Transport plays an integral role in the levels of mobility and socio-economic participation in any given society. Yet, traditional urban transport planning has neglected this important role and has limited its focus on the efficiency of the transport network itself, thereby overlooking the more difficult to measure socio-economic implications. This paper reports on the use of accessibility metrics for quantifying the effect of public transport and urban development interventions, such as BRT and social housing projects, in lowering the spatial mismatch between low income residents and their jobs, with examples from a World Bank commissioned project in Ahmedabad, India. In addition, we show how geo-spatial network modelling techniques can be used in measuring levels of accessibility for this purpose. Our findings show that the presented metrics and developed tool can highlight critical investment and policy reform needs for developing cities in India and beyond.

**Keywords**: Accessibility, Urban Poor, BRT, Developing Country, India
BACKGROUND AND INTRODUCTION

Transport plays an integral role in the levels of mobility and socio-economic participation in any given society. Yet, traditional urban transport planning has neglected this important role and has limited its focus on the efficiency of the transport network itself, thereby overlooking the more difficult to measure socio-economic implications. Recent research in sustainable transport has come to realize that the prevalent transport system and policies crucially impact on levels of social exclusion. Social exclusion results from both a lack of opportunities as well as a lack of access to those opportunities, which is highly impacted by inadequate access to transport infrastructure and systems (Wati, 2009).

With the fast growing urban population in developing countries and associated issues of urban planning and transport, such as rapid urban sprawling and increasing pressures on existing transport infrastructure, levels of transport-related social exclusion as experienced by the urban poor population are expected to increase even more.

Low-income dwellers in cities such as Ahmedabad in India are those that experience the highest levels of social exclusion. They spend long daily commutes to and from low-paying jobs, on overcrowded public transport vehicles for which fares continue to rise. This is particularly true for the poor residing in the marginalized areas with limited access to essential resources such as jobs.

Yet, many cities in India, like Ahmedabad, have embarked on urban renewal programs with the intention to provide more sustainable and equitable transport and housing solutions to the population at large, and the urban poor in particular. Examples include the development of Bus Rapid Transit (BRT) and metro systems, non-motorized transport infrastructure and provision of basic services, such as affordable housing. The key question to be addressed surrounding these programmes is how to intervene in a manner that provides the highest impact and aligns best with the overall policy objective of reducing social exclusion of the urban poor.

Better integration between urban development and transport may provide a way of preventing the low income and excluded groups to be locked out of the activities that are essential to support a good quality of life (Lucas, 2004). Accessibility metrics can quantify this level of integration as it measures the end benefit of the integrated land use and transport system by answering questions like how many destinations (generally jobs, but could also be shops, schools, entertainment and recreation facilities) can be accessed in a given time using a given mode of transport. Increasing accessibility – bringing people, job opportunities within easy reach of each other – as such provides an important step in addressing social exclusion in transport.

This paper reports on a small research project that was conducted in Ahmedabad with support of The World Bank. The aim of the project was to demonstrate the use of accessibility metrics in quantifying the possible effects of investments in public transport and urban development in terms of lowering the spatial mismatch between low income residents.
and jobs within reach by public transport and non-motorized transport. Given the crucial role that access to economic opportunity plays in economic development and improving the lives of the poor, the presented metrics - and developed GIS tool - can help highlight critical investment or policy reform needs in cities.

SUSTAINABLE TRANSPORT POLICY IN AHMEDABAD

Ahmedabad is the largest city and former capital of the Indian state of Gujarat located on the bank of Sabarmati river in the western part of India. The river divides the city in two halves, which mostly get referred to as East Ahmedabad and West Ahmedabad. Ahmedabad with currently more than 5.5 million inhabitants (figure 1) is the fifth largest city and seventh largest metropolitan area in India, and is one of the important trade and commerce centres in India. Its flourishing textile industry collapsed in the late 1980's, but the present city still accounts for 19% of the total urban workers in the state, and hosts several key textile, chemical, engineering and pharmaceutical industries.

