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EVALUATION OF TRAVEL TIME RELIABILITY IN URBAN AREAS USING MOBILE NAVIGATION APPLICATIONS IN JORDAN

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This study aims to assess the Travel Time Reliability (TTR) in urban areas in Irbid city, Jordan, using a mobile application (Ultra GPS Logger), which retains the current location, speed, and time every three seconds. The study evaluated the TTR at the Origin-Destination (OD) level and the segment level. Each OD was divided into several segments with different interruption types to determine which segments have the lowest reliability and the most extended delay. The evaluation was based on several measures according to the Federal Highway Administration (FHWA), such as the buffer time, Buffer Index (BI), Travel Time Index (TTI), 95th percentile, standard deviation, and Coefficient of Variation. Chi-Square test for independence was carried to study the association between the period during the day, day of the week, and section type with the BI Level, and other combinations. Results showed that the normal sections, without traffic signals and roundabouts, had a significant effect on TTR compared with 3-Leg intersections, 4-Leg intersections, and roundabouts. Results also confirmed that trips reliability does not mean there is no delay or congestion, but there is some certainty in travel time prediction for a specific route and journey.

Keywords: travel time reliability, prediction, navigation, origin-destination

1 INTRODUCTION

Global Positioning System (GPS), tracking devices, and travel time reliability have increased attention in the last decades. One of the most critical network performance indicators in the traffic operation field is travel time reliability (TTR) and operating speed. TTR is an increasing concern for travelers, shippers, and delivery companies. It helps authorities and decision-makers know whether the provided services are acceptable to users [1, 2], if users are satisfied with the services they get and if it is a contributing factor in users' mode choice. TTR is a crucial element in determining the level of service (LOS) of a roadway. Another critical performance factor is trip length, which is easily defined as the time required to travel from a point to another in the network; it plays a significant role in transportation planning. Developers also use information about trips from an origin to a destination to estimate impact fees and validate the quality of service related to the transportation network.

GPS technology makes the procedure of collecting data more accessible, cheaper, and more efficient. The travel time for the same route varies from one time to another significantly due to the dynamic change in traffic demand [3]. So, it can be said that any trip could be reliable if its recorded travel time has less variation across days. The importance of real-time travel time estimation is clear in helping travelers to understand better the traffic status in the network, which contributes to defining the available trip routes, choosing the best one, and as a result, saving travel time. Some could ignore such information and use his/her own experience based on weather conditions, time of the day, day of the week, and special events. Also, many travelers could have significant problems, resulting in being late to reach their destination. Travel time and TTR are two terms that could be used to identify or describe the traffic status, affecting travelers' mode choice. Moreover, TTR is one of the most critical factors that can be used to validate the transportation system's performance.

Many studies showed that travelers may not always prefer to use the shortest route among several alternatives because of the lack of information about traffic data and traffic systems' uncertainty issues [4]. Due to the rapid growth of population and vehicular traffic in developing countries, such as Jordan, pedestrian-vehicle conflicts are increasing tremendously; besides, there is a dire need for on-street parking and for establishing a relation between such types of parking with the traffic flow. TTR has several definitions depending on users' and agencies' perspectives. Chen et al. [5] defined TTR as an essential factor for highway performance, as it describes the homogeneity in the range of travel time for the same trip within specific criteria. Hamdar et al. [6] defined it as a critical element for travelers to plan for their departure time as well as for the route choice decision. They also stated that it is crucial to study the travel time distribution to better estimate TTR through several measures. Soza-Parra et al. [7] said that TTR is an indicator of the quality of services provided for users. It serves to evaluate the satisfaction of commuters for the same trip among several days. Travel time research have been excessively carried out on freeways but rarely done in urban areas [8]. Woodard et al. [9] investigated the TRR using smartphone GPS data in the Seattle, Washington State, United States. Approaches have been made to predict the reliability of road network routes' travel times based on mobile phone data, which is fast and easy to use. The road network in the Seattle metropolitan area has been shown to be accurate. Chen et al. [10] examined TRR as a measure of service in Los Angeles, California, United States. They showed that real data could be used to develop reliability measures by considering the impact on travel time of various incidents, weather, planned lane closures, and special events as an avenue for improvement. Also, they proposed using changeable message signs (CMS) to recommend alternate routes and provide drivers with travel time estimates.

Unreliable travel time and delay estimates, especially during peak hours, are viral and expected in vehicle movements worldwide. TTR includes the reliability in vehicle trips, goods movements, and air travelers. As defined by Federal Highway Administration (FHWA), TTR is a term used to describe the consistency or dependability in travel time, which is measured from one day to another and/or across different times of the day [11]. In general, planning for trips is an essential step for travelers, especially during peak driving times. Also, it is a popular way to avoid being confused because of delays and unexpected traffic incidents. Hence TTR measures emerged instead of the last thought about average travel time, which is away from accuracy. TTR is a crucial indicator of the variation in travel time of the same trip during different times in the day or different days in the week. One of the most common TTR measures is the 90th or 95th percentile, which is easy and straightforward to be understood for the public; it means that 90% or 95% of the travel time lies below this value [12]. Wakabayashi and Iida [13] found that improving travel time accuracy under traffic management involved three key phases: clarifying the importance of road network management and construction, identifying the propagation mechanism of OD and link flow variation, and performing a reliability analysis before and after traffic management introduction.

Many travelers may not always take the shortest route when deciding to make a trip due to their traffic data experience, traffic safety, and travel time uncertainty. Abdel-Aty et al. [14] used the stated preference techniques to investigate the effect of travel time reliability on travelers’ route choice and found that the shortest route could not be adopted by Advanced Traveler Information System (ATIS) until it reaches a significant level of reliability. In general, travelers care about travel time reliability to plan their trips and reach their destination on time or within an acceptable threshold they predefined. Using Geographic Information System (GIS), as well as GPS, in the field of the transportation network, has been increasing day by day. As expected, some uncertainties issues emerged. Hong et al. [15] found that travel time's reliability was not significantly affected by uncertain input data. TTR plays a crucial role in the travelers’ route choice. Moghaddam et al. [16] mentioned that many factors could affect users’ route choice; one of these factors was travel time reliability for each alternative.

