European Transport \ Trasporti Europei (2024) Issue 99, Paper n° 1, ISSN 1825-3997

https://doi.org/10.48295/ET.2024.99.1

Analysis of Vehicular Travel Time along the Urban Corridor Using Bluetooth Based Data

Mr. Mouli Singarapu[1*], B Raghuram Kadali[2], S Shankar[3]

[1]Former Post Graduate Soudent, Département of Civil Engineering, NIT Warangal, Warangal, India-506004,
[2]Assistant Professor, Département of Civil Engineering, NIT Warangal, Warangal, India. Pin 506004,
[3]Associate Professor, Département of Civil Engineering, NIT Warangal, Warangal, India. Pin 506004,

Abstract

There has been a tremendous increase in vehicular growth in the last few decades, which has increased congestion in urban areas. Travel time is one of the measures to understand the congestion levels of the urban corridors. The increased use of Bluetooth devices by vehicular drivers may enable the dynamic data collection of travel time through Bluetooth sensors in urban areas. In this context, the objective of the present study is to evaluate the travel time of vehicles using Bluetooth devices and check the reliability of this Bluetooth technology for traffic studies. To fulfil the stated objective, a Bluetooth application was installed on a smartphone in order to collect the vehicular travel time on a selected corridor. A video camera was setup for traffic data collection at a mid-block section, which is used for the validation of the collected travel time data. The K nearest neighbor (KNN) model was developed with travel time (TT) data. The average TT of cars and other vehicles is estimated and found to be higher in the evening compared to the morning. From the developed KNN model, it is also found that the predicted TT for the next time intervals shows that they follow the trend of the actual travel time data obtained from the Bluetooth app. From the results of this study, it is feasible to estimate the travel time in urban areas using Bluetooth devices, which is useful for engineers and planners for suitable policy decision.

Keywords: Bluetooth; travel time; detection; traffic flow; KNN model.

1. Introduction

Traffic analysis studies have gained immense importance in the present scenario. Traffic problems have also increased to a wider extent due to the increased use of public and private transport. Traffic congestion is one of those major traffic problems that not only has an impact on the environment but also on the economy. Much recent progress has emerged in traffic studies, and one such innovation is intelligent transportation systems (ITS). There are many applications of ITS, among which reducing congestion on the roads and enhancing the smooth and efficient movement of traffic is one. The efficient device is required for ITS solutions, and Bluetooth technology has received worldwide critical acclaim for its use in traffic management studies (Haghani and Hamedi, 2013; Friesen and McLeod, 2014). The main purpose of this research work is to study the use

* Corresponding author: B Raghuram Kadali (brkadali@nitw.ac.in)

of Bluetooth as a tool of ITS for-traffic data collection. Bluetooth is available on various devices, like smartphones, cars, bikes, and various other hands-free devices. The use of Bluetooth has undoubtedly become very popular nowadays, and statistics prove that soon there will be a drastic increase in the number of devices with inbuilt Bluetooth connectivity. Due to the widespread use of Bluetooth devices, this has drawn the attention of traffic engineers to their use in traffic data collection and vehicle tracking. Different Bluetooth detectors and sensors have been made, and those can find vehicles by figuring out which ones have Bluetooth turned on.

The calculation of the travel time of a vehicle is one of the most common applications done using Bluetooth detectors. A lot of background work is involved in the development of these Bluetooth detectors, and it involves various algorithms and servers that are used to collect, store, retrieve, and manage the data that has been collected. Travel time is the most dominant parameter for evaluating the quality of the traffic along the selected arterial roads or corridors. Urban travel times show a major variation because of the traffic conditions prevailing in an area. Implementing newly developed ITS tools, such as advanced traveller information systems (ATIS) and advanced traffic management systems (ATMS), requires careful consideration of travel time. The various methods for the estimation of travel time include the floating car technique, the license plate method, the moving vehicle method, the average speed method, video image processing, and various advanced Intelligent Transport Systems (ITS) technologies. Travel time forecasting, along with origin and destination data, is also important to predict the traffic conditions on that particular road stretch and can be used in ATMS and ATIS for traffic monitoring and management. In recent days, various monitoring systems based on Bluetooth have also been developed, and they identify the media access control (MAC) addresses of the devices, after which the corresponding calculation is done. The wait times are also obtained using this ITS tool. The collected data can be used for further research on traffic designs.

