AUTHORSHIP PAGE

EVALUATION OF URBAN ROAD NETWORK USING GEOINFORMATICS – A CASE STUDY OF SURAT CITY

GAURAV V. JAIN
Scientist \ Engineer
Space Applications Centre (SAC)
Indian Space Research Organisation (ISRO)
Ahmedabad, Gujarat, India – 380015
Phone: +91 79 2691 4362 (O)
Email: Gaurav.V.Jain@gmail.com

RITESH AGRAWAL
Scientist \ Engineer
Space Applications Centre (SAC)
Indian Space Research Organisation (ISRO)
Ahmedabad, Gujarat, India – 380015
Phone: +91 79 2691 4138 (O)
Email: ritesh@sac.isro.gov.in

DR. KAVITA SHARMA
Visiting Faculty
Faculty of Architecture
Sarvajanik College of Engineering and Technology (SCET)
Surat, Gujarat, India
Phone: +91 99257 94132
Email: ativak.sharma@gmail.com

R. J. BHANDERI
Scientist \ Engineer
Space Applications Centre (SAC)
Indian Space Research Organisation (ISRO)
Ahmedabad, Gujarat, India – 380015
Phone: +91 79 2691 4028 (O)
Email: rjbhanderi@sac.isro.gov.in, and

P. JAYAPRASAD
Scientist \ Engineer
Space Applications Centre (SAC)
Indian Space Research Organisation (ISRO)
Ahmedabad, Gujarat, India – 380015
Phone: +91 79 2691 6066 (O)
Email: jayaprasad@sac.isro.gov.in

EVALUATION OF URBAN ROAD NETWORK USING GEOINFORMATICS – A CASE STUDY OF SURAT CITY

Gaurav V. Jain, Space Applications Centre, Ahmedabad; Ritesh Agrawal, Space Applications Centre, Ahmedabad;
Kavita Sharma, Sarvjanik College of Engineering and Technology, Surat; R. J. Bhanderi, Space Applications Centre, Ahmedabad;
P. Jayaprasad, Space Applications Centre, Ahmedabad

Abstract

Travel-time studies gather information on travel time between important points within the study area so as to identify the segments in need of improvement. In recent years, with the lowering of hardware costs and improvements in measurement accuracy, application of Global Position Systems (GPS) for travel time measurement has gained wide-spread acceptance. This paper presents a methodology for travel time data collection and analysis using GPS and Geographic Information Systems (GIS) on urban roads in Indian cities. The study surveyed 45 km of urban roads in part of Surat city (Gujarat, India) using handheld GPS, and determined the average speeds over every 100 meter length segment along the survey roads and their intervening road intersections. The analysis of travel time variability on urban roads established the difference in peak and non-peak hour journey travel times, estimated the overall saving in travel time on account of flyovers, and computed the reduction in average speeds at road intersections. The study concludes that as the average speed on road intersections, which is 20.35 km/hr, is considerably lower than that over straight road segments (31.01 km/hr), road intersection improvements and access control measures assume significant importance towards achieving urban mobility goals as envisioned in India's National Urban Transport Policy.

Keywords: travel time, urban roads, probe vehicle, GPS

Introduction

Travel-time studies gather information on travel time between important points within the study area so as to identify the segments in need of improvement [12]. Travel times are subjected to variations due to traffic flow fluctuations, road accidents, weather conditions, and driving behaviours. In urban areas, factors such as pedestrian or bicycle movements, on-street parking, buses obstructing roads, and traffic signals may add to the delay [5]. Travel time is not only an important indicator of performance of road network, but it is also used to assign network impedances in route guidance and navigation applications. The measurement of travel time has therefore become an integral part of several Intelligent Transportation Systems (ITS) implementations all over the world.

The moving-observer method is the most common travel time data collection method, particularly for urban areas. This method involves driving test cars, also referred as probe vehicles, through the study section while an observer records elapsed times through the section and at key intermediate points within the section using a stop-watch. Automation of moving-observer method by introducing electronic distance measuring instruments (EDM) or global positioning systems (GPS) has been attempted in past [14]. With the lowering of hardware costs and improvements in measurement accuracy, application of GPS for travel time measurement has gained wide-spread acceptance. The position and speed of the test vehicle, as determined by GPS receivers, is used as an input in travel time studies in place of manual recording of time and distance using stop-watch and odometers.

