DETERMINATION OF VEHICULAR TRAVEL PATTERNS IN AN URBAN LOCATION USING BLUETOOTH TECHNOLOGY

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ABSTRACT

If a major land-use change, such as construction of a large health campus would be added to an already developed urban region, it is necessary to determine the origin-destination (OD) information for vehicles going through the region. For such studies, a relatively cheap alternative is to detect vehicles with Bluetooth via readers located at the major entry-exit points around the study region. As vehicles and/or travelers use this technology increasingly during their travels, this method may result more reliable data. Though it is really simple and straightforward in detecting movements along highways, use of this approach in urban locations is more challenging. This paper focuses on developing a methodology to distinguish vehicular movements and their travel characteristics from Bluetooth data, more specifically estimation of the OD matrix and corridor travel times. The numerical results were obtained from a 90-minute test data collected on a Saturday in Ankara, Turkey. The results showed that a high rate of unmatched MAC addresses was observed as expected in an urban region. Bluetooth technology use in travel time estimation for an urban corridor was very effective,

despite the small number of MAC matching. However OD estimation process would benefit more from repeated data collection and verification via other data sources.

Keywords: Origin-Destination Estimation, MAC address, Bluetooth Technology,

INTRODUCTION

In Etlik, an already developed urban region of Ankara, Turkey (see Figure1), construction of an integrated health campus with a capacity of 3500 beds has been proposed. The conceptual design of health complex required the estimation of existing traffic conditions at 10 major intersections and 4 main arterials around the block (see Figure 2). Furthermore, it was necessary to estimate the origin-destination (OD) information for the existing travel demand. In the absence of an updated transportation master plan for the city, current travel patterns around the campus location had to be determined via non-traditional methods such simultaneous video recordings at the intersections and Bluetooth technologies. The former was mainly used to get intersection counts and traffic compositions. MAC address data from 4 Bluetooth devices located as shown in Figure 2 were analyzed to estimate OD matrix between 4 major intersections (J1, J4, J6 and J7) and 2 urban corridors, (J1-J4) and (J4-J6) with lengths of 1381m and 964 m, respectively, in the study region.

