Analysis the Reliability of Travel Time in Urban Corridors in Baghdad City

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ABSTRACT

Travel-time reliability is a crucial performance measure for transportation systems. This research aims to estimate travel time and predict delay time on three routes in Baghdad city using GPS devices: Safi Al-Den Street, Palestine Street, and the Army Channel Expressway. The study was conducted northward from 7:00 a.m. to 9:00 p.m. Reliability indices for the first and second routes with signalized intersections, including buffer index, travel time index, and 95th percentile travel time, were determined. Safi Al-Den Street's buffer time index for links 1 to 3 is approximately 44.75%, 39.87%, and 39.12%, respectively. The highest travel time index value is observed in link 3 at 8.9%. Link 1 has the longest 95% travel time at 659 seconds. Palestine Street shows a high buffer time index in links 1 and 3 at around 32.39% and 24.65%, respectively. The highest travel time index is in link 3 at 6.84%, attributed to congestion from increased educational, medical, and commercial trips. The longest 95% travel time is 430 seconds in link 7. This study offers valuable insights into the reliability of travel time in urban corridors in Baghdad city, aiding transportation planners and engineers in making informed decisions on traffic management, infrastructure development, and policy-making.

Keywords: Delay of link, Buffer time index, Travel time index, Reliability, Urban street

تحليل موثوقية وقت الرحلة لممرات حضرية في مدينة بغداد

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الخلاصة

تعد موثوقية وقت الرحلة أحد أهم مقاييس الأداء لأنظمة النقل. الهدف من هذا البحث هو تقدير زمن الرحلة والتنبؤ بزمن التأخير لثلاثة طرق تمت دراستها في مدينة بغداد باستخدام جهاز **GPS**: الطريق الأول شارع صفي الدين؛ الطريق الثاني شارع فلسطين. والطريق الثالث طريق قناة الجيش السريع. تمت الدراسة في اتجاه الشمال من (7:00 صباحًا – 9:00 مساءً). تم حساب مؤشرات الموثوقية للطريقين الأول والثاني ذو التقاطعات ذات الإشارة الضوئية مثل مؤشر الوقت الاحتياطي، ومؤشر زمن الرحلة و95٪ بالمائة من وقت الرحلة المقدر. شارع صفي الدين أظهر مؤشر الوقت الاحتياطي الأعلى للمقاطع 1 إلى 3 بنسب تقريبية تبلغ 44.7%، 39.87%، و39.12% على التوالي. أطول 95% من وقت الرحلة في المقطع 1 بلغ 659 ثانية. وأنتج شارع فلسطين اعلى قيمة لمؤشر وقت الرحلة الاحتياطي في المقطعين 1و3 حيث يبلغ حوالي 32.39%، 24.65%. ويلاحظ أكبر قيمة لمؤشر وقت الرحلة في الرابط (3) وهو 6.84%. نتيجة الازدحام بسبب زيادة الرحلات التعليمية والطبية والتجارية. القيمة الأكبر 95% من وقت الرحلة المقدر في المقطع 7 والتي هي 430 ثانية، توفر هذه الورقة رؤى قيمة حول مدى موثوقية وقت الرحلة في الممرات الحضرية في مدينة بغداد، والتي يمكن استخدامها من قبل مخططي ومهندسي النقل لاتخاذ قرارات مستنيرة فيما يتعلق بإدارة حركة المرور، وتطوير البنية التحتية، وصنع السياسات

الكلمات المفتاحية: التأخير في المقطع، مؤشر وقت الرحلة الاحتياطي، الموثوقية، شارع حضري

1. INTRODUCTION

The travel time of urban arterials in urban cities significantly impacted the performance of the traffic transportation system. The research done on Palestine Street with links 1, 2, and 3 from the Al Mawall intersection to the Bairute intersection revealed that links (3), (1), and (2) have the worst reliability, with a buffer time index of approximately 78%, 64.3%, and 40% **(AL-Kaissi, 2022).** The stopping time reaches about 88% of the total control delay at some signalized intersections (Beirut and Bab Al Moatham) in Palestine Street at peak hours **(Al-Kaissi and Hussain, 2020)**. The travel time value was close to the delay value for each link along the selected three routes along the urban street in Baghdad city **(Estabraq, 2021).** Travel time reliability, as defined by the Federal Highway Administration (FHWA), refers to the consistency and dependability of travel time, both daily and during different periods of the day **(Systematics, 2005)**. The performance metrics for travel time reliability include the buffer index (BI), planning time index (PTI), and 95th percentile travel time. An examination of travel time reliability can provide insights into the fluctuations in travel duration and assist in the management of transportation systems **(Li et al., 2006)** . The study discovered that three indicators (congested hours, planning time index (PTI), and travel time index (TTI) consistently exhibit higher values on weekdays compared to weekends. This suggests that weekdays experience a greater level of congestion in comparison to weekends **(Wang**

et al., 2016). The study was conducted in the Columbus, Ohio, metropolitan region. Summary metrics were computed for each corridor direction, which included the average percentage of cars stopping ranging from 18% to 32%, the average delay ranging from 9.4 to 20.5 seconds, and the level of travel time reliability ranging from 1.23 to 2.73 **(Brenna and Venigalla, 2020)**.

