USE OF GEO-INFORMATION TO DETERMINE THE WORK PLACE ACCESSIBILITY USING PUBLIC TRANSPORT IN AHMEDABAD CITY, INDIA

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Abstract: This paper describes the use of geo-information technology in a study to determine accessibility to work places using public transport provided by Ahmedabad Municipal Transport Service in the city of Ahmedabad, India. The measures used to determine the accessibility levels were developed using the constraint-based approach based on Hägerstrands theory in time geography. The model had three distinct components *viz.* individual characteristics, land use (base location, activity locations) and transport network to determine the accessibility levels. A land use model was developed to store attributes and data related to individuals and activities and a public transport model was developed determine and store travel time between sets of land use clusters. The computed and stored values in the land use and public transport models were then used as an input in the model to determine individual accessibility levels.

Keywords: Public transport, work place, time use, travel time ratio, access, egress, main haul, accessibility, Ahmedabad,

1   INTRODUCTION

This paper describes the use of geo-information technology in a study to determine accessibility of individuals to work place location in the city of Ahmedabad, India using public transport. The accessibility levels were established by a model to find accessible activity locations, which was based on and formulated using Hägerstrands theory in time geography. The model is a GIS based model that uses spatial analysis capabilities of the ArcView software. The GIS based model had two components the land use component and the transport (public transport component). The analysis was based on empirical data collected in western part Ahmedabad city in 2001. For further details on the description of the data see Munshi et al (2003).

The following sections discuss the theoretical background and the derived accessibility models Section 3 describes how the data was handled in the ArcView GIS environment, section 4 describes the results and section 5 formulates the conclusions.

1.1   Context

The city of Ahmedabad is located in the western region of India in the state of Gujarat. Its urban agglomeration area is around 170 sq. km. and its population is around 4.5 million. The city population has experienced high growth rates over the past decade of over 3 % per annum. This enormous population growth has resulted in stress on urban development with more than 40% percent of the city population living in unplanned or illegal settlements (School of Planning 1999). These figures indicate that the city corporation has had very little control on location of residential areas or work/activity locations. The mass transit faculties within the city corporation area are also provided by the Municipal authority (Ahmedabad Municipal Transport Service (AMTS). The performance figures of AMTS indicate that AMTS buses account for only 0.8% of traffic on the roads and the percentage of total trips made using AMTS buses have decreased from 36% to 27% in the last decade (AMTS, 1999). These facts leads to the credence that although planning of activities and provision of public transport service is the responsibility of one organisation, the provision and planning of activities as land use and public transport provision has not been proper.

Because the goal of any transit system is to satisfy individual travel needs. The approach was chosen to investigate if the provision of public transport is in actual conformity with the individual travel needs. For this research the travel needs analysed is the travel to work places.

2   Concepts

The choice and importance of a transport mode is dependent upon how well it responds to peoples needs to engage in activities. The activities an individual can participate in are constrained by space and time (Kraan, 1996). Hägerstrands (1970) time geographic framework is a powerful and elegant perspective for analyzing constraints on individuals' participation in activities and opportunities. (Miller, 2003). Hägerstrand differentiated between three types of constraints. He identified capability constraints that refer to physical constraints e.g. time required by a person for physical need like sleep, eat etc. A person can also be at only one location at a particular point in time and the fact that there are limits on the maximum speed of different transport modes imply that activities that are too remote in space cannot be part of ones space-time path. Hägerstrand also distinguishes coupling constraints, that define "where, when and for how long the individual has to join other individuals, tools and materials in order to produce, consume and transact" (Hägerstrand, 1970). Another category of constraints is authority constraints, which prohibit the activity location at certain times, like for example, if a person reaches certain activities after they have already started they might not be able to participate in these.

