Application of GPS/GIS Based Travel Mode Detection Method for Energy Efficient Transportation Sector

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Abstract. The planning of efficient transportation systems is a central topic of concern as it saves energy and contributes to economic development both at national and household level. The development and optimization of highway and transportation engineering models such as transportation networks, parking facilities and as well as reduction of traffic congestion etc., require information on travel modes. To overcome the burdens for the respondent and the other drawbacks of the conventional methods related to travel mode detection, combination of Global Positioning System (GPS) and Geographical Information System (GIS) were tested in this research. After validating the accuracy of the smartphone based 'My Tracks' GPS mobile application, GPS travel route with a manually entered travel mode diary was used to collect data from randomly selected days and students in two faculties in the University of Peradeniya. Out of 125 datasets, 99 accurate datasets were selected for the analysis using 'ArcGIS' software coupling with 'STATA' statistical software. Rule-Based algorithms and heuristic based methods are two main approaches that were used to detect four travel modes (Walk, Bus, Motor Vehicles and Motor Bicycles). Differentiation of Bus mode from the motor vehicles (except motor bicycles) was the most challenging part of the research and a country specific novel method was introduced in this research. Travel mode detection results were compared with relevant correctly completed travel mode diaries to validate the methodology. The overall travel mode detection accuracy of the new method is 96% for the accurate data sets compared to conventional travel mode diary method. The success rate of collecting an accurate data set is 79%. The GPS/GIS based travel mode detection could be applied in energy efficient development in the transportation sector. In future research, the bus mode detection method invented in this research could be used to detect driver behaviour.

Keywords: Travel mode · GPS · GIS · My tracks · University of Peradeniya

1 Introduction

An efficient transportation system is crucial for the development of a country. An energy efficient transportation system contributes to the development of the economy both at national and household level and the sustainability of a green environment and

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ecosystem. The detection of travel modes plays a key role while designing energy efficient transportation system. Household travel surveys have been used as a tool since 1970's to collect data to build transportation models such as transportation networks and parking facilities (Zong et al. 2016). The Travel diary method is one of the conventional methods to carry out travel surveys. It has many drawbacks as it is a more time consuming and respondent burdening practice. Consequently, the use of Global Positioning System (GPS) devices for collecting travel mode data became popular in the recent years. It reduces the respondent burden while researcher uses the respondent as a passive data collector. Though the GPS records accurate location, time, elevation information, it cannot record details like travel modes and trip purposes. Therefore, in this study Geographical Information System (GIS) was used with GPS data to detect travel modes. Gong and Chen (2011) have studied GPS/GIS method for travel mode detection in New York City using GPS devices. At present, smartphones have GPS facility and therefore accuracy and applicability of GPS facility in the smartphones has become an alternative to GPS devices-based travel mode detection method. However, information on use of smartphones-based GPS in travel mode detection is scarce. Therefore, a study has been designed to investigate the applicability of GPS/GIS method using mobile GPS applications for travel mode detection in the University of Peradeniya. The objectives of the study are; (i) to detect the travel mode using smart phone-based GPS applications (ii) to compare the results of modal shares (iii) to evaluate the success rate of smart phone-based travel mode detection compared to that of travel diary-based travel mode detection method (iv) identify and compare the travel modes of students in the Faculties of Engineering and Science using novel smartphone-based travel mode detection method.

2 Background Information on GPS Based Travel Surveys

GPS based travel surveys have many advantages over traditional paper-based travel surveys or travel diary method. Because, in traditional paper-based surveys, respondents have to fill many pages manually. It is reported that respondents often forget to enter the trip segment and it is a time-consuming procedure. In GPS based travel surveys, respondents are acting as passive data collectors and therefore respondent burden is comparatively lower. The GPS method shows the traveller's exact route and because of the accuracy of the data, sample size can be reduced. Moreover, travel speeds can be calculated for the particular route at particular time period. It is a good indicator to assess the level of service for a given transportation network. Due to the easiness of the method, length of the survey can be extended from traditional single day survey to multiple day survey. Accuracy can be validated for the daily routine of the same respondent through this multiple survey. Though the advantages of the GPS based travel survey are higher compared to traditional methods, it has few drawbacks like any other method. Since GPS traces the respondent's exact route, it minimizes the privacy concern. Signal loss and degradations in shopping malls, tunnels, and urban canyons are the other drawback in this method as well as the fact that GPS cannot directly identify travel mode and trip purposes. In this research, the main focus is on combining GPS and GIS methods to give a solution for travel mode detection.

