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Travel Time Variability and Spatio-Temporal Analysis of Urban Streets Using Global Positioning System: A Review

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ABSTRACT

Travel Time estimation is largely caused by the stochastic process of arrivals and departures of vehicles and its reliability measurements considering important issues for improving operational efficiency and safety for traffic road networks. The exploration of travel time variability and spatio-temporal analysis of urban streets using the Global Positioning System (GPS) concluded that the mixed land uses and travel congestions caused higher travel times and delays. The accessibility indices were increased by increasing access points and decreasing traffic volumes. The Geographic Information System (GIS) networks can produce a model that overcomes some restrictions of accessibility indices. Different prediction models were developed to capture the main parameters related to travel time. It concluded that delay at signalized intersections in terms of stopping delay was the major parameter affecting the total travel time and total delay time of major urban streets. Travel time estimation algorithms based on speed data loop detectors induced insignificant differences when the study route was a relatively short and slow transition from free state to congestion state. Travel time results are affected by the location of sensors and their sparseness, hence estimation errors increase as detector spacing increases.

Keywords: Delay, GPS, Spatio-temporal analysis, Travel time, Urban streets.

1. INTRODUCTION

The performance of urban streets and their level of service are affected by the variability of travel time due to recurrent and noncurrent daily congestions that induce various travel patterns; and changes in traffic volumes and traffic compositions. The main objective of the transportation system is to move people and goods in the least possible travel time and minimum cost, so thinking about travel time rather than traffic volume is more meaningful to all users to evaluate the efficiency of urban networks and transportation systems. Based on the above, travel time estimates and develops models for its variability and the prediction

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of its reliability indices have been an important study topic since decades besides its benefits to engage with Intelligent Transportation Systems (ITS); Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS).

Different techniques of estimation methods using sensors have been developed to collect field traffic data of various parameters; travel time; traffic speed; traffic volume; occupancy; traffic density; headway time and vehicle trajectory collected from vehicle equipment with Global Positioning System (GPS) device. To describe the state of traffic conditions in urban streets, travel time is one of the most important measurements that can be used and generally varied with space and time which results in the complexity of traffic flow interaction and propagation. Therefore, travel time estimation is challenging because of the high cost of equipment and sensors to collect accurate field data as well as the choice of better decisions for the best model to describe the state conditions of traffic driver behavior. Traffic data variability makes difficult in travel time conclusions. Analyses of the cost-benefit have to take into consideration travel time variability **(Fosgerau, 2016)**. The route travel times can alter significantly because of the traffic congestion spread in urban streets and environmental conditions disproportionately **(Li and Gunopulos, 2017)**. In terms of accessibility and mobility, traffic congestion is a significant factor relating to travel time volume in urban streets **(Yazici et al., 2017)**. Urban transportation is affected by traffic congestions that are happened whenever the travel request overrides the capacity of the road (**Jiang et al., 2024)**. **(Ayob and Alkaissi, 2021)** concluded that the use of public transportation, legal parking, and activities distribution across regions, all contribute to minimizing traffic congestion. The three most essential factors employed in traffic management are travel time, delay, and speed **(Faghri and Hamad, 2002)**. Travel time data are significant in transportation, planning, management, and private travel **(Rahmani, 2015)**. **(Li et al., 2024)** mentioned that there is a need to take into account the variety of vehicle categories in the determination of travel times. Most currently available prediction models of travel times are intended for vehicles and failure use in truck data **(Wang et al., 2016)**. **(Mahdi et al., 2023)** proposed that route networks must be improved to achieve better interconnection especially beyond city center areas because of the land use changes. **(Ali et al., 2023)** stated that the roundabout improves traffic safety by reducing stop-and-go movement, accidents, congestion, and delays.