Travel being a derived demand from the need to participate in activities, travel time and activity time can be assumed to be interdependent. The interdependence between activity duration and travel time reflect that individuals aim to meet two basic needs sufficient time to engage in activities and a larger set of activity places (Dijst and Vidakovic, 2000). It is also considered that the longer the time one spends at the activity, the higher is its utility value to the individual (Kraan, 1996). The distance a person would wish to travel to perform an activity also depends upon the utility value the performance of the activity has for the individual. For higher utility activities people do not mind to travel more, because they have the urgency to reach to their desired location. An increase in travel time incurs the risk of not having sufficient time left for activity participation. Thus individuals have to trade-off activity time and travel time (Dijst and Vidaković, 2000). Dijst and Vidakovic (2000) proposed travel time ratio concept. They defined travel time as the ratio between the travel time and the sum of travel time and stay time. The travel time ratio τ is calculated by the following formula. Where τ is travel time ratio, T_t is travel time and T_s is stay time.

$$\tau = T_t / (T_t + T_s) \qquad\qquad (1)$$

Thus the time geographic framework recognizes that activity participation has both spatial and temporal dimensions, i.e., activities occur at specific locations for limited time periods. Transportation resources allow the individuals to trade time for space to travel and participate in activities at dispersed locations. Travel is anchored by certain activities that are relatively fixed in space and

time The space–time framework dictates the necessary (but not sufficient) conditions for most human interaction and individual participation is also very much dependent upon the persons socio-demographic characteristics as individuals with different socio-demographic background behave differently (Miller, 2003). Therefore to analyze why the public transport system in Ahmedabad is not performing well it was important to relate public transport provision in the city to the travel needs of different socio-demographic groups.

2.1 Accessibility Model

An overall data model was developed which combines Hägerstrands constraints and concept of travel time ratio. The model performs four checks to establish the accessible activities using AMTS as a transport mode.
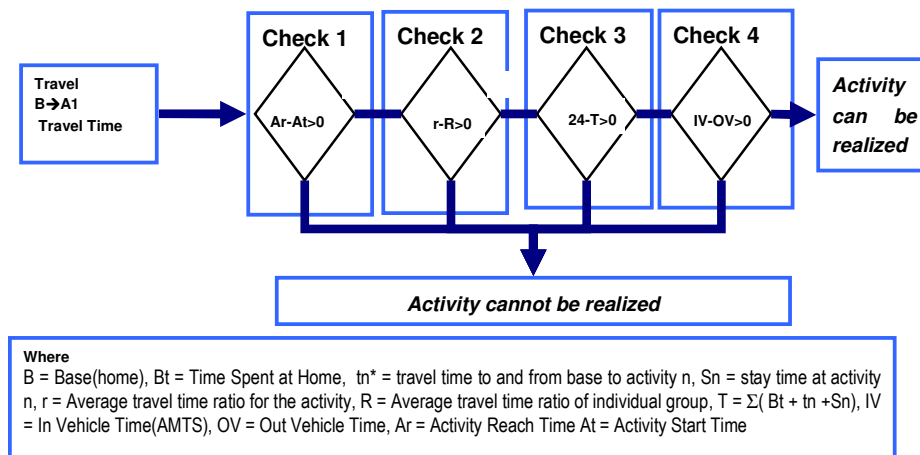

Figure 1.   Accessibility Model

At first, it was checked if the activity for a given residential location could be reached before the activity start times at the given location. It was assumed here that if a person cannot reach an activity before its start time, the person will not be able to participate in the activity. This check relates to Hägerstrands authority constraint. The second check relates to the capability of the individual to travel, where the sum of the time spent at home, the stay time at activity and travel time is used as a check. If this time exceeded 24 hrs, it was assumed that the person would not be able to participate in the activity. The third check was made related to the travel time ratio concept. For this study, the base location was considered as home and only travel from base to work place was considered. A tolerance margin for 1/2 SD (standard deviation) was used for calculating the threshold travel time ratio. If the computed travel time ratio for travel from home to work place was more than the threshold travel time ratio for the combination of the particular socio-demographic group and activity type, it was assumed that the individual would prefer either to choose another mode for travel or participate in another work

place. The fourth check relates to the use of public transport. If the ratio between out vehicle time and in vehicle time was found to be more than one than it was assumed that an individual would not use ATMS to participate in that particular activity (AMTS, 1999).