3 Literature Review

Shalaby and Chung (2005) developed a trip reconstruction software tool that automatically identifies the travelled road links and modes used by the respondent using GPS traces. Conventional GIS map matching algorithm was adopted in this method to identify road links while rule based algorithms were used to identify four travel modes (walk, bicycle, bus and passenger car). GPS travel data and the multimodal transportation network model of downtown Toronto has been used for the evaluation of the developed software tool. It is reported that said method correctly matched 79% of all links travelled and 92% of all trip modes. However, they only allowed for one-purpose trips and maximum of two possible modes per trip.

Zong et al. (2016) developed a hybrid procedure for travel mode detection and it was presented using large-scale origin-destination survey conducted in Beijing in 2010. They determined the subway mode separately from other modes and used two methods to detect the subway mode. It is reported that 53.8% success rate for multinomial logit model while 97.8% success was for GIS algorithm. Results revealed that the GPS/GIS method provides higher accuracy for subway modes. Nested logit model was employed to determine the modes of Walking, Bicycle, Car and Bus. Combined success rate of the hybrid procedure was 86%.

Gong and Chen (2011) developed a GIS algorithm to automatically process data that was traced from GPS based travel surveys. They have detected five travel modes (Walk, Car, Bus, Subway and commuter rail) and those detected results from GIS algorithm were compared against conventional travel diaries. They have conducted two small GPS surveys and success rates of that combined survey was 82.6%. In their research, they allowed an unlimited number of mode transfers within a trip. Furthermore, they built connectivity into their multimodal transportation network in GIS to find the right link for matching the GPS traces, or interpolate the underground subway mode. In their multi modal transportation network, the success rate for the subway mode detection equals to 65.6%.

Clifford et al. (2008) used set of developed heuristic rules to determine both travel modes and trip purposes. Heuristics based on speed and route of travel, as well as some demographic information. In this study, four different travel modes (walk, bicycle, private vehicle and public transport) have been considered. They compared results with respective travel diaries.

4 Methodology

4.1 Study Area

The study area is University of Peradeniya, a state university in Sri Lanka. It has nine faculties and about 11000 students.

4.2 GPS Data Collection

Instead of handheld GPS loggers, smartphones with GPS facility were used for this research. Several GPS tracking applications such as *My tracks, Geo tracker, Track Me, GPS Trip recorde*r were tested and '*My tracks' and 'Geo tracker'* were selected as GPS tracking applications based on the performance of said two applications. It was noticed that internet facility is needed for tracking paths in *Geo tracker* occasionally and GPS signal losses were higher than the *My tracks* application. Finally, 'My tracks' was selected as the best tracking application. Accuracy of the mobile GPS application was checked against a GPS receiver called etrex10. Obviously, the traced data points for a given route was low in the mobile phone compared to the GPS receiver. But we checked the accurate data points that were traced from the mobile phone. After three consecutive days of pilot travel survey with two different mobile phones, we found that the average accuracy of the traced data points of two mobiles phones were 88.6% and 93% respectively. Since the accuracy of the 'My Tracks' application is greater than 75%, it was selected for the study. It was noticed that the signal losses were occurred in both etrex10 GPS receiver and the two GPS enabled mobiles phones in shopping malls and the tunnels.

4.3 GIS Data Collection

In Sri Lanka, local agencies do not have transportation networks as GIS layers. As a result, to get an initial idea whether the traced GPS data points are correct or not, first travel routes were exported to the Google earth. Also, bus halts were identified using Google earth as an indicator to separate bus mode from the other modes.

4.4 Socio Demographic Data Collection

Peoples' mode choices are changed with their socio demographic information like age, gender, vehicle ownership, location of residence etc. Therefore, before selecting participants, questionnaire-based survey was conducted for total student population to collect socio demographic data.

