within stations. Also—though carbon credits do not make up a substantial portion of nonfare revenue—DMRC has broken new ground for urban railway networks by earning carbon credits through the United Nations Framework Convention on Climate Change. Carbon credits are earned by saving energy in operation (through regenerative braking) and by achieving modal shift. DMRC estimates that the Delhi Metro has generated savings of 217 tons of fuel and 492 tons of emissions (including carbon dioxide) and prevented 161 road deaths, resulting in approximately US$500,000 in credits earned through energy savings and US$3 million in credits earned through modal shift.

The Delhi Metro is accessible to persons with disabilities and has elevators installed at multilevel stations. Personal escorts from station entrances to exits also are offered on request via telephone. Real-time next-train arrival information is provided at stations as a customer amenity, and tap-and-go smart "tokens" are used for single journeys. As opposed to tickets with magnetic strips, these tokens cut processing time at fare gates, reduce waste, and can be carried safely in a pocket with no concern about damage caused by inadvertent bending or folding.

Shanghai's metro system operates 12 routes on 420 kilometers of track and carries 5.2 million passengers per day (Figure 6). The city plans to expand this system to 600 kilometers by the year 2015. Traffic congestion is a major problem on the highways leading in and out of Shanghai.

To accommodate demand, peak headways on Shanghai's metro rail routes are as short as 2.5 minutes. Even so, congestion within the system can grow so acute that control center staff must restrict entry to certain stations for short periods. Real-time entry/exit data is processed at fare gates and transmitted to the operations control center to aid in such decisions. Congestion information is provided to passengers on digital line diagrams posted in stations and on the system's website using the familiar colors of red, yellow, and green to represent loads. A special traffic information radio station also broadcasts this information throughout Shanghai; the station maintains a broadcast studio (also used for television reporting) in the metro rail operations control center.

Figure 6 Shanghai Metro carries 5.2 million passengers per day.

Bicycle-Share Programs

Both China and India have historically had a strong bicycle modal share. The disbursement of industrial employment and the rapid expansion of highly urbanized areas have, however, led to a sharp drop-off in the use of bicycles for commuting, particularly in China. In Delhi, the share of bicycle trips fell from 17% in 1981 to 7% by 1994. Transit agencies in both countries are attempting to increase the use of bicycles by incorporating bicycle-share programs into their public transit systems. India's NUTP states that "non-motorized modes are environmentally friendly and have to be given their due share in the transport system of a city," and that "the central government would give priority to the construction of cycle tracks and pedestrian paths in all cities."[8]

Bicycle sharing was introduced to Delhi as part of the GreenBike Cycle Initiative during the build-out and implementation of the BRT facility. This initiative was led by and is managed by DIMTS as part of its programming. Five bicycle-sharing stations

[8]NUTP, pp. 11–13.

were established along the BRT corridor to integrate the new program with bus-based transport, and DIMTS signed an agreement with Planet Advertising Pvt. Ltd. to build, operate, and manage the bike stations for a period of 5 years. As in management schemes for bicycle-share systems elsewhere, the concessionaire agreed to make the initial investment and bears the recurring charges for the maintenance and upkeep of the facilities, paying 20,000 rupees (US$450) per month per station to DIMTS. The concessionaire earns revenue by selling advertisement space on cycle stations and from rental charges.[9]

Like Delhi, Guangzhou implemented its bicycle-share program coincident with the implementation of a BRT system. Guangzhou was the first city in China to include bicycle parking and bicycle sharing in its BRT station design, in hopes that more BRT riders would make their "last mile" connection on a bicycle. The government of Guangzhou initiated the bicycle-share program and created the Guangzhou Public Bicycle Operations and Management Corporation to manage and operate the service. Planning and design of the bicycle stations within the BRT system was done by GMEDRI with the assistance of ITDP. The bicycle-share program also involved construction of new bicycle infrastructure, including hundreds of kilometers of greenways and single- and double-tier bike parking.[10]

The bicycle-share program opened just months after the BRT opened in 2010. Initially, the bicycle-share program comprised 18 stations offering 1,000 bicycles to the public.[11] Two months later, the program had nearly quadrupled, expanding to meet the increased demand for its services. In less than a year, the bicycle-share program had grown to 113 stations offering 5,000 bicycles along the BRT line. As the city's population approached 15 million, the program had to quickly be expanded to meet the continuing growth in demand for bicycle-share services in a viable way.