3   ACCESSIBILITY MODEL AND USE OF GIS

The GIS component of the model had two components, the representation of the data and getting the accessibility results. As stated earlier, the spatial elements in the model consisted of the transport network (road network + public transport network) and the land use (the origins (residential locations and destinations (activity locations))

3.1   Transport Network

The characteristic of the public transport service is that it can never be instantly available at all times of day and night, and it can never be so comprehensive as to cover every road and street within the area. Therefore travel by public transport requires an individual to combine several modes to complete a 'door-to-door' journey (Figure 2). Therefore to generate travel time from sets of origins to sets of destinations it is required to establish the access time, egress time and line haul time. The access time would be based on the distance from the activity to the nearest bus stop and the egress time from the distance from the base (residence) to the nearest bus stop.
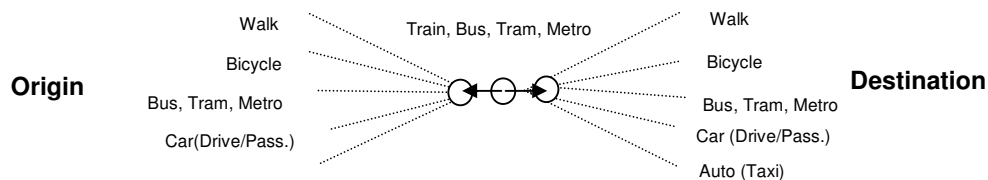

Figure 2.   Elements of Public Transport Network

To represent the public transport network and generate the travel times using public transport from different origin points to destination points, it was required to create a separate model for public transport. The developed model was based on the Public Transport Data Model for Cairo prepared by Luan (2002). The data relationships and elements used to construct this data base model are shown in Figure 2. Broadly the six network elements *viz.* public transport network, routes, stops, transfers, moving time (line haul time), tariff and fare were used to model public transport.
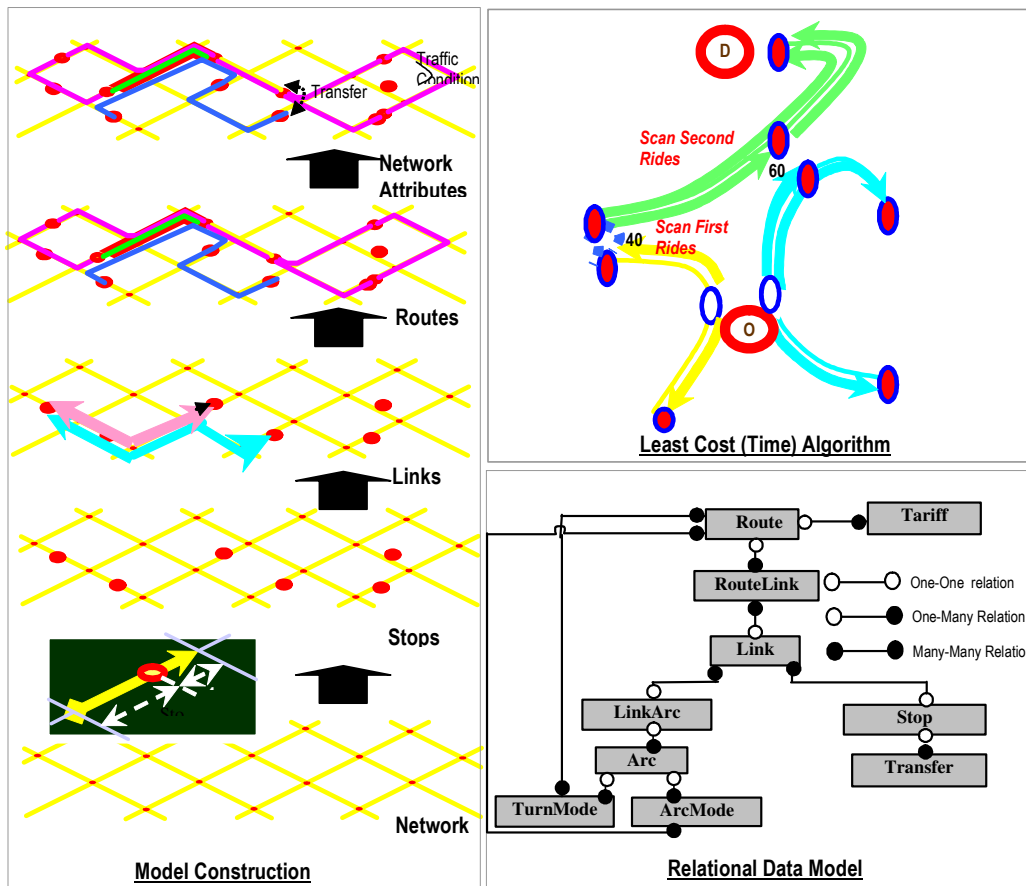
Figure 3.   Modelling Public Transport Network