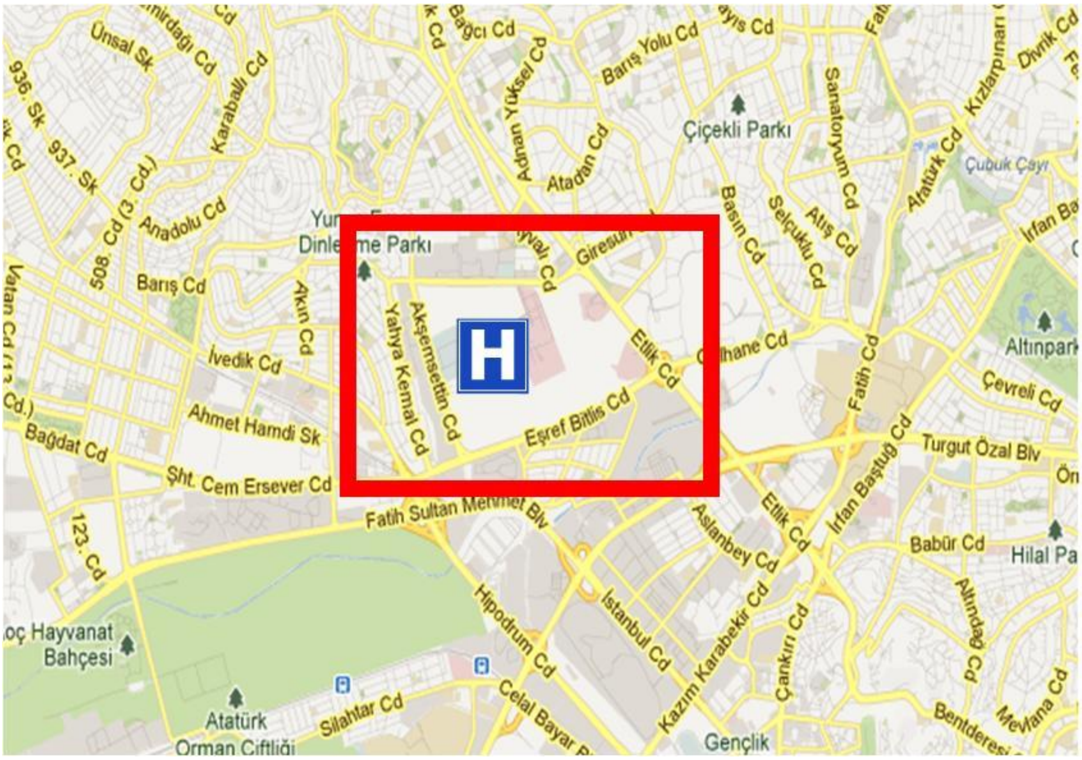


Figure 1 The block in Etlik region of Ankara, selected as the location of the new health complex

The main challenge of using Bluetooth in this study was using it to study an urban traffic region, which is an open-system. Here, “open system” refers to traffic network where all the possible traffic entry and exit points (streets, parking lot entrances, etc.) could not be surveyed. As a result the total entry and exit flows within the system do not necessarily match and could not be verified. This would reflect on the Bluetooth readings such that all detected MAC addresses would not be utilized to estimate travel patterns. Secondly, in an urban region all matched trips would not necessarily be vehicular ones; thus, a filtering approach has to be included in the methodology to the vehicular ones.

