Development of a Telematics Based Advanced Public Transportation System

SrinivasKodali[1], Akhilesh Koppineni[2], Krishna Chaitanya[3], Siddharth K[4], Lelitha Vanajakshi[5*]

[1, 2, 3]Former Under GraduateStudents, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, 600036, India
[4]Former Under GraduateStudent, Department of Mechanical Engineering, Indian Institute of Technology Madras, Chennai, 600036, India
[5]Associate Professor, Department of Civil Engineering, Indian Institute of Technology Madras, Chennai, 600036, India

Abstract

Advanced Public Transportation Systems (APTS) is one of the components of Intelligent Transportation Systems (ITS). APTS apply information technologies to public transit systems to increase efficiency of operations and improve the services to the passengers. Most of these ITS systems need real-time data from the field, which can be catered by the Telematics system. Using this data, fleet managers can improve the productivity of workers, reduce collision risks for drivers and other road users, improve fleet performance and ensure compliance with relevant regulations. The present paper is in the use of Telematics for public transit systems in India using algorithmic approaches and visualizations. It will help to bring real time information to the users and fleet managers using web and mobile applications. The study aims the development of a completely automated bus arrival time prediction system prototype and to evaluate its performance under varying traffic conditions. The other objective is to develop and deploy a fleet monitoring system for the bus managers to efficiently manage the bus fleet. The complete system developed will be of direct use to transport corporations for routing and scheduling of their fleet as well as for passenger information facilities.

*Keywords:*Public transport management, mathematical modelling, Developing countries, Intelligent Transportation Systems (ITS), GPS, Advanced Public Transportation Systems (APTS).

1. Introduction

Transit operators across the world are always under strong pressure to improve the efficiency and enhance the attractiveness of the transit system (Best Operational and Maintenance Practices, 2013). To manage this demand, one of the options is the use of Intelligent Transportation Systems (ITS). ITS systems are transportation services and technologies, aimed at making transportation systems more efficient, safer, reliable and environmental friendly, without constructing new infrastructure. Advanced Public

[*] Corresponding author: Lelitha Vanajakshi (lelitha@iitm.ac.in)

Transit Systems (APTS) is one of the many components of ITS. APTS apply information technologies to public transit systems to increase efficiency of operations and improve the services to the passengers. Most of these ITS systems need real-time data from the field for the successful operation and Telematics systems are the most popularly adopted ones for APTS.

Telematics commonly refers to vehicle-based systems that integrate GPS sensors with wireless communication and computer applications. These systems can provide fleet owners and operators with extensive information and intelligence on vehicle location and performance, driver behaviour and a wide range of other parameters. Using this data, fleet managers can improve the productivity of workers, reduce collision risks for drivers and other road users, improve fleet performance and ensure compliance with relevant regulations (Lin and Zeng, 1999). There were studies reported on the use of smart devices and Information and communication technologies (ICTs) for APTS applications (Gao et al. 2014; Blankshtain and Mindali, 2013). The present study is in the area of telematics for public transit systems to cater to some of the needs of users, fleet managers and user agencies in India using algorithmic approaches and visualizations. It aims to bring access to the information from telematics using web and mobile applications to the users and fleet operators helping them to manage the trips more efficiently.

For the user side, development of a completely automated bus arrival time prediction system and its evaluation under varying traffic conditions is carried out. Such systems are reported to be useful since studies show that passengers use their time quite actively while riding and waiting for buses (Gao et al. 2014). Bus arrival prediction systems are implemented in many Western countries. However, implementation of such systems is challenging in countries like India where automated traffic data collection is still in its nascent stage. Most of the existing systems reported from other countries are based on historic data base and are not suitable to the Indian scenario where the data base is just being developed. Also, any methodology based on data pattern may not be the best solution due to the highly stochastic and heterogenic nature of Indian traffic. Other popularly adopted field approaches such as estimating travel time based on the real time distance to the next bus stop and average speed maintained by the vehicle may not work due to the wide variation in driving conditions even within small distances. Thus, the development of a bus arrival time prediction system under Indian conditions is very challenging. A few transportation agencies in India have already attempted to implement bus arrival prediction systems. Some examples are theDelhi Integrated Multi-modal Transit System, Metropolitan Transport Corporation, Chennai, Indore City Transport Service Limited, and Bangalore Metropolitan Transport Corporation. However, most of them have concentrated on demonstration of feasibility rather than the accuracy of the information being provided. In most cases, the accuracy of arrival time prediction is poor, perhaps because of deficiencies in algorithms used for prediction. In most cases, the details of the prediction algorithms are not available since they were implemented by an external agency. Many of these implementations used methodologies developed for western countries that have homogenous traffic, which may not be suitable in the heterogeneous Indian traffic conditions. The present study addresses many of these problems and develops a prototype of a real time bus arrival prediction system, making it suitable for implementation in scenarios without a historical data base.

The proposed bus arrival prediction system uses real-time data from GPS units installed in public transport buses. The algorithm used is a model-based approach using Kalman filtering technique. Travel time data from the previous two buses that plied the same route were used as inputs, obviating the need for a historic data base. The development of such a system involves overcoming several challenges such as difficulties in real time data collection, quick data analysis, accurate prediction methodology, uninterrupted communication facility and designing an overall system which will combine all the above in an automated setup that will work in real-time. The reported study also discusses issues related to the system integration process in order to develop a real time, automated, field implementable system for bus arrival prediction under Indian traffic conditions. This include addressing many practical problems such as automated data quality control, communication delays, integration of real time data with the algorithm, taking into account practical difficulties such as bus break down, congestion, overtaking, traffic jam, and common India-specific difficulties such as abrupt stoppage of services, unscheduled changes in routes, frequent shifting of buses from one route to another. The predicted arrival time information can be disseminated to the passengers through display boards in bus stops and buses. Travel time information for selected origin destination can be disseminated through web sites and SMS as well. This involves integration of the output of the algorithm with the information display systems which is also carried out in the study.

The other objective is to develop and deploy a fleet monitoring system for the bus managers to efficiently manage the bus fleet. The operators portal uses the GPS data to generate daily logs and speed violation reports as well as helps in dynamic scheduling of buses. The complete system developed will be of direct use to transport operators for routing and scheduling of their fleet as well as for passenger information facilities. A prototype fleet monitoring system is also developed integrating with real time GPS data. The monitoring system can be used to find violations in speed and delays in scheduled time. This is demonstrated taking the IIT Madras campus fleet as an example. A map application showing the current and past known location of the buses and other details of interest to the operator is developed, in addition to reporting speed violations and schedule delay information.