4.5 Sample Selection

The target population could be stratified by three main attributes, namely, (i) Respondent type, (ii) Location of stay/residence wise and (iii) faculty wise. By respondent category, population can be classified as students, academic staff and non-academic staff. By location of stay/residence category, population can be classified as within the university and out of the university. By faculty, population can be classified into nine different faculties. The target group of this investigation was limited to the students of the Faculties of Engineering and Science. The reasons for selecting those faculties to this research was that the Faculty of Engineering is isolated from other faculties as well as it is the faculty of the research team while the Faculty of Science is inside the University premises and there is a higher number of students in that faculty. Academic and non-academic staff were not selected for this sample because of their busy life style. Under location of stay category both students in hostels and residential students were selected. The final sample of 100 students was selected using stratified random sampling technique from both Science and Engineering faculties. Of these 100 students, 79 students were selected for data collection as others have shown problems in data recording using mobile application.

4.6 Key Steps in Methodology

4.6.1 GPX Data

In 'My Tracks', the GPS routes are saved as GPX files. In that file there is no velocity data indicated directly. Velocity is the main parameter to separate travel modes. So that first GPX file was exported to the ArcGIS and route was projected from WGS 1984 to Kandawala, Sri Lanka grid. Example for a projected route is presented as Fig. 1. Then X, Y coordinates were created in the attribute table. After that, attribute table was exported to the MS Excel.

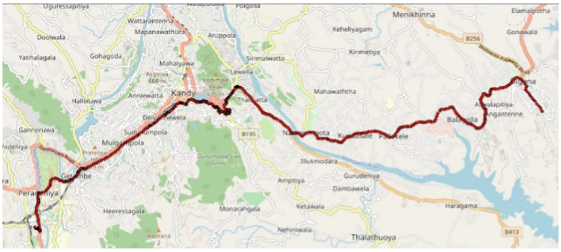

Fig. 1. Example for a projected route

4.6.2 Erroneous Data

After exporting the attribute table to the MS Excel, erroneous data were filtered by elevation. Erroneous elevation data were represented as −9999. The accuracy level of the data set was calculated using the Eq. 1 given below and data sets with accuracy more than 80% were selected to detect travel modes. Table 1 represents the accuracy results for ten datasets.

$$Accuracy = \frac{(a - b) * 100}{a} \quad (1)$$

Where,

a = Traced data points
b = Erroneous data points

Table 1. Accuracy results for ten datasets

Dataset	Traced data point	Erroneous data points	Accuracy %
1	1409	97	93.1
2	489	145	70.3
3	1615	123	92.4
4	752	299	60.2
5	3403	18	99.5
6	1168	19	98.4
7	485	14	97.1
8	1267	11	99.1
9	343	201	41.4
10	954	4	99.6

4.6.3 Velocity Calculation

X and Y coordinates for each and every point in the route were calculated in the ArcGIS. After exporting the attribution table with those coordinates, consecutive point velocities can be calculated in MS Excel.

4.6.4 Travel Modes Calibration in STATA Statistical Software

STATA statistical software is used to detect travel modes. Commands were generated according to local speed guide lines and set of data sets. Set of travel survey routes from ‘My Tracks’ were used, because though the local speed limits are indicated, actual level of service may be changed with the corresponding study area.

Data sets with calculated point velocities generated in Excel sheets were exported to STATA statistical software. Primarily, data points were categorized into three modes considering the velocities. Velocity ranges and corresponding travel modes are as below.

$$\text{Travel mode} = 0,\ \text{Standstill},\ \text{if Velocity} \leq 0.2\,\text{km/h}$$
$$\text{Travel mode} = 1,\ \text{Walk},\ \text{if}\ 0.2\,\text{km/h} < \text{Velocity} \leq 8\,\text{km/h}$$
$$\text{Travel mode} = 2,\ \text{Vehicle},\ \text{if}\ 8\,\text{km/h} < \text{Velocity} \leq 70\,\text{km/h}$$

Then the data set was further categorized into 300 s intervals and average velocities were taken in each 300 s intervals. Using those average velocities Vehicle mode was categorized as below.

$$\text{Travel mode} = 3,\ \text{Bus},\ \text{if}\ 8\,\text{km/h} < \text{Average velocity} \leq 30\,\text{km/h}$$
$$\text{Travel mode} = 4,\ \text{Motor Vehicle},\ \text{if Average velocity} > 30\,\text{km/h}$$