GPS provides huge spatio-temporal data for traffic mobility **(Li et al., 2015; Nguyen et al., 2020)**. The essential exponent in a broad range of accessibility measurements is the travel time **(Liao et al., 2020)**. Latitudes, longitudes, dates, and times measured by GPS provide vehicle information (travel times, speeds, and distances) between origin and destination **(Jiménez-Meza et al., 2013).** GPS devices are used to restore travel times and delays at peak hours that are then analyzed providing reliable measurements for origin-destination optimal route selection **(Mallem et al., 2009; Macababbad and Regidor, 2011)**. **(Wu et al., 2016)** argued GPS mobile data gathering for travel surveying and stated their benefits and drawbacks. There are many factors impacting travel times in urban areas. **(Hadachi, 2013)** condensed the geometry of the road network for correcting raw GPS data and map-matching operations. Obstacles (buildings, tunnels, and dense trees) cause GPS signal losses, so in these cases, manual data collection is necessary **(Belliss, 2004; Faghri et al., 2015)**. One of the Global Navigation Satellite Systems (GNSS) applications is the use of cellular phones to determine the user position. In addition, GNSS has been efficiently applied in transportation, Geographic Information Systems (GIS), mapping, and monitoring **(Alhamadani and Saeed, 2018)**.

The study aims to investigate and describe all previous field tests and theoretical analyses that capture the main parameters affecting travel time on urban streets. Different traffic conditions are considered; reliability index of travel time, mixed land uses, and travel behavior.

2. METHODS OF FIELD ESTIMATION

The accurate estimation of travel time data is important to gain better information about traffic state conditions and hence better management policies for traffic authorities. The indirect methods or traditional methods of travel time measurement are based on the volume, speed, and occupancy of vehicles which are collected from roadside detectors such as; Infrared detectors; radar surveillance cameras, and Inductance loop detectors **(Traffic Detector Handbook, 2006)**. However, these methods could not measure travel time directly in the real world and have limitations in capturing a wide area of traffic facilities. GPS, Bluetooth, and floating cars are modern procedures for data collection and traffic competence judgment nowadays **(Civcik and Kocak, 2020)**. Recent advances in the technology of information, such as GPS and the cellular phone provided benefits in measuring real-time world travel time and for wide areas using probe vehicles that produced highly accurate traffic data information.

There are many GPS navigation and traffic applications for Android and IOS smartphones. GPS navigation, Google Maps, and Waze applications can readily estimate travel time between the origin and destination. **(Alomari et al., 2020)** validated travel times along trips obtained from three different applications. The estimated arrival time accuracies are (70%), (57%) and (52%) for Google Maps, HERE WeGo, and Waze navigations, respectively. Google Maps and Waze predict travel times depending on distances and speeds of vehicles, without taking into account route curvature. **(Tamin et al., 2022)** applied the cubic Hermite curve to evaluate travel times as compared with Google Maps and Waze GPS applications. **(Woodard et al., 2017)** offered a method called Trip for estimating accurate travel time distribution from smartphone GPS routes in Seattle city. The proposed Trip is like Bing maps in travel time prediction.

(Alkaissi et al., 2021) developed a dependable model for travel time data gathered by Teltonika FMA 202 GPS supplied with a cable and a control button. Travel delays on urban streets can be divided into route delays and intersection delays. Deceleration, stopping, and acceleration represent total delay components. Delays along the road can be brought on by the heavy traffic through the driver who has passed the intersection and attempts to pick up speed and return to the normal vehicle speed. **(Taher and Alkaissi, 2024)** used GPS to determine travel and delay times in three urban corridors in Baghdad city. Buffer, travel time, 95th percentile travel time reliability indices were evaluated and compared on these routes. **(Alomari et al., 2022)** measured times, speeds, and positions every 3 seconds by Ultra GPS-Logger mobile in Irbid, Jordan. Travel times were evaluated depending on different reliability measures. Travel reliability implies that there is some confidence in estimating trip travel times. Links without roundabouts and signals have an impact on travel time reliability in comparison with three and four-leg intersections.

(Sihag et al., 2022) investigated the GPS data along trajectories as well as developed methods for forecasting accurate travel times in India compared with classical methods. Better prediction accuracies have been obtained by linking data with statistical algorithms: regressions, random forests, and decision trees. The classical methods are restricted because of the sensor installation requirement (cameras, induction loop, and detectors).

(Gallotti et al., 2015) presented a duration model that permits depicting travel time costs using accessibility and budget between twenty-four cities in Italy assembled from vehicle GPS data. **(Chawuthai et al., 2022)** predicted the vehicle travel times using GPS trucking (every minute) on route segments in Thailand resulting in (12.15) minutes per (100) kilometers mean absolute error. **(Puangprakhon and Narupiti, 2017)** collected data using GPS vehicles in Bangkok and proposed a procedure for travel time allocation relating to positions, times, and instant speeds.