2. Literature Review

A variety of prediction models for forecasting bus arrival time and bus travel time have been reported over the years. The five most widely used models for these predictions are historical data based models (Jeong, 2004; Lin and Zeng,1999), time series models (Ahmed and Cook, 1979; Al Deek et al.1998; Thomas et al.2010; Lee and Fambro,1998; William and Durvasula,1998), regression models (Jeong, 2004; Patnaik et al. 2004; Ramakrishna et al.2006), machine learning models (Yu et al. 2010; Chien et al.2002; Yasdi,1999) and model based approaches using Kalman filtering (Chein and Kuchipudi, 2003; Chen et al.2004; Shalaby and Farhan,2004; Vanajakshi et al.2008). It has been generally accepted by many researchers (Kirbyet al. 1997; Zheng, et al. 2006) that there is no single predictor that is applicable to varying traffic conditions. Models based on historical data base assume that traffic patterns are uniform which can be found out from extensive historical data analysis. Such models are thus suitable for areas where there is stable demand and uniform traffic pattern. Time series, Regression and Machine learning techniques have been reported as possible solutions for bus arrival prediction. However, all of these are data driven techniques and require a large data base for reliable performance.

Overall, most of the existing bus arrival prediction algorithms are based on historical arrival patterns. Indian cities are starting to equip their buses with automatic vehicle locators and such a database does not exist yet. Moreover, most of the reported studies have been carried out in homogenous and lane disciplined traffic conditions. The traffic in India is heterogeneous in composition. A variety of vehicles – two, three and four wheelers, in addition to a large pedestrian population, share the Indian urban road. The lack of lane discipline further complicates the problem and makes the system more dynamic and stochastic. All these factors, in addition to the increasing number of vehicles on the roads, lead to a chaotic traffic situation, particularly during peak periods on major urban roads. Thus, models which worked for the homogeneous and lane disciplined conditions may not work well for the Indian conditions. One may need a model which can capture this stochastic behavior better with less data requirement and that is the type of model used in the paper.

There have been few reports on bus arrival prediction under heterogeneous conditions (Ramakrishna et al., 2006; Vanajakshi et al., 2008; Kumar and Vanajakshi, 2014) and practically none on field implementation. As seen in the preceding review of literature, very few bus arrival predictions have been carried out under Indian traffic conditions and there have been no systematic studies using theoretically sound prediction algorithms. Most of these implementations use methodology based on simple assumption of speed being constant and calculate travel time based on that. Mostly offline information based on average performance of the present vehicle is used. However, Indian scenario is very dynamic and use of offline data alone may not be able to capture the real time variations in the data.Thus, there is a need for models that can capture the stochastic behavior of Indian traffic with little data requirement. This paper reports the development of a real time bus arrival time prediction system that suits Indian traffic conditions.

Also, none of the bus arrival prediction systems in India have any information on the accuracy of the predictions. One of the major factors responsible for failure of prediction systems is its reliability. If the information provided is not reliable, users will reject the system making it a failure. Below are some of the studies that reported accuracy of bus arrival prediction systems elsewhere.

The expected level of prediction accuracy by the commuters is less than 2minutes if the headway is less than 15 minutes (Lin and Bertini, 2002). Another study (Yasdi,1999) reported that the commuters consider it reasonable when the deviation is within 5 minutes. The land transport authority of Singapore indicated in its fact-book that the deviations in their bus-arrival information system are within +/- 3 minutes, 80% of the times (Chein et al. 2002). In London, the accuracy of information of bus arrival prediction was reported to be less than +/- 1 minutes 50% of the time and +/- 2 minutes 75% of the time and +/- 5 minutes for 96% of the time (Chein and Kuchipudi, 2003). For a bus travel time of 1.5 hours, the acceptable level of accuracy was 5 minutes(Bhandari, 2005).

All the above evaluation of prediction accuracy was carried out in places with available schedule times and the buses there adhere to the schedule. Commuter's tolerance at these places is low compared to commuters in places like the study area where, the actual schedule is not known to the users. Still, in this study +/- 3 minutes was kept as the maximum tolerance based on earlier studies and the reliability of the prediction system was evaluated.

3. Study Route, Data Collection and Analysis

Data for this study was collected using GPS/GPRS from the19B route of public transport buses in Chennai, India.19B route is about 31.5 kilometers long and it takes about 90-100 minutes to travel from one terminus to the other. There are 17 buses in this route with headway of around 15 minutes and 12 bus-stops along the route. GPS units have also been installed in eight buses within Indian Institute of Technology (IIT) Madras campus network for testing of the applications developed in this study.

Data from the GPS units were typically sent to a dedicated server every 5-10 seconds. Data from each bus were stored in a different file every day. Files were archived daily and new files created to store the incoming data everyday at 00:00:00. The real-time data received in the server were immediately processed in order to make a real-time prediction of the arrival time of the bus. In all earlier studies this was carried out manually and hence the process was offline in nature. Since the bus arrival predictions in this study have to be implemented in real-time, the data must be processed automatically and was performed as part of the study. This involved identifying the routes, trips, and then direction of movement within the same route. This process was carried out throughout the day and the data were segregated into different trips during that day. These trip data files were stored under the folder name 'routeID_date'. Further analysis of the data for bus arrival time prediction used this filtered dataset.

4. Prediction Methodology

The prediction algorithm adopted in the present study is based on already developed one (Vanajakshi,et al.,2008). The algorithm predicts the arrival time/travel time of the vehicle of interest, called as Test Vehicle (TV), using data from the two previous buses traveling in the same route, which are called as Probe Vehicle1 (PV1), and Probe Vehicle 2 (PV2). The route under consideration is divided into N subsections and it is assumed that the evolution of travel time of two consecutive subsections is related as

$$x(k+1) = a(k)x(k) + w(k), \quad (1)$$

where, $x(k)$ is the travel time for covering the k^{th} subsection, $a(k)$ is a parameter which relates the travel time in the $(k+1)^{th}$ subsection to the travel time in the k^{th} subsection and $w(k)$ is the process disturbance associated with the k^{th} subsection. The measurement process is assumed to be given by

$$z(k) = x(k) + v(k), \quad (2)$$

where, $z(k)$ is the measured travel time of the k^{th} subsection and $v(k)$ is the measurement noise. It is assumed that both $w(k)$ and $v(k)$ are zero mean Gaussian white noise signals. These assumptions were checked and were found to be agreeing. The prediction scheme consists of the following steps:

1. The parameter $a(k)$ is calculated for each subsection using the travel time data for PV1 thorough

$$a(k) = x_{pv1}(k+1)/x_{pv1}(k) \tag{3}$$

where, $x_{pv1}(k)$ is the travel time taken by PV1 to cover the k^{th} subsection.