The emerging urban fabric of Ahmedabad is more orderly, has pedestrian friendly design, with a dense and good mix of land use in the locations that developed in the pre-colonial era. However, the development of the city after independence has been piecemeal and has lacked vision of a balanced development of the metropolis (Pandya, 2002). The built form pattern is marked with lopsided and heterogeneous development. The population density ranges from 2,293 persons per hectare in certain locations in the walled city area to densities of 150 to 370 persons per hectare in the western part of the city. Ahmedabad still has a substantial urban poor population; about 25% of the total population (AMC et al., 2006) live in slums and an additional 14% live in tenement houses, or chawls (Mahadevia, 2001; Mohupa and Government of India, 2010), spread over the city.
In terms of transport, present mean trip lengths in Ahmedabad are low compared to for example Bangaluru, Hyderabad and Pune (Pai, 2008) but the fast sprawling city and rapid rise in motorized vehicle ownership and use are matters of concern. There are two mass transit modes currently in operation in the city, i.e. the Ahmedabad Municipal Transport Service (AMTS), with around 540 buses, and routes oriented mostly to serve the central portions of the city, and a Bus Rapid Transit System (BRTS), which now runs successfully on the connecting radials. In addition, Ahmedabad has advanced plans for the construction of a metro system (MRT) linking Ahmedabad and neighbouring Gandhinagar.

The BRTS project is implemented under the Jawaharlal Nehru National Urban Renewal Mission (JnNURM). This urban renewal mission also supports several slum improvement programs, such as the Basic Services to Urban Poor (BSUP), which includes the Socially and Economically Weaker Section Housing (SEWSH) project, which is considered in this study. The key question in this study is what are the anticipated impacts of investing in sustainable transport initiatives such as BRTS and MRT to the accessibility of the urban poor in Ahmedabad? This is done by demonstrating how readily available network and GIS analysis tools can quantify and graphically illustrate the effects of different public transport improvements in addressing this problem.
Specifically the impacts on accessibility of the urban poor to employment locations through public transport (AMTS, BRTS, MRT) in combination with non-motorized access modes (cycling, walking) from their housing locations (general or specifically BSUP) are addressed.

ACCESSIBILITY AS A MEASURE OF SOCIAL EXCLUSION

The interaction between land use and transport is highly complex. Everything that happens to land use has transport implications and vice versa. Urban development generates travel, and travel generates the need for new facilities, which in turn affects accessibility and may attract further development. These interconnections are particularly vivid in a city like Ahmedabad where rapid urbanization and urban restructuring are transforming the urban area. At the same time urban infrastructure is being reshaped in response to fast economic growth and further urbanization.

Sustainable transport policy can only be effective if it manages to thrive in this complex reality. Geographical Information Systems (GIS) provide a good platform to calculate and visualize metrics of transport sustainability in response to different proposed interventions, i.e. for Ahmedabad these are the next phases of the BRTS development, the introduction of a metro, the revitalization of the AMTS, provision of cycling-related feeder systems, low cost housing projects etc.

In this study the level of accessibility of different low-income groups in the city is used as an indicator of social exclusion. To date, simplified infrastructure focused mobility indicators (typical mobility metrics that focus on travel speeds and modal splits alone) have generally been used in most analyses, as they are easy to understand, measure, and communicate (Geurs and Ritsema van Eck, 2003). However, from the perspective of households and firms, the transport system itself is not important – its importance is that it provides them with access to spatially and temporally dispersed opportunities. Accessibility metrics that consider this give planners the opportunity to use it as a policy design tool (Straatemeijer, 2008; Groenendijk et al., 2003). Furthermore, accessibility metrics allow distinguishing between social-economic groups, hence studying social exclusion. In addition, recent advances in GIS make the use of high quality visualizations possible that can be more readily used and understood by planners, policy makers, and the general public. The rapid development of these tools is a benefit for all those interested in understanding the complex interactions that take place in cities.

Accessibility indicators and applications

In a highly dynamic globalized economy, adequate access to spatially and temporally dispersed resources (consumers, jobs, suppliers) are vital conditions for firms and households in order to thrive or even just to survive (Castells, 1996). Accessibility is the potential for interaction between these resources and is influenced by the qualities of the transport system (reflecting the travel time or costs of reaching a destination) on the one hand and by the qualities of the land use system (reflecting the qualities of potential...
destinations), on the other hand (Handy and Niemeier, 1997). Accessibility can therefore be used as an indicator of the integration between land use and transport. To date, simplified infrastructure focused mobility indicators have generally been used in most analyses, as they are easy to understand, measure, and communicate. Examples of such infrastructure-based indicators are the level of congestion, travel time, or travel cost, all of which have strong methodological disadvantages (Geurs and Van Wee, 2004) as compared to the accessibility metrics presented here.