The Bluetooth techniques are considered a promising technology for the direct measurement of travel times. Several studies from homogenous traffic conditions utilized these techniques. **(Haghani et al., 2010)** used the Bluetooth sensors as a new method and effective for data collection of travel time for the freeway segment. The resulting data were compared with floating car techniques and stated the average sampling rate of Bluetooth sensors. They showed the suitability of new technology and promising methods for measured travel time and usable for intelligent transportation system applications. **(Carrese et al., 2020)** acquired urban traffic data by Bluetooth technology and inspected various statistical models for best forecasting travel times. **(Vo, 2011)** deduced that Bluetooth technology is capable of recording travel times as that obtained from GPS probes. **(Martchouk et al., 2011)** observed travel time data from Bluetooth complementing with microwave sensors. Also, statistics are employed to find the relation between travel times and traffic factors indicating the possibility of agreeable prediction accuracy for travel time averaging and variability. **(Jedwanna and Boonsiripant, 2022)** mentioned the influences of Bluetooth penetration rates on travel time prediction on roads with tolls in Bangkok (Thailand).

The estimation of travel time algorithms based on speed data loop detectors showed insignificant differences when the travel route was relatively short and the transition from free flow condition to congestion condition was slow hence the instantaneous measurement of travel time could be adopted for its simplicity. On the other hand, the use of speed data from different lanes caused significant differences in travel time results, so speed data from the middle lane only were used during the free flow condition, and for recurrent congestion periods, speed data were used for all lanes. The performance of travel time evaluation with different spacing of detectors induced that, relative error increased as detector spacing increased and the travel time results became more sensitive to finer resolution data, sparse and locations of sensors **(Xuegang et al., 2010)**. **(Yildirimoglu and Geroliminis, 2013)** developed stochastic congestion maps for clustered data that combined the historical analysis and real-time data (based on detector data) on freeways to predict travel times at the starting time of a trip. The obtained results stated that the proposed method is suitable for promising travel time predictions under different traffic conditions. Also, **(Erkan and Hastemoglu, 2016)** stated that Bluetooth techniques were a cost-effective technology promising for the estimation of travel time for heterogeneous traffic conditions. **(Ding et al., 2019)** applied the Wi-Fi signal data to acquire traffic data information and the evaluation confirmed the feasibility of applying Wi-Fi signal data to acquire traffic information and could be used as a supplementary data source for monitoring real-time traffic states.

Focusing on the fusion of different data sources to achieve an accurate estimate of travel time was done using a large data set and probe vehicle data to develop vehicle trajectories **(Bock et al., 2020; Genser et al., 2022)** utilized different methods of data sources in Zurich, Switzerland including thermal camera sensors; processed video data with automated license plate recognition (ALPR) and Google Distance Matrix data from the particular area for travel time estimation. The obtained results of post-processed data sources were compared to the empirical ground truth measurements and found the traffic measurement with thermal camera and Google Distance Matrix API allowed the compilation of data set with true travel time values and indicated a mean absolute percentage of error between 18% -58% and a mean percentage of error for ALPR of 8%. The removable of outliers is difficult in cameras, sensors, and Bluetooth scanners. Traffic videos allow more event images. GPS travel time measurement and cumulative counts consistency seem more confident **(Jie et al., 2011)**.

3. TRAVEL TIME ANALYSIS AND PREDICTION MODELS

The estimation of travel time is a process of calculating travel time for vehicles along the route path and with known traffic conditions. On the contrary, the prediction of travel time is the process of determining the travel time for future traffic conditions. Different prediction models were developed to capture the main parameters related with. The prediction models play the main role in the development of complex patterns in various field data factors such as weather; driver behavior; profile; pavement conditions; period within a day; traffic state conditions and the selected routes by the drivers. Several studies using different techniques and variables were implied for travel time prediction models as presented in the next paragraphs.