The study done in Baghdad revealed that stations 8, 9, and 10 of the Baghdad elevated train project that will be constructed, which represent Route 1 in this research, indicate this project has successfully reduced travel times between Jamila and Al-Sadr City **(Hussein and Asmael, 2021).** The results of the paper done on Abi Talep Street, located west of the Army Canal expressway. The inclusion of the buffer time index results in deteriorated reliability situations. Link (2) had a buffer index of around 74.5%, while Link (4) had a buffer index of 66.6%. Link (1), which runs from the Al-Shaab Bridge Intersection to the Army Canal Expressway Intersection, also had a buffer index of 62 percent, which is parallel with link 2 in route 1 in this station, and link (3) has a buffer index of 67.7%. These presented the reliability as the worst of links (2), (4), (1), and (3), respectively **(Mahawi and Abduljabbar, 2023)**. Numerous theories and models of TTR have been established by **(Zang et al., 2022)** and many of these have been incorporated into project appraisals, transportation models, many of these have been incorporated into project appraisals, transportation models, and transport regulations using a network perspective.

The travel time depends on factors such as driving conditions, traffic, and the availability of infrastructure in urban areas. Traffic characteristics refer to the speed and number of vehicles, whereas physical characteristics refer to the width of the road, its shape, and the regulations in place for crossing. Reliability has been taken into consideration as a key indicator of transportation system performance and service quality **(Mahawi and Abduljabbar, 2023). (Al-Jabbar et al., 2011)** conducted a study on the factors contributing to congestion and delays that impact the dependability and reliability of travel time in the streets of Baghdad city, one of the significant factors identified was the unregulated entry of automobiles following the conflict in 2003. Reliability is a form of travel time that drivers are unable to predict. In the context of passenger traffic, the standard deviation was altered due to the reliability measure **(Afrin and Yodo, 2020). (Yu and Choi, 2012)** introduced the concept of uncertainty in traffic data as a comprehensive measure of overall performance to explain the variability of route time, which is now no longer reliably expected. Reliability travel time is a measure of quality used to evaluate a road, highway, or road section, estimating the number of trips that fail or achieve a given standard of success **(Pankaj, 2019)**. It can be expressed using metrics such as on-time or percentage failure, based on the minimum goal or journey time **(Jeekel, 2010)**. Drivers are typically conscious and plan to deal with daily congestion, but sudden congestion from random events is generally unpredictable **(Hellinga, 2011)**. Reliability is important for network users and can influence user behaviour, including the choice of destination, route, time of departure, and mode **(Genter et al., 2008). (Rakha et al., 2004)** employed the determinist queuing model, simulations of shock waves, the stochastic delay model, and the stationary state's stochastic delay model. Several researchers, including **(Dey and Biswas, 2011; Arasan and Koshy, 2005),** have found that the speed measures of traditional car methods are unreliable. The analysis results reveal that the Ahmed Urabi roundabout runs under the level of service F, with an average control delay of 300 seconds per vehicle during peak hours. **(Al–Azawee, 2018). (Najwan, 2023)** found that the simulation results have verified that the Dual-Spike Neural Networks (DSNN) model can improve the accuracy of traffic classification by 5%. The efficacy of the priority model has also been proven in relation to round-trip time (RTT). In

addition, another study found a good indication of the convergence between simulated and field data is a maximum error of 8% and below 10% for traffic flow rate, and that provided a successfully simulated model by VISSIM for urban traffic behavior **(AL-Kaissi, 2022)**. The study examined the patterns and distribution of passenger flow on weekdays and weekends at bus stops in both peak and off-peak hours in Sulaimani city. The study results indicate that the number of passengers on Thursday is more closely comparable to the number of passengers on Friday, as opposed to the number of passengers on Wednesday **(Salih et al., 2020)**. Another study in Sulaimani found that both VISSIM and SIDRA predicted a higher capacity compared to the HCM2010; in general, accurately predicting capacity value relies on factors such as the flow of looping traffic, the exiting traffic flow, driver behavior, and variations in the road's geometry **(Ali and Majid, 2023)**. Several studies **(Wang et al., 2004; Zhu, 2007; Wang et al., 2005)** have created models for GPS acceleration or deceleration. These models specifically focus on the leading vehicle in a line under optimum conditions. **(Abma, 2014)** found that the second model of the buffer time index with a median time of travel will always be equal to or greater than BTI, but never less than BTI. **(Rohde and Schwartz, 2019)** found that the canyon effect is a notable challenge in large urban areas, where tall buildings and landscape characteristics can disrupt and reflect signals. Travel time, which is measured as the time between two locations, is a widely recognized and shared metric among transport engineers, designers, and customers **(Lopez, 2018)**. The transition in demand and supply on metropolitan arterial roads affects transport quality and journeys regularly **(Taylor and Somenahalli, 2010)**. The most widely applied theory of travel time uncertainty modelling is based on probability, allowing reliability analysis of links, routes, and network travel times **(Zheng et al., 2017).** Many studies aim to improve urban street performance by analysing daily, average daily travel time, weekly, and seasonal travel times **(Delhome et al., 2017).** The major factors that determine an increase in noise level are traffic volume and vehicle speed **(Ali and Albayati, 2022).**

The major aims of this study are to estimate the travel time of two urban streets in Baghdad, namely Safi Al-Den Street and Palestine Street, analyse the factors contributing to the delay at signalized intersections on these two routes, and estimate the reliability indices, such as the buffer time index, travel time index, and 95th percentile travel time for three selected routes.