There are three important reasons why planners should move away from merely focusing on infrastructure-based indicators (Straatemeijer, 2008):

- From the perspective of households and firms, the transport system itself is not important – its importance is that it provides them with access to spatially and temporally dispersed opportunities.
- Accessibility defined in this way gives planners the opportunity to assess the effects changes in transport and land-use system have on the potential for interaction, and can be used as a policy design tool (Groenendijk et al., 2003).
- For politicians, citizens and firms it may be easier to discuss the quality of access to education services and markets than it is to discuss the inefficiencies of the transport system.

A whole range of improved accessibility measures have been proposed in scientific literature. However, more complex indicators also require more analytical skills from users (Handy and Clifton, 2001) and they place high demands on available data. Activity-based measures provide an important class of measures as they analyze the accessibility of locations, typically on a macro-level such as Traffic Analysis Zones (TAZ). Typical measures are the cumulative opportunities (or contour) measures that, for example, measure the number of jobs within 30 minutes by car from the origin location, and the potential measure (or gravity measure) that discounts these opportunities over time (or distance) using a distance-decay function. This is done to count an opportunity closer by as more important than at a distant location. More complex location-based measures explicitly incorporate capacity restrictions of supplied activity characteristics to include competition effects (Geurs and Ritsema van Eck, 2003). This type of measure was used in recent applications such as in Tel Aviv and Ha Noi for assessing the difference between potential accessibility by car and public transport (Benenson et al., 2010; Hong Ha et al., 2011), in Boston, Los Angeles and Tokyo to compare potential accessibility to jobs versus different urban form (Kawabata and Shen, 2006), and in Finland to study the relation between potential accessibility by road and railway to population change (Kotavaara et al., 2011) and in China to develop an Urban Accessibility Planning Support System.

**LOCATIONS OF THE URBAN POOR**

In Ahmedabad about 40% of the population resides in informal settlements. It is believed that most of the urban poor reside in these locations. The two dominant types of informal settlements are slums that involve illegal occupation of the marginal areas of the city by
migrants and squatters and chawls that are residential units originally built for workers in the mills and factories. Most slum dwellers tend to settle along the waterways in the city, on the vacant land or on low lying areas (Bhatt, 2003).

To identify the locations of the urban poor in Ahmedabad it is assumed that the urban poor mostly live in these slum and chawl areas in the city. The data on their locations were collected from CEPT University in Ahmedabad as part of the Slum Free City: Ahmedabad project. The survey data for these areas contains the number of huts in total, the number of huts that are poorly built (kutchha), the number of huts that are of good construction (pucca) and one class in between (semipucca). The three types of housing conditions are used as proxies to classify the urban poor into the least-poor (occupying pucca housing), middle-poor (occupying semipucca housing) and very poor (occupying kutchha housing) categories, and to estimate the number of (potential) workers assuming 2 potential workers per hut irrespective of housing type, following (Bhatt, 2003).

Figure 3 shows clusters and (kernel) densities of (potential) workers (all urban poor classes combined) in the city based on the slum and chawl locations.

![Kernel density of all potential urban poor workers per .25 hectare.](image)

**LOCATIONS OF EMPLOYMENT OPPORTUNITIES**

To identify employment opportunities and map their locations at an appropriate spatial scale, job locations, job types and their densities were derived using 2011 property tax data of
Ahmedabad. These data were spatially disaggregated to obtain job density grids (using 100m x 100m grid cells) and clusters by known employment sector data, i.e. distinguishing industrial, retail, government, education, transport and logistics, and office and commercial jobs. The employment data per grid were then grouped into three categories: salaried (education, banks, government, hotels and commercial), self-employed (one for each retail job) and casual labour (storage godowns and industries) jobs, a typical urban employment subdivision that can be linked (but not exclusively) to the identified worker categories, i.e. the least poor, middle-poor and very poor respectively, following Ray (2010). These categories represent different levels of wages or poverty rates and uncertainty of income. The percentages of these job categories and worker classes in Ahmedabad is depicted in the chart in figure 4, where matching colours indicate matching job categories and urban poor classes. There is a surplus of potential jobs, which obviously may also be occupied by the non-poor workers. Competition for jobs as such is not considered in this study.