(Alkaissi, 2017) explored the spatiotemporal distribution of travel time within different periods of a day and for different three-segment lengths of Palestine urban arterial streets in Baghdad city and the maximum peak hour of delay and travel time are presented in **Table 1**. Travel time fluctuated during the periods of study analysis from 12:00 p.m. to 4:00 p.m. Link (1) induced the maximum peak hour of delay at 1:45 p.m. -2:45 p.m. with the maximum travel time of 518.5 second and about 88% of travel time is lost due to traffic condition state on the link (1). The GPS essentials with cell phones were based on measuring the total travel time of the signalized intersections along the urban street; including acceleration, deceleration, and stopping time respectively, and the concluded percentage of travel time is presented in **Table 2** with the maximum proportion of stopping delay was obtained as compared with acceleration and deceleration delay for the studied signalized intersections. The traditional methods of measuring travel time show some difficulties and cost consuming, therefore the GPS become a new era for traffic data collection. Also, it deals with other transpoeration issues such as smart road assist management.

Table 1. Peak Hour of Delay and Travel Time.

Link (No.)	Peak Hour of Delay	Peak Hour of Travel Time
1	1:45-2:45 p.m.	1:30-2:30 p.m.
2	1:45-2:45 p.m.	1:30-2:30 p.m.
3	1:45-2:45 p.m.	1:30-2:30 p.m.

Table 2. Proportions of Total Delay at Intersections of Selected Links.

Link (No.)	Proportions of Travel Time (%)		
	Deceleration Delay	Stopping Delay	Acceleration Delay
1	12%	67%	21%
2	8%	69%	23%
3	14%	48%	38%

(Alkaissi and Hussain, 2020) extended the study of **(Alkaissi, 2017)** research to analyze the spatio-temporal travel time for Palestine arterial streets from Al-Mawal to Maysaloon Square intersection in Baghdad city. Using the GPS for 60 test runs in the north and south directions at peak period (12:00-3:00) p.m. The trajectories and travel time for the study area are presented as figures **(Alkaissi and Hussain, 2020)** for both north and south directions. The obtained results of travel time were 17.3 min. and 14.4 min. for the north and south directions, respectively. **(Alkaissi, 2022)** developed a simulation traffic model to predict the capacity of the urban street of heterogeneous traffic characteristics. A good convergence with a maximum error of 8% and below 10% induced a successful traffic simulation model utilizing VISSIM software. This technique helps reduce the team of observers in the collection field data method. Also, it captures the travel time and speed of the whole traffic journey.
Different predicted models developed by **(Alkaissi, 2017; Alkaissi and Hussain, 2020)** for studying Palestine Urban Street have been made based on the obtained field data as shown in **Table 3** and Eq. (1) .

Table 3. Travel time model by **(Alkaissi, 2017)**.

Link (No.)	Travel Time Model	R^2
1	Travel Time = 1.012 Delay Time at signalized intersection + 67.870	0.882
2	Travel Time = 1.148 Delay Time at signalized intersection + 30.464	0.936
3	Travel Time = 1.028 Delay Time at signalized intersection + 30.432	0.970

The control delay model at signalized intersections was represented by Eq. (1) with R^2 equals to 0.909 **(Alkaissi and Hussain, 2020)**.

$$\text{Control Delay Time} = 18.290 + 1.108\, Stopping\ Delay \qquad (1)$$

It concluded that delay at signalized intersections in terms of stopping delay was the major parameter affecting the total travel time and delay time of major urban streets.
(Zheng et al., 2017) developed the travel time distribution model for urban signalized roads. The main factors were the effect on travel time distribution; arrival; departure; traffic control schemes (cycle time, green split, and offsets), and variability of delay and running time. The proposed model was dependent on GPS field data and was not significantly different from field travel time distributions.
(Ahmed et al., 2021) estimated the arterial travel times comprising the speeds, stops, and delays using Wenk GPS. The traffic data were collected for 45 days for private vehicles. Two routes were selected in Baghdad city: the highway Route 1 (Bayaa intersection-Bab Al Moatham intersection) and the downtown Route 2 (Bayaa intersection-Bab Al Moatham intersection). Average travel times for these routes were observed at (a.m.) and (p.m.) peak hours in January and February 2021. Route 1 had higher travel times and delays due to mixed land uses and traffic congestion. The travel speeds for selected routes were below the speed limit (70 kilometers per hour). From the data analysis, it was found that the maximum travel times were (71 and 37 minutes) for Route 1 and Route 2, respectively. On the other hand, the traffic congestion led to (45 and 20 minutes) delay times for Routes 1 and 2, respectively.
Statistical measures can directly be used to estimate travel time variability. **(Banik et al., 2022)** studied different statistical measurements and improved a capacity buffer index to

assess the reliability of travel times gained from GPS probes and Wi-Fi. **(Alattar et al., 2021)** employed Teltonika Wenk 122 GPS device to collect traffic data in three selected urban streets in Baghdad city. The study used buffer and travel time indices for travel time reliability assessment. **(Singh et al., 2019)** studied Wi-Fi detection traffic data and noted that the index of buffer time shows travel time variations better than other reliability factors like the indices of planning time and travel time in urban streets (Chennai).