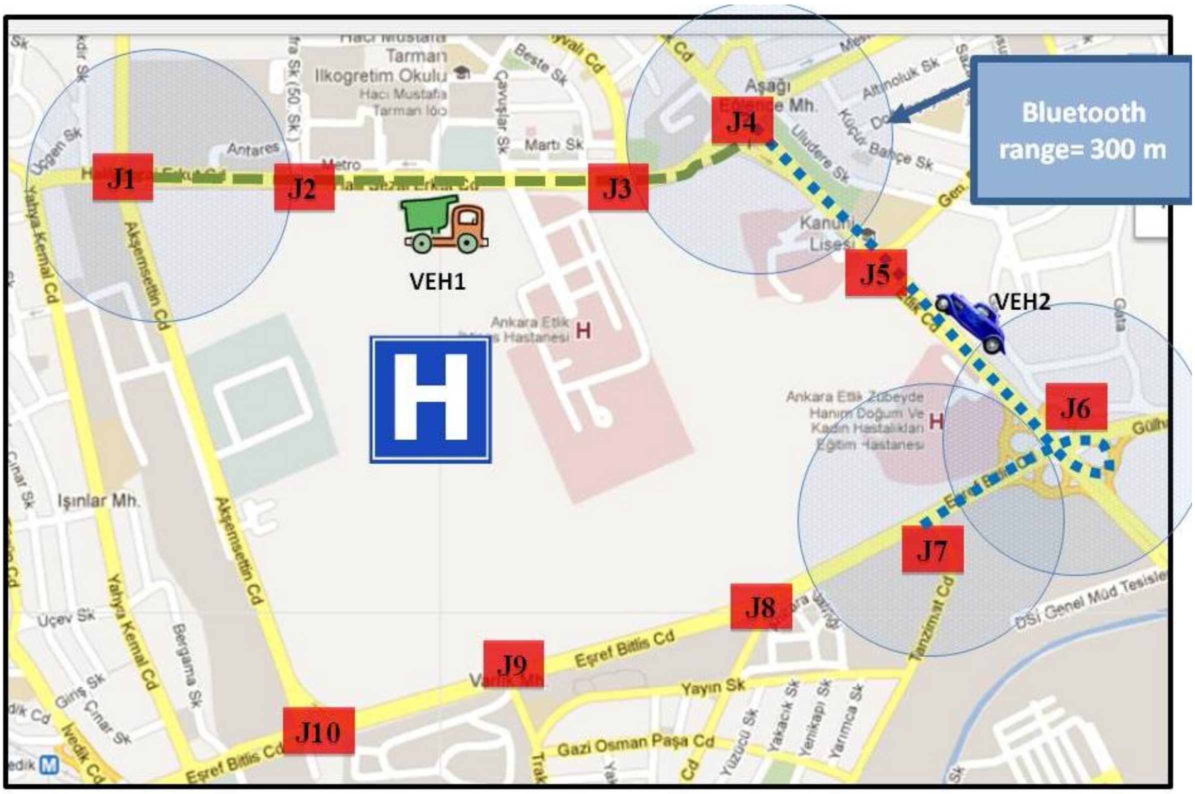


Figure 2 Locations of Bluetooth readers in the study region

RELATED WORK

Bluetooth is basically a wireless technology using a special radio frequency (2.4 GHz) to transmit data in short distances, mainly because of low power consumption and the security issues. Bluetooth protocol uses electronic identifiers, which are named Media Access Control (MAC) addresses. Bluetooth monitoring has been used in different studies in transportation field already, including dynamic traffic management applications *(1)*, Intelligent Transportation Systems (ITS) applications (*2*). Especially time-stamping and fast data transfer properties make it a good data collection alternative for real-time traffic management (3, 4, 5, 6, 7). Another interesting application area of Bluetooth monitoring focused on pedestrian movements, their travel and dwell times (*8*), and waiting times within airports (*9*).

Bluetooth Use in Transportation Studies

Travel time measurement and estimation are key issues for real-time traffic management, which took advantage of Bluetooth technology, first. To estimate travel time of a corridor, using MAC addresses and time stamps obtained from Bluetooth sensors are generally filtered and matched. Two corridor applications of this nature were presented for i) a freeway corridor in Barcelona with 11 entry and 12 exit locations (*3,10*) and ii) a motorway (with 6 MAC readers) and an arterial corridor (with 29 MAC readers) in Brisbane (*11*). As a consistency check, number of MAC addresses and total traffic volume at a station, called MAC-to-Volume ratio, was given in (*11*). Li Jie et al. (*12*) focused on the reliability of travel time measurements in urban locations by GPS-accessorized probe vehicle and Bluetooth readers. The study had two corridor segments of 600m and 935m with 1-hour data collection. The results of this rather limited control study showed that travel time estimations by Bluetooth monitoring has higher uncertainty, raising concerns about belonging of the captured MAC address to a vehicle, and possible existence of multiple Bluetooth devices in one vehicle.

Quality of travel time estimation based on Bluetooth technology was also assessed in a study by Haghani et al., in which more than 13,300 hours worth of travel time data was collected with Bluetooth; in the conclusion, this new technology was found promising method to collect high quality travel time that could be used as ground truth (*13, 14*). A similar study focused on network stratification based on the ground truth determination using Bluetooth (*15*). Looking at the issue from a reverse angle motivated some researchers to study travel time outliers on highways and arterials, measured by Bluetooth technology again (*4*).

Some other studies focused on measuring travel time via Bluetooth to assess shifts in traffic assignments due to road closures, workzones (*5*), or even signal timing optimization (*16,17*). Travel time measurements made by Bluetooth probe vehicles were used to capture detour choices for an unexpected bridge closure northwest Indiana (*18*).

Use of Bluetooth technology in OD estimation is rather new and limited, so far. In the Brisbane pilot study, Blogg et al. (*11*) estimated demand for only two OD pairs; one along the motorway and the other in the arterial network. The estimates for the motorway OD were compared with the automatic number plate recognition (ANPR) cameras and loop detector traffic volumes; for the arterial OD, control data was collected from traffic counts and a manual video OD survey at the two end stations. MAC address based estimates were found close to those with ANPR and video OD estimates, while further research on expansion methods from MAC based results was recommended. Authors concluded with the fact that MAC data collection was a cost effective way to collect OD in small and controlled networks, which could be used to supplement OD estimation in large complex networks. In the corridor study in Barcelona (*3, 10*), in addition to travel time estimation, a simulation experiment was conducted to estimate dynamic OD along an approximately 12 km corridor. OD estimation in urban locations is a more complex and challenging problem due to a) larger number of OD pairs, b) the availability and complexity of the alternative paths and c) larger number of Bluetooth device to identify all or the majority of the OD matrix. Barcelo et al (*19*) also studied the problem of Bluetooth detector layout problem for urban location studies, which showed the complexity of the OD estimation from MAC address capturing. Carpenter et al. (*20*) also focused on the issue of detector locations to estimate route specific OD matrix, which is a more important issue for urban locations with more alternative and partially overlapping paths (*18*).