2. THE STUDY AREA

The study area in Baghdad city, in the Al-Rusafa area, is where an elevated train will be built. It will have a length of 20 km and a width of 10 m, with 14 stations. Each station will be 100m long, 24m wide and 24m high [Ministry of Transportation]. Stations 8 and 9 are located in Jamila, a commercial region, and Al-Sadr City, one of the most populated regions in the city. The train will pass through Safi Al-Den Street, specifically three stations: 7, 8, and 9 (see **Fig. 1). Fig. 2** shows the three routes chosen for this study. Route number 1 is Safi Al-Den Street, which passes through three signalized intersections. It consists of three links, spanning a length of 2.6 km, from 83 Square to the AL-Mawall intersection. Route 2 is Palestine Street, one of the main and most important routes in Baghdad city. It is surrounded by a diverse range of land uses, including residential, commercial, and educational areas. This mix of land uses creates a high demand for transportation, resulting in a large number of daily trips. This route passes through eight signalized intersections and consists of seven links, spanning a length of 8.3 km, from AL-Mawall Intersection to Maysalon Square. It is situated to the east

of Baghdad and runs parallel to Route 3. Route 3 is the Army Channel Expressway, which spans a length of 8.3 km and consists of four links that pass through two tunnels.

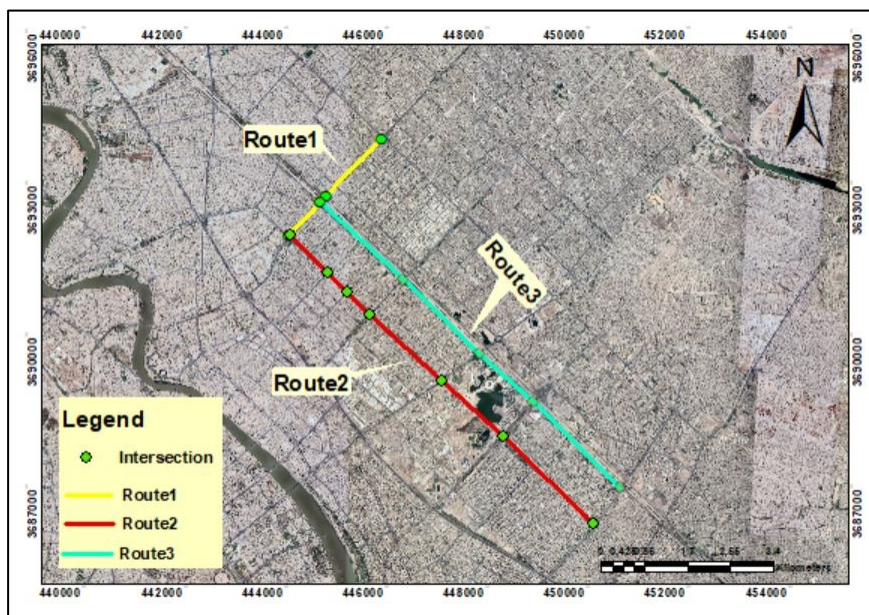**Figure 1**. Location of Baghdad elevated Train passing through route 1 (Safi AL-Den street)

Figure 2. Links for Route 1 (Safi AL-Den Street), Route 2 (Palestine Arterial corridors) and route 3 (Army Chanel expressway)

3. METHODOLOGY AND DATA COLLECTION

3.1. Methodology of the study

The methodology for data collection in this study involved recording field control delay and travel time for selected links, which were then stored in Excel sheets. Engineers from the integrated services corner were able to access the server using specific login credentials after collecting the data using the Global Positioning System (GPS). A designated test vehicle