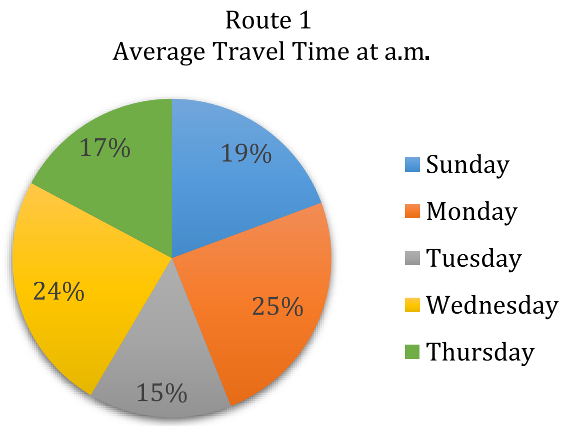
(Osei et al., 2022) used multiple linear regressions to develop a model for predicting the travel time of arterial urban streets. Data were collected by My Trucks GPS android application mounted in the vehicle. The study found that traffic and access point density, weekday trips, on street parking represent the main factors effectively increasing travel times while multiple travel lanes decrease travel time. **(Choi and Chung, 2002)** introduced the merged algorithm depending upon voting, regression, and Bayesian methods for travel time prediction in congestion trajectories. The validation of this algorithm is made by GPS and detector data in urban streets. **(Bauer et al., 2019)** described a model for errors in estimating the full distribution of path travel times in a street network. Although model errors of neighboring links are strongly correlated, the correlations dissolve with the distance increasing. **(Torrisi et al., 2017)** analyzed various statistical measures like standard deviation, congestion index, and variation coefficient force observing travel time reliability in Catania, Italy urban area. The study found experimental relationships between the variation coefficient and congestion index. **(Carrion and Levinson, 2013)** evaluated the reliability of GPS travel times by integrating three measures (standard deviation, shortened right range, and interquartile range) for model estimation. However, based on how the reliability is defined, it is statistically considerable. **(Kajalić et al., 2018)** gathered travel time data by GPS in urban streets and calculated root mean square error (RMSE) compared with some models such as the Highway Capacity Manual, Akcelik, Singapore, and Skabardonis Dowling models.

(Zhan et al., 2013) suggested a model that evaluated urban travel times in New York City using taxi GPS information and recommended dividing the whole area into small parts such as (1.5 × 1.5) kilometers to apply the proposed model. Trucks traveling long distances have less credible travel times than trucks traveling short distances **(Zhao and Li, 2022)**.

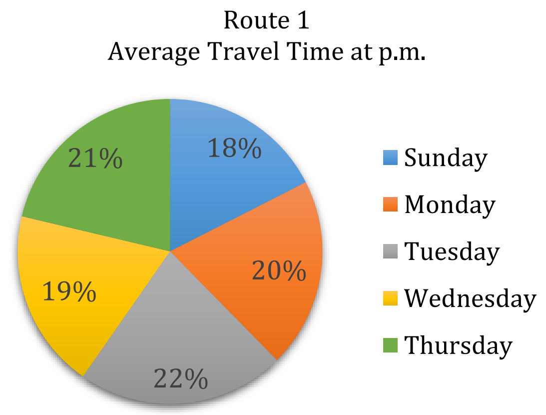
4. ANALYSIS OF TRAVEL TIME USING GIS

Geographic Information Systems, in particular, ArcGIS application contains various extensions and tools for route network analysis. The GPS traffic data can be measured in the study area, imported to Excel sheets, and then opened in ArcGIS as a shapefile or geodatabase.