The integration of GPS with Geographic Information Systems (GIS) further adds value to travel time data collection and analysis as demonstrated by several studies in past. A systematic methodology for performing travel time studies using global positioning and geographic information system technology is discussed by [11]. The methodology examined the GPS data over 300 miles (482 km) of urban highways in metropolitan areas of Louisiana to determine appropriate length of segments, track point interval and central tendency of travel time data. The application of GIS in collection and analysis of travel time, delay and congestion data for urban roads using an instrumented probe vehicle mounted with GPS is discussed by [13]. The methodology was demonstrated over two parallel routes in a major arterial corridor in metropolitan Adelaide, South Australia. [9] analyzed day-to-day variability of travel time in Tochigi city and Toyota city in Japan using GPS and GIS. [4] discussed a methodology for travel time and delay analysis using GIS and GPS based on experiments performed on around 15 km of urban roads in Manila, Philippines. They compared the results with the stop-watch based measurements and found the results of both the approaches in agreement. The travel time data collection using GPS has not remained confined to exclusive probe vehicles alone. [3] proposed an approach for estimating travel times in a road network using observations collected by consumer GPS products, thereby overcoming the shortcomings of limited number of probe vehicles. The Nayoga Probe Vehicle Demonstration (NPVD) Project used the data collected by 1570 taxis in Nayoga city, for arterial road travel time study [10]. A study on possibility of using buses as probe vehicles for the analysis of travel time variability and its applications in Hirakata City based on GPS data collected by 18 bus routes was demonstrated by [15].

The application of positioning technologies such as GPS for travel time data collection in urban area is largely restricted to major arterial roads and urban highways. Moreover, these studies have focussed on evaluation of individual corridors, but area-wide travel time data collection is necessary for the evaluation of network performance as a whole. In developing countries such as India, a well-defined hierarchical road network obeying the functional classification is rare, and the width of right-of-the-way is the sole criteria defining road hierarchy. The mixed traffic on urban roads in India coupled with poor traffic regulation practices pose questions about viability of such methods for travel time estimation. Area-wide evaluation of road network using GPS mounted probe-vehicles will be immensely useful for policy-makers and transportation professionals in developing countries, who are often challenged by the immense resource constraints.

This study attempts to develop a methodology for travel time data collection and analysis using GPS and GIS for part of Surat City. Surat, with a population of 4.46 million is the second largest city of Gujarat, and ninth largest urban agglomeration of India, as per the provisional estimates released by Census of India, 2011. It is an important centre of trade and commerce in the region, with a flourishing industrial base known for its diamond polishing and textile manufacturing units, contributing to its vibrant economy. The city, with its heterogeneous traffic composition, poor traffic management, and lack of functional road hierarchy, is reminiscent of any other metropolitan region in the developing countries. The paper comprises of five sections. Section 2 details the study methodology and elaborates on various aspects of travel time data collection and analysis using handheld GPS and its integration with GIS. Segment-size analysis outlines the effect of variation in travel time data aggregation using different segment-sizes. The results of the study particularly the effect of flyovers and road intersections on travel time variability are discussed in section 4. Final section of the paper presents the conclusions of the study along with the applicability of geo-informatics based methodology for road network evaluation in cities of developing countries.

Methodology

A. Survey roads and data collection

The road network of the study area was mapped at 1:10,000 scale using Indian remote sensing satellite images, acquired by Cartosat-1 PAN and IRS-P6 LISS-IV sensors acquired in December, 2009. A handheld GPS device (Garmen's Omega 550) was used to collect time and local coordinates at one second interval along the track followed by the probe-vehicle driven at "average-speed" of traffic stream. In order to avoid issues pertaining to visibility of GPS satellites due to urban canopy, roads wider than 18.0 m right of way alone were selected for the survey. Figure 1 shows the survey routes travelled by the probe vehicle for collecting track logs using handheld GPS.