2. The Kalman filter algorithm is then used for predicting the travel time of the test vehicle. The general steps of KFT are implemented for the specific problem under consideration as follows:

If $x_{tv}(k)$ is the travel time for the test vehicle to cover the k^{th} subsection, then it is assumed that $E[x_{tv}(1)] = \hat{x}(1)$, and $E[(xtv(1) - \hat{x}(1))^2] = P(1)$, where $\hat{x}(k)$ is the estimate of the travel time for the test vehicle in the k^{th} subsection. The following steps are then applied recursively for subsections k=2 to N-1:

i. The a priori travel time estimate is calculated using

$$\hat{x}^i(k+1) = a(k)\hat{x}^{ii}(k), \tag{4}$$

where, the superscript 'i' denotes the a priori estimate and the superscript 'ii' denotes the a posteriori estimate.

ii. The a priori error variance is given by

$$P^i(k+1) = a(k)P^{ii}(k)a(k) + Q(k), \tag{5}$$

where, $Q(k)$ is the variance of the process distribution $w(k)$.

iii. The Kalman gain 'K' is given by

$$K(k+1) = P^i(k+1)\left[P^i(k+1) + R(k+1)\right]^{-1} \tag{6}$$

iv. The a posteriori estimate of the travel time I is given by,

$$\hat{x}^{ii}(k+1) = \hat{x}^i(k+1) + K(k+1)\left[z(k+1) - \hat{x}^i(k+1)\right], \tag{7}$$

where, $z(k+1)$ is the measured travel time of PV2 to cover the $(k+1)^{th}$ subsection.

v. The a posteriori error variance is calculated using

$$P^{ii}(k+1)=[I-K(k+1)]P^i(k+1) \tag{8}$$

The a posteriori travel time estimate is taken as the final travel time estimate for every subsection.

5. Automated System Development

When the travel time data from the buses are received at the server, it goes through various processing steps. Many new attributes are added to the dataset before it is sent to the algorithm. The offline testing of the algorithm is easy since the input are static and kept ready to be read by the algorithm. However, for real time implementation, all the steps have to be automated as discussed below.

As mentioned earlier, the arrival prediction for the test vehicle in this study was based on the travel time of the previous two vehicles that traveled in the selected route. Thus, a prediction can be made for the third vehicle onwards within a day. Different attributes were assigned to the buses, for identifying the states in which a bus can possibly be at any given point of time, such as IDLE- The bus has not been assigned a route and its speed>0, SLEEP- The bus has not been assigned a route and its speed=0, JAM- The bus has been assigned a route and its speed=0, CONTINUE- The bus has been assigned a route and its speed>0. Each of these attributes have a corresponding counter attached to it. Throughout the runtime of the application, a speed check was continuously performed for every bus.

All steps, starting from identifying the file to be read, data filtering, to field issues such as bus overtaking, rerouting, bus break down etc. must be automated for final implementation. The following are the field issues that were addressed to enable real-time output from the algorithm.

- Choosing the correct test vehicle(s), for which the arrival time information need to be/ canbe displayed
- Identifying buses plying in different routes
- Separating vehicles in the same route based on the direction of movement
- Factoring missing bus stop locations between two data points
- Tackling the difference in total distance travelled
- Considering en-route bus detours
- Incorporating bus breakdowns and traffic jams during the trip
- Including bus overtake events

An application is developed to address these issues for reliable prediction of bus arrival at bus-stops in real time. Some of the specific issues that were addressed are choice of the correct test vehicle and the corresponding previous vehicles, identifying the correct bus for prediction to each bus stop, predictions for multiple buses (upcoming next three buses), bus stop location identification, identification of the direction of movement (upward or downward), bus break down and traffic jams, and over taking of vehicles. Each of these adds extra complexity to the prediction problem and were addressed in a real time automated mode in this study.

6. Evaluation of Performance of the Application

Performance evaluation of the developed application was carried out during different times of the day. Trips made during the morning peak, evening peak and off-peak periods were separately analyzed. The time periods given in Table 1 were selected as peak and off-peak periods for evaluating the system accordingly.

Table 1. Peak and off-peak periods

Period	**Time of the day**
Morning Peak	7:30 AM - 10:30 AM
Off-peak	10:30 AM - 4:30 PM
Evening Peak	4:30 PM - 8:00 PM

The evaluation was carried out by comparing the predicted arrival time with the actual time at which the bus reached the bus stop. The difference between these two values is the error in prediction and is checked for both peak and off-peak conditions separately. Figures 1-3 show sample results for selected trips in morning peak, afternoon peak and off-peak respectively.

It can be seen that the deviations are less than 200 sec after the initial period and the error converges as the bus is closer to the bus-stop. Deviation values for various intervals before the bus reaches the bus-stop have also been analyzed. To test the reliability of prediction system across different trips, average deviations values for different trips at a single bus-stops was carried out.

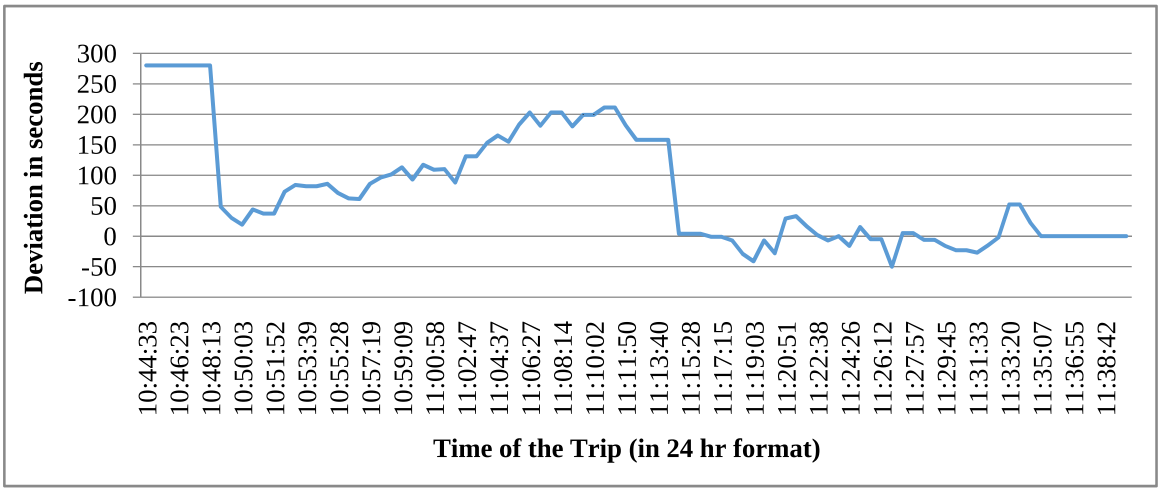


Figure 1: Error in an off-peak hour trip.