was used for the field data collection, allowing the determination of travel times for the routes and the necessary sample size to be acquired. **Figs. 3 and 4** display the travel time of segments, travel time of links, total delay at intersections, and delay of links during peak periods in the northbound direction for Safi Al-Den Street. These values represent the average travel time during morning peak periods over two months. Similarly, for route 2 (Palestine Street), **Figs. 5 and 6** illustrate the travel time of segments, travel time of links, total delay at intersections, and total delay of links during peak periods in the northbound direction, with values representing the average travel time during morning peak periods over two months. GPS devices were connected to the user's account to provide comprehensive data on the test vehicle every ten seconds, including travel time, speed, coordinates, position, vehicle condition, and fuel consumption. **Fig. 7** depicts the output data of the GPS device for the three selected routes.
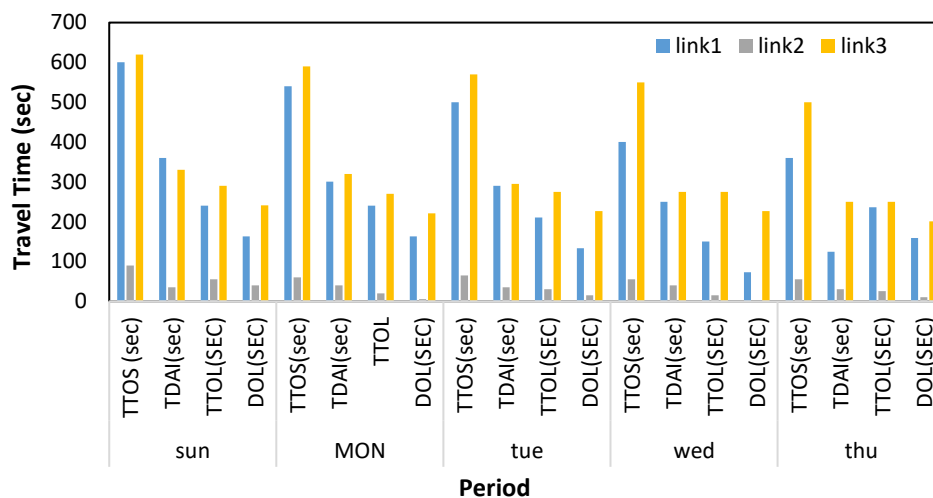
Figure 3. Travel Time (sec) for North Direction in links (1-3) for Safi AL-Den Street at morning peak period 8:00 -9:00a.m.
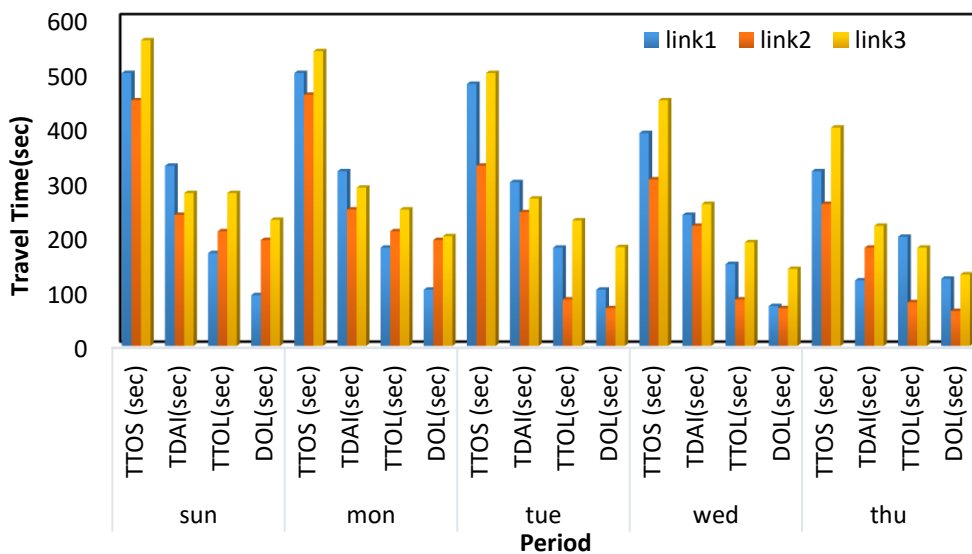

Figure 4. Travel Time (sec) for North Direction in links (1-3) for Safi AL-Den Street at evening peak period 2:00 -3:00 a.m.
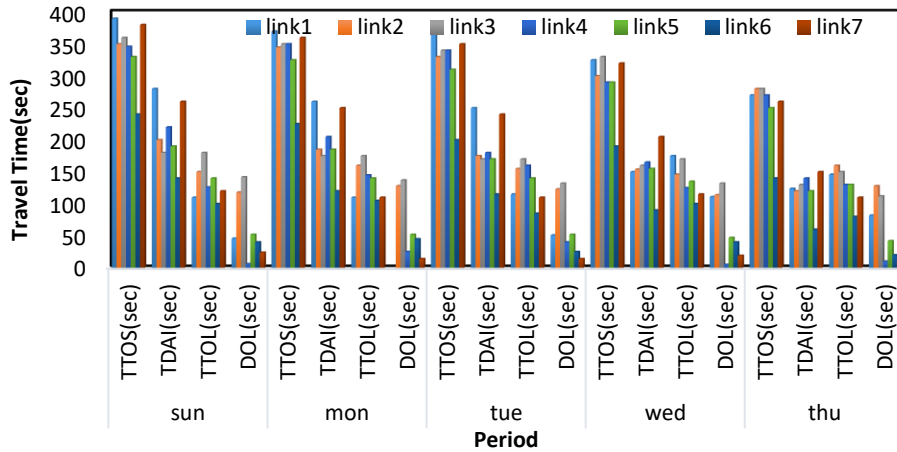
Figure 5. Travel Time (sec) for North Direction in links (1-7) for Palestine Street at morning peak period at 8:00-9:00 a.m.
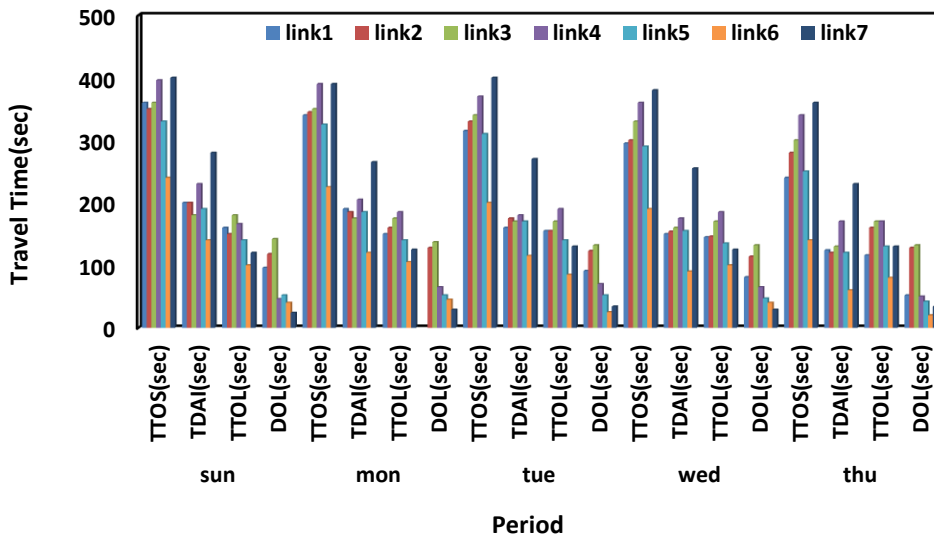

Figure 6. Travel Time (sec) for North Direction in links (1-7) for Palestine Street at evening peak period at 2:00-3:00 a.m.