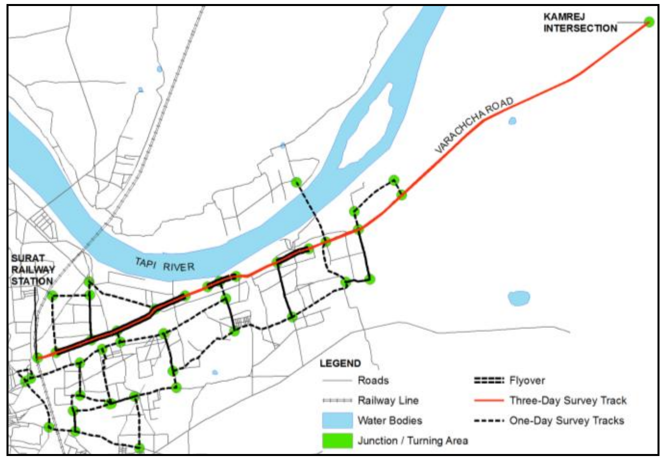

Figure 1: Survey Roads in Surat city

The 60.0 meter wide Varachcha road, originating near Surat railway station located in the heart of city, and ending at Kamrej intersection located at the outskirts of the city (Figure 1), was surveyed for three consecutive week-days. The length of this road is about 13.75 km, and it has three flyovers along its length. This radial road may be considered as a major arterial road on the basis of its width. In addition to this road, ten paths covering adjoining roads with an average length of around 4.4 km were also surveyed for one-day each. This ensured complete coverage of the study area, incorporating roads of different right-of-ways and passing through all types of predominant land use categories. The total length of the roads surveyed as a part of the study was 45.212 km.

The end points of each path were defined by orthogonal section lines and all points beyond these sections were discarded, which eventually resulted into 89,089 points along major arterial road i.e. Varachcha road and 1,58,022 points on other adjoining paths for further processing. The data for 3-day survey on Varachcha road was collected in 67 trips made during the period of 19th to 21st September 2011, while that for one-day survey on all remaining paths was collected from 27th September 2011 to 12th October 2011, in 219 trips. A unique identifier was assigned for each trip between a pair of orthogonal section lines on each path.

B. Data transformation

The data collected by probe vehicle comprises of GPS track logs containing position and time information recorded at one second time interval, in GPX file format. These files were converted to ESRI Shapefile format for further processing in GIS software. This data needs to be processed and transformed into link travel time and speed estimates. The major tasks involved in data transformation are discussed in the following sections.

C. Map-matching

The intersections of roads are organised as point features in the spatial database. The roads within 100 meter buffer of the intersection points are eliminated, thereby separating straight road sections and intersection buffers. The straight road sections were further split into 100 meter segments. These segments as well as road intersections were assigned unique identification number, for each GPS point recorded by the probe as per map-matching procedure. In case of the points along the straight road segments, GPS track points are assigned the SEGMENT-ID of geographically nearest road segment, whereas for the points within 100 meters of intersection, a unique INTERSECTION-ID was assigned to each such point corresponding to the overlaying road intersection

D. Data reduction

The data reduction procedure filters and aggregates GPS data to compute travel time and speed along the segments for a single trip. The minimum time and maximum time corresponding to each trip over each segment identified by a unique SEGMENT-ID, was assigned as start and end time of that trip for that segment. The difference of start time and end time provided the respective travel time in seconds. Moreover, as sampling interval is of one second, the number of points for each trip is equal to the difference between its start and end times. The average speed for segment i corresponding to its n^{th} trip may be computed as per equation (1):

$$V_{i,n} = \frac{L_i}{(ET_{i,n} - ST_{i,n})} = \frac{L_i}{P_{i,n}} \tag{1}$$

Where, L_i is length of segment i; $ST_{i,n}$ is the time when probe vehicle enters segment i during its n^{th} trip; $ET_{i,n}$ is the time when probe vehicle leaves segment i during its n^{th} trip; and $P_{i,n}$ is total number of GPS points along segment i during its n^{th} trip.