1.1 Background of Bluetooth technology

Using a special Media Access Control (MAC) address, Bluetooth allows for short-range wireless communication between eligible devices. It is also known as the IEEE 802.15 standard. Intelligent transport systems (ITS) have gained huge importance when related to various traffic studies. Bluetooth is one such latest advancement that can be used as an ITS tool for various traffic studies like travel time estimation, origin-destination studies, and route choice (Hainen et al., 2011). The data collecting devices utilizing Bluetooth technology capture and store the temporal information of distinct Media Access Control (MAC) addresses that are linked to various devices. Various manufacturers of electronic equipment, including but not limited to mobile phones, computers, hands-free headsets, vehicle stereo speakers, and GPS gadgets, allocate unique 48-bit addresses known as MAC addresses. The Bluetooth traffic monitoring system utilizes the process of matching MAC addresses at predetermined and consecutive sites in order to calculate journey times. The temporal discrepancy seen in the MAC address time stamps provides a quantifiable metric for determining journey duration and average velocity in relation to the distance separating consecutive stations. In this context, the present study explores the analysis of vehicular travel time estimation and prediction for the selected corridor in Warangal City, India.

The rest of the paper is structured as follows: Section 2 summarized the literature review. Section 3 discusses the methodology and data collection. The model results are presented in Section 4. The discussion of the model results and the conclusion sections were given in Sections 5 and 6 respectively.

2 Literature Review

The research by various researchers emphasizes the significance of Bluetooth technology, the need to use it as a traffic management strategy, and the software created to assess the various parameters affecting the travel time prediction for vehicles. For better understanding, research done by various authors is briefly explained, along with the methodology and techniques to calculate the vehicular travel time.

2.1 Estimation of travel time

Travel time is the most dominant parameter for evaluating the quality of the traffic along a road. Urban travel times show a major variation because of the traffic conditions prevailing in an area. Travel time is also a critical performance measure to assess the various real-time traffic conditions and the congestion along the roadway. Due to a lot of uncertainty in urban traffic conditions, the travel time uncertainty is also greater, which creates a negative impact on the road user. The travel time depends on the geographical conditions, geometrical conditions, road users' and vehicle characteristics, and various other factors. Travel time is a key factor when analyzing the various traffic data analytics and also for the origin and destination studies for route-specific analysis (Dunlap et al., 2016). Various emerging ITS tools like ATMS and ATIS have been developed in recent years, and in order to implement those technologies, travel time is very important.

There are an adequate number of studies that have been done for the estimation of travel time using Bluetooth technology (Friesen and McLeod, 2014; Namaki et al., 2015; Erkan and Hastemoglu, 2016). Researchers have conducted origin and destination studies and assessed route choice by developing a 4-step filtering algorithm (Haghani et al., 2010; Dunlap et al., 2016). In another study by Barcelo et al. (2010), the Kalman filtering algorithm approach is used to determine the O-D (origin-destination) matrices and the forecast of the travel time. The O-D pairs for the different routes are generated and analyzed using Bluetooth technology, and the pair that has the least travel time can be preferred to be used. Also, studies done by Jie et al. (2011) and Aliari et al. (2012) have shown that the comparison between Bluetooth data, video image processing, and GPS data and results concluded that Bluetooth data is closer to other data techniques. Few researchers have focused on pedestrian travel times and their densities. Malinovskiy et al. (2012) focused on the evaluation of pedestrian travel times and their detection in two different locations: Montreal and Seattle. This is done with the help of Bluetooth sensors located at a particular interval of 100m between them and close to the location where the pedestrian survey is conducted. Carpenter et al. (2012) developed the route-specific origin and destination tables by using Bluetooth MAC technology with the help of travel time estimation by fixing Bluetooth sensors at some fixed locations along the corridor. Researchers have also evaluated the use of Bluetooth and RFID (Radio Frequency Identifier) sensors to predict travel times in scenarios with mixed traffic, and they have discovered that RFID sensors work exceptionally well in this case (Jayan and Anusha, 2020). Hu et al. (2013) examined the use of Bluetooth signal collectors in order to determine the transfer time, and the main emphasis was laid on the survey of pedestrians. In a few studies, travel time prediction is also done with the Bluetooth data obtained. With the use of Bluetooth data, Qiao et al. (2016) estimated the short-term travel time for freeways. Studies have investigated the feasibility of using Bluetooth data for estimation of travel time in urban areas and concluded that the prediction of travel time with emerging technology is useful in congestion pricing policies (Carresea et al., 2021). Researchers have proven that efficient estimation of travel time prediction plays a crucial role in predicting driver route choice behaviour in urban areas (Civcik and Koçak, 2020).