3.2 Data Collection

Field data were collected for the selected routes (1), (2), and (3), respectively, considering local traffic conditions and congestion patterns. The data collection times were determined based on morning periods from 8:00 a.m. to 1:00 p.m. and evening periods in the north direction from 2:00 p.m. to 9:00 p.m. The field data was collected over a two-month period, from 1/11/2022 to 1/1/2023. To explore the variations in total travel time and delay times during peak hours, the chosen periods were from 7:00 a.m. to 9:00 p.m., focusing on the peak periods from 8:00 a.m. to 1:00 p.m. in the morning and from 2:00 p.m. to 9:00 p.m. in the evening for each link in the selected site of the three routes. To determine the peak hour in the north direction on the two arterial routes, GPS measurements provided by a cell phone were used to compute travel time. 50 test runs were recorded for the north direction on each selected route.
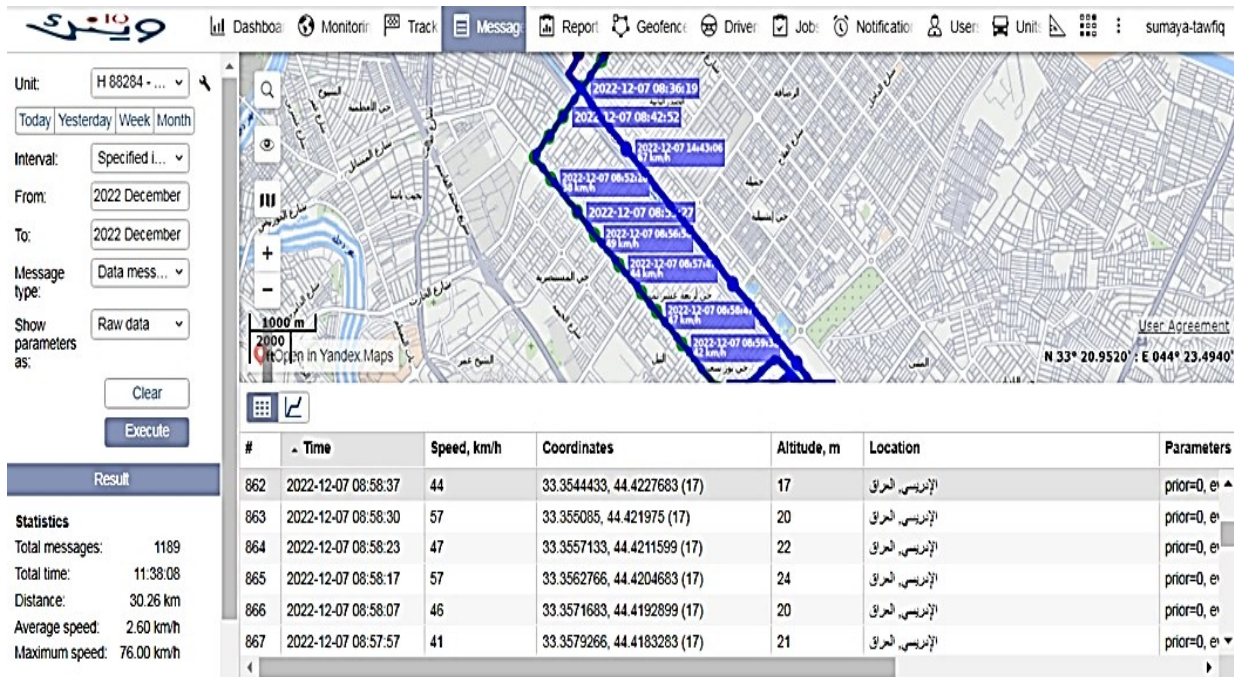
Figure7. Output data of GPS device for three routs

4. RESULTS AND DISCUSSIONS

4.1. Analysis of Travel Time

In a research study, traffic congestion significantly influenced travel times during peak hours at signalized intersections for routes 1 and 2. **Figs. 8 to 10** illustrate the travel time, total delay time at intersections, and delay of each link for the selected northbound route.
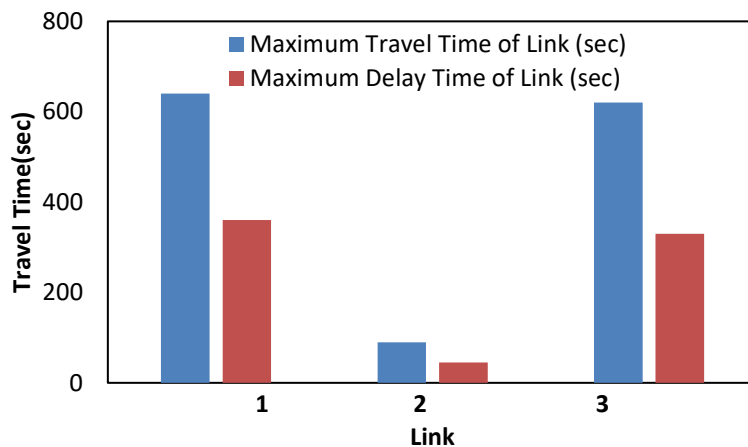