E. Data aggregation

The data aggregation process aggregates the data from multiple trips into meaningful indices. Average running speed and its standard deviation were computed for each segment to assess the central tendency of the speed. The average speed of probe vehicle at segment i is computed using equation (2):

$$\bar{V}_i = \frac{1}{N}\sum_{n=1}^{N} V_{i,n} \tag{2}$$

Where, $V_{i,n}$ is space mean speed of segment i during its n^{th} trip, and N is total number of trips passing through segment i. The standard deviation of average speed of segment i is computed using equation (3):

$$\sigma_i = \sqrt{\frac{\sum_{n=1}^{N}(V_{i,n} - \bar{V}_i)^2}{N}} \tag{3}$$

Segment-size analysis

Segment-size selection is an important factor, which may influence the results of travel time data analysis. The recommended short segment lengths ranging from 0.2 to 0.5 miles long (300 - 800 meters), specifically for detecting localised traffic effects [11], however it was observed that path-based travel times are better than link-based for travel time prediction models [1]. In order to assess the influence of segmentation-size on speed profile, straight road segments were split into 100.0, 200.0, 300.0, and 500.0 meter lengths. This was followed by map-matching, data reduction and data aggregation procedures as discussed in methodology. Table 1 shows the mean and standard deviation of average speed of all segments corresponding to segmentation schemes of 100, 200, 300, and 500 meter lengths.

Table 1 Segment size analysis

Segment Size (m)	No. of Segments	Average Segment Length (m)	Average Speed (km/h)	Standard Deviation (km/h)
100	281	94.5	31.01	12.33
200	152	197.5	29.24	11.42
300	101	325.0	28.10	10.55
500	61	576.4	27.23	9.86
No Segmentation	48	650.0	26.88	9.52

It may be observed that smaller the link size, greater is the variation in speed as evident by its high standard deviation. Smaller segment size is appropriate for identifying congestion spots and studying localized variations in level of service of the urban roads. It was further observed that the 95th percentile speed on 100 meter length links is around 58 km/hr, which will result into merely five GPS track point observations over that link. If the link size is decreased further, it is likely to result into even lower number of GPS observation points along the travel direction. This may introduce error in computation of average speed by the methodology adopted in this study as it depends upon the minimum and maximum time of track points over a segment, and will thereby necessitate interpolation of time at start and end points for each segment in place of topological map-matching.

Results and analysis

The GPS track points, collected along the survey roads and transformed into GIS software supported format, were used for the analysis of variation in travel time characteristics on urban roads. The travel times measured on each of the segments were converted to corresponding average speeds. Figure 2 shows the cumulative speed distribution on the segments of major arterial road (using flyovers), adjoining urban roads and the intersections of adjoining urban roads. It is evident that average speeds on intersections are much lower than that on straight road segments on urban roads, which are slower as compared to major arterial roads. The steepness of the curves further indicates that the travel on major arterial road has high variability in speed as compared to the road intersections and adjoining urban roads. This is primarily due to the lack of access control along this road.

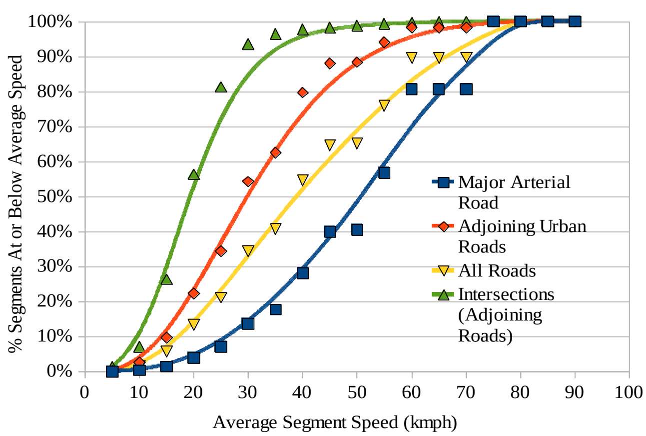

Figure 2: Cumulative average speed distribution

Intersections are the major cause of travel time delays and congestions on urban roads. The road intersections in the study area are mostly unmanned and without traffic signals. The difference in average speeds at intersections and straight road sections of adjoining roads is evident from the percentile speeds as shown in Figure 2. The 10th percentile speed on road intersections is merely 11.30 km/hr while for straight road segments of adjoining roads it is 15.65 km/hr. Similarly 90th percentile speeds for intersections and straight road segments are 27.34 km/hr and 51.43 km/hr respectively. The difference between 90th percentile speeds and 10th percentile speeds indicate the width of distribution [5], which is 16.04 km/hr for intersections, and 35.78 km/hr i.e. more than double, for straight road segments of urban roads.