Figure 3 shows the public transport model that was constructed in the GIS environment, the method to generate the shortest time paths between origin and destination points, and the relational data base. The model uses an arc-node data model where arcs are used to represent road network and nodes are used to represent (planar) junctions. A separate map was digitised for bus-stops (points). The bus-stop points were then related to the nearest position on the road network and their percentage position was determined and added to the stop attribute table. This was then used to generate the stop locations on the network. The public transport network was constructed by creating links between stops and then connecting these links to build the network. Routes and stops were thus generated over the network and were represented as links between the stops. These links could be shared by more than one route. Two tables were created to store sequence and direction of these links for particular routes, which helped in querying direction and movement on the routes. Attributes of speed, stop-type and stop-time were attached to the links between stops. Three types of stops were considered in the model: (i) normal stop (in between stop), (ii) via stop (where the bus would not stop, and (iii) terminal stop (where the route ends). The waiting time for

each route was attached to the route attributes. The waiting time of 1/3 of the frequency was used in case of this research, which was found very close to result of survey of AMTS users (AMTS, 1997;(Forer and Kivell, 1981). The time lost at turnings was stored in a separate table. The least-cost algorithm was used to generate a travel path between a set of origin and destination points, where scanning of the shortest path was related to the availability of the public transport and the shortest travel time. The travel time/distance between two places in the city could be found by identifying one or many origin points and one or many destination points. In this case the all the bus stop locations were the origin points and also the destination points.

The access and egress time were determined using the base road layer in combination with a virtual grid network of 100x100 metre hexagons. The virtual grid network was used to compensate for the local roads and to provide a representation of pedestrian access into the model. This network was used to determine the shortest walking distance to the nearest bus stop. By combining the shortest path time for egress, access and line haul time total travel time using public transport from all bases to all work locations could be determined.

3.2   Land use Model

Data related to land use, socio-demographics and information on activity participation was stored in the model. The land use was extracted from the SETU publication map (Setu, 1998) that was converted into a hexagon grid map of 100 metre side hexagons. Two separate maps were created; one for residential locations and one for activity locations. Centres of these clusters were generated and were used to store location of the cluster, data on activity type for activity clusters and dominant economic group and other attribute data in case of residential clusters. (Figure 4).