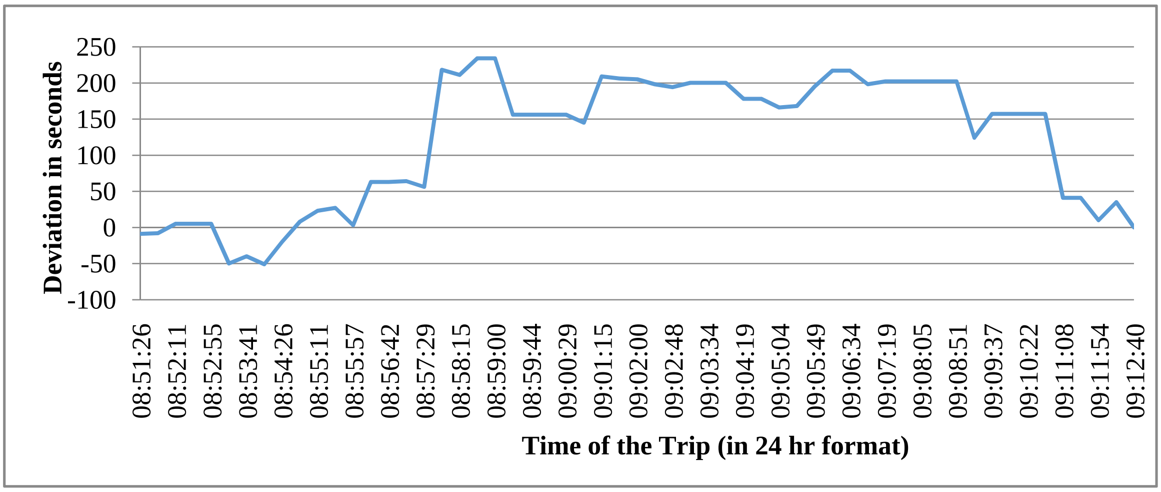


Figure 2: Error in a sample morning peak hour trip.

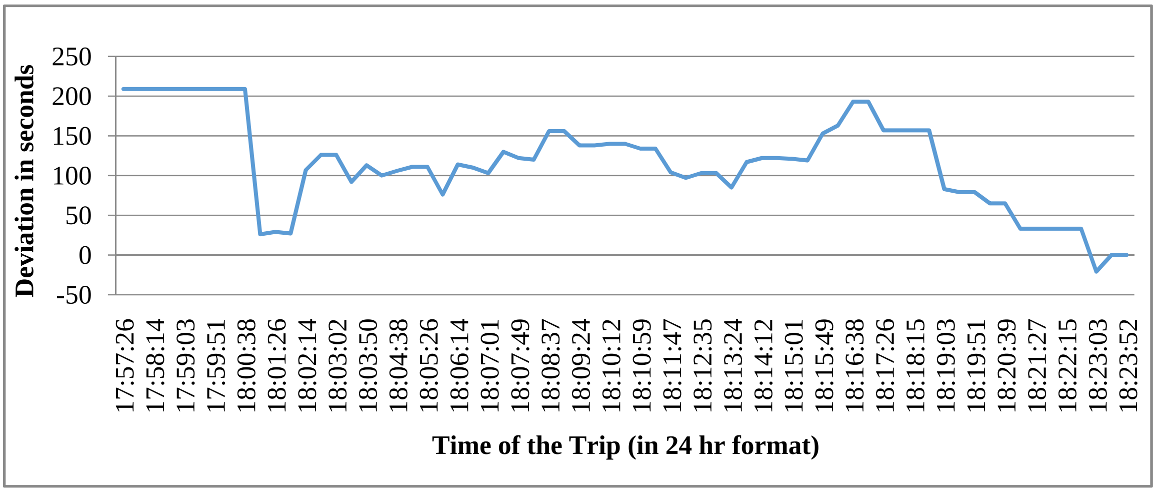


Figure 3: Error in a sample evening peak hour trip

The average deviation values for 0-5 minutes before the bus has reached the bus-stop have been measured for intervals of 1 minute. The deviations have been averaged if there are multiple predictions during the interval. If there are no points available for the respective interval, the earlier available deviation is considered. Figure 4 shows a bar plot of average deviations across different intervals of time (before the bus reaches its destination) for 10 trips at a selected bus stop. It can be seen that the error values improving as the trip gets closer to the bus stop of interest.

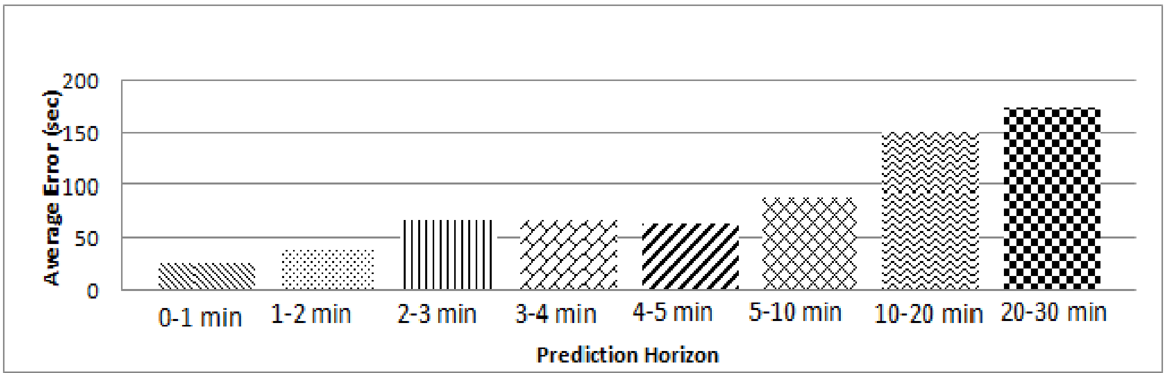


Figure 4: Average Deviations values over different intervals of time.

Performance across different trips was also carried out. Figures 5 shows a sample plot of deviation in the last 5 minutes before the bus reaches the bus-stop across several trips. This indicates that the reliability of the system increases as the bus gets closer. Similar analysis across different bus-stops for a single trip was also carried out and is shown in Figure 6. It can be observed from the figures that the deviations for the initial bus-stop in the trip is higher when compared to the other bus-stops, which is expected as the Kalman filter require more data points for better performance. It can also be seen that the prediction accuracy increases as the trip proceeds.