The unreliable travel time would result from different factors such as traffic incidents, work zone, environmental conditions, and fluctuation in the travel time from one time to another due to the demand and capacity, traffic bottlenecks, and special events [17]. Several indices are used as travel time measures to describe variability in travel time; some are Standard Deviation (SD) and Coefficient of Variation (CV). Buffer Time Index (BTI) and the Planning Time Index (PTI) are also widely used to determine the travel time reliability in different studies [18]. Kaparias et al. [19] indicated that the TTR of a route could be measured by the TTR of several segments of the same route. Ali et al. [20] identified traffic congestion and suggested mitigation measures in Lahore, Pakistan, based on stakeholders' perceptions of the city's central area. According to the research findings, the primary causes of traffic congestion and extended travel times were illegal parking on the roadside, bad attitudes among drivers and shopkeepers, encroachments, and conducting business on public streets. The authors said that strict enforcement, enough parking spaces, overhead pedestrian bridges, and public education about traffic rules should be done in Lahore to help cut down on traffic jams.

Intelligent Transportation System (ITS) has several applications; one of these applications is Probe-vehicles, which are designed primarily for traffic data collection in real-time. Jintanakul et al. [21] defined probe vehicles as vehicles driven by expert drivers to collect several traffic data types under specific roadway conditions. In the past, traffic data were collected generally from agencies only. These days several companies in the private sectors such as Here, TomTom are marketing for their own collected data via probe vehicles [22]. Alomari et al. [23] validated the trip travel time provided by three selected navigation applications, including Google Maps, HERE, and Waze. They examined the error in the Estimated Time of Arrival (ETA) provided. It was found that Google Maps has the most distinguished accuracy (up to 70%). Bechtel et al. [24] stated that the use of probe vehicles became a critical need; they considered them reliable tools to study TTR and traffic status and congestion in urban and rural areas. GPS loggers were used widely in the last years, especially in the process of data collection and extracting information. Jonker and Venter [25] used GPS loggers to study trip lengths to and from a shopping mall and examine the factors which affect travel time in urban and suburban areas. The results showed that the shopping mall's size has a significant effect on travel time; hence, trips towards larger shopping malls are longer than those to smaller ones. Yang et al. [26] studied TTR based on origin-destination based; data were collected from a GPS enabled device from taxicabs in China. The lognormal mixture models (LMMs) were used to study the standard deviation and coefficient of travel time reliability variation. Ahmad et al. [27] performed simulation-based research using PTV VISSIM software on optimizing Toll Plaza with various lane arrangements in Lahore, Pakistan. According to the results, changing the lane configuration can significantly reduce waiting times in various scenarios. Compared to the existing scenario during peak hours, the results showed that waiting times could be reduced by up to 93.66%, queue lengths could be reduced by up to 57.69%, and throughput could be increased by up to 75.94%.

Historical data from several sources have been adapted to evaluate traffic status, traffic delay, and congestion. Ahmed et al. [28] mentioned that investigating the traffic status or getting accurate information for further uses depending on historical data has less accuracy and confidence because of the continuous change in the traffic network as well as in the capacity of the roads from one time to another. Also, in general, road users need to get real-time information about road status to avoid congestion [29].

Several studies have shown that TTR is an essential element for both users and agencies. After reviewing several studies concerned with TTR, it can be concluded that most of the researchers investigated TTR on freeways. However, most roads are rural or urban in Jordan, and freeways rarely exist. Hence, all the data points were collected by trained drivers instead of crowdsourcing data. Therefore, the data used for this study will be more accurate and suitable for this study. Moreover, this study considers the peak-off peak hours, the time of day, and the day of the week. Both segment-based and origin-destination-based data are discussed.

This research aims at studying travel time and TTR in urban areas in Irbid, Jordan, by determining the travel times for several trips, which will be conducted for several pairs of origins and destinations at different times and conditions (peak hour, off-peak hour, crosswalk existence, pedestrian existence, on-street parking existence, signalized intersection, and traffic calming measure distribution within the study area). The used GPS equipment has the capability of recording data at the time of vehicles' movements, the latitude/longitude for the starting point (origin) as well as for the ending point (destination), the speed of the vehicle, trip duration, routes used, and the exact traveled distance. The present research investigates the factors and conditions that cause travel time variation across weekdays, weekends, and the time of day. It also determines the segment/s that cause the variation at the OD level.

2 METHODOLOGY

Jordan was under total lockdown from March 21 to the end of May 2020, after some COVID-19 cases were recorded [30]. The curfew prevented the free movement of most people and closed all shops. Data were collected during July 2020 after Jordan partially lifted the curfew. The peak and off-peak hours were affected by the curfew and its aftermath during the data collection phase from 12:00 A.M. to 6:00 A.M.

Drivers involved in data collection were trained to drive at the maximum possible and safe speed and not exceed speed limits and comply with all applied traffic rules in Jordan. Speed reduction was only allowed due to the delay caused by interruptions, including traffic signals, roundabouts, on-street parking, pedestrian crossing, or any incident which might force the driver to slow down. The route between each OD has been drawn on ArcMap [31], and several trips were conducted for the same OD pair in different times and conditions: (peak hours, off-peak hours, crosswalk existence, pedestrian existence, on-street parking, traffic calming measures distribution within the study area).

Data were collected for seventeen OD pairs in the urban roads of Irbid city, three times a day, five days a week; the days were chosen representative days (weekdays and weekends). This study proposed the time from 8:00 A.M. to 10:00 A.M. as off-peak hours, 1:00 P.M. to 4:00 P.M. and 8:00 P.M. to 11:00 P.M. as peak hours based on historical data from Google Maps. The collected data included speed limits, time, location, speed (tracking data), and actual travel time for each trip. For this research, the data were collected in Irbid, Jordan, the second major governorate in Jordan after Amman (the capital), with 1,957,000 residences [32]. Ultra GPS Logger [33], which is a tracking application working on the Android operating system, was used to retain the speed of vehicle, location, and trip time. Fig. 1 shows the traversed routes for the whole study area, illustrating the difference in the trip times among the three periods each day.

The final structure for stored data includes OD number (from route number 1 to route number 17), the period for data collection (1 refers to the morning period, 2 refers to the afternoon period, and 3 to the night period), the day of the week (Sunday, Wednesday, Thursday, Friday, and Saturday), and the date.