Developed Methodology

The logic behind developed methodology bases on use of i) redetection capability of a MAC address at different locations in a study area, and ii) regional travel characteristics (i.e. corridor speed) to distinguish potential vehicular movements from others, and iii) travel patterns (travel routes, OD matrix and corridor travel times). The details of this methodology can be summarized as follows:

Step 1: MAC address matching: If a MAC address is read only at one reader, it is not possible to know whether it is from a Bluetooth device on a stationary point or a moving object traveling through the region. Thus, to generate travel information , the same MAC address has to be read at least at two locations within the study zone; for example, MAC address “00:0D:18:A0:0C:68” in Table 1 was observed at J1 and J4 intersections.

Table 1 Excerpts of MAC reading data from four readers

@J1	@J4
"2012-04-07 16:22:05","A0:71:A9:42:84:C2"," "2012-04-07 16:22:07","00:0D:18:A0:0C:68"," "2012-04-07 16:22:08","6C:83:36:2E:08:20"," VEH1	"2012-04-07 16:24:43","00:E0:0C:57:4B:3D"," "2012-04-07 16:24:43","00:0D:18:A0:0C:68"," "2012-04-07 16:24:49","00:2F:6D:6D:00:66"," VEH1 "2012-04-07 16:23:14","28:D1:AF:4F:F8:A1"," "2012-04-07 16:23:15","00:02:C7:F7:75:B5"," "2012-04-07 16:23:15","78:CA:04:09:C6:8D"," VEH2
@J6	**@J7**
"2012-04-07 16:19:24","60:A4:C1:70:66:12"," "2012-04-07 16:19:26","00:02:C7:F7:75:B5"," "2012-04-07 16:19:28","00:07:80:9B:8C:AB"," VEH2	"2012-04-07 16:18:46","3C:8B:FE:4E:FE:1F"," "2012-04-07 16:18:49","00:02:C7:F7:75:B5"," "2012-04-07 16:18:52","04:A8:2A:E6:C8:71"," VEH2

Step 2: Detection of vehicular movement: Observance of a MAC address at consecutive intersections reveals a movement. However, in urban locations, the movement of a device with Bluetooth technology can be attributed different occasions (potential pedestrian or bikers with active Bluetooth device) and only some of them will be related to vehicular movements. To distinguish the vehicular ones from the others, the easiest way is to get average corridor travel speeds between consecutive MAC reader locations and used an appropriate lower speed (or an upper travel time) limit to mark vehicular ones. For example, the first example in Table 1(VEH1) was observed at J1 and J4 with time stamps 16:22:07 and 16:24:43, respectively. Considering the distance of 1381 m between J1 and J4, this suggests a speed of approximately 32 km/hr, which is more likely to happen in a vehicular movement.

Step 3: OD Estimation: Looking at two consecutive Bluetooth reader data at a time does not always produce the real vehicular trip information in the region; a vehicle may follow a route visiting more than 2 reader locations, as in the example of the second vehicle (VEH2) in Table 1. So, to detect the real OD locations of a vehicular trip in the region, it is important to detect route of a vehicle with an active MAC address. To detect a trip, time stamps of a MAC address at consecutive reader locations along the possible route must be checked for continuity: if the speeds between consecutive readings are above the selected threshold, the vehicle can be assumed to have a continuous trip. If the estimated travel times are lower than the threshold, the vehicles must have stopped in between or traveled a longer route, either case suggesting trip chaining within the study zone or with an out-of-study zone destination. Only after this careful check of trip continuity in space and time, it is possible to identify possible start (origin) and end (destination) points of vehicular trips in the region. Eventually, total number of trips with the same OD points is summed up to get the OD Matrix for the locations with Bluetooth readers. The size of the OD matrix also determines the minimum number of Bluetooth readers needed in a study; thus, in OD estimation of highway corridors, it is necessary to locate Bluetooth readers at all on- and off- ramps.