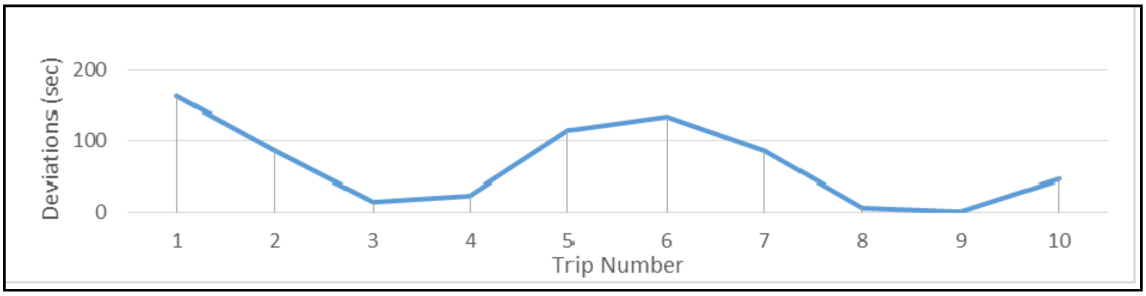


Figure 5: An average deviation across different trips 5 minutes before the bus reaches the destination

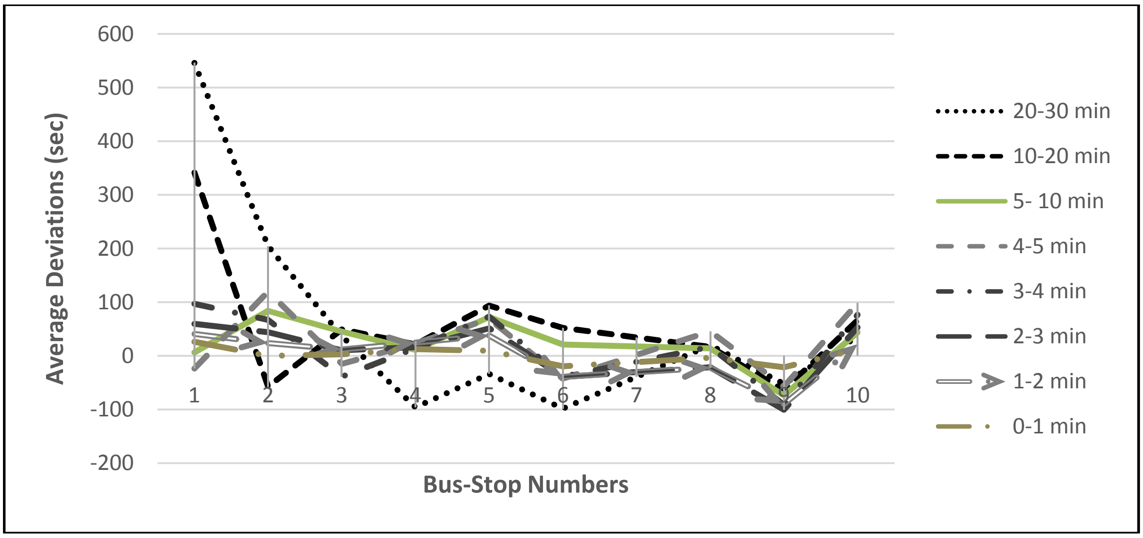
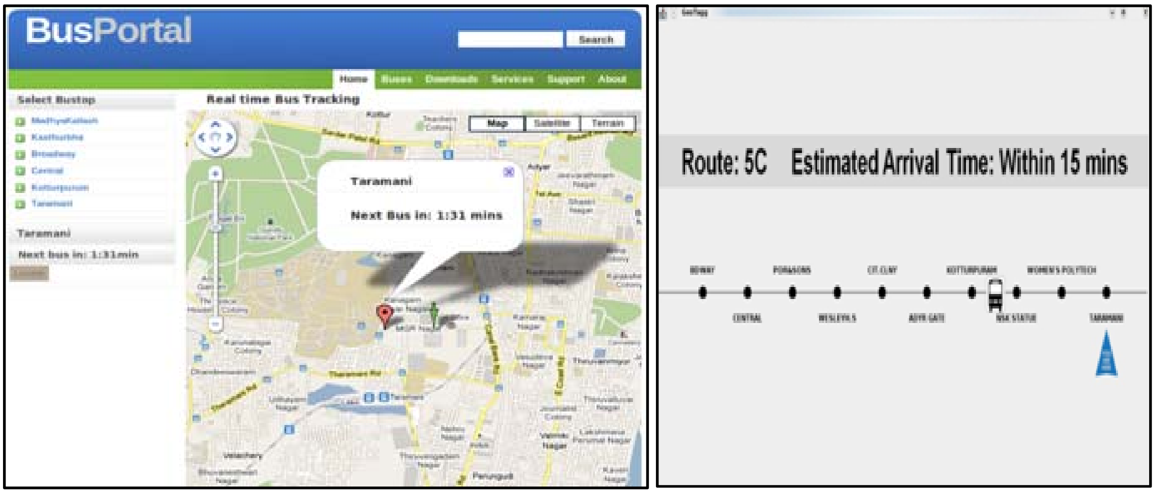


Figure 6: Comparison of Deviations across different bus-stops over various prediction horizons.

7. Information Dissemination for Users and Operators

7.1 User Information.

The study also developed prototype systems for information dissemination which can be readily implemented in the field. Prototypes for three different information dissemination modes viz., bus stop VMS display, Kiosk display at bus stops and web based, mobile and SMS application were developed. This needed the algorithm output to be passed to the information dissemination units such as VMS, kiosk etc. in an automated fashion. A client side web- application having a map-view with bus icons rendered dynamically was developed to visualize the processed data in web pages. The mobile application runs on a thin-client environment, wherein all the calculation intensive steps are performed at the server level, making the application very efficient in terms of memory usage and power consumption. The bus locations are overlaid using third party Maps library Leaflet (Leaflet 2014) and view on Open Street Map (Open street map, 2014) data. All data transfer between the device running the application and the server happens via mobile GPRS connection. The application was built to operate on any Mobile Operating System. An Android application was developed to show the compatibility of the application. A demonstrative SMS application for arrival time of the buses has also been developed using txtweb (http://www.txtweb.com/) platform. Messaging a keyword with bus stop id and route number to a service provider number will generate an SMS containing the required information by the commuter. The message sent by the user to the service provider performs a real-time query on the server with the travel time predictions. The query is filtered using the route number and bus stop id. The resulting message is sent to the user through the service provider number. All the frameworks and tools used to develop the application are fully open-source or have been attributed under the available licenses. Sample pictures of some of the prototypes developed are shown in Figure 7.



a. mobile and SMS application b. Kiosk and web

Figure 7: Screenshots of prototypes developed

7.2 Operator Information.

For operators to maintain their bus-network effectively, a prototype operations portal was built and implemented for the IIT Madras campus bus-network. The portal can be used for real-time bus-tracking to know the last–known position of the bus along with time and bus id. To monitor the speed violations by the operators, the GPS data received from the bus is analyzed and monitored 24x7 using an automated process. Whenever the speeds exceed the 40 kmph speed limit, the “bus-speed”, “bus-id”, “latitude”, “longitude”, “time and “date” are stored separately with an alert number for each violation. The bus manager can see these violations over a map for any past date by selecting the date for which he intends to check the violations. The over-speeding locations by each bus were also visualized over a heat map, to find out the zones where frequent over-speeding occurred. Figure 8 shows a heat map of over-speeding by buses in IIT Madras on 5th May 2013. The larger area indicates more number of violations over that stretch. This feature will be useful for city officers to increase location based control measures. Figure 9 shows other functionalities of the portal in terms of real time tracking and daily report generation.