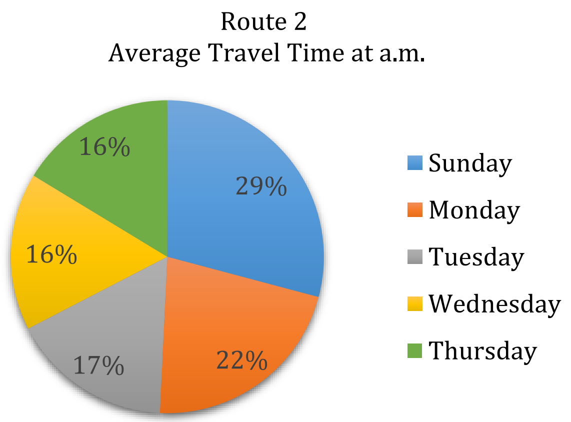
(Alkaissi et al., 2022) evaluated the accessibility levels of three selected streets in Baghdad city. The accessibility indices were calculated from travel times and running times using the gravity model equation. The three routes were classified into highway route 1 (Bayaa-Bab Al Moatham intersections), downtown route 2 (Bayaa-Bab Al Moatham intersections), and route 3 (14-Ramadan street-Bab Al Moatham intersections). The travel time data surveyed more than 45 transportation days using Wenk GPS for all weekdays excluding the holidays (from 1 January 2021 to 28 February 2021). Average travel times at (a.m.) and (p.m.) were shown in **Fig. 1** for selected routes. **Fig. 2** shows the average travel times and average running times, while **Fig. 3** displays the average accessibility indices for the three routes. The obtained data were analyzed by building spatial networks using ArcGIS software. The results showed that the average accessibility indices were 0.67, 0.58, and 0.59 for routes 1, 2, and 3, respectively. The accessibility indices are increased by increasing the access points and decreasing traffic volumes. The obtained model from GIS networks overcomes some limitations of accessibility indices. The study produced a map of accessibility indices of selected routes.



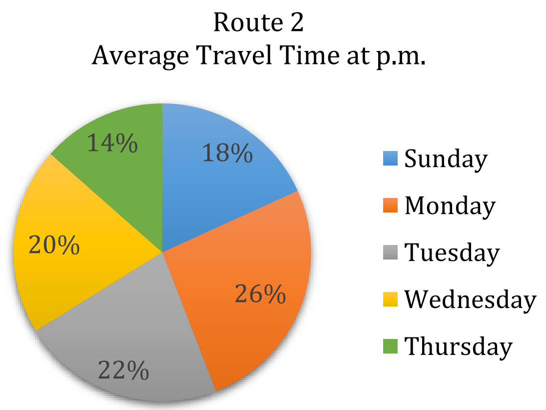
(a) Average Travel Time for Route 1 at a.m.



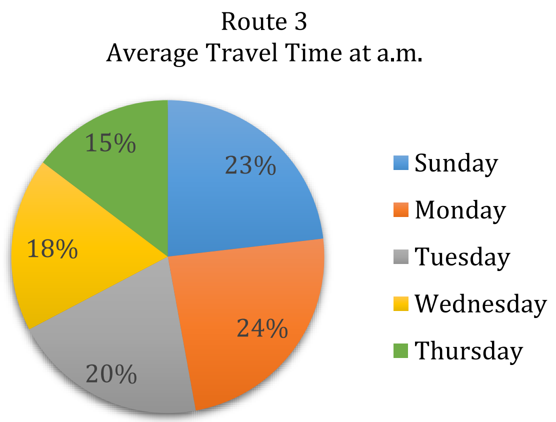
(b) Average Travel Time for Route 1 at p.m.



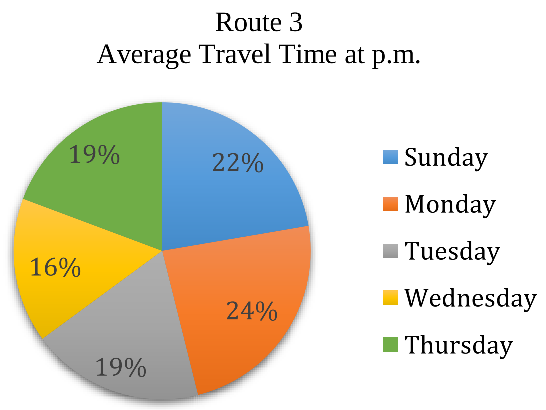
(c) Average Travel Time for Route 2 at a.m.