For the accessibility analysis both the locations of the urban poor and employment locations have been aggregated to a 400 x 400m grid.

**MODELLING PUBLIC TRANSPORT SYSTEMS**

A transport system consists of network, routes, nodes and terminals. Each specific mode in a transport system represents a sub-system of the whole transport system with its own network and routes and with contact points or exchange points at the nodes or terminals where it is possible for people to change from one mode to another. In the case of Ahmedabad, the following modes are considered:

- Non-Motorised Transport (NMT) modes (walking and cycling), operating mostly on sidewalks for walking and on the general road network for cycling with the exception of some bicycle paths along the BRTS.
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- The Ahmedabad Municipal Transport Service (AMTS), operating fixed routes on the general road network.
- The Ahmedabad Bus Rapid Transit System (BRTS), operating fixed routes on dedicated BRTS infrastructure. Phase 1 of this system is currently in operation, while phase 2 is under construction.
- The Ahmedabad Metro rail (MRT), which will be operated on dedicated rail infrastructure.

There are no private motorised modes used in the model. It is assumed that the urban poor hardly own and use those. The influence of these motorized modes on the average operating speeds of the other modes such as cycling and AMTS is considered.

A GIS network dataset that contains all four modal networks has been developed, i.e. a geo-database including the general road network layer (used for modeling access and egress trips by walking or cycling), the AMTS network, the BRTS network and part of the proposed MRT network. All networks include stops or stations where trip makers can enter, exit or transfer within or between the modal networks. As such, a fully connected and functional 3-dimensional multi-modal network model of Ahmedabad has been implemented for use within a GIS environment (figure 5).

![Figure 5: The 3-D public transport model for Ahmedabad](image)

Travel time and distance are considered as the main impedances in this model, although the database allows for adding other attributes such as distance-based fares etc. The time cost is the sum of all time spent using a mode or transferring between modes. Figure 6 shows how the various transport system attributes are combined into one multi-modal network model. The multi-modal network model is complemented with walking or bicycle access and egress times. In this way the GIS database can be used to link the urban poor locations and their respective job locations.
ACCESSIBILITY TO JOBS OF THE URBAN POOR

Two types of accessibility metrics have been implemented and mapped for several scenarios (varying between mode combinations, poverty classes and locations of interest). The first contour-based accessibility metric maps the area that can be reached in different time bands of travel (10, 20, 30, 45 and 60 minutes) around one or more fixed locations. Travel times are calculated in the multi-modal network model, based on the estimated travel speeds and attributes such as average waiting times at bus stops. The number of jobs within reach of one contour can be calculated by counting the number of jobs (by employment category) in a GIS overlay operation. The second potential accessibility metric is an extension to the contour measure and discounts jobs that are further away from a location using a negative exponential decay function that is fit to represent Ahmedabad conditions. The two types of accessibly metrics are implemented in model scripts.

Three examples of possible applications are presented to demonstrate the functionality and use of the model. A comparison of levels of accessibility to jobs by multi-modal combination, including a defined access and egress mode, by class of urban poor (thus employment category) and by location is shown. For the latter we look at the city as a whole as well as at 21 Socially and Economically Weaker Section Housing (SEWSH) locations in the city that are part of the BSUP low cost housing project. In this project in total 976 buildings are expected to relocate 78,080 poor residents from nearby slum locations.