Many models are developed in order to analyze the collected data, like the Kalman filtering algorithm, historical average, K-nearest neighbors (KNN), and KNN-T methods. The KNN-T model is found to be the most accurate method for analyzing the data as it is a non-parametric method (Cai et al., 2016). Various Bluetooth device types are present, and based on the Dedicated Inquiry Access Code (DIAC), the device type can be identified. Díaz et al. (2016) exclusively used the most effective Bluetooth monitoring systems for estimating the travel time in real-time. Araghi et al. (2014) compared the level of accuracy. Video recordings and Automatic Number Plate Recognition (ANPR) are simultaneously used with the Bluetooth sensors under real-time traffic conditions. Mathew et al. (2016) estimated the travel time under Indian conditions for two different routes in Chennai, which include the Velachery-Taramani link road and via the Sardar Patel Road and Rajiv Gandhi Salai. The Bluetooth sensors were deployed at four locations, and the data was collected for four days. The type of device is also detected by using the Raspberry Pi Bluetooth sensor. The Bluetooth sensors have proven to have the potential to estimate travel time accurately in Indian conditions. Park et al. (2016) examined the use of travel times collected by Bluetooth sensor systems for automatic incident detection (AID). An AID algorithm is developed based on those messages where automatic incidents are acquired. The sensors are placed along a stretch of road of around 15 km, for which the analysis needs to be done for AID requirements. The delay at an intersection can also be commented on with the obtained Bluetooth data. Further, studies have explored the innovative Gated Recurrent Unit (GRU)-based model to predict vehicle travel time in urban areas and concluded that the travel time prediction is more accurate by GRU due to consideration of road link type (Li et al., 2023). Bluetooth technology is capable of vehicle detection and generating O-D matrices, which is essential for traffic management in urban areas (Gheorghiu et al., 2021).

With the aid of travel time data obtained from the data collector units (DCU) by Bluetooth technology, Karatsoli et al. (2017) analyzed the performance of an intersection. Besides travel time estimation and origin-destination studies, a few studies have also been done on pedestrian travel time, densities, and dwell times. Kurkcu and Ozbay (2017) studied the use of Bluetooth sensors for determining wait times, pedestrian densities, etc. Video imaging is a method for pedestrian tracking, but it is not preferred because it is very expensive and difficult to install. So, these sensors (Bluetooth) are used, and specific algorithms are developed in order to track individual pedestrian movements. In this work, four algorithms are used for the initial filtering of the devices. The pedestrian sensor used in this study is the Raspberry Pi, which is a small computer (of low cost). In this direction, the present study explored the estimation of vehicular travel time on the selected corridor using Bluetooth technology. Further, the study extends the prediction of vehicular travel time with the help of the K-nearest neighbors (KNN) method in order to understand the effect of the vehicular flow on vehicular travel time on the selected corridor.

3 Methodology

3.1 Data Collection

In the present study, Bluetooth technology is used to collect and analyze traffic data. However, the data obtained from this is relatively small compared to other conventional methods, such as GPS, etc., of collecting travel time data. In the present study, the data has been collected using a Bluetooth scanner mobile application, and it has been placed at different locations with the help of graduate students. The devices on which Bluetooth is enabled detect the various devices of the travellers along the selected corridor, and further analysis can be done by exporting the data. The time stamp of the vehicles, the type of device, the name, and the MAC address of the cars are obtained.

3.2 Field implementation

This study uses a Bluetooth scanner application to collect the data, and the application must be installed on a smartphone to detect the Bluetooth devices enabled within a range of 5 to 20 meters. An extreme edition of this app must be purchased for effective use and export of the data collected. The application has many features to help us better understand the device type that is detected and the device that is used to detect the devices of the travellers. In the filters, it can be classified into various Bluetooth device groups like a computer, phone, health, audio-video, and wearable. It also shows the type of device detected, name, signal strength, MAC addresses, and time stamp, which can be used for the analysis. The data can be exported in the form of a CSV file.