Each trip between a pair of ODs was divided into several types of segments (3-leg intersections,4-leg intersections, roundabouts, normal sections without traffic control devices). A total of 134 segments resulted. Fig. 1 shows the assigned segments in the study area in Irbid city. Also, Fig. 2 shows the flowchart of travel time reliability analysis.

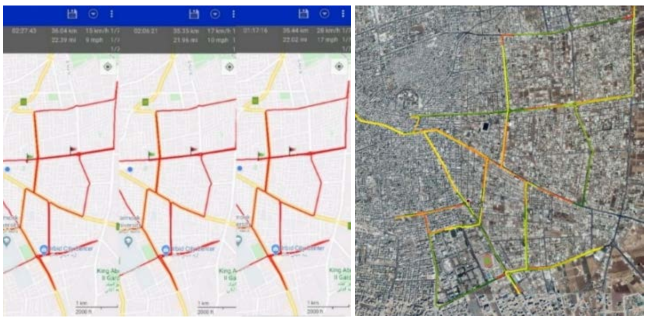

Fig. 1. Traversed Routes for The Study Area (Left) and Study Area Segments (Right).

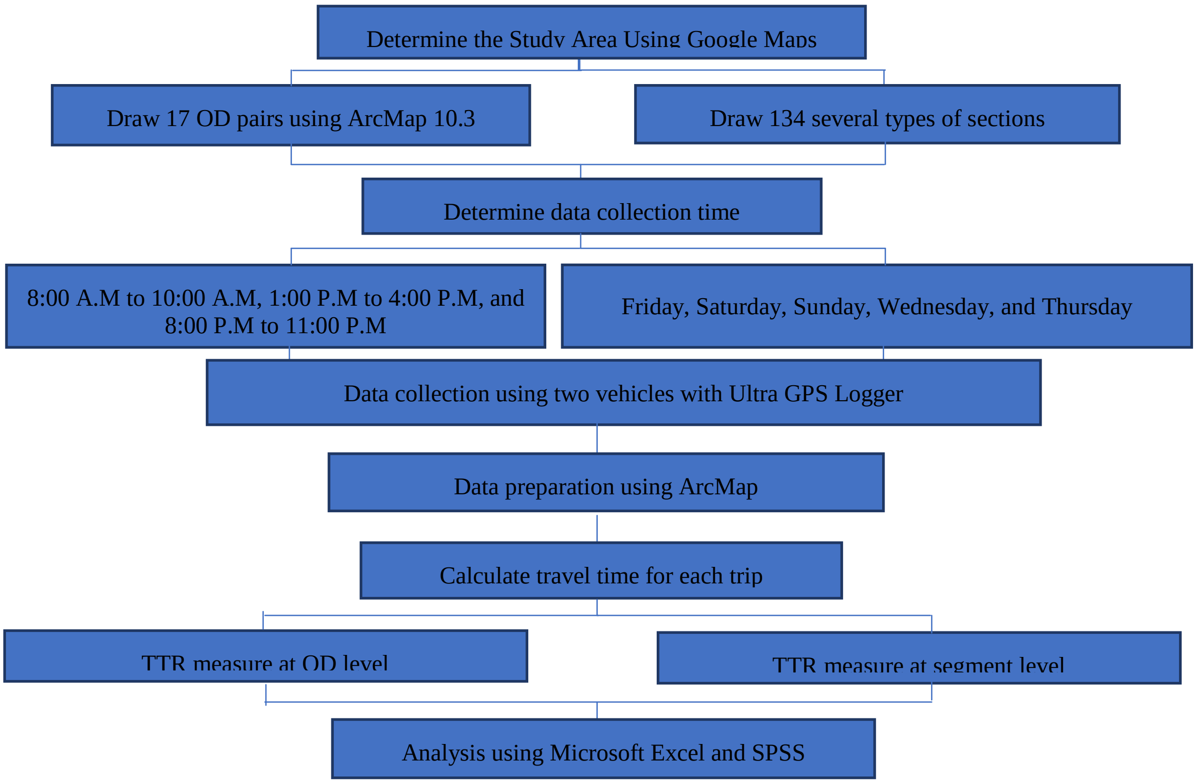

Fig.2. Flowchart of TTR Analysis.

3 RESULTS AND DISCUSSION

Determining the time for data collection was based on historical data from Google Maps, considering the new peak hours and off-peak hours resulting from the curfew due to COVID-19. Also, the 17 OD pairs were chosen based on commuters' experience. After determining the OD pairs, two trained drivers were employed to run these trips three times each day, five days a week (Wednesday, Thursday, Friday, Saturday, and Sunday), which means a total of 57 trips for each OD pairs and total trips equal to 969. Each route was divided into several types of sections: roundabouts, signalized intersections, normal sections; both roundabouts and signalized intersections (3-leg and 4-leg) were supposed to begin before 150 meters because of the effect of traffic control on the speed of vehicles. Also, the normal section was determined as the section without any traffic control. One hundred thirty-four sections resulted and were drawn on ArcMap [31].

In addition to the statistical measures for TTR such as SD, FHWA [11] conducted several TTR measures such as:

- *90^{th} or 95^{th} percentile travel times*: 90% or 95% of the measured trips take less than this time for any route.
- *Buffer Index (BI)*: it is the extra time the users must add to average travel time to ensure on-time arrival. Equation 1 represents the difference between the 95% travel time and the mean travel time divided by mean travel time.

$$BI = \frac{95\ percentile travel time \quad - Mean travel time}{Mean\ travel time} * 100\% \tag{1}$$

- *Planning Time Index (PTI)*: it is the total travel time that should be expected when adequate travel time is included. However, it compares the near worst-case travel time to travel time in the free flow speed (FFS).

$$PTI = \frac{95\ percentile travel time}{15\ percentile\ travel time} \tag{2}$$

- *Frequency Congestion*: it represents the percent of days or travel time exceeding a specific threshold of minutes or travel speeds that fall below a specific threshold of miles.