Step 4: Determination of corridor travel times: As travel times for a MAC address at two consecutive reader locations is already calculated to detect vehicular movements in Step 2, analysis of all these travel times between the reader locations reveals information about the corridor characteristics, such as average corridor travel time, differences between two travel directions, variability of the speed distribution along the corridor, etc. Travel time comparisons among the weekday and weekend days may further give an idea about peak hour congestion, as well.

CASE STUDY: OD AND TRAVEL TIME ESTIMATIONS IN ANKARA

The OD matrix for the flow between the four selected intersections and travel times along the two urban corridors around the health campus block (see Figure 2) was goal of the case study. Before the Bluetooth observations, traffic counts at 10 intersections around the block with the proposed health campus were taken for two weekdays during morning, noon and evening periods. These studies showed that major in and out flows were observed at J1, J4, J5, J6, J7 and J10. Total travel time around the block was approximately 8 minutes (for 5.5 km), which corresponds to an average speed of 40 km/hr during off-peak periods. As for the non-motorized travel, while there were significant pedestrian activities at the intersections of the study areas, there was limited pedestrian movement between intersections due to long walk distances and lack of pedestrian attraction points in between. There is almost no bicycle use in the City of Ankara.

Bluetooth Data Collection

For a Saturday evening, four available Bluetooth reader devices were located in the center of the junctions J1, J4, J6 and J7, to capture the major flows expected between these points. The two major corridors that were studied,(J1-J4) and (J4-J6), and were respectively. These corridors were main arterial roads with at least 3-lanes in each direction and separated by a median.

All the devices were Class 1 type Bluetooth sensors (UD 100) from Sena Technologies, Inc., and were accessorized with stub antenna (see Figure 4) providing an approximately 300 meters range (see Figure 3). This reading range was appropriate to capture vehicle movements on roads in the study region where curb-to-curb widths and even at the grade-separated interchange laid out in an area of approximately 400mx300m. As the focus of Etlik study was to get the OD for the weekend travel demand, Bluetooth data collection and majority of the tasks discussed above were performed offline and manually. On the day of the Bluetooth application at (17:00-18:00), traffic at all the intersections was recorded again. Traffic videos were deciphered to detect different vehicle types: cars, *dolmus* (a public transit mode with minibuses), minivan/buses, large vehicles such as trucks, tankers, etc.).

Figure 3 Class 1 type Bluetooth reader device with antenna (range 300m) used in the Etlik study

MAC Address Matching results

The results of simple MAC address matching between the 4 reader logs are presented in Table 2. Out of 1917 unique MAC address readings at 4 locations, only 550 were observed at another location. To have an idea of the sampling capability with Bluetooth technology, it is helpful to see the MAC-to-volume ratios at the observation points. During the 90-mınute observation period, traffic counts and MAC address detections (for 5 minute intervals) were studied to generate MAC-to-Volume ratios as done by *(11)*. As expected, the high traffic counts at J6 resulted in also higher MAC detections, with a MAC-to-Volume ratio of 9.9%. This ratio is close to those observed at J4 and J7. There were slightly more MAC addresses detected at J1 with an MAC-to-Volume ratio of 14.4%. These rates are not much different than reported penetration rates in other studies *(11)*.

Table 2 MAC address matching statistics

Unique MAC address observations		MAC matchings with				Unmatched MAC addresses
at	**total #**	**J1**	**J4**	**J6**	**J7**	
J1	450		57	21	8	364
J4	481	48		67	8	358
J6	612	22	92		106	392
J7	374	15	23	83		253
Total	**1917**	**550**				1367

OD Estimation for Etlik Health Campus

MAC address time and location information for 550 matched cases, were further studied as described in the steps 2 and 3. Considering the 8 minutes travel time to drive around the block, a conservative upper limit of 5-minute travel time is accepted to identify potential moving vehicles along study corridors. The 5-minute threshold corresponds to minimum vehicular speed limits of 16.5 km/hr and11.5 km/hr for the J1-J4 and J4-J6 corridors. Travel times larger than this were regarded as out-of-region trips between the locations or non-motorized trips; and were eliminated from the OD estimation.