Real time monitoring of schedule delay of buses along with date, time, bus-id and location is also included in the operations portal. Often buses get delayed in the traffic and reach their destinations late. This delays the start of the consecutive trips. Schedule of the buses need to be updated on a constant basis with the recent trends in traffic. The transit managers need to know exact times when a bus is starting from its origin and reaching individual bus-stops to improve the service to commuters. This has been demonstrated at a smaller scale for the buses in the campus.

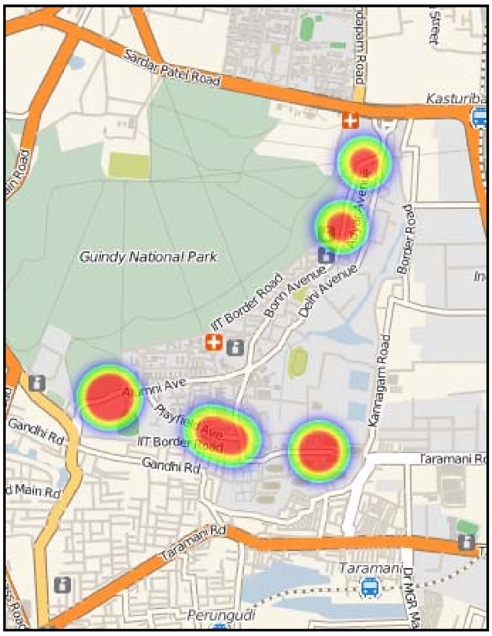


Figure 8: Heat map of over-speeding in IIT Madras

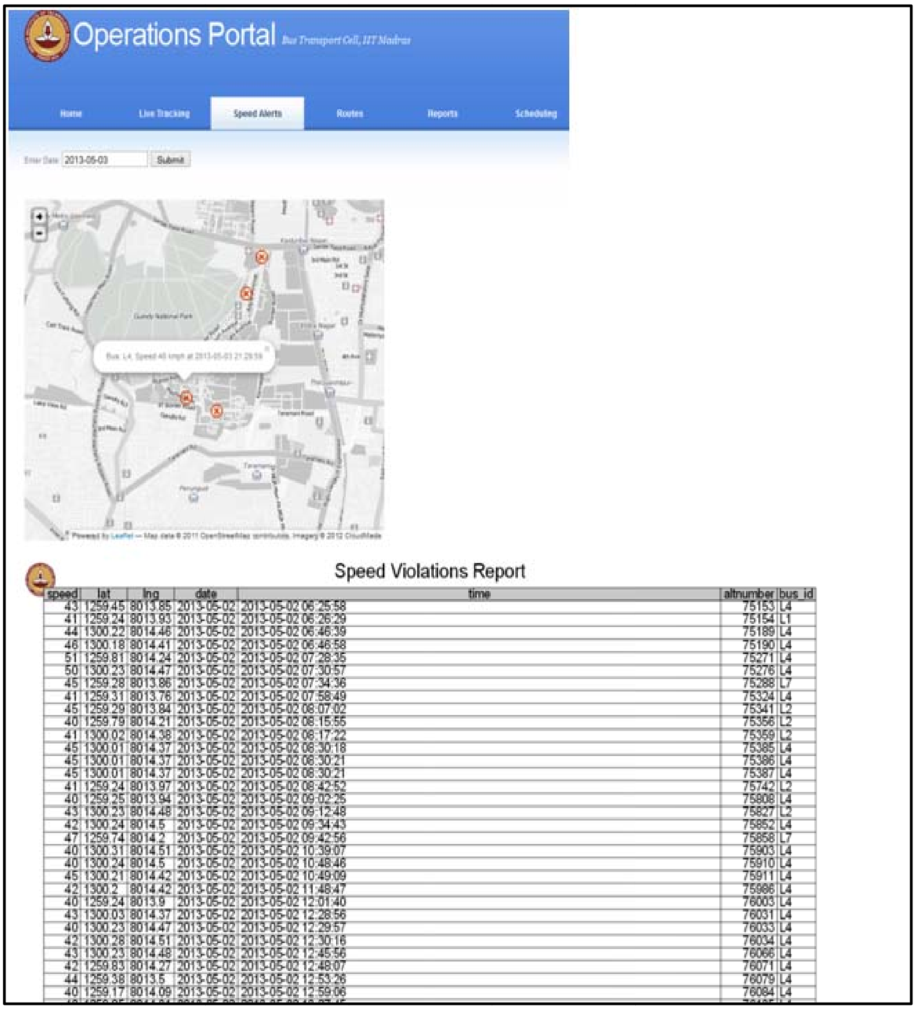
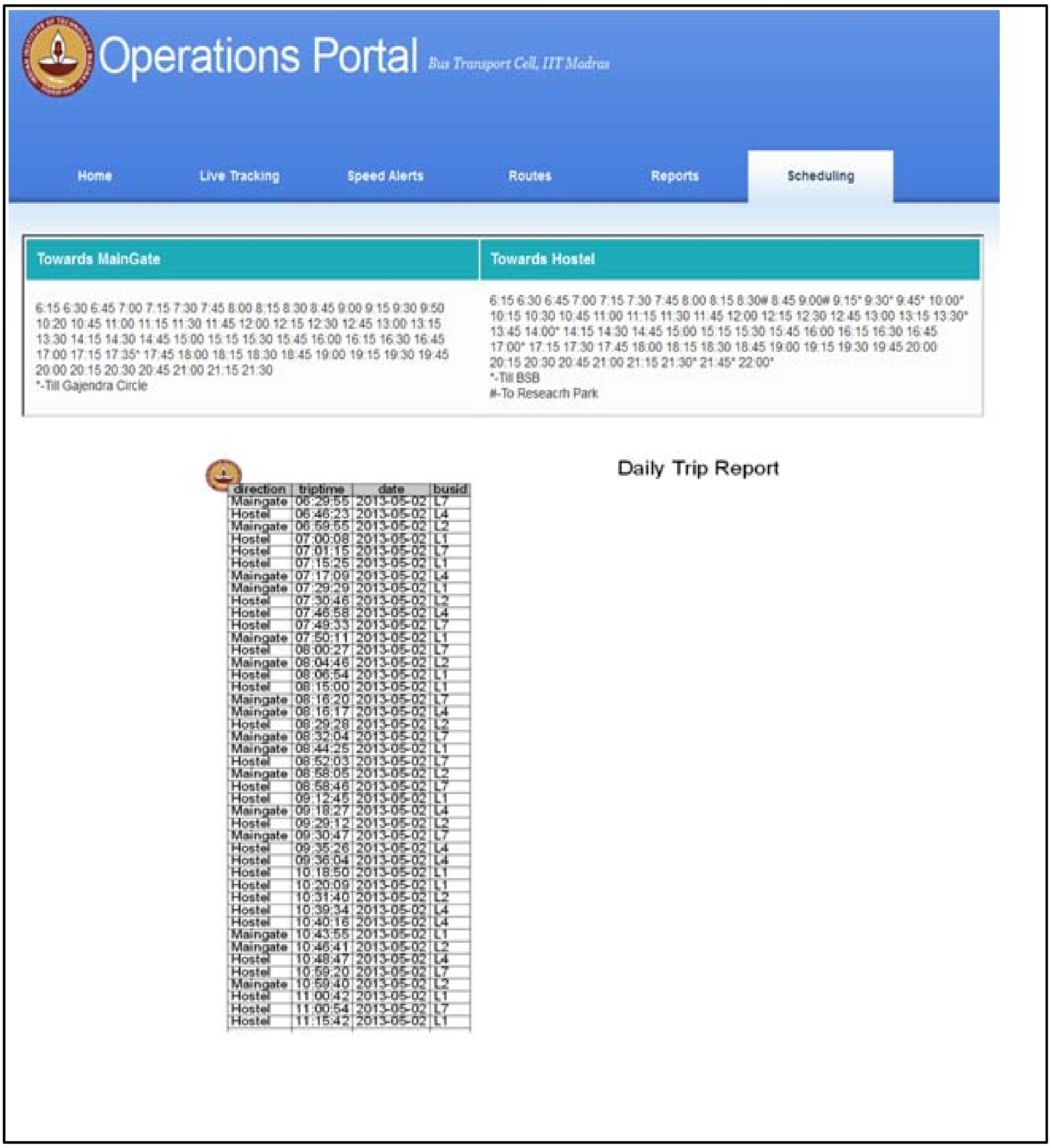