The attribute data for the different clusters was collected using different methods but the methods followed to store these were similar (figure 4). A questionnaire survey was conducted to for the individual residing in the western part of city to determine their individual behaviour and travel habits. The data related to individuals collected by a questionnaire survey was first stored spatially; the residential address of the respondent was used to assign the spatial location. The spatial information related to the time individuals spend at home, their usual start time for travel and their average travel time ratios were then aggregated to travel zones for three income groups *viz.* low, medium and high. The aggregated attribute data was then transferred to the residential clusters (100 x100 metre hexagons) for the particular income by spatial query techniques. The data related to start time, stay time and end time for various activities was collected by interviewing individual in the area and from the Ahmedabad Municipal Authority, these data was also aggregated according.
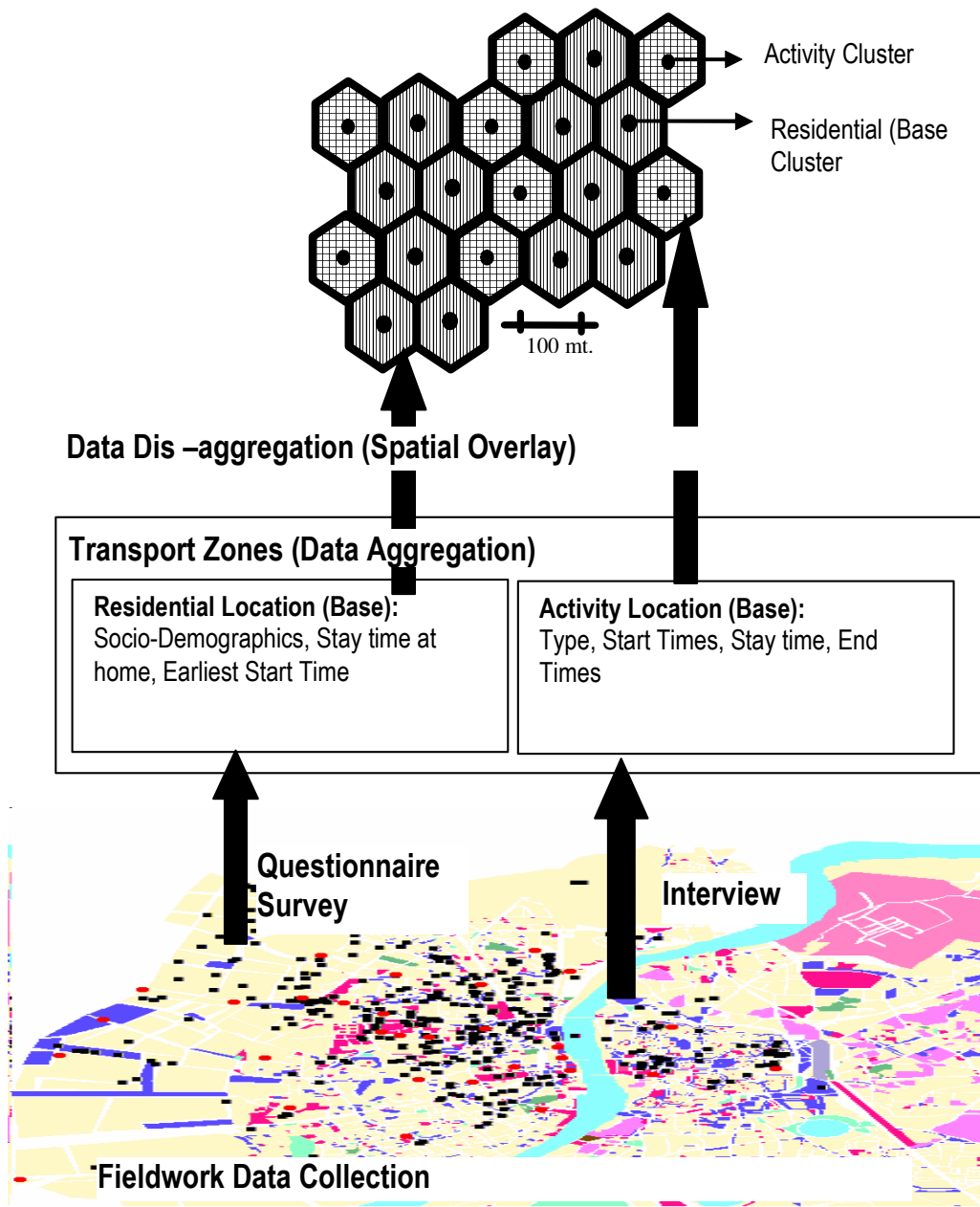
Figure 4.   Representation of Land use