The variation in average speed along the Major Arterial Road, while travelling from *Surat railway station* towards *Kamrej intersection*, can be observed from the space-speed profile as shown in Figure 3. The high points in the curve indicate the segments with high average speed, while the low points indicate the segments with congestion and in need of improvement. These points of congestion primarily correspond to road intersections along Varachcha road. It is evident that these drops are more pronounced during peak hour journeys, which signifies greater delay at such points during peak hours on account of increased traffic and vehicular interactions. The non-peak average speeds are otherwise only marginally higher than peak hour speeds on most of the straight road segments.

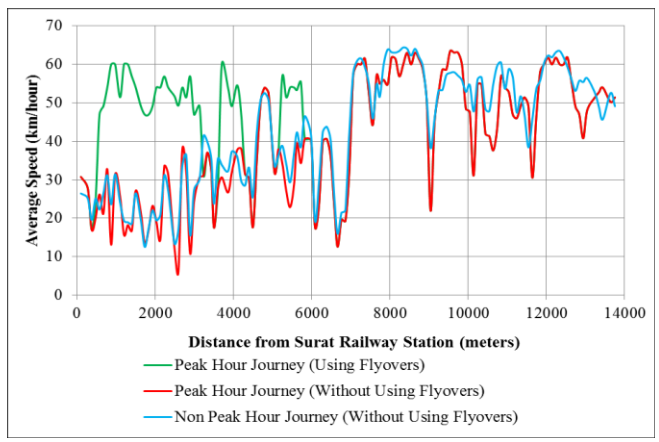

Figure 3: Space-speed profile along major arterial road

The journey time along Major Arterial Roads is significantly influenced by the use of flyovers. The average travel time on Varachcha Road while travelling from *Surat railway station* to *Kamrej intersection* without using flyovers was observed to be 1510 seconds (25 minutes and 10 seconds) and its corresponding travel time on return journey, again without using flyovers was observed as 1524 seconds (25 minutes and 24 seconds). The average journey time however is saved by 312 seconds when flyovers are used. The corresponding average speed over flyovers is 55.19 km/hr while that under the flyovers is merely 28.22 km/hr. Figure 3 shows that though the flyovers have improved average speeds along this road, they have also resulted into congestions at the entry and exit points of flyovers. The impact of flyovers is further evident from the period-to-period travel time variability along the Major Arterial Road, with and without use of flyovers, as shown in Figure 4.

The characterization of the travel time variability as comprising of three parts [8]: vehicle-to-vehicle variability, period-to-period variability, and day-to-day variability. As the study used only single probe vehicle, and as the survey was done only for a very short period of time, vehicle-to-vehicle variability and day-to-day variability could not be estimated. However, period-to-period variability is shown in Figure 4, which indicates that the period between 18:00 Hrs to 21:00 Hrs with maximum mean travel time of 1372 seconds and 1684 seconds with and without flyovers use respectively, may be regarded as peak-hour. The travel time starts to increase after 16:00 Hrs when most of the industries along this road undergo a labour shift-change. The travel times may show an average increase of 251 seconds during peak hour as compared to non-peak hours for the journeys performed without using flyovers.

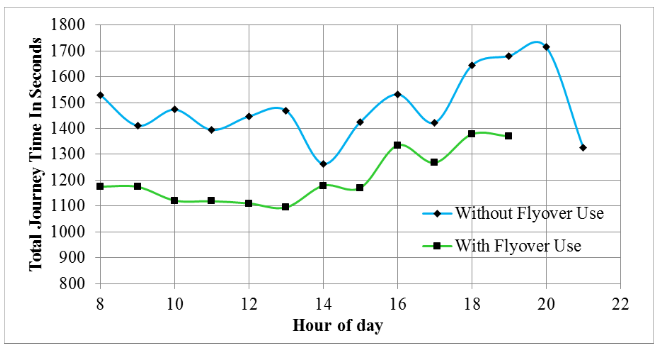

Figure 4: Hourly variations in travel time along major arterial road

As the average speeds at intersections and straight road sections on urban roads have different characteristics, separate classification ranges were used as shown in Table 2. The average speed of 149 segments out of 281 segments covering 52% of surveyed road length is less than 30 km/hr. Moreover, the average speed on 22 out of 36 intersections was found to be less than 20 km/hr.