Most of Guangzhou's 800,000 daily BRT passengers also use the bicycle-share program. Cycling jumped 50% to 100% in different sections of the BRT corridor during the first 6 months of operation.[12] As the BRT network continues to expand, so will the bicycle-share program.

A user of the bicycle-share system must first register and pay a deposit of 300 yuan (US$46). The first hour of bicycle use is free, and the next hour costs 1 yuan (US$0.15). Each subsequent hour costs 3 yuan (US$0.46). This fee structure was designed to encourage the use of bicycles for short trips around the city. Most users tend to use the service for about 10–20 minutes. Users access the bicycles with their smartcards.

Hangzhou, just 45 minutes away from Shanghai via the new high-speed train, has the largest bicycle-share system in the world, with 60,000 bicycles available at 2,411 bicycle-share stations. In the city's main districts, the average distance between two service points is just 200–300 meters (less than one-fifth of a mile), which means a bicycle-share station is situated on almost every block in the city. In the suburbs, the average distance between two service points increases to 500–800 meters (less than one-half mile). When the program was established in May 2008, it included 61 stations and 2,800 bicycles. In 2010, 75 million bicycle trips were made using Hangzhou's bicycle-share system—an average of 205,000 trips each day.

The Hangzhou Public Bicycle Company is an affiliate of the Public Transportation Group operated by the municipal government. It is responsible for the construction, operation, and development of the public bicycle system in the city. The focus of the program is to provide an attractive alternative to driving a private automobile. The first hour's use of the system is free, with the second hour charged at 1 yuan ($0.15), the third hour charged at 2 yuan ($0.31), and any subsequent hours charged at 3 yuan ($0.46). The success of Hangzhou's bicycle-share program is due to the convenient locations of the bike stations throughout the city.

The Hangzhou Public Bicycle Company plans to expand the bike-share system to 175,000 bicycles by 2020. A company manager said,

> During the peak hours, there is heavy demand for bikes. At this point we have station attendants to help with the drop-off of bikes in many of our

---

[9]GreenBike Cycling Rental and Sharing Scheme. www.slideshare.net/jaaaspal/greenbike-cycle-sharing-concept-in-india.

[10]Fjellstrom, K. Year of the Transit Tiger in Guangzhou. *Sustainable Transport,* Vol. 22 (Winter) 2010, pp. 10–15.

[11]Warrier, N. Summary of the Process of Implementing the Public Bicycle System in Guangzhou, China. www.slideshare.net/rgadgi/guangzhou-bike-share-nitin-warrier.

[12]Fjellstrom, K. Year of the Transit Tiger in Guangzhou. *Sustainable Transport,* Vol. 22 (Winter) 2010, pp. 10–15.

> high volume stations, particularly in the morning. We have more people dropping off bikes than drop-off banks available. The attendants help us with recalibrating the system. There is high demand for this program.

The manager also emphasized that customer service was the priority in supporting the growth of the system, saying, "It is important for us to resolve any issue fast. On a recent customer public survey, the public bicycle system had the highest satisfaction rate among all the projects in city development." When asked about the management of the system and any incidents of robberies, he added, "There are many service points in the city. People don't need to steal our bicycles because they are basically free to use."

An interoperable smartcard is available for use in renting bicycles at each bike-share station and for riding the city's BRT system, local buses, parking, and taxis. Each of these modes is considered an integral part of the transit network in the city, and together they provide a strong incentive for residents to limit their use of private automobiles.