Most frequent travel mode for the points in the 300 s interval was used as the travel mode in that 300 s interval. Then detected travel modes for each 300 s intervals were plotted against time. Mode changes can then be identified from that plot. But the drawback in the plotting method is that sometimes due to traffic congestions motor vehicles can be categorised from time to time in the bus category as presented in Fig. 2. Therefore, to differentiate motor vehicles from bus category, a bus halt layer was created in Google earth around the University of Peradeniya area as presented in Fig. 3 and points representing standstill, walk and vehicle in each dataset were separated in ArcGIS. Then, that bus halt layer was exported to Arc GIS and 75 m buffer zones were created around the bus halt. After that, standstill and walk points inside the buffer zones were clipped as shown in Fig. 4. If more than 90% of standstill and walk points near the bus halts coincide with the buffer zone, it was filtered as a Bus Mode. Filled questionnaires were used to differentiate motor bicycles from the motor vehicles. Finally, one day mode changes in each respondent were tabulated.

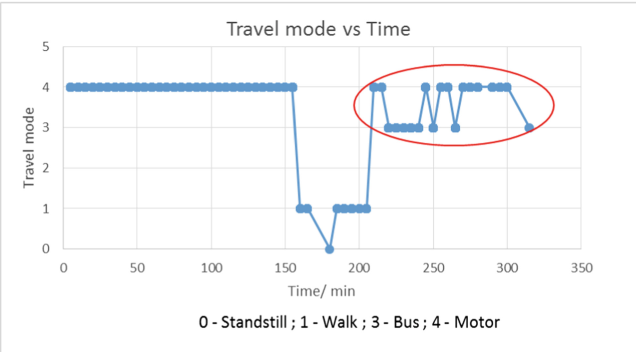

Fig. 2. Travel mode vs. time

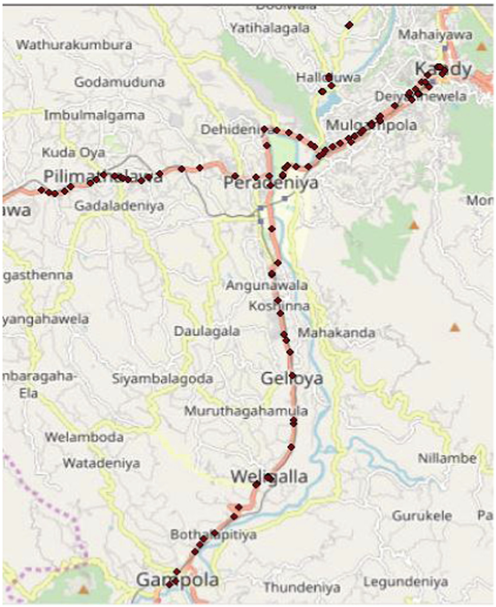

Fig. 3. Bus halt layer around Kandy area

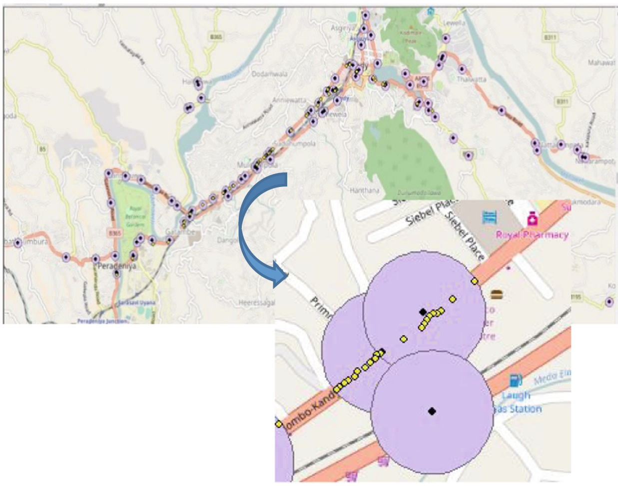

Fig. 4. Clipped standstill and walk points

5 Results and Discussions

5.1 Travel Mode Detection

Analysis of data revealed that travel modes such as walk, bus, motor vehicle and motor bicycles could be detected using the smart phone-based GPS application. It was found that about 31% of the respondents use only one travel mode - for example walk mode – in their daily travel. About 61% of respondents use 2 travel modes and 6% use 3 travel modes in their daily travel (Table 2). The majority of respondents use Walk travel mode plus any one of other travel modes in their daily travelling. But their mode selections can be changed with several factors like distance, time, salary, level of service of the transportation networks etc. In this study we mainly focused on the applicability of smartphone-based method and the accuracy of the travel mode detection.