The remaining MAC address matchings were reviewed manually to seek trip continuity to get the routes of the vehicles with active Bluetooth. A total of 444 vehicle trips were identified; 394 of them were indicating travel between two reading points, and only 50 of them traveled through 3 reading points, and none were capture traveling all four station points. Finally, the estimated OD matrix was found as shown in Table 3. However, since the total numbers of trips may be misleading due to certain bias in detection and sampling process, it is more useful to derive the percent distribution of trips at origins. This way, major travel demand between J1 and J4, can be seen easily. Similarly a large flow is observed from J4 to J6: this was expected as J4-J6 is a major arterial serving bigger demand originated at the northern part of the study region destined to the city center in the south. Another major demand between J6 and J7 is parallel to the high transit demand served by the interchange; this was also parallel to the high traffic counts at the J6 interchange and J7 intersection. Though this high demand is using only the southeast corner of the study region network, any congestion at these locations can cause problems in the accessibility of the health campus by the emergency vehicles.

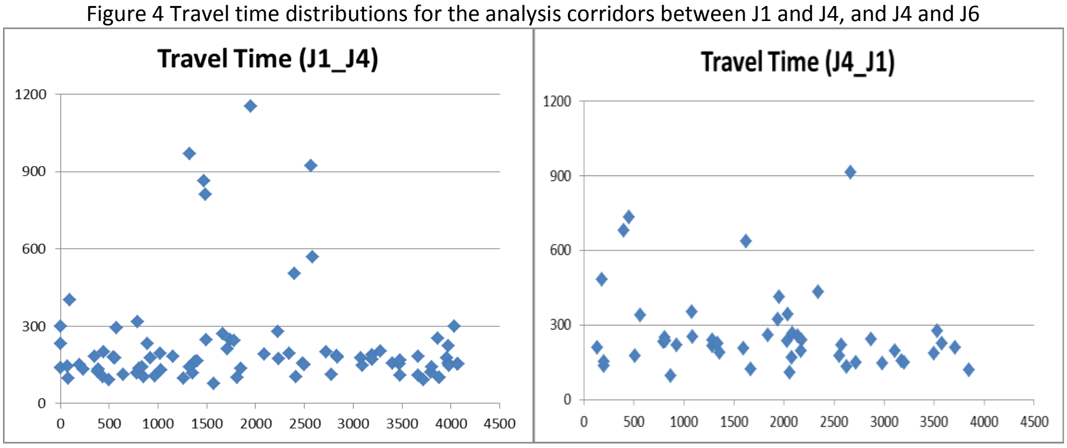
Table 3 Estimated OD matrix and Percent Distribution at Origins for Etlik Study

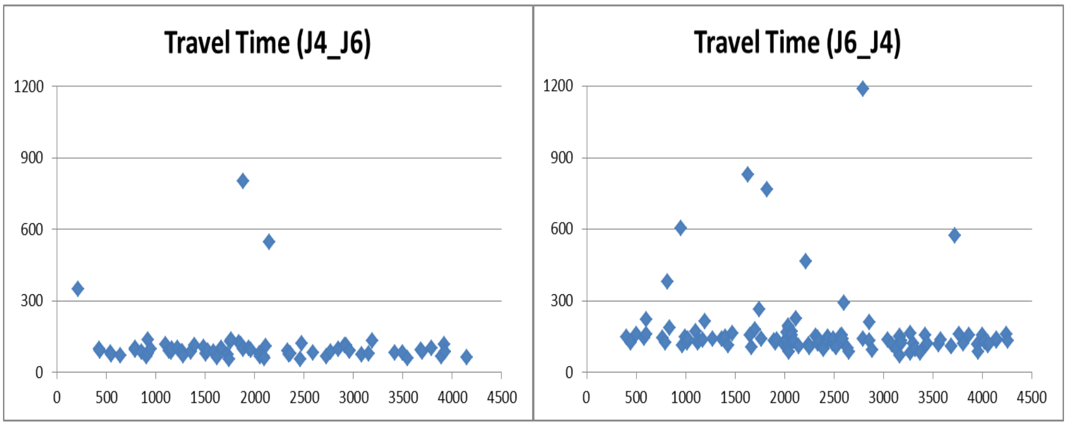
OD (by counts)						**OD (by percent distribution at the origin)**					
O\D	**J1**	**J4**	**J6**	**J7**	Row sum	**O\D**	**J1**	**J4**	**J6**	**J7**	Row sum
J1		44	15	7	66	**J1**		**67**	23	11	100
J4	35		63	8	106	**J4**	33		**59**	8	100
J6	21	69		91	181	**J6**	12	38		**50**	100
J7	6	19	66		91	**J7**	7	21	**73**		100
Column sum	**62**	**132**	**144**	**106**	**444**						