- *Travel Time Index (TTI)*: it is the ratio between mean travel time to the 15% travel time.

$$\text{TTI} = \frac{Mean\ travel time}{15\ percentile travel time} \tag{3}$$

– *Buffer Time*: represents the "extra time" above the average that drivers must budget to reach their destination "on time" for 95% of the trips.

$$BufferTime = \frac{BI}{100} * MeanTravelTime \quad (4)$$

– *Misery Index*: it is the ratio between the worst travel time scenario to free flow travel time.

$$MiseryIndex = \frac{97.5\ percentiletraveltime}{15\ percentiletraveltime} \quad (5)$$

$$CoeficientofVariation = \frac{Standarddeviation}{Meantraveltime} \quad (6)$$

Table 1 provides names and lengths for the 17 OD pairs. The shortest distance of OD was approximately 1 km, and the longest OD was 4.6 km; these ODs were fairly distributed in Irbid's urban arterial streets to cover all the conditions which help to evaluate TTR. Table 1 also shows the estimates for TTR measures. Routes 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 16, and 17 show a big difference between the shortest travel time and the longest travel time during the three periods and five days per week. Hence, the Standard Deviation (SD) recorded higher values. The location and the length of the trip affect travel time; for example, OD 15 has the shortest distance, and just one roundabout, so the minimum travel time was 1.5 minutes, and the maximum was 5.4 minutes. The other extreme was OD 6, one of the longest trips in this study; the extreme values reflect the big difference in travel time, which varies from 7 minutes to 38minutes. There were three roundabouts and one 3-leg intersection while making this trip, in addition to on-street parking and one pedestrian crossing.

Table 1. Calculations Needed for Reliability Measures

OD	Length (Km)	N	Min	Max	Mean	SD	90%	15%	97.5%
1	3.403	57	5.500	12.017	7.636	1.588	9.723	5.533	11.469
2	1.999	57	2.733	5.350	3.611	0.632	4.627	2.783	5.328
3	1.482	57	2.467	7.750	4.599	1.302	6.297	2.617	7.660
4	1.530	57	1.950	9.083	3.418	1.260	5.233	2.167	7.643
5	3.094	57	3.967	27.133	11.076	4.894	16.960	5.00	26.001
6	4.420	57	7.450	37.667	18.124	8.050	28.713	8.083	36.039
7	3.776	57	5.117	25.000	11.510	4.957	18.383	6.167	24.250
8	3.381	57	5.483	17.367	10.658	2.867	14.473	5.75	17.239
9	4.197	57	6.867	23.533	13.424	3.859	19.533	8.617	22.543
10	4.615	57	6.950	17.233	11.356	2.468	14.693	7.433	17.143
11	1.674	57	2.450	23.417	6.655	3.895	10.877	2.983	21.272
12	0.955	57	1.550	14.033	5.114	3.129	9.793	1.783	14.026
13	1.451	57	2.633	17.300	6.096	3.630	12.660	3.733	17.030
14	1.895	57	2.317	16.500	7.860	3.565	13.563	3.817	16.043
15	0.937	57	1.500	5.483	2.522	0.714	3.513	1.783	4.906
16	2.680	57	3.950	27.933	11.875	5.714	20.213	4.533	27.341
17	2.125	57	3.150	20.550	8.162	4.025	13.730	3.533	17.993

Table 2 shows the results of several measures of reliability, according to the FHWA. For any route, there is a 95th percentile, which represents the worst scenario; for OD 1, for example, the 95th % travel time was 10.6 minutes which means that only 5% of the travel time for this trip lies above this value (10.6 min) and 95% of travel time lies below this time. The buffer time represents the "extra time" above the average that drivers must budget to reach their destination "on time" for 95% of the trips. OD 6 has the highest buffer time among the 17 OD pairs; however, OD 2 has a lower buffer time. The buffer time for OD 6 was 15 minutes, which is near the mean travel time for this trip. As a result, the driver should plan an extra 15 minutes for his/her trip to ensure on-time arriving.

Table 2. Reliability Measures for OD and the Number of Traffic Controls in Each Segment

OD	BI%	Buffer Time (min)	95th %	PTI	Misery Index	TTI	CV	No. of Roundabouts	No. of 3-leg Intersections	No. of 4-leg Intersections
1	38.88	2.969	10.605	1.917	2.073	1.380	0.208	4	0	1
2	39.29	1.419	5.03	1.807	1.914	1.297	0.175	3	0	0
3	50.47	2.321	6.92	2.645	2.927	1.758	0.283	0	1	1
4	63.77	2.180	5.598	2.584	3.528	1.578	0.369	2	0	0
5	82.03	9.086	20.162	4.032	5.200	2.215	0.442	2	1	1
6	83.32	15.101	33.225	4.110	4.458	2.242	0.444	6	2	1
7	100.1	11.524	23.033	3.735	3.932	1.866	0.431	5	0	4
8	51.14	5.450	16.108	2.801	2.998	1.854	0.269	3	1	2

OD	BI%	Buffer Time (min)	95th %	PTI	Misery Index	TTI	CV	No. of Roundabouts	No. of 3-leg Intersections	No. of 4-leg Intersections
9	58.81	7.895	21.318	2.474	2.616	1.558	0.287	5	1	2
10	39.56	4.492	15.848	2.132	2.306	1.528	0.217	9	1	1
11	162	10.780	17.435	5.844	7.130	2.231	0.585	3	0	1
12	137.4	7.028	12.142	6.808	7.865	2.868	0.612	1	0	1
13	173.5	10.574	16.67	4.465	4.562	1.633	0.596	2	0	1
14	84.78	6.663	14.523	3.805	4.203	2.059	0.454	0	2	0
15	58.23	1.468	3.99	2.237	2.751	1.414	0.283	1	0	0
16	93.58	11.112	22.987	5.071	6.031	2.619	0.481	3	1	0
17	80.86	6.600	14.762	4.178	5.092	2.310	0.493	1	3	0

Table 2 also shows the number of roundabouts, 3-leg signalized intersections, and 4-leg signalized intersections for each OD. The number of roundabouts and junctions increased as the length of OD increased. Each segment was started at 150 m before the roundabout or the intersection to consider the effect of these controls on the vehicle's speed.