Bicycle-share locations have focused on density, with most stations located near residential complexes, employment and activity centers, and major travel corridors. With the construction of the first metro line in Hangzhou, the city is now moving toward modal integration.

Hangzhou has attracted a new market for bicycling through its extensive network of bike lanes. Most of the system's bike lanes are separated from other forms of traffic to make bicycling more appealing. The bicycle-share stations are located conveniently near bus stops and parking lots. According to officials in Hangzhou, 40% of the bicycles provided by the bicycle-share program are used for commuting, 40% are used as feeders to the buses, 10% are used by tourists, and 10% are used for exercise.

Staff at a state-of-the-art operations and control center monitor bicycle-share stations through closed-circuit television. Individual rental transactions also can be monitored at the control center because each station is connected through a fiberoptic network and customer call boxes. Up to 10 telephone operators are on staff at any given time, and up to five additional employees are required to monitor the streaming video and data from the bike-share stations.

The control center serves as the general customer information center for all transportation services provided by the city. (Complaints about city services unrelated to transportation also are handled by this center.) Bicycle-share customers experiencing problems with point-of-sale machines or bike-locking mechanisms can often be assisted electronically, as agents in the control center are able to issue manual transaction overrides. They are also able to dispatch maintenance staff to handle problems with the bicycles. Some maintenance work can be performed on site, but more serious overhauls and the quarterly maintenance checks are performed at the maintenance depot. Between 1,000 and 1,500 bicycles are worked on each day, and the bicycles have an expected usable life of 3 to 5 years.

The bicycles are mechanically simple. They operate in only one gear, and they are equipped with hand brakes and warning bells. Bicycles with varying seat heights generally are available at each station. The seats are adjustable, but the height can be changed only by staff. The bicycles are brightly colored and have highly visible branding. The geometry and features of the bicycles make them easily recognizable (Figure 7).

Shanghai is moving forward with its bicycle-share program as it expands its impressive transportation network. Currently, 20,000 bicycles are available for rent in one of the city's districts and, on average, each bike is used to make four or five trips per day. Users pay a deposit of 200 yuan (US$29) and the first half-hour is free, after which bicycle users are charged 1 to 3 yuan per hour on a progressive system designed to encourage short-term rentals and quick turnover. Planning is underway to expand the bicycle-share system throughout Shanghai.

Figure 7 Bicycle-sharing station near Hangzhou's popular West Lake.

ALTERNATIVE FUEL AND VEHICLE TECHNOLOGIES

One of the first sustainability steps taken in the cities visited was the replacement of diesel public transit vehicles, including taxis, with fleets running on CNG. In Ahmedabad, the BRT line operates the India Starbus, consisting of 145 dedicated CNG, raised-floor, special-purpose buses. The Starbus is manufactured in India. In Delhi, the DTC operates an all-CNG fleet of more than 6,000 buses, the largest such fleet in the world.[13]

The auto-rickshaw is a popular, efficient, and affordable taxi used throughout Ahmedabad. In 2005, the city was home to more than 50,000 three-wheeled auto-rickshaws. About 15,000 of these vehicles were more than 20 years old, and a majority of them used adulterated fuels (diesel and kerosene). In an aggressive attempt to improve air quality in the city, the AMC ordered all rickshaws registered before 1991 off the road. In addition, the state government prohibited rickshaws from using diesel inside the urban areas of the city and mandated that those rickshaws be converted to CNG. Low-interest loans were made available to operators to assist with the purchase of new eco-friendly CNG auto-rickshaws (Figure 8). In 2004, the AMC also banned heavy-duty diesel trucks from operating within the urban growth boundaries of the city.

In Delhi, the courts decided in 1998 that all buses, rickshaws, and taxis were to be converted to CNG and that 70 CNG fueling stations were to be made available. The courts asked that financial incentives be provided for these conversions. By December 2002, the last diesel bus had disappeared from Delhi's roads.