Figure 9:Speed Violations report and locations shown along with details of bus

The starting schedule of the buses at both ends of the route in campus has been identified. The available GPS data is analyzed to identify the starting time of the buses from either of these two bus-stops and is stored along with the bus-ids, direction and date. This can be compared with the expected schedule and identify the delays. Figure 10 shows the delays along with the direction and bus-ids for a typical day of 2nd May 2013.



direction	triptime	date	busid
Maingate	06:29:55	2013-05-02	L7
Hostel	06:46:23	2013-05-02	L4
Maingate	06:59:55	2013-05-02	L2
Hostel	07:00:08	2013-05-02	L1
Hostel	07:01:15	2013-05-02	L7
Hostel	07:15:25	2013-05-02	L1
Maingate	07:17:09	2013-05-02	L4
Maingate	07:29:29	2013-05-02	L1
Hostel	07:30:46	2013-05-02	L2
Hostel	07:46:58	2013-05-02	L4
Hostel	07:49:33	2013-05-02	L7
Maingate	07:50:11	2013-05-02	L1
Hostel	08:00:27	2013-05-02	L7
Maingate	08:04:46	2013-05-02	L2
Hostel	08:06:54	2013-05-02	L1
Hostel	08:15:00	2013-05-02	L1
Maingate	08:16:20	2013-05-02	L7
Maingate	08:16:17	2013-05-02	L4
Hostel	08:29:28	2013-05-02	L2
Maingate	08:32:04	2013-05-02	L7
Maingate	08:44:25	2013-05-02	L1
Hostel	08:52:03	2013-05-02	L7
Maingate	08:58:05	2013-05-02	L2
Hostel	08:58:46	2013-05-02	L7
Hostel	09:12:45	2013-05-02	L1
Maingate	09:18:27	2013-05-02	L4
Hostel	09:29:12	2013-05-02	L2
Maingate	09:30:47	2013-05-02	L7
Hostel	09:35:26	2013-05-02	L4
Hostel	09:36:04	2013-05-02	L4
Hostel	10:18:50	2013-05-02	L1
Hostel	10:20:09	2013-05-02	L1
Hostel	10:31:40	2013-05-02	L2
Hostel	10:39:34	2013-05-02	L4
Hostel	10:40:16	2013-05-02	L4
Maingate	10:43:55	2013-05-02	L1
Maingate	10:46:41	2013-05-02	L2
Hostel	10:48:47	2013-05-02	L4
Hostel	10:59:20	2013-05-02	L7
Maingate	10:59:40	2013-05-02	L2
Hostel	11:00:42	2013-05-02	L1
Hostel	11:00:54	2013-05-02	L7
Hostel	11:15:42	2013-05-02	L1

Figure 10: Schedule timings and trip report along with details of bus

8. Summary and Conclusions

Bus travel time/arrival time prediction systems are predominantly found in western countries and are based on historic data base or travel time patterns. These may not be the best solution for countries like India, where automated data collection is still in its infancy. Moreover, the stochastic nature of the heterogeneous Indian traffic and lack of lane discipline adds complexity and any methodology based on data pattern may not be the best solution. Thus, the development of bus arrival time prediction systems under Indian traffic conditions is very challenging. Only a limited number of implementations of bus arrival predictions have been reported under Indian traffic conditions, most of which were feasibility studies with less focus on performance. This paper reported the development and performance evaluation of an automated, real time, busarrival prediction system developed under Indian traffic conditions. This study reported the complete development of the system with automated real time data collection, communication, data base generation, data analysis, prediction algorithm, and information dissemination tools. Prototypes were also developed and the performance of the system was tested.

An automated data collection and analysis system without manual intervention was required for the development of the real-time automated application. Furthermore, the prediction algorithm was required to be quick in processing the data received. The methodology for prediction had to be less data intensive, due to lack of historic data base, without compromising on the prediction accuracy. A model based prediction scheme using the Kalman Filtering Technique was used to predict the travel time of buses. Travel time data from two previous buses plying the same route were directly fed into the prediction algorithm for automated processing. Practical issues, such as effect of traffic jams, overtaking among the buses on the same route, bus breakdown and abrupt changes in bus routes were identified and addressed to aid real time processing.