When an adequate buffer time is included in travel time for any trip, PTI can be calculated as a comparison between the near worst cases of travel time to the free-flow travel time, which is the shortest travel time. CV for travel times will vary depending upon the physical and traffic control characteristics of the roadway (e.g., number of signals, number of roundabouts) and traffic conditions (e.g., free-flow versus stop-and-go congestion). The values of CV for the travel time were from 0.17 to 0.612. The highest variation, the more unreliable the trip [34]. To evaluate TTR based on the day of the week, the same trip was conducted five days each week, three times each day, and all indices were calculated. For OD 1, Sunday recorded the highest BI, CV, 95%, and buffer time. For OD 2, Thursday marked the highest BI, buffer time, and CV. Also, results showed that 35% of routes have maximum BI on Friday, 12% of routes have maximum BI on Saturday and Wednesday, 18% of routes have maximum BI on Sunday, and 23% of routes have maximum BI on Thursday.

Tables 3 shows the calculation and reliability measures for OD Period. Each day is divided into three periods: Period 1 (8:00 A.M. to 10 A.M.), Period 2 (1:00 P.M., to 4:00 P.M.), and Period 3 (8:00 P.M. to 11:00 P.M.); nineteen trips were traversed for each period for the same trip. The lowest travel time mean and SD for all trips were in the morning period.

The BI, TTI, and PTI for period 2 showed higher values than those for periods 1 and 3, except for OD 4, which recorded higher values in period 3. Trips from OD 1 to OD 10 were traversed near the biggest three shopping malls in Irbid city, which is considered as attractive OD, especially at the night period and recorded the highest travel time for all routes, except for OD 2, OD 5, and OD 8. For trips from OD 11 to OD 17, period 2 recorded the highest travel time; these trips were traversed in the city center of Irbid. The congestion in this area almost always occurs in the afternoon period. Also, many pedestrian crossings and on-street parking were there. Sunday and Thursday have the highest travel time in the city center. Period 1 recorded the lowest travel time among all the trips.

Several studies highlighted TTR measures at the OD level, but less attention was given to the TTR at the segment level. The importance of studying TTR on segment level lies in determining which links have the most contribution on a particular trip reliability level to provide a choice for commuters or travellers to avoid such segments or take the delay due to these segments' consideration. The number of sections investigated in this study is considered large (134 sections), and not all of them can contribute to the reliability level for a particular OD. Hence, only sections showed a TTI > 2 or BI > 100 for the same OD, which has a TTI > two or BI > 100. The section code consists of (OD-Section number); for example, section code 13-3 means that OD number is 13, and section number is 3. Table 4 shows the sections code with their mean travel time and other reliability measures.

Table 3. Reliability calculations and measures for OD-Periods

OD	Period	N	Min (Min)	Max (Min)	Mean (Min)	SD (Min)	15% (Min)	97.5% (Min)	BI%	CV	Buffer Time (Min)	95% (Min)	PTI	Misery Index	TTI
1	**1**	**19**	5.500	6.500	5.954	0.303	5.533	6.421	6.517	0.051	0.388	6.342	1.146	1.160	1.076
1	**2**	**19**	6.283	10.583	8.031	0.485	6.883	10.151	21.021	0.060	1.688	9.719	1.412	1.475	1.167
1	**3**	**19**	7.700	12.017	8.924	1.167	7.867	11.443	21.798	0.131	1.945	10.869	1.382	1.455	1.134
2	**1**	**19**	2.733	4.017	3.168	0.334	2.783	3.930	21.337	0.106	0.676	3.843	1.381	1.412	1.138
2	**2**	**19**	2.933	5.350	4.152	0.739	3.167	5.326	27.725	0.178	1.151	5.303	1.675	1.682	1.311
2	**3**	**19**	3.017	4.017	3.514	0.246	3.283	3.930	9.373	0.070	0.329	3.843	1.171	1.197	1.070
3	**1**	**19**	2.517	4.733	3.542	0.748	2.617	4.670	30.079	0.211	1.065	4.608	1.761	1.785	1.354
3	**2**	**19**	2.467	7.550	4.722	1.362	3.117	7.220	45.907	0.289	2.168	6.890	2.211	2.317	1.515
3	**3**	**19**	4.117	7.750	5.532	0.861	4.633	7.286	23.320	0.156	1.290	6.823	1.473	1.573	1.194
4	**1**	**19**	1.950	3.150	2.431	0.299	2.167	2.977	15.348	0.123	0.373	2.804	1.294	1.374	1.122
4	**2**	**19**	2.483	3.967	3.113	0.414	2.600	3.927	24.881	0.133	0.775	3.888	1.495	1.511	1.197
4	**3**	**19**	3.350	9.083	4.711	1.336	3.483	7.574	28.712	0.284	1.353	6.064	1.741	2.174	1.353
5	**1**	**19**	3.967	7.767	6.469	1.038	5.000	7.727	18.834	0.160	1.218	7.688	1.538	1.545	1.294