Guangzhou operates the largest fleet of liquefied petroleum gas (LPG) vehicles in the world. Here, more than 8,000 buses and 15,000 taxis run on LPG. In promoting the use of LPG (known as Autogas), Guangzhou city leaders touted the usual advantages of lower emissions and lower prices. China began promoting Autogas in 2001, when the fuel was introduced in nine major cities, including Beijing and Shanghai. Its use has had a positive impact on air quality.

Hangzhou is unique in its adoption of electric vehicles. Most of these are two-wheeled vehicles that are allowed to operate in bicycle lanes. Unlike Shanghai, where two-wheeled vehicles of any kind are banned from the city center, electric two-wheelers have the right-of-way in all parts of Hangzhou and are very popular.

Figure 8 CNG-powered auto-rickshaws are a common sight and an efficient, affordable mode of transport in Ahmedabad.

Currently, however, electric vehicles move emissions from the tailpipe to the smokestack. Given that most electricity generation in China is still coal-based, electrification of the fleet probably represents an increase rather than a decrease in GHG emissions. If all or most electric power becomes generated through renewable, non-emitting sources, fleet-electrification could represent a strategy in overall GHG emissions reduction.

Natural gas has not been a popular fuel choice in Shanghai. In 1998, the first CNG station opened in the city. Because of the uncertainty of gas supply and the lack of economic incentives, only 281 CNG buses are operating today. This may change as China continues to expand natural gas availability and infrastructure.

As an innovative alternative, China has deployed a "super-capacitor" quick-charge bus in downtown Shanghai (Figure 9). This vehicle combines the use of conventional batteries and super-capacitor technology. Although the life cycle of the batteries has been improved, their weight and size still present technical hurdles.

China is the world's largest manufacturer of new battery technology for automobiles, buses, and small- to medium-duty trucks. China's electric bus production is progressing in conjunction with new battery technology development. Through joint ventures, several large car and bus manufacturers are supplying

[13]Delhi Transport Corporation. Fact Sheet, p. 1.

Figure 9 Shanghai's super-capacitor bus combines conventional batteries with super-capacitor technology.

100% battery-powered zero-emission vehicles to the transit market in China and abroad. In 2009, the Chinese government launched the "Ten Cities, Thousand Vehicles" program to stimulate electric vehicle and new-energy bus development through large pilot programs in 10 cities. This program has now been expanded to 25 cities and includes consumer incentives in five cities.

PLANNING AND OUTREACH

Four planning elements have set a path to sustainability in the cities visited:

1. Making public transportation a priority, with the intent to ensure mobility.
2. Creating multimodal systems consisting of pedestrians, bicycles, buses, metro, and rail (high-speed in China).
3. Using transportation as a planning instrument to guide development.
4. Using technology to address air quality problems (CNG vehicles, hybrids, electric vehicles, etc.).

In the mid-1990s, officials in India and China recognized that inadequate infrastructure and services were impediments to sustainable development in their large cities. Consequently, plans were put in place to tackle the challenges of rapid urbanization and motorization by accelerating the supply of infrastructure and services while promoting sustainable public transportation and eco-governance at the regional level.

For example, in India, the national government launched several policies and initiatives as part of its plan to foster sustainable urban transportation systems. The NUTP, created in 2006 by the Ministry of Urban Development to facilitate the implementation of people-centric urban transportation solutions, set forth a vision, goals, and objectives that were a significant departure from traditional urban transportation practices in Indian cities. Essentially, the NUTP articulates an emphasis on public transportation and the development of non-motorized modes that provide high-capacity, efficient public transportation. The NUTP includes the following objectives:

- Incorporation of urban transportation as an important element at the master planning stage, rather than a consequential requirement
- Implementation of plans and projects that are people-centric
- Promotion of cleaner technologies
- Establishment of quality, integrated, multimodal public transportation systems that provide seamless travel across all modes
- Equitable allocation of road space, with emphasis placed on movement of people rather than movement of vehicles
- Reduction in pollution
- Recognition of road safety concerns