(d) Average Travel Time for Route 2 at p.m.



(e) Average Travel Time for Route 3 at a.m.



(f) Average Travel Time for Route 3 at p.m.

Figure 1. Percentage of Average Travel Time for Routes 1, 2, and 3.

(Susilawati et al., 2020) improved a model builder in ArcMap, ArcGIS connecting geoprocessing tool sequences to simplify the loop operations of delay extraction at signalized intersections. Travel time dispersion and more delay peaks result in reliability reduction and variability of travel times. (**Quiroga, 1997; Faghri et al., 2003)** discussed traffic data depending on GPS and GIS technologies compared with traditional methods. GPS-GIS furnishes dense, automation, and the best accuracy in speed and travel time observations. **(Mallem et al., 2009)** measured travel times and delays by GPS in Newark city and imported data tables to ArcGIS. Subsequently, ArcObject was developed by visual basic programming for representing optimal routes as a map using Network Analyst tools. Maps of travel times show origin-destination routes.
(Antwi et al., 2020) gathered traffic data in the Oforikrom region (Ghana) using GPS and then compared accessibility and travel time estimation between private and public transportation. Numerous accessibility surveys state that the selection of public transportation is simpler than selecting a private one to go to the center of activities. GPS locations then combined Google Earth and ArcGIS to produce a digital route map. This work focus on accessibility and measuring travel time of public transportation, utilizing GPS in obtained field data for evaluation and capture the route map.

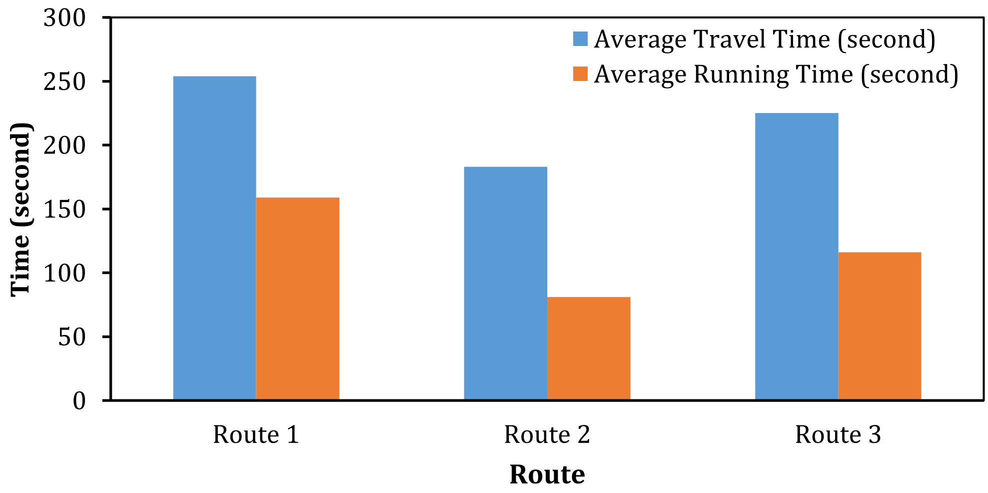


Figure 2. Average of Travel Times and Running Times for Selected Routes.

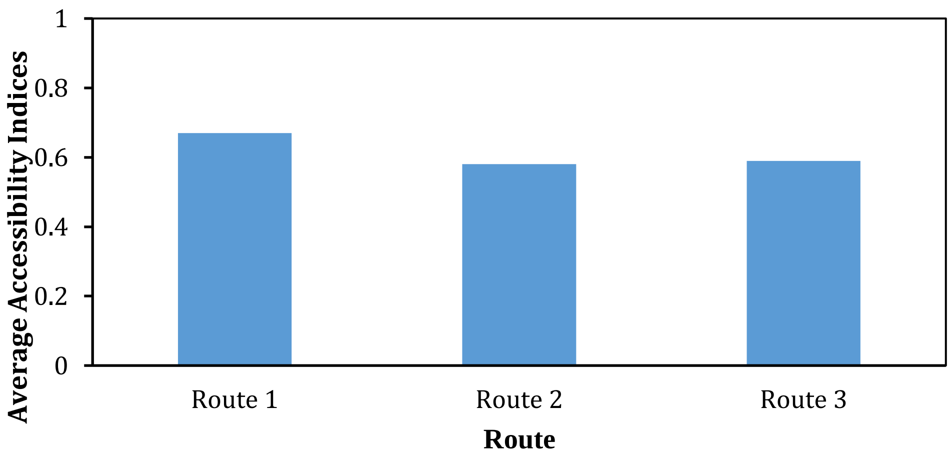


Figure 3. Average of Accessibility Indices for Selected Routes.