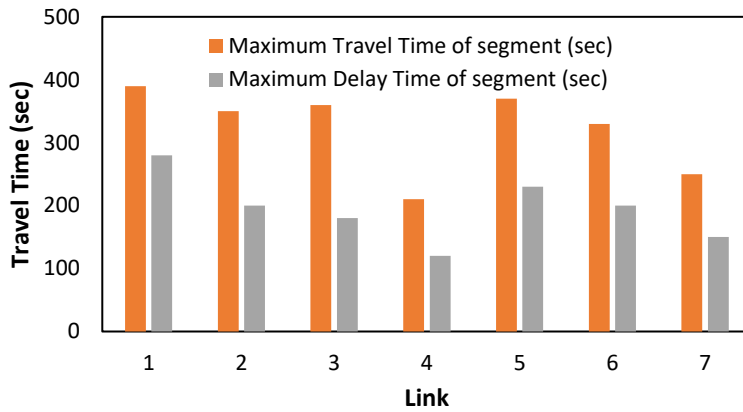**Figure 8**. Maximum Travel Time and Delay Time for Safi AL-Den Street North Direction

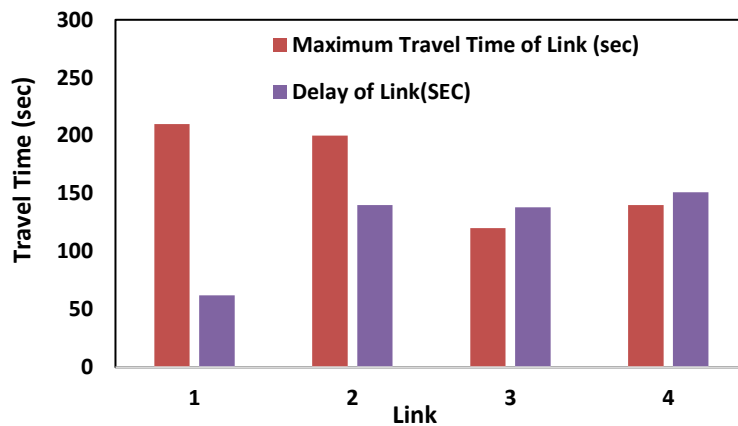**Figure 9**. Maximum Travel Time and Delay Time for Palestine Street North Direction

Figure 10. Maximum Travel Time and Delay Time for Army Channel Expressway North Direction

The total intersection delay comprises deceleration delay, acceleration delay, and stopping delay at the specified site across 50 samples. Notably, Route 1 in the north direction, particularly Link 1 from 83 Squire to the Army Channel Expressway intersection 1, exhibited the highest travel time value of 640 seconds, with an intersection delay of 360 seconds. This spike can be attributed to heavy traffic congestion during peak morning hours, specifically at 8:00–9:00 a.m., influenced by densely populated areas like Talebia, Binok, Jamila, and Al-Sadr City. Approximately 56% of travel time is lost due to these congestion issues. Similarly, Route 2 in the north direction experiences congestion, with the highest travel time and delay time observed in Link No. 1 from the AL-Mawall intersection to the Bab Al-Muadham intersection during the peak hour at 8:00–9:00 a.m. Here, travel time peaks at around 405 seconds, while the intersection delay reaches about 290 seconds, constituting 71.6% of the total travel time lost due to congestion in the Bab Al-Muadham area. Additionally, travel times on Palestine Street in the North Direction have decreased by approximately 16% compared to 2017, particularly in Link 1, aligning with findings in **(Al-kaissi, 2022)**, attributed to the removal of a checkpoint on this route. Route 3 in the north direction experiences delays, notably in Links 1 and 2 at 3:00 p.m., totalling around 210 sec, 200 sec, primarily due to a significant influx of trucks (approximately 20%) from the Jamila area. Comparing Route 2 (Palestine Street) to Route 3 (Army Channel Expressway) for the same distance (8.3 km), Route 2 takes 2040 seconds, while Route 3 takes about 790 seconds for maximum travel time. Consequently, intersection delays account for 61.2% of the total travel

time lost. The overarching issue is the heavy traffic congestion on Baghdad City's urban streets due to urban expansion, necessitating the implementation of modern transportation projects to alleviate pressure on urban roads and reduce travel time delays.

1. If the Baghdad Elevated Train project is constructed, it will alleviate congestion along Route 1 (Safi Al-Den Street) and significantly reduce travel times. The efficient operation of the Baghdad Elevated Train ensures short stops at each station, with an average duration of approximately 90 seconds, resulting in a total travel time of around 270 seconds along this route encompassing three stations.

2. Another project scheduled for implementation along Route 2 is the bus rapid transit (BRT) system **(Ministry of Transportation)**. This initiative is designed to reduce travel time and minimize delays within this corridor. To address congestion and intersection delays on both Route 1 and Route 2, the most effective solution is the deployment of intelligent transportation systems (ITS). These systems have the capability to improve traffic flow and alleviate congestion.