Counting job opportunities to and from SEWSH locations

Using the contour-based accessibility measure the number of job opportunities of the potential working population (all three urban poor classes together) in 21 selected SEWSH
locations is derived. Various travel time bandwidths are distinguished. Figure 7 shows two
contour maps for one central SEWSH location (Ahmedabad cotton mill – SESWH No. 5)
showing the impact of the current and planned investments in the BRTS and MRT systems
on job accessibility as compared to the situation with walking and AMTS only. The spatial
extent of the job opportunities reachable within one hour travel time clearly increases as,
particularly near the current and planned corridors, travel times reduce. To see the effect on
job accessibility in terms of the number of opportunities we spatially overlay with the
employment map (all three urban poor classes combined) to get the chart in figure 8. The
chart shows the total job opportunities reachable for each of the 21 SEWSH locations in
stacked bars indicating the different travel time bandwidths. For all 21 locations together, the
BRTS and MRT investments increase the level of job accessibility for the urban poor within
30 minutes travel time by 16.5% as compared to the AMTS situation only, while this figure is
almost 50% for trips up to 60 minutes.

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<td>Ahmedabad Cotton Mill, Sarangpur</td>
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<td>18</td>
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<td>Ajit Mill, Rakhiyal</td>
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<td>Ishanpur</td>
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<td>21</td>
<td>Bag-e-Firdosh</td>
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Figure 7: Contour-based accessibility plots for Ahmedabad cotton mill for walking and AMTS only (left) and all
current and planned public transport modes + walking (right) for different contour bandwidths (all urban poor
workers).

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Figure 8: Contour–based accessibility levels per SEWSH location for different contour lengths (in minutes) in stacked bars. walking (left), walking + AMTS (middle) and all modes (right) (all urban poor workers).

Figure 9: SESWH locations 1, 13-16 showing the BRTS network and planned station (green triangle) and the existing AMTS route (grey circles); job densities indicated in pink colour intensities (all urban poor workers).

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Five locations (SESWH locations No. 1, 13-16) stand out in the analysis and show low overall levels of job accessibility. Detailed analysis of these locations in figure 9 further reveals that they are located relatively far away from current or planned public transport stops, and also in areas with relatively lower job densities.

City-wide potential accessibility analysis

The potential accessibility measure explicitly combines job opportunities of the poor and the difficulty of travel. Job opportunities are discounted with increasing travel time using a decay function; a distant job is valued less than one close by. A negative exponential function with a decay factor -0.03838 is used, which makes that a job 60 minutes away is 10 times less attractive than a similar job in the present location. The differences in this potential accessibility value can be substantial across modes. Figure 10 visualizes the potential number of jobs by the least-poor worker class accessing salaried jobs in Ahmedabad comparing walking only with that of the currently implemented public transport system (AMTS + BRTS phase 1). The 3D visualization shows job concentrations in the base layer and depicts potential job accessibility per grid cell by walking only in the purple bars (colour intensities and height indicate the level of potential accessibility) while the floating green squares show the added level of job accessibility offered by the current AMTS and BRTS phase 1 systems. Clearly, the contribution of the AMTS and BRTS phase 1 systems to potential job accessibility is highest in the areas surrounding the centre locations with high job-density. More jobs can be reached in a shorter travel time, and these are valued higher because of the decreased travel time to reach them. The average overall contribution of the AMTS and BRTS phase 1 to the level of potential job accessibility for the urban poor class compared to walking alone is estimated at 138%.
Figure 10: Job-based potential accessibility for the least-poor worker class, comparing walking only with current public transport options (AMTS and BRTS); also showing the density of salaried job opportunities in red in the base layer.

Next, figure 11 shows the gain in potential accessibility levels for all urban poor classes combined from the situation with walking and AMTS only to the situation where the BRTS and MRT have been implemented fully. The top maps in figure 11 show the potential jobs for the two different mode combinations, while in the bottom map both scores are divided. Clearly, the BRTS and MRT corridors are visible in the resultant map. This indicates that the effect of the BRTS and MRT systems on potential job accessibility is substantial in these areas. The average overall contribution of the BRTS and MRT systems to the level of potential job accessibility (for the whole city) compared to the walking and AMTS combination only, is estimated at 8%.