The data is collected along the Devarpula-Hanamkonda highway for a road stretch of 2.5 km, where seven different mobiles installed in the mobile application are placed at predetermined distances along the corridor. The road stretch starts from NIT Warangal to Adalat Circle, Telangana, India, and there is also another location along Hunter Road, Telangana, India, to collect the Bluetooth data. The locations where the smartphones are placed with a Bluetooth application installed are numbered as shown in Figure 1 in a Google map image. The average travel time and speed are estimated at different road sections between these locations and are compared based on both morning and evening data. Moreover, a video camera was set up to collect the actual field data, including vehicular composition, flow, and travel time at a specified distance (30 m), simultaneously with Bluetooth data. It helps in the validation of the Bluetooth data. The video camera used for data collection is the Sony HDRCX405 9.2MP HD Handy Camera. This camera is mounted on a tripod on top of the building at location 1, near the NITW main gate, which covers a distance of 30 meters. In the present study, the video camera captures the data for two hours each morning and evening for six days.

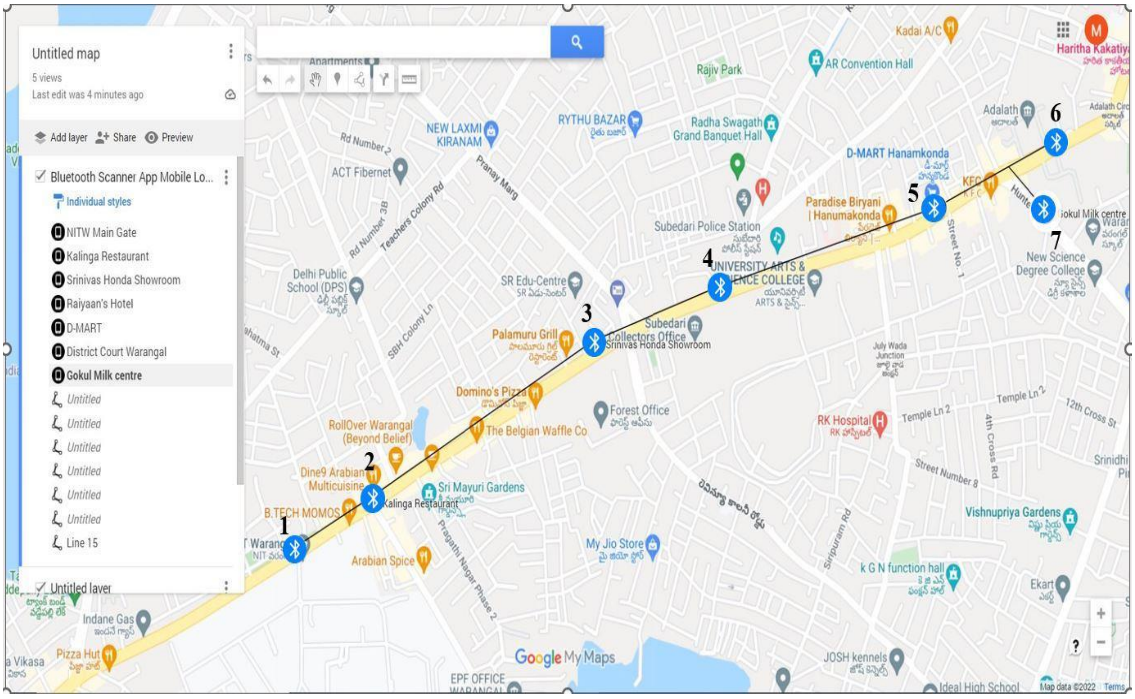

Figure 1: Study area showing the different locations for data collection

4 Data Analysis and Results

4.1 Travel time analysis

The data collected from the Bluetooth scanner application is exported and obtained as a CSV file. The data collected at the two locations of a particular road section with unique MAC addresses is matched. The travel duration is determined by comparing the times at the two different locations. The calculation of the average travel time and average travel pace is possible by utilizing the estimated travel time for the diverse array of devices that were detected. Therefore, this mean travel duration illustrates the discrepancy between the intended velocity and the practical velocity of a vehicle along the selected corridor. The travel time analysis of any given vehicle consists of the aforementioned procedure applied to iteratively compute the discrepancy between the time stamps of the matched MAC addresses. Using the Bluetooth application to identify the type of vehicle is a complex process, but the type of device detected is known. To know if it is a car, the type of Bluetooth device detected is audio_video_car_speaker. So, all the Bluetooth devices detected as audio-video car speakers are classified as cars, and their MAC addresses and time stamps are taken and used for estimating travel time for each car.