3. Addressing delays occurring at specific points along links No. 1 and 2 on Route 3 can be achieved through enhancements to pavement quality. Additionally, to prevent traffic jams resulting from accumulated rainwater within tunnels along Route 3 during adverse weather conditions, the implementation of improved drainage systems and regular maintenance measures is imperative.

4.2 Reliability Measurement

The variation in travel time affected the measurement of its reliability, resulting in additional arrival time and associated costs. Furthermore, the reliability of travel time is crucial for enhancing road user safety and quality of life by minimizing travel delays. It also serves as a valuable indicator for improving the overall operations and management of the system. Eq. (1) presents the buffer time index measure **(Lomax et al., 2003)**.

$$\text{Buffer Time Index (\%)} = \frac{\text{95th \% travel time} - \text{Average travel time(sec)}}{\text{Average travel time (sec)}} \qquad (1)$$

The buffer time index is expressed as a percentage, with this value increasing as reliability decreases. Travel time index measure is explained as shown in Eq. (2): **(Pankaj, 2019)**

$$\text{Travel Time Index } = \frac{\text{Average Travel Time}(sec)}{\text{Free Flow Time}(sec)} \qquad (2)$$

Figs. 11 to 13 demonstrate the reliability measures of the buffer time index (BTI), (95%) percentile travel time, and travel time index (TTI). For links (1) to (3) in the north direction along Safi Al-Den Street, they will have a BTI of 44.75%, 39.87%, and 39.12%, respectively. The highest value was observed in Link 1 due to increased education and commercial trips. The 95th percentile travel time for links (1-3), which represents the additional delay experienced on each connection, is 659, 87, and 611 seconds. Link (1) has a higher value for the 95% travel time.

Additional time can be added to the free travel time to determine the average travel time needed to traverse the specified links during peak periods. The travel time index values for route 1, links (1 to 3) in the north directions are increasing by more than 1.0. This means that the travel time on Route 1 links (1-3) takes about 4.55%, **4.**22%, and 8.96% of the free travel time. Due to the significant rise in the number of educational and business trips, link (3) displays the greatest variation in TTI at 8.96%.

Figs. 14 to 16 demonstrate the reliability measure of the buffer time index, (95%) percentile travel time, and travel time index. For links 1 to 7 in the north directions along Palestine Street, it will have a buffer time index of 32.39%, 20.91%, 24.65%, 23.17%, 21.32%, 11.61% and 23.56%. The largest value is in Links 1, 3, 7, 4, 5, 6, and 6, respectively, due to increased education, medical, and commercial trips.

The 95th percentile travel time for the links (1–7) in this route represents the additional delay experienced on each connection. The delays are as follows: (358.5, 199.5, 359, 395, 330, 250, 430) sec, with the longest 95% travel time at 430 seconds in link 7.

The travel time index values for this route (links 1–7) in the north direction are increasing by more than 1.0. This means that the travel time on links (1–7) takes about 4.71%, 4.69%, 6.84%, 2.67%, 3.64%, 3.73%, and 3.76% of the free travel time. The greatest variation in travel time index is observed in link (3), which is 6.84%. Because of congestion, there is an increase in the average travel time and an increase in the travel time index, contributing to the low reliability of this link.
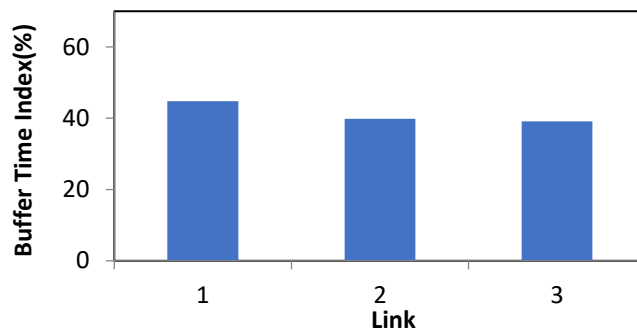

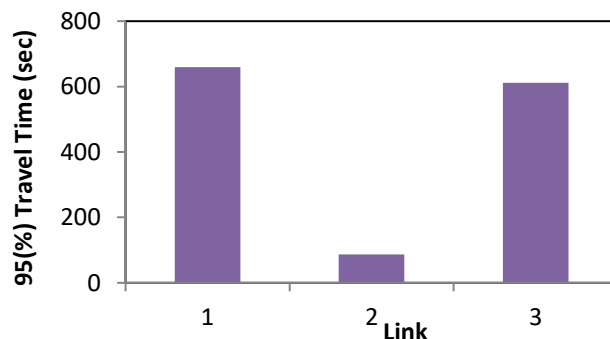**Figure 11.** BTI (%) for Links (1-3) for Safi AL-Den Street north Directions

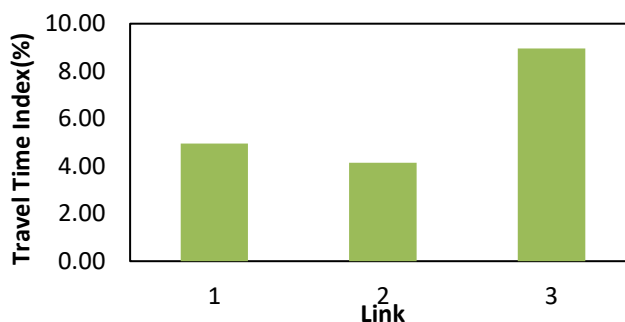**Figure 12.** 95% Percentile Travel Time for Links (1 -3) for Safi AL-Den Street north Directions