In India, transit planning for BRT and metro is a much-abbreviated process compared with that in the United States. Government officials discuss public outreach in terms of months, not years. Core project planning in terms of mode selection, financing, amenities, and locations appears to be done before presenting the project to the public. Public universities and their transit programs provide support for government agencies, giving students and professors real-world application for their work. Anecdotal information on the public outreach process suggests it is largely focused on schedule of operations, mitigation of construction impacts, and relocation of the urban poor, as well as working with the adjacent landowners and businesses on property redevelopment and exactions. Planning and development projects are ultimately integrated into urban development in India because rail and highways are specifically enabled by the national constitution, but urban transport is not.

In China, the central government plays a role in the development of sustainable public transport, including BRT, metro, and clean energy technologies. Officials from Guangzhou, Hangzhou, and Shanghai indicated that the central government provides funding or subsidies for public transportation investment. Although many public transportation investments have been financed by public funds at the national, provincial, and local levels, many large-scale infrastructure projects, such as BRT and metro systems, have required the involvement of public-private partnerships.

Varied instruments and mechanisms were used to engage public participation in the planning and implementation of BRT in Ahmedabad, Delhi, Guangzhou, Hangzhou, and Shanghai. In Ahmedabad, for example, various media streams were used to disseminate information, engage the public, and solicit input. Regular press releases were distributed by the city, and concerted efforts were made to promote Janmarg BRT's branding among citizens. Public events and workshops were conducted along the corridor. Religious leaders were used as conduits to disseminate information and answer questions. Information displays were set up at CEPT University and other venues. In Delhi and Guangzhou, the public participation process was somewhat similar to that used in Ahmedabad, but focused mainly on media and press releases. Although the degree and extent of the public participation process in the BRT and metro projects in Hangzhou and Shanghai was not discussed, both cities used workshops, demonstrations, and media as means of informing the public.

SUCCESSFUL PRACTICES

BRT

In Ahmedabad, real-time bus arrival and departure information is available at all BRT stations, and GPS tracking helps ensure on-time performance through active management from the control center. The city's master planning program is strongly connected to decisions about which BRT corridor to bring on line next. Implementation of the BRT network focuses on connecting major activity hubs identified in the master plan and on serving streets with substantial right-of-way for BRT integration. Public-private partnerships have been used aggressively to gain benefits from competition among operating companies and keep public staffing to a minimum. Officials recognize that if a system is unaffordable it is unsustainable.

In both Guangzhou and Hangzhou, the direct service model for BRT allows for seamless transfers between local buses and the BRT line and reduces fare-collection costs. Full integration of BRT services and bicycle-share stations was considered in the development of BRT lines, allowing the stations to be designed to incorporate bicycles.

Metro

Delhi's disciplined crowd-management procedures on metro are extremely effective at improving the efficiency of boarding and alighting. The city has the first railway system in the world to be registered under the Clean Development Mechanism of the United Nations Framework Convention on Climate Change, a status that enables Delhi to claim carbon credits.

In Guangzhou, three-dimensional signs depicting both metro station layouts and built features surrounding the stations have made the system much more accessible to visitors, especially those who do not speak the local language.

Bicycle-Share Programs

In Guangzhou, a large pool of bicycles, numbering in the thousands, was easily accessible from the outset of the service. In both Guangzhou and Hangzhou, graduated price structures encourage use of the bicycle-share system for short trips throughout the day. Bicycles are so easily available that little incentive exists to steal them; they can be used for free during the first hour and for nominal sums thereafter, and they are available all over the city. Bicycle-share stations are staffed during peak periods to facilitate quick drop-off and to redistribute bicycles as necessary to ensure sufficient capacity.