However, the only type of vehicle that can be classified is a car, so the travel time for all the other vehicles is estimated collectively without categorizing them. In contrast to the device type audio/video car speaker, all the different Bluetooth device types detected are taken together for analysis. Except for audio or video car speakers, various other Bluetooth devices, like generic phones, wearable watches, wearable headsets, etc., are taken as other vehicles, and the travel time is calculated. Table 1 shows the t-test result for cars, which is found to be a significant difference in travel time between the morning and evening of the four sections along the selected corridor. It is also observed that the evening travel time is greater when compared with the travel time of a car during the morning, which clearly indicates the high traffic conditions in the evening. Also, for other vehicles, the t-test results showed that there is a significant difference in morning and evening travel time, which is presented in Table 2.

Table 1: Travel time of t-test result for car during Morning versus Evening

Road Sections	Time of Day	Mean (s)	Standard Deviation	t-statistic	*p-value*
1-3	Morning	81.550	6.642	-4.370	.000
	Evening	98.379	18.074		
3-4	Morning	93.344	23.963	-7.373	.000
	Evening	142.690	23.981		
4-5	Morning	81.981	18.272	-3.746	.000
	Evening	95.000	17.809		
5-6	Morning	75.250	34.963	-2.180	.000
	Evening	92.340	18.477		

Table 2: Travel time of t-test result for other vehicles during Morning versus Evening

Road Sections	Time of Day	Mean (s)	Standard Deviation	Number of samples	t-statistic	*p-value*
1-3	Morning	70.663	13.368	386	-40.499	.000
	Evening	90.663	13.369	386		
3-4	Morning	80.292	23.870	496	-15.766	.000
	Evening	101.623	18.121	496		
4-5	Morning	83.622	16.914	408	-9.080	.000
	Evening	93.828	15.464	408		
5-6	Morning	74.127	24.462	305	-6.540	.000
	Evening	88.662	28.014	305		

4.2 Sample rate and device classes

One primary constraint of using Bluetooth technology is that the detection rate is too low, at around 5 to 10% (9). Additionally, different filtering algorithms can prevent the detection of the same Bluetooth device multiple times. The data obtained is precise, and the sample data detected would be sufficient for analyzing the average travel time. Various types of device classes are recorded in the Bluetooth scanner application. Figure 2 shows the different classes of Bluetooth devices detected and shown in the form of a pie chart. Each device has its own unique Media Access Control (MAC) address, which is represented by the central number in the pie chart (see in Figure 2). As shown in Figure 2, 77% of the detected devices are smartphones (phone generic), and the rest are mostly wearable watches (3%), wearable bands (4%), audio/video car speakers (7%), and audio/video headsets (9%). Mobile phones are the devices that are predominantly detected compared to other device classes.