5. CONCLUSIONS AND RECOMMENDATIONS

Travel Time estimation is largely caused by the stochastic process of arrivals and departures of vehicles and its reliability measurements considering important issues for improving operation efficiency and safety of traffic roads networks; the following concluding remarks are given below:

1. Mixed land uses and travel congestions cause higher travel times and delays.
2. Travel times and running times can be used to evaluate accessibility indices using the gravity model equation. The accessibility indices are increased by increasing access points and decreasing traffic volumes. GIS networks can produce a model that overcomes some restrictions of accessibility indices.
3. Different prediction models were developed to capture the main parameters related to travel time. It concluded that delay at signalized intersections in terms of stopping delay was the major parameter affecting the total travel time and delay time of major urban streets.
4. Travel time estimation algorithms based on speed data loop detectors induce insignificant differences when the study route is a relatively short and slow transition from free state to congestion state.
5. Travel time results are affected by the location of sensors and their sparseness, hence estimation errors increase as detector spacing increases.
6. The employment of legal parking, activity allocation, and public transportation, all contribute to reducing traffic congestion.

To overcome the difficulties of travel time field estimation, traffic microsimulation techniques are recommended to be used and expanded for prediction models of urban streets by reducing estimation errors. Also, the determination of spatio–temporal transitions would be more significant to simulate the traffic dynamics. GPS is considered an efficient tool available for transportation applications, and provides real-time spatial and temporal measurements. Future work may be important to conduct more analysis including different types of GPS and their applications in traffic engineering.

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Credit Authorship Contribution Statement

Zainab Ahmed Alkaissi: developed the concept, aim, and idea of the research, contributed to the final manuscript, and supervised the editing of the final manuscript. Ruba Yousif Hussain: collected previous studies, interpreted results, and contributed to the editing of the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تباين زمن الرحلة والتحليل المكاني الزمني للشوارع الحضرية بإستخدام نظام المواقع العالمي: مراجعة

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الخلاصة

يرجع تقدير زمن الرحلة الى حد كبير الى العملية العشوائية لوصول ومغادرة المركبات وقياسات موثوقيتها مع الاخذ بالإعتبار قضايا مهمة لتحسين كفاءة التشغيل وسلامة شبكات الطرق المرورية وخلص إستكشاف تغاير زمن الرحلة والتحليل المكاني الزمني للشوارع الحضرية بإستخدام نظام المواقع العالمي (GPS) الى إن الإستخدامات المختلفة للأراضي وزحام النقل يؤدي الى زيادة زمن الرحلة والتأخير، وإن مؤشرات إمكانية الوصول تزداد بزيادة نقاط الوصول وتقليل الحجم المروري، ويمكن لشبكات نظام المعلومات الجغرافي (GIS) انتاج نموذج يتغلب على بعض القيود المفروضة على مؤشرات إمكانية الوصول. تم تطوير نماذج تنبؤ مختلفة لتحديد المعاملات الرئيسية المتعلقة بزمن الرحلة. خلصت النتائج الى أن التأخير في التقاطعات المسيطر عليها بالإشارات الضوئية كان من العوامل الرئيسية المؤثرة على إجمالي زمن الرحلة و إجمالي زمن التأخر في الشوارع الحضرية الرئيسية. إن خوارزميات تقدير زمن الرحلة المستندة على الكاشفات الحلقية لبيانات السرعة تتسبب في حدوث إختلافات طفيفة عندما يكون مسار الدراسة قصيراً نسبياً والإنتقال البطيء من الحالة الحرة الى حالة الزحام، وتتأثر نتائج زمن الرحلة بموقع المستشعرات وقلة جودتها وبالتالي تزداد أخطاء التقدير بزيادة التباعد بين الكاشفات.

الكلمات المفتاحية: التأخير، نظام المواقع العالمي، التحليل المكاني الزمني، زمن الرحلة، الشوارع الحضرية.