Since the study zone was an open traffic system and there were limited number of Bluetooth reader devices available, it is not totally correct to say that the first and the last observation points were the true OD points of a vehicle trip in the region. By considering the potential exit points and the outflow volumes between Bluetooth locations, it is possible to further distribute the demand among potential destinations at the trip end using the correction factors. To check potential bias based on shared-ride vehicles, total shares of larger or high occupancy vehicles (public transit buses, minibuses, minivans, etc.) at the four reader locations were calculated. The results showed that the shared-ride vehicles constituted only 5-8% (of the total intersection volumes).

The appropriateness of the 5-minute (300 seconds) threshold value can be verified by analyzing the travel times of all the selected movements between the reader locations as shown in Figure 4. The horizontal axis shows the progression of time during the 90-minute study period and vertical axis shows the travel time of the captured movements in seconds. On (J4-J6) corridor, estimated travel speeds from the matched MAC time stamps showed that majority of the movements took much less than 5 minutes. Also, the majority of the movements on (J1-J4) corridor took upto 5 minutes.

Figure 4 Travel time distributions for the analysis corridors between J1 and J4, and J4 and J6





Corridor travel time estimations

As the lengths of the two corridors are rather short, most of the travel times were less than 300 seconds (5 minutes). The average travel times along (J4→J6) and (J6→J4) directions were found as 110 and 164 seconds. Considering the 964m corridor length, this corresponds to an average space mean speed of 32 and 21 km/hr. Similarly, space mean speed of (J1→J4) and (J4→J1) segments were calculated as 23 and 19 km/hr. The higher dispersion of travel times along both directions of (J1-J4) suggests either more.

RESULTS AND CONCLUSIONS

To summarize, the strength of this method is the tracking capability of a movement including Bluetooth device over time and space. In uncongested traffic conditions, looking at the corridor speeds, moving vehicles can be distinguished from the others. However, filtering based on a simple corridor speed (or travel time) value may not be correct for peak hours. Instead, time-dependent speed thresholds can be selected to represent traffic regime during different periods. A key issue is the sampling ratio of vehicles using Bluetooth based estimations; this depends on the penetration ratio of Bluetooth technology in a region. If more vehicles are accessorized with Bluetooth devices, more reliable travel data can be generated. On the other hand, a potential problem is having multiple Bluetooth devices active in one vehicle: while this may not be a high probability in single-occupant vehicles, it can be critical in high-occupancy ones, such as transit buses, shuttles, etc. Both cases would harm estimation of OD matrices, but not corridor travel times. This can constitute a bigger problem in the future, when the use of Bluetooth devices in the vehicles and by the travelers increases drastically.

Although it is possible to get an estimate of the OD matrix between reader locations, it is hard to know the reliability of the data without any other supportive data. More repetitive observations may help to decrease uncertainty about OD matrix estimation. Validation of the OD estimation for Etlik is under process using traffic simulation and intersection traffic counts.

Despite all shortcomings, Bluetooth technology certainly presents an alternative and relatively easy-and-cheap way of travel study, even for an urban region. For larger applications trip detection must be automated to handle complex traffic networks.

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