The performance of the system was evaluated under varying traffic conditions. The results showed that the performance of the proposed system to be promising. The study also developed prototype systems for information dissemination which can be readily implemented in the field. Prototypes for different information dissemination modes were developed viz., bus stop VMS display, Kiosk display at bus stops, web based application and mobile based application. This complete system can be used for bus arrival prediction system wherever buses are equipped with automated vehicle location systems.

A prototype of web based operators portal was also demonstrated using campus buses in IIT Madras. Since the study used real field data, the observations made and the results arrived at facilitate implementation in the real environment. This can be extended to bigger bus fleets, provided the buses are equipped with the vehicle-based telematics systems.

9. Acknowledgement

The authors acknowledge the support for this study as part of the project CIE/10-11/168/IITM/LELI by Ministry of Urban Development, Government of India, through letter No. N-11025/30/2008-UCD.

References

Ahmed, M.S., Cook, A.R. (1979) "Analysis of Freeway Traffic Time-Series Data by Using Box-Jenkins Techniques", *Transp. Res. Record: J. of Transp. Res. Board*,722, pp. 1-9.

Al-Deek, H., Angelo, M.D and Wang, M. (1998) "Travel Time Prediction with Non-Linear Time Series", In *Proceedings of the ASCE Fifth International Conference on Applications of Advanced Technologies in Transportation Engineering*, New Port Beach, California, pp. 317-324.

Bhandari, R. (2005) "Bus Arrival Time Prediction using Stochastic time series and Markov chains", Ph. D. dissertation, Dept. of Civil Engg., New Jersey Institute of Technology, Newark.

Blankshtain, G. C., Mindali, O.R. (2013) "Key Research Themes on ICT and Sustainable Urban Mobility", *International Journal of Sustainable Transportation*, DOI: 10.1080/15568318.2013.820994.

Chen, M., Liu, X.B., Xia, J.X. (2004) "A Dynamic Bus Arrival Time Prediction Model Based on APC Data", *Computer Aided Civil and Infrastructure Engineering*,19(5),pp. 364-376.

ESMAP (Energy Sector Management Assistance Program). (2011) Best Operational and MaintenancePractices for City Bus Fleets to Maximize Fuel Economy. http://www.esmap.org/sites/esmap.org/files/ FINAL_EECI-BusGuideNote_BN010-11.pdf.

Guo, Z., Derian, A., Zhao, J. (2014) "Smart Devices and Travel Time Use by Bus Passengers in Vancouver, Canada", *International Journal of Sustainable Transportation*, DOI: 10.1080/15568318.2013.784933.

Jeong, R.H. (2004) "The Prediction of Bus Arrival time Using Automatic Vehicle Location Systems Data", Ph.D. Dissertation at Texas A&M University.

Kirby, H., Dougherty, M., Watson, S. (1997) "Should We Use Neural Networks or Statistical Models for Short Term Motorway Traffic Forecasting?", *International Journal of Forecasting*,13(1), pp. 43–50.

Kumar, S.V., Vanajakshi, L. (2012) "Pattern identification based bus arrival time prediction", *Proceedings of the Institution of Civil Engineers- Transport*, http://www.icevirtuallibrary. com/content/article/ 10.1680/tran.12.00001.

Leaflet *An Open-Source JavaScript Library for Interactive Maps* . http://leafletjs.com/.

Lee, S., Fambro, D.B. (1998) "Application of Subset Autoregressive Integrated Moving Average Model for Short-Term Freeway Traffic Volume Forecasting", *Transp. Res. Record: J. of Transp. Res. Board*,1678(22),pp. 179-188.

Lin, W., Bertini, R.L. (2002) "Modelling Scheduling Recovery Processes in Transit Operations for Bus Arrival Time Prediction", In *Proceedings of The IEEE 5th International Conference on Intelligent Transportation Systems*, Singapore, pp. 857-862.

Lin, W.H., Zeng, J. (1999) "Experimental Study of Real-Time Bus Arrival Time Prediction with GPS Data", *Transp. Res. Record: J. of Transp. Res. Board*,1666(12),pp. 101-109.

OpenStreetMap. http://www.openstreetmap.org/copyright.

Patnaik, J., Chein, S., Bladihas, A. (2004) "Estimation of Bus Arrival Time Using APC Data", *Journal of Public Transportation*,7(1),pp. 1-20.

Ramakrishna, Y., Ramakrishna, P., Laxshmanan, V., Sivanandan, R. (2006) "Bus Travel Time Prediction Using GPS Data", In *9th International Conference on Geographic Information, Technology and Applications, Map India*, New Delhi, India. http://www.gisdevelopment.net/proceedings/mapindia/2006/student%20oral/mi06stu_84.htm.

Shalaby, A., Farhan, A. (2004) "Bus Travel Time Prediction for Dynamic Operations Control and Passenger Information Systems", CD-ROM. *82nd Annual meeting of the Transportation Research board*, National Research Council, Washington, D.C.

Sij, C., Ding, Y., Wei, C. (2002) "Dynamic Bus Arrival Time Prediction with Artificial Neural Networks", *Journal of Transportation Engineering*,128(5),pp. 429-438.

Sij, C., Kuchipudi, C.M. (2003) "Dynamic Travel Time Prediction with Real-Time and Historic Data", *Journal of Transportation Engineering,*129(6): pp. 608-616.

Thomas, T., Weijermars, W.A.M., VanBerkum, E. C. (2010) "Predictions of Urban Volumes in Single Time Series", *IEEE Transactions on Intelligent Transportation Systems,*11(1),pp. 71-80.

Vanajakshi, L., Subramanian, S.C., Sivanandan, R. (2008) "Travel Time Prediction under Heterogeneous Traffic Conditions Using Global Positioning System Data from Buses", *IET Intelligent Transport Systems*, 3(1), pp. 1-9.

William, B.M., Durvasula, P.K., Brown, D.E. (1998) "Urban Freeway Traffic Flow Prediction: Application of Seasonal Autoregressive Integrated Moving Average and Exponential Smoothing Models", *Transp. Res. Record: J. of Transp. Res. Board,*1644(1),pp. 132-141.

Yasdi, R. (1999) "Prediction of Road Traffic Using a Neural Network Approach", *Neural Computing and Applications* 8(2),pp. 135–142.

Yu, B., Yang, Z. Z., Wang, J. (2010) "Bus Travel-Time Prediction based on Bus Speed", *Proceedings of the Institution of Civil engineers –Transport,* 163,pp. 3-7.

Zheng, W., Lee, D.H, Shi, Q. (2006) "Short-Term Freeway Traffic Flow Prediction: Bayesian Combined Neural Network Approach", *Journal of Transportation Engineering,*132(2), pp. 114-121.