OD	Period	N	Min (Min)	Max (Min)	Mean (Min)	SD (Min)	15% (Min)	97.5% (Min)	BI%	CV	Buffer Time (Min)	95% (Min)	PTI	Misery Index	TTI
5	**2**	**19**	5.817	27.133	13.633	5.222	6.817	23.611	47.357	0.383	6.456	20.090	2.947	3.464	2.000
5	**3**	**19**	7.600	24.617	13.125	3.525	10.633	21.433	39.045	0.269	5.125	18.249	1.716	2.016	1.234
6	**1**	**19**	7.450	12.267	9.986	1.526	8.083	12.102	19.536	0.153	1.951	11.937	1.477	1.497	1.235
6	**2**	**19**	9.583	27.833	18.782	6.208	10.633	27.078	40.156	0.331	7.542	26.324	2.476	2.547	1.766
6	**3**	**19**	17.917	37.667	25.604	5.595	19.483	35.961	33.785	0.219	8.650	34.255	1.758	1.846	1.314
7	**1**	**19**	5.117	8.533	7.071	0.962	6.167	8.391	16.673	0.136	1.179	8.250	1.338	1.361	1.147
7	**2**	**19**	6.933	17.900	10.854	3.480	7.117	17.578	58.974	0.321	6.401	17.256	2.425	2.470	1.525
7	**3**	**19**	11.167	25.000	16.604	3.842	13.500	24.214	41.099	0.231	6.824	23.427	1.735	1.794	1.230
8	**1**	**19**	5.483	12.450	8.677	1.957	5.750	11.672	25.541	0.226	2.216	10.893	1.895	2.030	1.509
8	**2**	**19**	6.567	17.367	11.501	3.459	7.517	17.233	48.676	0.301	5.598	17.099	2.275	2.293	1.530
8	**3**	**19**	9.200	16.000	11.796	1.875	10.000	15.355	24.711	0.159	2.915	14.710	1.471	1.536	1.180
9	**1**	**19**	6.867	11.633	10.013	1.355	8.617	11.508	13.671	0.135	1.369	11.382	1.321	1.335	1.162
9	**2**	**19**	8.483	21.317	13.132	3.091	8.783	19.060	27.956	0.235	3.671	16.804	1.913	2.170	1.495
9	**3**	**19**	13.433	23.533	17.125	2.847	14.733	22.495	25.296	0.166	4.332	21.458	1.456	1.527	1.162
10	**1**	**19**	6.950	10.800	9.111	1.065	7.433	10.698	16.297	0.117	1.485	10.595	1.425	1.439	1.226
10	**2**	**19**	8.467	14.633	11.275	1.923	9.000	14.523	27.828	0.171	3.138	14.413	1.601	1.614	1.253
10	**3**	**19**	11.733	17.233	13.682	1.754	11.783	17.139	24.579	0.128	3.363	17.044	1.446	1.454	1.161
11	**1**	**19**	2.833	7.550	4.378	1.233	2.983	6.622	30.065	0.282	1.316	5.694	1.909	2.220	1.468
11	**2**	**19**	2.450	23.417	9.360	5.532	3.833	21.168	102.143	0.591	9.560	18.920	4.936	5.522	2.442
11	**3**	**19**	4.400	8.583	6.227	1.301	4.917	8.394	31.771	0.209	1.978	8.206	1.669	1.707	1.267
12	**1**	**19**	1.550	4.300	2.593	0.697	1.783	3.954	39.164	0.269	1.016	3.608	2.023	2.217	1.454
12	**2**	**19**	1.917	14.017	6.725	3.418	2.883	12.948	76.641	0.508	5.154	11.878	4.120	4.491	2.332
12	**3**	**19**	2.967	14.033	6.024	2.822	3.767	13.042	100.075	0.469	6.028	12.052	3.200	3.463	1.599
13	**1**	**19**	2.633	5.650	4.000	0.559	3.733	5.116	14.528	0.140	0.581	4.581	1.227	1.370	1.071
13	**2**	**19**	3.117	17.300	8.452	5.032	3.567	17.017	97.994	0.595	8.282	16.734	4.692	4.771	2.370
13	**3**	**19**	3.6	10.45	5.835	2.191	3.817	10.159	69.114	0.376	4.033	9.868	2.585	2.662	1.529
14	**1**	**19**	2.317	7.683	4.961	1.242	3.817	7.266	38.090	0.250	1.889	6.850	1.795	1.904	1.300
14	**2**	**19**	2.85	16.5	10.779	3.934	4.95	16.02	44.175	0.365	4.762	15.541	3.140	3.236	2.178
14	**3**	**19**	4.6	11.95	7.84	2.157	5.2	11.486	40.589	0.275	3.182	11.023	2.120	2.209	1.508
15	**1**	**19**	1.5	3.05	2.138	0.405	1.783	2.995	37.512	0.189	0.802	2.940	1.648	1.679	1.199
15	**2**	**19**	1.717	3.967	2.78	0.684	1.917	3.849	34.223	0.246	0.951	3.731	1.947	2.008	1.450
15	**3**	**19**	1.783	5.483	2.647	0.845	2.167	4.878	61.391	0.319	1.625	4.273	1.972	2.251	1.222
16	**1**	**19**	3.95	11.067	7.174	1.967	4.533	11.027	53.168	0.274	3.814	10.988	2.424	2.433	1.582
16	**2**	**19**	5.5	26.617	13.865	5.419	6.333	23.81	51.489	0.391	7.139	21.004	3.316	3.760	2.189
16	**3**	**19**	6.367	27.933	14.585	5.753	6.817	25.409	56.913	0.394	8.301	22.886	3.357	3.728	2.140
17	**1**	**19**	3.15	8.35	5.11	1.321	3.533	7.634	35.408	0.259	1.809	6.919	1.958	2.161	1.446
17	**2**	**19**	3.7	20.55	11.422	4.275	4.067	17.814	32.012	0.374	3.656	15.078	3.708	4.381	2.809
17	**3**	**19**	4	14.867	7.954	3.047	4.467	14.552	78.993	0.383	6.283	14.238	3.188	3.258	1.781

Table 4. Reliability measure at segment level

Section Code	Mean	95%	Buffer Time	Buffer Index	PTI	Misery Index	TTI	CV	Section Type
5-2	0.978	2.062	1.083	110.726	3.671	4.533	1.742	0.495	Roundabout
5-3	0.449	0.990	0.541	120.717	4.243	4.539	1.922	0.558	Normal Section
5-4	0.901	2.180	1.279	141.908	4.404	5.024	1.821	0.575	Roundabout
5-7	2.910	10.68	7.767	266.940	13.154	16.900	3.585	0.991	Normal Section
5-8	2.540	5.970	3.430	135.007	6.597	6.731	2.807	0.647	3-Leg Sig
6-1	2.663	7.060	4.397	165.099	6.619	6.849	2.497	0.659	3-Leg Sig
6-2	1.349	2.895	1.546	114.677	4.866	5.906	2.266	0.592	Roundabout
6-4	1.492	4.535	3.043	204.052	8.074	15.365	2.656	1.152	Normal Section
6-5	2.284	7.417	5.132	224.693	11.209	14.054	3.452	0.886	Normal Section
6-6	1.422	3.042	1.620	113.911	4.919	7.297	2.300	0.622	Roundabout
6-7	1.626	3.022	1.395	85.798	5.380	5.656	2.896	0.463	4-Leg Sig
6-8	0.824	1.910	1.086	131.721	3.859	5.961	1.665	0.624	Normal Section
6-9	1.451	3.828	2.377	163.759	5.015	6.483	1.901	0.662	Roundabout
7-1	1.254	3.653	2.400	191.449	7.913	9.594	2.715	0.854	Roundabout
7-2	0.140	0.250	0.110	78.497	3.750	3.887	2.101	0.365	Normal Section
7-3	0.723	1.768	1.045	144.450	4.889	7.147	2.000	0.673	Roundabout
7-4	0.468	0.943	0.475	101.386	3.773	4.170	1.874	0.443	Normal Section
7-5	0.822	2.205	1.383	168.271	5.513	5.877	2.055	0.629	Roundabout