LESSONS LEARNED

Rapid economic growth and urbanization in India and China present extraordinary challenges to sustainability. Federal, state, and local agencies have made impressive strides in building and operating robust public transit systems as components of their transportation systems. They have implemented well-built, well-designed, and well-planned systems that contain many lessons for public transit agencies in the United States.

Create a culture of using public transit. Both China and India have established cultures that support public transit. Although market share data is difficult to gather and standardize, public transit has a relatively high share of total transportation trips. This strong market penetration provides an excellent basis for political support and customer knowledge and for acceptance of transit as an important element of the transportation system.

Adopt proven best practices. In the cities that the team visited, the policy makers and the planning staff were very aware of best practices in transit worldwide and had in several instances conducted international surveys of best practices. For example, in India, the government commissioned a study of BRT systems worldwide to identify key characteristics of various BRT systems. This focus on best practices is reflected in thoughtful, well-planned facilities with good pedestrian access, signage, and intermodal access.

Enact national policies to support transit. The national governments of both India and China have enacted a policy framework that supports the development and operation of public transit as an important element of national development strategies.

Implement technology-based fare collection systems. Both India and China have implemented integrated fare-collection systems based on smartcard technologies. Although some cities lack a full modal integration of payment systems, technology-based fare collection systems are widely applied. Use of these systems encourages ridership, provides important ridership data, supports bicycle-share systems, and ultimately benefits multimodal integration.

Integrate land use and transit planning. The integration of land use and transit planning is a critical element for the sustainability of any transit system. A well-built transit system that is not aligned with the land use and permitting structure of an urban area will not be fully effective. Given the very high pace of urbanization in both India and China, the effective integration of land use and transit planning may be the most important factor in determining the ultimate make-up of urban areas. The team encountered several examples of effective, integrated land use planning around station areas in Ahmedabad, Guangzhou, and Hangzhou. One of the strongest examples of integrated planning was the Janmarg BRT system in Ahmedabad. The system was planned in coordination with the local university (CEPT University). Given the inherent orientation of the university's program toward land use patterns, the resulting BRT planning was integrated into the local land use patterns from early design.

Focus on quality service. The team was impressed with how the officials at the visited transit agencies were focused on providing quality transit services to customers. The officials viewed the provision of air-conditioned, clean, comfortable, and not-overcrowded buses and trains as essential design elements of the systems.

Make aggressive use of public-private partnerships. Officials were invariably focused on financial sustainability. Given the limited resources available for transit expansion, particularly in India, the visited cities have abandoned the legacy government-run systems and instead are relying on private operation for their new BRT and metro services. The Janmarg BRT system, for example, has only six employees. The Guangzhou BRT system has as many as six private operators providing service on its system.

Convert to alternative fuels. All the visited systems have moved aggressively to eliminate diesel-fueled bus fleets as a response to the need to improve air quality. Delhi Metro operates the world's largest fleet of CNG buses. Guangzhou's air quality improved following the introduction of CNG buses and the banning of gasoline-powered taxis and motorcycles. The world's only operational super-capacitor bus system operates in downtown Shanghai. The Chinese government's "Ten Cities, Thousand Vehicles" program will eventually result in the deployment of 10,000 alternative fuel buses.

Avoid debt financing. In addition to the aggressive use of public-private partnerships, the Indian and Chinese systems viewed by the team were built with little or no public debt. This "pay as you go" financing approach will provide substantial financial flexibility in future years.

CHALLENGES

Despite the impressive progress toward building sustainable transit systems, the team did note some areas that will continue to be challenges for the transit systems in both countries.

Air quality. Despite the aggressive introduction of alternative fuel buses, the banning of mopeds, and the conversion of taxis to CNG, both countries continue to experience serious, and in some cases severe, air quality problems.

Design quality. The systems viewed by the team were well-designed, impressive facilities. In some cases, however, structures did not appear to be aging well and might have benefited from stronger design and construction standards. Both countries were faced with building transit infrastructure on a schedule that would meet the challenges of rapid urbanization; as a result, long-term benefits might not have been given the attention they deserved in balancing the need for quick construction with extending the useful life of assets.