4   Results.

The land use and the transportation model explained in section 2.1 were used to store details on individuals, activities and travel. These data had to be queried further for the four checks in the Accessibility Model to obtain the accessibility results.
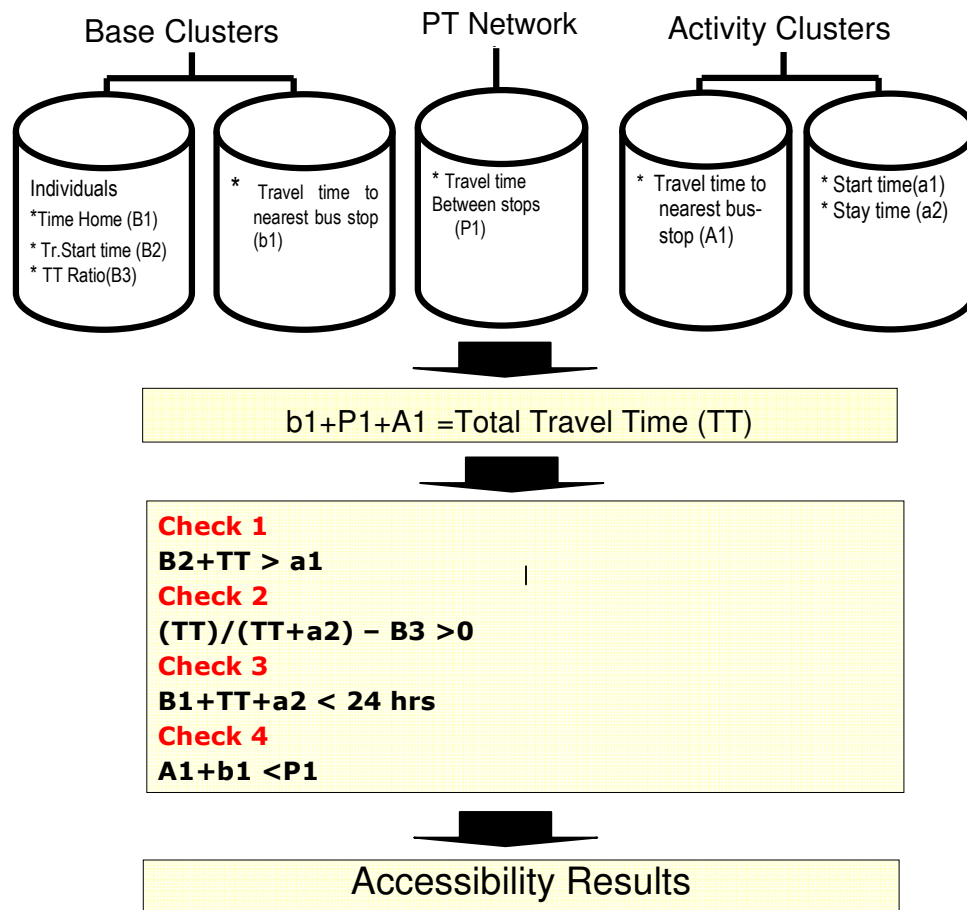

Figure 5.   Querying Accessibility Model

Figure 5 shows how different data sets were used to carry out the checks on accessibility constraints. Figure 6 shows the visualisation of the results of the Accessibility model. The free time available to the individual after spending time at his/her work activity and physical-biological needs (i.e. the time he spends at home) and travel was calculated. Available free time gave an indication if another second activity can be performed after performing the work activity.

It was observed that the start times of work activities varied between 8:30 a.m. to 11:00 a.m. These times were dependent upon characteristics of work place and participating individuals. The peak hours for travel to work mostly ranged between 8:15 a.m. to 10:45 a.m. for all income groups. Early activity start times were observed for the lower income group individuals. The middle-income and the high-income group individuals mostly started work after 9:00 a.m. Because most of the lower income group individuals started their activities and travel earlier than other income groups, lower income residential location had more chance to reach activity location before activity start times.

The observed median value for travel time ratios for travel to work place by all socio-demographic groups was 0.179 and it varied within the range from 0.034 to 0.33. The range of travel time ratio for the lower income groups was much higher than the other income groups; this was because individuals from this group participated in activities across the city, therefore travel time to the work activities also varied accordingly. Sometimes they had to commute for longer times to participate in activities of shorter duration. The higher travel time ratios for lower income group individuals who also spent more time on activities suggest that this group of individuals spends the least time at home. The middle-income group had a much smaller range; however the median ratios observed were much higher than that of high-income groups, suggesting more time spent on travel as compared to activity time. The travel time ratio to work place (institutional and office) observed for high-income group are comparable to those observed by Schwanen and Dijst (2002) for a study in the Netherlands. The observed higher travel time ratios for lower income groups (low-income and middle-income), who also constitute more than 85 percent of city population is indicative of the work opportunities available to these socio-demographic groups and in general of the traffic and transport condition in the city. The higher travel time ratios for lower income groups, indicated that these groups don't mind travelling for longer times, therefore also have a better chance in second check in the accessibility model to participate in activities.

Table 1:   Travel time ratio for socio-demographic groups.