Table 2 Average speeds on urban roads

Urban Roads (Straight Sections)			Road Intersections	
Speed Range	**No. of Segments**	**Length in km**	**Speed Range**	**No. of Intersections**
<20 km/hr	51	4.8 km	<15 km/hr	8
20–30 km/hr	98	9.7 km	15–20 km/hr	14
30–40 km/hr	76	7.5 km	20–25 km/hr	10
40–50 km/hr	32	3.3 km	25–30 km/hr	1
> 50 km/hr	24	2.4 km	>30 km/hr	3
Total	**281**	**27.7 km**		**36**

Figure 5 shows the spatial distribution of average speeds on urban roads and their intersections. The desired performance for urban roads as recommended in Urban Development Plans Formulation and Implementation guidelines given by Ministry of Urban Affairs and Employment [6] corresponds to Level of Service 'C', which as per Indian Road Congress [2] stipulates an average overall travel speed above 30.0 km/hr. It therefore, follows that the road segments with average speed less than 30.0 km/hr may be considered for performance improvement and capacity augmentation. In this case of Surat, merely three out of 36 intersections have an average travel speed above 30 km/hr, road intersection improvements and access control measures assumes significant importance in achieving urban mobility goals as visualized in National Transport Policy [7].

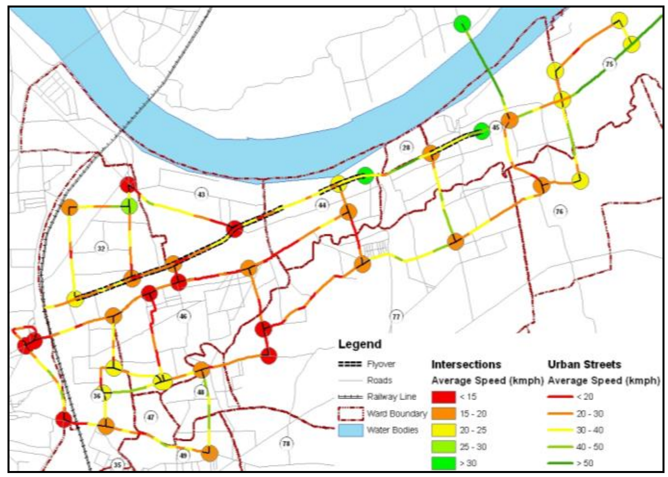

Figure 5: Average speeds on urban roads

Conclusion

Travel time is not only an important indicator of performance of road network, but it is also used to assign network impedances in several route guidance and navigation applications. The conventional method of License Plate Matching may provide path-based travel time with reasonable accuracy, but it requires very high sampling to ensure sufficient number of license plates matching between the designated points. Moving-observer method, on the other hand provides link-based travel time, and is therefore, the most appropriate method for evaluating performance of urban roads. This method could be augmented with the use of Distance Measuring Instruments (DMI) and Global Positioning Systems (GPS), thereby improving its accuracy and reducing overall cost of data collection.

This paper presented an integrated methodology for travel time data collection and analysis on urban roads using global positioning systems and geographic information systems, particularly for area-wide travel time study on urban roads in developing countries with mixed traffic, non-existent functional road hierarchy, and ineffective traffic management. Several segmentation schemes were evaluated for determining appropriate aggregation level for determination of space mean speed, and it was concluded that 100.0 meter long segments are suitable for the area-wide travel time studies in urban areas. The study determined that the road intersections are the major cause of delay on urban roads as evident from the reduction in average speed from 31.01 km/hr on straight road segments to 20.35 km/hr at intersections. The use of flyovers along the major arterial road, although resulting in saving of 312 seconds on average journey time, is also causing traffic congestions at the entry and exit points of the flyovers. It was also observed that the travel time increased by 250 seconds during peak hour period of 18:00 Hrs – 21:00 Hrs. The paper concludes that the moving observer method of travel time data collection, supported by a GPS receiver to record time and position coordinates of probe vehicles at fixed time intervals, provides a cost-effective and accurate method for area-wide travel time data collection for developing countries.