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Finally, the three urban poor classes, who live in different locations and who are employed in different job categories are looked at specifically. Analysing the expected gain in their potential accessibility levels from the current AMTS and BRTS phase 1 systems to one with the BRTS phase 2 and MRT phases 1 and 2 fully implemented reveals a potential increase of 5.1% for the least-poor workers, 5.7% for the middle-poor workers and 3.9% increase for the very poor workers. The very poor workers (accessing casual labour jobs) will benefit less than the other 2 groups of the planned extensions, while the middle-poor workers (accessing self-employment jobs) benefit the most.
Effect of promoting bicycle feedering for SEWSH locations

To show the impact of facilitating cycling options from and to the bus stops and metro stations on the level of potential job accessibility, figure 12 shows the relative share of cycling-related potential accessibility to that of walking-related potential accessibility for the 21 SEWSH locations in the city in the situation that all proposed public transport interventions have been implemented. The assumption is here that cycling is three times as fast as walking. This is reasonable, especially when proper cycling facilities are made available throughout the city. On average the level of potential accessibility for the 21 locations improves by 135%, which is substantial. Interestingly, this is particularly caused by the improved access and egress in the 5 locations, mentioned in example 1 (figure 7), which have low (contour-based) accessibility levels (NOs 1, 13-16). These locations are relatively far from public transport stops. The improved bicycle access and egress makes that more jobs are reachable in the shorter travel time band widths, thus discounted less.

Figure 12: Potential accessibility in SEWSH locations for all urban poor workers. Comparing walking and cycling feeders to all public transport options.

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CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to measure the effect of public transport (sustainable transport initiatives BRTS and MRT in particular) on the level of job accessibility for the urban poor in Ahmedabad, India.

In order to carry out this task, different spatial data sets on the locations of the poor, their employment opportunities and the various transport systems needed to be synthesised and developed in a GIS environment. A fully functional integrated public transport system was developed that allows for the analysis of accessibility levels over the different systems and provides the user the opportunity to evaluate the competition between systems on the basis of their contribution to improved levels of jobs accessibility.

Our findings show that there is variation between accessibility to jobs for the different urban poor groups. Compared to walking, public transport does improve job accessibility, particularly through the extensive AMTS network, that can be accessed relatively easily from all locations in the city. The current and planned investments in BRTS and MRT improve this accessibility to jobs considerably further, but mostly in the catchment areas of these systems.

The present results consider walking as an access and egress mode. When cycling is introduced – the current modal share of cycling being around 19% of the total trips in Ahmedabad – potential accessibility levels improve further as cycling provides a good last-mile access and egress to and from the BRTS and MRT stations.

Public transport fares have not been considered in this analysis (although the model could handle such data if available). Including fare information may affect the results for the contributions of BRTS and particularly MRT to the level of job accessibility as these fares are generally higher than for AMTS, let alone for walking or cycling.

Which lessons can be learned for policy making?

It is clear from the analysis that the current and planned public transport interventions do benefit the poor in terms of their accessibility to jobs. These benefits are significant, despite the low spatial extent of the BRTS and MRT systems, except for those areas that are both lacking good access to the bus and metro stops and where the job densities (in the specific categories) are low, forcing them to make long journeys.

To improve the benefit of systems like BRTS, particularly for the urban poor, more attention needs to be paid on the routing of the various systems in view of the locations of the urban poor and their jobs, also keeping in mind that several of the informal settlements and part of low cost housing projects such as the BSUP. Their formalization should be done in conjunction with the future planning of transport.
Feeder functions of cycling and walking, in access trips, but potentially also in egress trips through the implementation of public bike schemes should be considered also. Besides it is clear that the AMTS system already provides a high level of job accessibility to the urban poor. Investments in good feeder systems and investments geared towards further improvement of the existing AMTS (e.g. planning and scheduling) as well as possible integration with the BRTS and MRT systems are seen as good ways forward.

To push the agenda of social inclusion of the urban poor forward this study shows that local planning effort should concentrate on public transport improvement, the NMT feeder function as well as integrated urban land use and transport development strategies, acknowledging the home and job locations of the urban poor as to bring employment opportunities closer to the urban poor and vice versa.

The results of this pilot project demonstrate that accessibility metrics provide valuable insight to decision makers on key issues that concern levels of accessibility for the lower income groups and on the role public transport and feeder systems can play in this.

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The findings, interpretations, and conclusions expressed in this work do not necessarily reflect the views of The World Bank, its Board of Executive Directors, or the governments they represent.
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