Section Code	Mean	95%	Buffer Time	Buffer Index	PTI	Misery Index	TTI	CV	Section Type
7-6	1.159	3.162	2.003	172.846	7.296	10.487	2.674	0.896	Roundabout
7-7	1.852	3.768	1.916	103.436	5.210	5.823	2.561	0.502	4-Leg Sig
7-8	1.606	5.640	4.034	251.216	8.460	12.535	2.409	1.064	Normal Section
7-9	1.001	2.117	1.116	111.481	4.006	4.058	1.894	0.512	Normal Section
11-1	1.332	3.928	2.597	195.013	5.309	9.164	1.799	0.904	Normal Section
11-2	0.785	2.550	1.765	224.684	6.923	10.163	2.132	0.878	Roundabout
11-3	1.528	6.482	4.953	324.092	9.555	10.173	2.253	1.014	Roundabout
11-4	2.176	4.173	1.998	91.813	4.891	5.015	2.550	0.494	4-Leg Sig
11-5	0.655	1.675	1.020	155.622	4.568	7.416	1.787	0.725	Roundabout
12-1	0.939	3.558	2.619	278.876	13.599	17.248	3.589	1.178	Normal Section
12-2	1.907	6.242	4.335	227.350	11.015	14.631	3.365	0.934	Roundabout
13-2	2.015	5.473	3.458	171.602	6.352	6.957	2.339	0.740	4-Leg Sig
13-3	1.022	5.165	4.143	405.416	12.396	14.196	2.453	1.341	Normal Section
13-4	1.419	4.517	3.097	218.232	6.658	7.190	2.092	0.752	Roundabout
13-5	0.909	1.968	1.060	116.593	3.810	4.424	1.759	0.531	Roundabout
14-3	1.401	3.600	2.199	156.875	4.625	6.582	1.801	0.667	Normal Section
14-4	1.276	3.997	2.721	213.284	12.621	15.645	4.029	0.991	Normal Section
14-5	1.918	3.855	1.937	101.038	5.417	5.854	2.694	0.534	3-Leg Sig
14-6	1.135	2.902	1.767	155.765	5.803	5.870	2.269	0.624	Roundabout
17-2	1.478	3.668	2.190	148.135	4.520	5.570	1.821	0.582	Normal Section
17-3	1.836	5.600	3.764	205.065	8.615	10.610	2.824	0.885	Normal Section
17-4	1.651	3.618	1.967	119.138	5.610	5.917	2.560	0.546	Roundabout
17-5	1.062	1.937	0.875	82.362	3.873	4.417	2.124	0.480	3-Leg Sig
17-6	1.335	3.855	2.520	188.745	6.407	9.079	2.219	0.819	Normal Section
17-7	2.266	5.013	2.748	121.268	6.995	8.866	3.161	0.721	Normal Section
18-2	1.866	4.438	2.572	137.842	5.666	7.836	2.382	0.718	Normal Section
18-3	2.113	6.675	4.562	215.922	9.379	11.491	2.969	0.920	Normal Section
18-5	0.467	1.310	0.843	180.538	5.240	8.170	1.868	0.782	Normal Section
18-6	1.001	2.005	1.004	100.207	4.051	4.530	2.023	0.483	Normal Section
6-10	0.621	1.553	0.932	149.995	5.683	6.409	2.273	0.659	Roundabout
6-11	0.824	2.138	1.314	159.514	8.553	9.100	3.296	0.732	Normal Section
6-13	0.318	0.862	0.544	171.104	6.463	16.925	2.384	1.311	Normal Section
6-14	0.777	3.023	2.246	288.860	8.638	13.624	2.221	1.153	Roundabout
7-11	0.804	1.660	0.856	106.444	3.689	3.909	1.787	0.429	Roundabout

Section 5-7 has a misery index equal to 16.9, which represents the worst travel time to the free-flow travel time and a buffer time two times and half the mean travel time, which indicates low reliability in this section in the city center between a roundabout and a 3-leg intersection. Hence, 5-7 is a normal section without traffic controls, so there are no expected delay sources like signalized intersections, which increases the free-flow travel time, resulting in significant variation between traversing the section during free-flow conditions and peak periods. Normal sections have the highest CV values, followed by roundabouts, and then signalized intersections, which relate to the nature of each type of section.

The reliability at the segment level, which investigated the effect of the day on the trip reliability, showed less reliability level on period 2 (from 1:00 P.M. to 4:00 P.M.) for all trips except for OD 4. The uncertainty of travel time for period 2 was for all days because of the variation of day. However, periods 1 and 3 for all days showed high reliability. The reliable trip does not mean there was no congestion or delay; it means that it recorded a slight variation in travel time for the same trip. This study showed that the unreliability in period 2 resulted from Friday, which has the shortest travel time in period two, unlike period 2 in the rest of the days (Sat, Sun, Wed, and Thu). At the same time, periods 1 and 3 recorded longer travel times for all days, and Thursday and Saturday marked the maximum travel time. The BI was categorized into three levels: H: less than 50, M: 50 to 100, and L: more than 100. Hence three BI Levels resulted. Chi-Square test for independence was conducted to determine whether there is a significant association between BI Level with section type, and BI Level with period. The null hypothesis for this test was: the BI level and section type are independent, while the alternative hypothesis was the BI Level and section type are dependent, at significance level 5%. Chi-square test p-value was less than the significance level 5% at 95% confidence interval; hence, the null hypothesis was rejected, and the data provide sufficient evidence at a 5% level of significance to conclude that section type and BI Level are dependent. The same test was conducted to investigate the association between Period and BI Level at the same confidence level. The data provide sufficient evidence at a 5% level of significance to conclude that period and BI Level are dependent. Table 5 shows the symmetric measures for the Chi-Square analysis and the result of the independence Chi-Square test between section type, period, and the BI Level.