Acknowledgments

The authors would like to thank Shri A.S. Kiran Kumar, Director – Space Applications Centre, for all the support and guidance during the course of this study. We would also like to express our sincere gratitude to Dr. J. S. Parihar, Dr. Ajai, Mr. Tapan Misra, and Dr. A. S. Rajawat. Thanks are also due to Prof. Persi Engineer of Sarvajanik College of Engineering and Technology for all the help extended towards data collection.

References

[1] M. Chen and S. Chien, "Dynamic Freeway Travel Time Prediction Using Probe Vehicle Data: Link-based vs. Path-based", TRB Paper No. 01-2887, Transportation Research Board, 80th Annual Meeting, Washington, DC, Jan 7-11, 2001.

[2] IRC, IRC 106- 1990: Guidelines for Capacity of Urban Roads in Plain Areas. Indian Roads Congress (IRC), New Delhi. 1990.

[3] F. Jensen and T. V. Larsen, "Travel-Time Estimation in Road Networks Using GPS Data", Master's Thesis, Aalborg University, Denmark, 2007.

[4] C. Maricio, R. C. Santos, J. R. F. Regidor and N. C. C. Tiglao, "Travel time and delay analysis using GIS and GPS." in proceedings of the Eastern Asia Society for Transportation Studies, Vol.4, pp 688-700, 2003.

[5] E. Mazloumi, G. Currie and G. Rose, "Using GPS Data to Gain Insight into Public Transport Travel Time Variability", Journal of Transportation Engineering, Vol. 136, No. 7, pp 623-631, 2009.

[6] Ministry of Urban Affairs and Employment, Urban development plans formulation and implementation (UDPFI), Government of India, New Delhi, 1996.

[7] Ministry of Urban Transport, National Urban Transport Policy, Government of India, New Delhi, 2006.

[8] R. B. Noland and J. W. Polak, "Travel time variability: a review of theoretical and empirical issues." Transport Reviews, Vol. 22, No. 1, pp 39–54, 2002.

[9] N. Ohmori, Y. Muromachi, N. Harata and K. Ohta, "Analysis of Day-to-Day Variations of Travel Time Using GPS and GIS." Proceedings of the Third International Conference on Traffic and Transportation Studies (ICTTS 2002), Vol. 2, pp 1306-1313, 2002.

[10] Li Qiang, "Arterial Road Travel Time Study using Probe Vehicle Data", Doctoral Dissertation, Nagoya University, Japan, 2007.

[11] C. A. Quiroga and D. Bullock, "Travel time studies with global positioning and geographic information systems: an integrated methodology." Transportation Research Part C, Vol. 6, pp 101-127, 1998.

[12] R. P. Roess, E. S. Prassas and W. R. McShane, Traffic Engineering, Third Edition, Pearson Prentice Hall, New Jersey, 2004.

[13] M. A. P. Taylor, J. E. Woolley and R. Zito, "Integration of the global positioning system and geographical information systems for traffic congestion studies", in J.-C. Thill, Geographic Information Systems in Transportation Research, Elsevier Science Ltd., Oxford U.K., 2000.

[14] S. M. Turner, W. L. Eisele, R. J. Benz and D. J. Holdener, Travel Time Data Collection Handbook, Report No. FHWA-PL-98-035, Federal Highway Administration, Washington, DC, 1998.

[15] N. Uno, F. Kurauchi, H. Tamura and Y. Lida, "Using Bus Probe Data for Analysis of Travel Time Variability", Journal of Intelligent Transportation Systems, Vol. 13, No. 1, pp 2-15, 2009.

Biographies

GAURAV V. JAIN received the B.E. degree in Civil Engineering from the Saurashtra University, M. Planning degree in Urban and Regional Planning from the CEPT, Ahmedabad. Currently, he is a Scientist at Space Applications Centre, ISRO. His working areas are in the field of applications of geo-informatics for urban and regional planning. He may be reached at gvj@sac.isro.gov.in.

RITESH AGRAWAL received the B. E. and M. Tech degree in Civil Engineering from the Indian Institute of Technology, Roorkee, Uttarakhand, India in 2000 and 2002 respectively. Currently, He is a Scientist in Space Applications Centre, ISRO. His working areas are in the field of topographical studies and GPS applications. He may be reached at ritesh_agrawal@sac.isro.gov.in.