Capacity. The rate of construction of new systems, particularly in China, was very impressive. High levels of crowding were noted on some systems, however, causing the team members to wonder if even the high level of infrastructure being put in place was going to be sufficient to meet the country's growing needs. Overcrowding could undermine ridership growth and also increase wear-and-tear on the system.

Automobile growth. India and China are experiencing upwards of 20% annual growth in their automobile fleets. The environmental and quality-of-life effects of this growth could offset many of the gains from the impressive investment both countries are making in public transit. Both countries are investing heavily in their automobile industries and their highway infrastructure. As incomes rise, the appeal of car ownership will be every bit as strong as it has been in other countries. With the exception of license-plate auctioning in Shanghai, the team found no evidence of attempts to limit the expansion of private automobile ownership and use. Efforts were focused on enticing, through the provision of exceptional public transportation service, riders from their cars and onto buses and trains.

Land use. In both countries, the team found evidence of cases in which officials were integrating land use and transit planning. The pace of development in both countries does appear to be outstripping these efforts, however, especially outside the city cores.

State of good repair. One of the key public transit challenges in the United States is keeping its system in a good working condition. Although officials in India and China were aware of the need to plan for capital replacement and mid-life maintenance of their rapidly growing systems, the team found little evidence of substantial planning for these requirements. Some of the assets the team toured, although relatively new, were already showing signs of wear and neglect.

System integration. The team noted the effort made in both countries to integrate their transit systems. Particularly noteworthy were the direct BRT-metro connections in Guangzhou and bicycle-BRT-metro connections in Hangzhou and Guangzhou. The integration of newer options with legacy bus systems was less well developed, however, even though those systems still carry the majority of the transit riders in the country. The fact that these legacy bus systems are operated by separate governmental entities than the newer systems may impede fuller system integration.

Environmental protection culture not pervasive. The primary focus in both countries is in building new systems to meet the demands of extraordinary urban population growth. Given this understandable orientation, the team did not see much evidence of an environmental protection culture within the transit agencies. To the extent that environmentally friendly policies or initiatives were being introduced, this often was done to bring an agency into conformity with national environmental regulations.

APPENDIX A—STUDY MISSION TEAM MEMBERS

(Affiliations listed were current at the time of the study mission.)

Kevin Desmond *(Team Leader),* General Manager, King County Metro Transit, Seattle, Washington

Clinton Bench, Deputy Director of Planning, Massachusetts Department of Transportation, Boston, Massachusetts
Anthony Carr, Deputy Regional Administrator, Federal Transit Administration, Region 2, New York, New York
Todd Daniel, Maintenance Manager, Link Transit, Wenatchee, Washington
Projjal K. Dutta, Director, Sustainability Initiatives, New York State Metropolitan Transportation Authority, New York, New York
Mariate T. Echeverry, Transportation Planning Manager, City of Asheville, Asheville, North Carolina
Heather Ferguson, General Manager, Scheduling, Chicago Transit Authority, Chicago, Illinois
David W. Kilmer, Executive Director, Red Rose Transit Authority, Lancaster, Pennsylvania
Marla L. Lien, General Counsel, Regional Transportation District, Denver, Colorado
Brian McCartan, Executive Director, Finance and Information Technology, Sound Transit, Seattle, Washington
Roma McKenzie-Campbell, Senior Project Manager, Massachusetts Bay Transportation Authority, Jamaica Plain, Massachusetts
Felix Nwoko, Transportation Planning Manager/Administrator, Durham-Chapel Hill-Carrboro Metropolitan Planning Organization, Durham, North Carolina
Geoff Straw, General Manager, ASUCD Unitrans, Davis, California
Circe Torruellas, Program Analyst/Lead Planner, District of Columbia Department of Transportation, Washington, DC
Kathryn Harrington-Hughes *(Mission Coordinator),* Project Manager, TCRP International Transit Studies Program, Harrington-Hughes & Associates, Inc., Easton, Maryland
Valerie Sunderland *(Mission Coordinator),* Project Coordinator, TCRP International Transit Studies Program, Harrington-Hughes & Associates, Inc., Easton, Maryland