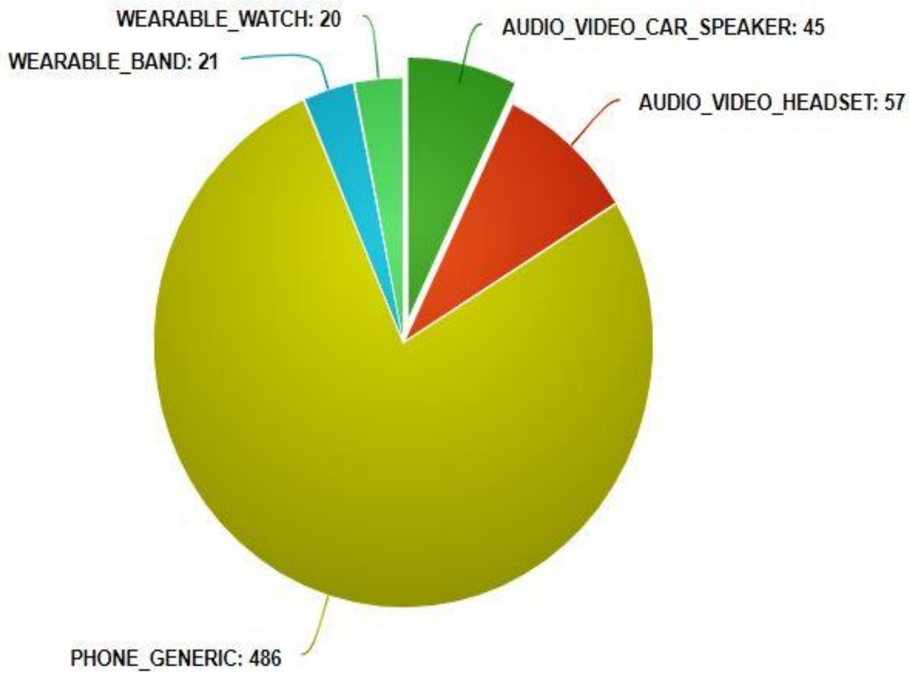

Figure 2: Type of Bluetooth Devices Detected

4.3 Validation of the data

The travel time of cars and other vehicles is estimated using the Bluetooth app, but validation has to be done with some conventional method to rely upon the Bluetooth travel time obtained. In this study, the video data is taken for a midblock section of 30 metres along the stretch where the Bluetooth data is collected. A comparison has been made between the travel times of vehicles obtained from the Bluetooth data and video data. An analysis reveals that the average travel durations derived from video data and Bluetooth data are not significantly different. This facilitates the application of the travel times derived from Bluetooth data to traffic analysis studies, demonstrating their dependability. Table 3 shows the t-test results between the Bluetooth data travel time and the travel time from video data, which is insignificant. There is a mean difference of 1.604 s of travel time for the car, which indicates that the Bluetooth data is reliable. The process is repeated for all other vehicles, and it also shows that there is no significant difference between the travel time data collected from the video and Bluetooth data.

Table 3: T-test result of Car Bluetooth TT vs. Video TT

Travel Time in s	Mean	Standard Deviation	t-statistic	*p-value*
Bluetooth Travel Time	22.678	4.312	-1.723	0.096
Video Travel Time	24.282	5.074		

4.4 Travel time prediction model

Travel time prediction is significant and keeps road users and traffic system controllers aware of the future trend of travel time along the roadways. This helps enhance the road user's effective use of the roadways. Travel time prediction is significant and keeps the road users and the traffic system controllers aware of the future trend of travel time along the roadways, which might be the input for the ATMS and ATIS of the ITS applications.

4.5 K Nearest Neighbor Model (KNN)

The K-Nearest Neighbor Model (KNN) is a non-parametric model based on supervised learning techniques. It stores and manages all the input data and works effectively by giving input of the newly obtained data into the most similar category. The KNN model is used for classification and regression. In this study, the basic KNN model is used to predict travel times using previously obtained travel times from the Bluetooth scanner app. The time interval is related to the observed travel times by means of this model. The travel times for a given time interval are grouped together, and the travel times for the subsequent time interval are predicted using the values of the nearest neighbors. The subsequent estimated travel time is computed by averaging the k nearest neighbors that were acquired subsequent to the execution of the KNN model. A sequential KNN algorithm for predicting the travel time for the subsequent time interval has been developed. The step-by-step procedure is described below:

- Develop a dataset with the time interval (15 to 20 minutes) with the actual travel times.
- Select a time interval of 20 minutes and take them as one group.
- In KNN, many distance calculations exist, but in this study, Euclidean distance is used to obtain the nearest neighbors.
- Obtain a set of K's nearest neighbors.
- Predict the travel time for the next interval by creating a new dataset containing time intervals for which predictions must be made.