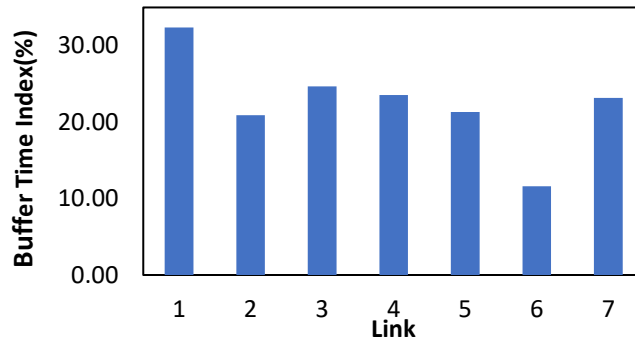**Figure 13.** TTI (%) for Links (1-3) for Safi AL-Den Street north Directions

Figure 14. BTI (%) for Links (1 to7) for Palestine Street north Directions
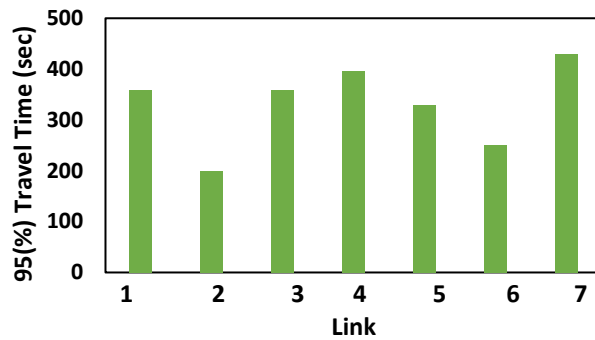

Figure 15. 95% Percentile Travel Time for Links (1-7) for Palestine Street north Directions
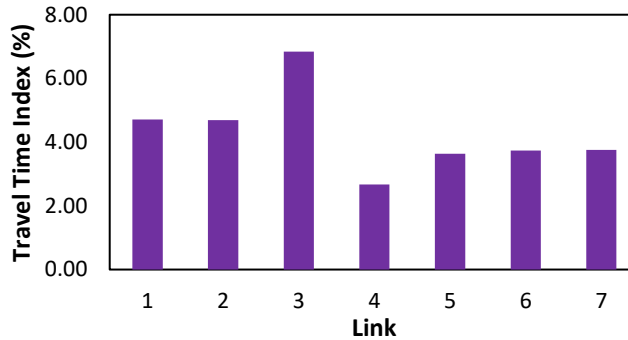

Figure16. TTI (%) for Links (1 -7) for Palestine Street north Directions

5. CONCLUSIONS

It can be inferred from the following points:

1: Route 1, Safi Al-Den Street, experiences the most significant delay in the north direction during peak hours (8:00–9 a.m.) on Link 1, accounting for approximately 56% of travel time.

Moving on to Route 2, Palestine Street, the highest travel time and delay occur in the north direction on Link 1. This is primarily due to the significant number of trips to the Bab Al-Muadham area during the morning peak hour (8:00–9:30 a.m.), leading to a delay of approximately 71.6% of travel time.

Lastly, on the third route in the north direction, delays in travel time are observed on Links 1 and 2 during peak periods (3:00–4:30 p.m.), amounting to approximately 210 sec, 200 sec.

2: The most significant deviation in buffer time index is evident in the northward direction for link 1 on Route 1 and for link 1 on Route 2, standing at 44.7% and 32.39%, respectively. The most substantial fluctuation in travel time index is noted in Route 1 (Safi Al-Den Street) northern direction link (3), calculated at 8.96%. Similarly, the most notable fluctuation in travel time index is seen on Route 2 (Palestine Street) in the northern direction at link (3), which was determined to be 6.84%. It is essential to highlight that the link with the highest travel time index experiences congested conditions, leading to an escalation in average travel time and an increase in the travel time index, which contributes to the low reliability of this link.

3: The travel time delay on Route 3, also known as the Army Channel Expressway, is attributed to delays occurring at specific points along links No. 1 and 2. This includes the presence of two tunnels, where delays can be experienced due to expansion joints in the pavement within these tunnels.

4: During inclement weather, particularly on rainy days, congestion builds up on Route 3 because of rainwater pooling in the tunnels.

5: There is a traffic jam accumulating on route 3 (Army Channel Expressway) in the north direction during peak hours (3:00–4:30 p.m.) due to the significant volume of vehicles (20%) traveling through it, originating from links 1 and 2 on route 1, Safi Al-Den street in the north direction (Jamila commercial area).

NOMENCLATURE

Symbol	Description	Symbol	Description
DOL	Delay of link (sec)	TTI	Travel time index (%)
PTI	Buffer time index (%)	TTOS	Travel time of a segment (sec)
TDAI	Total delay at intersection(sec)	TTOL	Travel time of link (sec)

Credit Authorship Contribution Statement

Shaymaa Hasan Taher is responsible for collecting data, analyzing and interpreting the writing.
Zainab Ahmed ALKaissi supervised, developed the research aim and concept, reviewed, and edited the 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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