APPENDIX B—STUDY MISSION HOST ORGANIZATIONS

Ahmedabad, India

CEPT University

R. N. Vakil, Director
H. M. Shivanand Swamy, Executive Director
Manjiri Akalkotkar, Associate Professor
Sandeep Paul, Architect/Urban Designer

Ahmedabad Janmarg Ltd.

I. P. Gautam, Chairman
Utpal Padia, Executive Director
Akhil C. Brahmbhatt, Dy. General Manager (Operations)

Ahmedabad Municipal Corporation

Mahendra S. Patel, Deputy Municipal Commissioner
Kelvin C. Kapadia, Deputy Assessor & Tax Collector

Delhi, India

Ministry of Urban Development, Government of India

Ashok Kumar Saroha, Director, Urban Transport
Sanjeev Kumar Lohia, OSD (Urban Transport) & Ex-Officio Joint Secretary

Delhi Transport Corporation, Govt. of NCT of Delhi

V. K. Gautam, Sr. Manager (Traffic) & Depot Manager
Naresh Kumar, Chairman & Managing Director
R. S. Minhas, Sr. Manager (Traffic)

Delhi Metro Rail Corporation

E. Sreedharan, Managing Director
Anuj Dayal, Chief Public Relations Officer
Mohinder Yadav, Senior PRO (Operations)

Institute of Urban Transport (India)

B. I. Singal, Director General

MRTS

Sumit Chatterjee, Deputy Secretary

Guangzhou, China

Construction Commission of Guangzhou Municipality

Lu Yuan, Vice Director

Guangzhou BRT Operations Management Co., LTD

Haixin Ying, Vice General Manager

Guangzhou Municipal Engineering Design & Research Institute

Xiong Zheng Yuan, Vice Director
Xiaomei Duan, Dean of Transportation Division/ Chief Engineer
Sui Jun, Director
Su Zhuo Jun, Traffic Engineer

Guangshou Traffic Engineering Research Center

Ying Zeng, Engineer

Institute for Transportation & Development Policy

Liang Yin, Communications & Program Manager
Dani Simons, Director of Communications & Marketing (New York)

Hangzhou, China

Hangzhou GST Tech Co., Ltd.

Sheng Genghua
Huang Jin, BRT Manager

Hangzhou Public Bicycle Transport Services Development Co., Ltd.

Zhang Liqiang, General Manager

Hangzhou Public Transportation Group Co., Ltd, Trolleybus Branch

Chen Qui Wei, Fleet & Station Manager BRT

Shanghai, China

School of Transportation Engineering, Tongi University

Lun Zhang, Associate Professor & International Affairs Coordinator
Lin Hangfei, Vice Dean
Wu Jiaorong, Vice Chairman of the Dept & Associate Professor

Shanghai Aowei Technology Development Co., Ltd.

Yuan Min, Vice Director

Shanghai Municipal Transport & Port Authority

Du Jian, Coordinator, Exchange and Cooperation
Pan Shaojie, Foreign Affairs Dept
Shen Yi Cheng, Deputy Director, Comprehensive Planning & Construction Dept
Wang Jianjun, Passenger Transport Division/Rail Transport Division
Wang Dajun, Technology & Information Dept
Jing Yongnian, Deputy Chief Economist

TRB

Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

ISBN 978-0-309-21372-1

Subscriber Categories: Public Transportation

These digests are issued in order to increase awareness of research results emanating from projects in the Cooperative Research Programs (CRP). Persons wanting to pursue the project subject matter in greater depth should contact the CRP Staff, Transportation Research Board of the National Academies, 500 Fifth Street, NW, Washington, DC 20001.