Table 2. Number of travel modes used by respondents

No. of modes	Freq.	Percent	Cum.
1	19	31.67	31.67
2	37	61.67	93.33
3	4	6.67	100
Total	60	100	

Table 3. Number of respondents and their selection of modes

Travel mode	No of respondent
Walk	79
Bus	39
Motor vehicle	13
Motor bicycles	8

The result in Table 3 indicates that all the respondents had walked in their daily routines. Among students in the Faculties of Engineering and Science, it was found that the bus mode usage in the Faculty of Science is higher than that of Engineering (Fig. 5). Common reason for that may be the distance from the location of stay to the Faculty of Engineering is short compared to the Faulty of Science.

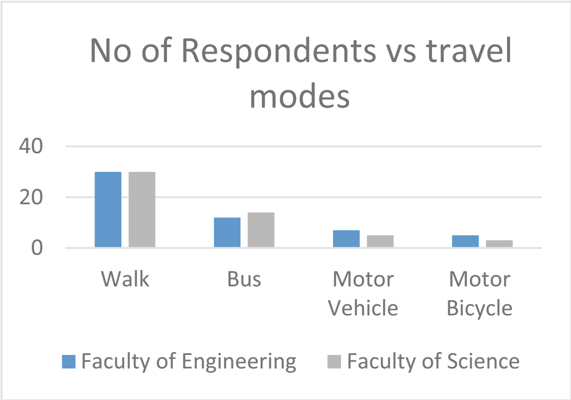

Fig. 5. Comparison of travel modes used by responded of two faculties

5.2 Modal Shares

Modal share percentage per day was identified for each respondent.

Figure 6 shows the results of the comparison of modal shares. It indicates that walk and bus combination is the highest share followed by walk and walk with motor vehicle combination.

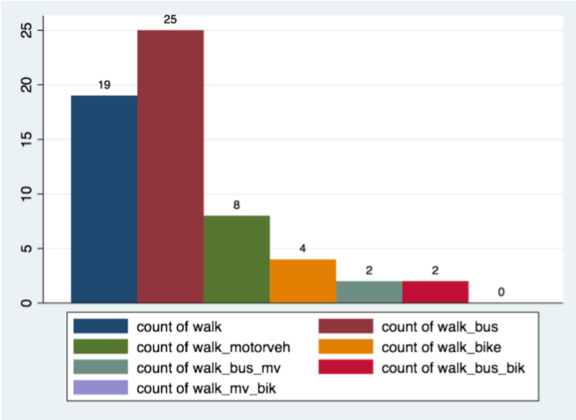

Fig. 6. Modal share of 60 students in both faculties

5.3 Success Rate of Travel Mode Detection Using Smart Phone-Based GPS Application

The travel modes detected using smartphone-based GPS/GIS method was compared with the travel diaries of relevant responded. It was found that out of 79 dataset results 76 were matched with the relevant travel diary. Therefore, the success rate of detecting travel modes in this research is 96%.

Among routes with more than 80% accurate data sets, overall travel mode detection accuracy is 96% and the success rate of collecting accurate dataset is 79%.

6 Conclusion

The new method of smartphone-based GIS/GPS application could be used to detect travel modes accurately. About 61% of the study population use two travel modes in their daily travel. The new method has a success rate of 96% compared to the conventional travel diary method. In this study location - University of Peradeniya - the high share associated with the walk mode is because more than half of the respondents are from university residences. Due to lack of owned vehicles, students had used buses to complete their trips. Overall, this new method is accurate, faster and less respondent burden and hence it can be used to detect travel modes in an institute or a city. Those results can be used to develop transportation facilities (Access roads, Parking, Shuttle services, etc.) in that area.

Travel planning using smart phone-based GPS/GIS application helps develop energy efficient transport facilities and would therefore contribute to sustainable management of green energy, environment and ecosystem services.

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