The KNN model is developed, and the travel times for a targeted time interval are calculated. R Studio is used to run the code for creating this KNN algorithm. For the required dataset, randomly different K values are considered, and it is found that up to $k = 35$, the r-value is improving, but when $k = 40$, it is found that the value of the r-value for prediction has reduced. So, to predict travel time, $k = 35$ is considered, and then the code is run for further analysis. The mean absolute error (MAE), root mean square error (RMSE), and r (Pearson correlation coefficient) values are estimated. After various trials with different k values, starting with $k = 5$, 10, 20, 30, 35, and 40, it was found that $k = 35$ gave the best results. The next time intervals (as a group) are given as input, and using R Studio software, the code is run, and the travel time values are predicted. For $k = 35$, all the calculations are done at different locations. In this case, $k = 35$ is considered, as it can be seen that up to $k = 35$, the r-value increases, but after $k = 40$, the r-value reduces. So, $k = 35$ is the most suitable for predicting travel times. Here, $k = 35$ means that 35 nearest neighbors of the travel time are created, and based on that, the upcoming travel times will be predicted. So, 35 nearest neighbor KNN models are developed, and, based on the observed and predicted data, the future travel times are calculated for each group's corresponding time interval of 20 minutes. The predicted travel times for the corresponding time intervals during the morning and evening are given in Tables 4 and 5, respectively. Hence, a short-term travel time prediction is made using the KNN model. Figure 3 shows the observed versus predicted travel time line graph for vehicles. Table 6 shows the MAE, RMSE, and r for the predicted travel time of vehicles.

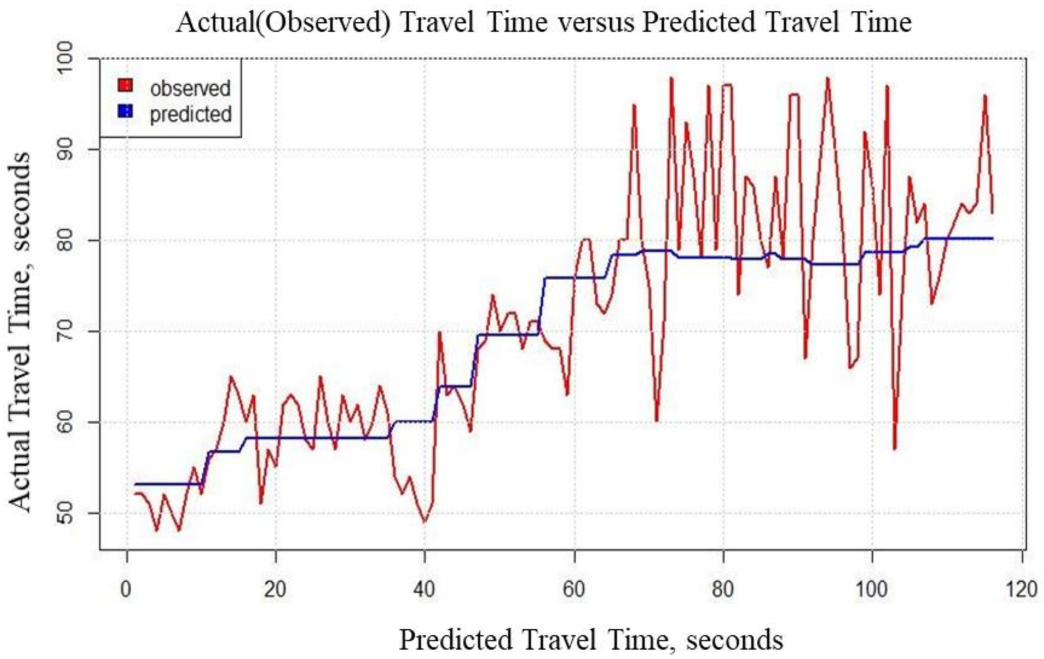

Figure 3: Observed versus predicted travel time

Table 4: KNN Model Results of Observed Versus Predicted Travel Time during Morning

S.No.	Time Interval (as a group of 20 min each)	Observed Travel Times (s)	Predicted Travel Times (s)	Error	Error in Percentage
1	21	51.632	53.143	1.511	2.927
2	22	53.154	56.628	3.474	6.536
3	23	55.611	58.263	2.652	4.769
4	24	61.034	66.795	5.761	9.438
5	25	70.533	75.857	5.324	7.548
6	26	73.700	78.000	4.300	5.834
7	27	73.241	78.585	5.344	7.296
8	28	75.966	79.341	3.375	4.443
9	29	76.571	79.333	2.762	3.607
10	30	79.929	80.087	0.158	0.198

Table 5: KNN Model Results of Observed Versus Predicted Travel Time during Evening