Income Group	Work Activity	T.T Ratio Observed		
		Min	Max	Median
Low Income	Institutional/Office	0.09	0.21	0.13
	Industrial/Labour	0.16	0.36	0.24
	Commercial	0.12	0.36	0.23
Middle Income	Institutional/Office	0.14	0.18	0.16
	Commercial	0.03	0.31	0.15
High Income	Institutional/Office	0.07	0.13	0.97
	Industrial/Labour	0.04	0.19	0.12
	Commercial	0.13	0.17	0.14

High access and egress distance severely affects the performance and effectiveness of the public transport system. In the case of AMTS it was observed that more than 30% of residential locations were more than 15

minutes walking time away from the nearest bus stop. A very high percentage of around 56% of the work locations were more than 15 minutes walking distance from their nearest bus stop location. As a result, more than half of the individuals had to spend more than one hour in travel if they were to use AMTS as a mode. This was also the case for most of the low income residential clusters. Out vehicle time was biggest deterrent factor preventing individual from accessing the work location.

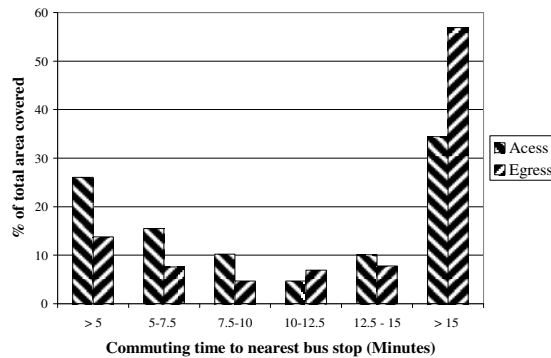**Figure 6.   Access and egress times to nearest bus stop and percentage of area covered**

Table 2:   Number of Activity Clusters Accessible

Number of Activity Clusters (Work) Accessible	Residential cluster that have Access.(Nos.)		
	High Income	Middle Income	Low Income
Unto 30 Minutes free time*			
< 50	25(12)	135(11)	87(14)
51-100	37(18)	122(10)	77(12)
101 – 150	21(10)	136(11)	66(10)
151 – 200	3(1)	89(7)	6(1)
201 – 250	13(6)	67(5)	14(2)
> 250	3(1)	55(4)	16(3)
No cluster	104(50)	677(53)	368(58)
30 to 60 Minutes free time*			
<50	71(34)	191(15)	143(23)
51-100	30(15)	103(8)	42(7)
101 – 150	0(0)	95(7)	5(1)
151 – 200	10(5)	80(6)	32(5)
201 – 250	18(9)	58(5)	8(1)
> 250	19(9)	54(4)	7(1)
No cluster	58(28)	700(55)	397(63)
> 60 Minutes free time*			
<50	15(9)	162(13)	40(6)
51-100	23(11)	89(7)	7(1)
No Cluster	168(82)	1030(80)	587(93)
Total Clusters	206(100)	2178(100)	634(100)

Value in the () are percentages of the total area
*This is free time available to the individual after participating in work activity.

The results generated after running this model and aggregating the values are shown in table 2. The result indicates that when free time available of 60 minutes or more is considered, more than 80 percent of the residential areas do not have access to any work place, more so for the low income group for

whom AMTS is the essential mode of transport; more than 90 percent of the residential areas with low income dominant population did not have access to any work activity. Even for free time more than 30 minutes and less than 60 minutes it was observed that more than 50 percent of the middle and low income group residential clusters did not have access to any work place and more than three quarters of these clusters had access to less than 100 work place clusters. The access to work place for higher income groups in this category was slightly better. The accessibility levels increased slightly when the free time was decreased to 30 minutes. However a significant percentage of area 50, 53 and 58 for high, middle and low income respectively did not have access to any work place. It was also found that the accessibility to the work places on the eastern part of the town was very low. The establishments in that part of the city cater mainly to low-income jobs. Moreover poor accessibility to activities in the eastern part of the city also suggests poor connectivity from the main public transport hub situated in the central part of the town.

Figure 7.   Number of Residential Clusters that can access Activity (Work) Clusters

5   Conclusions

The Accessibility model could be used successfully to determine the accessibility levels for different residential areas to work places and likewise for different work locations. The model also gives a realistic view of the reasons why public transport service in Ahmedabad is not performing well. The main reasons relate to a poor understanding of individual travel needs. Because the model uses simple computation methods it can be replicated and used for other studies.

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