S.No.	Time Interval (as a group of 20 min each)	Observed Travel Times (s)	Predicted Travel Times (s)	Error	Error in Percentage
1	21	71.632	73.143	1.511	2.110
2	22	73.154	76.628	3.474	4.749
3	23	75.611	78.263	2.652	3.507
4	24	80.034	86.795	6.761	8.447
5	25	84.533	95.857	11.324	13.396
6	26	88.700	98.000	9.300	10.485
7	27	93.241	98.585	5.344	5.731
8	28	94.966	97.341	2.375	2.501
9	29	96.571	99.333	2.762	2.860
10	30	100.029	100.087	0.058	0.058

Table 6: Calculation of MAE, RMSE and r for Predicted Travel Time

S. No.	Road Section	Time of Day	MAE	RMSE	r
1	1-2	Morning	3.917	4.565	0.974
2		Evening	2.433	2.748	0.993
3	1-3	Morning	3.466	3.860	0.986
4		Evening	4.556	5.689	0.942

5 Discussion

From the results obtained, it is evident that the travel time prediction with the use of Bluetooth technology is quite effective. The reliability studies have also been done over a wider scope, which has turned out to be effective. The Bluetooth data is validated with video data, and the difference between the Bluetooth and video data travel time values is 1.604 s, which indicates that the travel time estimation with Bluetooth is quite reliable. The vehicle detection rate was 5–8% in this study. Likewise, Mathew et al. (2016) also found the vehicle detection rate in the range of 5 to 10%. The vehicle detection also has a lower range of detection using the Bluetooth scanner application when compared to various other devices like Bluetooth traffic monitoring systems, Bluetooth probe devices, Bluetooth signal collectors, blip track systems, and various other Bluetooth devices. Various factors, like the height at which sensors are placed, the distance from the road section, and the angle at which the antennae are placed, subsequently affect the data collected. But in the Bluetooth scanner application, the main constraint is the use of personnel for collecting data for a long duration, as the application must be monitored continuously. Similarly, Araghi et al. (2014) have done reliability analysis with the use of GPS data to calculate the actual travel time. In both cases, the use of Bluetooth data is reckoned to be counted upon for analysis of the travel time in a real-time scenario.

6 Conclusions

The present study explored the estimation of travel times using a Bluetooth scanner application in Warangal, India. Further, a K-nearest neighbor (KNN)-based prediction model was established in order to check the prediction capability of estimated travel times on the selected corridor. The K nearest neighbor (KNN) model has proven to be effective in predicting future travel times at K = 35. Also, the t-test results show a significant travel time difference between morning and evening data at different road sections along the selected corridor. Furthermore, the t-test outcomes comparing the travel times of vehicles as recorded by Bluetooth and video data indicate a negligible disparity in travel times. This finding bolsters the credibility of the data gathered via Bluetooth. The KNN algorithm yields results indicating that the projected travel periods for the upcoming time intervals correspond to the following day of equivalent duration. On the same day that the predicted travel times are compared to the observed data, the resulting MAE, RMSE, and r values are computed and find them to be satisfactory. It can be inferred that Bluetooth equipment possesses the capability to assess and examine real-time travel time investigations in urban environments.

In spite of these results, the study has some limitations. Multiple detections of devices are one of the significant issues observed, and these can be minimized by removing the duplicate values after exporting the data. When compared to other vehicle detection technologies, the sample rate is low. The vehicle detection rate is around 5% to 8%. Another difficult task is determining the type of vehicle, and the research should be expanded to include pedestrian detection. However, the data collected through the Bluetooth scanner application has proved to be very cost-effective and easy to implement. The results are useful to traffic engineers in order to plan for an advanced traveller information system and an advanced traffic management system in urban areas.

Acknowledgments

The authors would like to express their gratitude towards the following graduate students of NIT Warangal; Mr. R.Bhargav, Mr. Kaushik Pandey, Mr. Ashar Khan, Mr. Gugulothu Akhil, Mr. Koushik Shesham, Ms. Ramya Karnati, Ms. Rashmitha Ramineni, Mr. Vatipally Bhanu Prakash Reddy, Mr. Subrat Kumar, Ms. Jyothi, Mr. Devendra, Mr. Suyash Agarwal, Ms. Sankeerthana and Ms. Shilpa Nandhyala, who helped in data collection.

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