The section type has a higher association with BI Level than Period has. For 3-Leg intersections and 4-Leg intersections, most segments have medium (M) BI Level. On the other hand, the normal sections are distributed equally between the three BI Levels. In comparison, a significant number of roundabout sections have BI lower than 100%. Also, Period 1 has the least segments with High (H) BI Level, while period 2 has the most BI Level among the other periods. Moreover, to investigate the association between BI Level and section type, BI Level and Day, where the Chi-square test for independence was conducted at a significance level of 5%, as seen in Table 6.

Table 5. Chi Square Test for Independence between Section Type and BI Level

		BI Level			Total
		H	L	M	
Based on Section Type					
3-Leg Signal	Count	1	6	26	33
	% Within sec type	3.00%	18.20%	78.80%	100.00%
	% Within BI Level	1.00%	4.30%	16.00%	8.20%
	% Of Total	0.20%	1.50%	6.50%	8.20%
4-Leg Signal	Count	6	8	25	39
	% Within sec type	15.40%	20.50%	64.10%	100.00%
	% Within BI Level	6.1	5.7	15.4	9.70%
	% Of Total	1.50%	2%	6.20%	9.70%
Roundabout	Count	36	60	57	2
	% Within sec type	23.50%	39.2	37.30%	100.00%
	% Within BI Level	36.40%	42.60%	35.20%	38.10%
	% Of Total	9.00%	14.90%	14.20%	38.10%
Normal Section	Count	56	67	54	177
	% Within sec type	31.60%	37.90%	30.50%	100%
	% Within BI Level	56.60%	47.50%	33.30%	44%
	% Of Total	13.90%	16.70%	13.40%	44%
Total	Count	99	141	162	402
	% Within sec type	24.60%	35.10%	40.30%	100%
	% Within BI Level	100%	100%	100%	100%
	% Of Total	24.60%	35.10%	40.30%	100%
Based on Period					
Period 1 (8:00 A.M. to 10 A.M.)	Count	20	65	49	134
	% Within Period	14.9%	48.5%	36.6%	100.0%
	% Within BI Level	20.2%	46.1%	30.2%	33.3%
	% Of Total	5.0%	16.2%	12.2%	33.3%
Period 2 (1:00 P.M., to 4:00 P.M.)	Count	43	30	61	134
	% Within Period	32.1%	22.4%	45.5%	100.0%
	% Within BI Level	43.4%	21.3%	37.7%	33.3%
	% Of Total	10.7%	7.5%	15.2%	33.3%
Period 3 (8:00 P.M. to 11:00 P.M.)	Count	36	46	52	134
	% Within Period	26.9%	34.3%	38.8%	100.0%
	% Within BI Level	36.4%	32.6%	32.1%	33.3%
	% Of Total	9.0%	11.4%	12.9%	33.3%
Total	Count	99	141	162	402
	% Within Period	24.6%	35.1%	40.3%	100.0%
	% Within BI Level	100.0%	100.0%	100.0%	100.0%
	% Of Total	24.6%	35.1%	40.3%	100.0%

* Section Type & BI Level: Phi = 0.314, Cramer's V = 0.222, Sig. = 0.000.

** Period & BI Level: Phi = 0.239, Cramer's V = 0.169, Sig. = 0.000.

Table 6. Chi Square Test for Independence between Section Type and BI Level

		BI Level			Total
		H	L	M	
Based on Section Type					
3-Leg Signal	Count	8	15	32	55
	% Within sec type	14.5%	27.3%	58.2%	100.0%
	% Within BI Level	4.1%	7.1%	12.1%	8.2%
	% Of Total	1.2%	2.2%	4.8%	8.2%
4-Leg Signal	Count	10	13	42	65
	% Within sec type	15.4%	20.0%	64.6%	100.0%
	% Within BI Level	5.1%	6.2%	15.8%	9.7%
	% Of Total	1.5%	1.9%	6.3%	9.7%
Roundabout	Count	78	83	94	255

		BI Level			Total
		H	L	M	
Based on Section Type					
	% Within sec type	30.6%	32.5%	36.9%	100.0%
	% Within BI Level	40.0%	39.5%	35.5%	38.1%
	% Of Total	11.6%	12.4%	14.0%	38.1%
Normal Section	Count	99	99	97	295
	% Within sec type	33.6%	33.6%	32.9%	100.0%
	% Within BI Level	50.8%	47.1%	36.6%	44.0%
	% Of Total	14.8%	14.8%	14.5%	44.0%
Total	Count	195	210	265	670
	% Within sec type	29.1%	31.3%	39.6%	100.0%
	% Within BI Level	100.0%	100.0%	100.0%	100.0%
	% Of Total	29.1%	31.3%	39.6%	100.0%
Based on Day					
Friday	Count	41	46	47	134
	% Within Day	30.6%	34.3%	35.1%	100.0%
	% Within BI Level	21.0%	21.9%	17.7%	20.0%
	% Of Total	6.1%	6.9%	7.0%	20.0%
Saturday	Count	35	51	48	134
	% Within Day	26.1%	38.1%	35.8%	100.0%
	% Within BI Level	17.9%	24.3%	18.1%	20.0%
	% Of Total	5.2%	7.6%	7.2%	20.0%
Sunday	Count	45	36	53	134
	% Within Day	33.6%	26.9%	39.6%	100.0%
	% Within BI Level	23.1%	17.1%	20.0%	20.0%
	% Of Total	6.7%	5.4%	7.9%	20.0%
Wednesday	Count	51	24	59	134
	% Within Day	38.1%	17.9%	44.0%	100.0%
	% Within BI Level	26.2%	11.4%	22.3%	20.0%
	% Of Total	7.6%	3.6%	8.8%	20.0%
Thursday	Count	23	53	58	134
	% Within Day	17.2%	39.6%	43.3%	100.0%
	% Within BI Level	11.8%	25.2%	21.9%	20.0%
	% Of Total	3.4%	7.9%	8.7%	20.0%
Total	Count	195	210	265	670
	% Within Day	29.1%	31.3%	39.6%	100.0%
	% Within BI Level	100.0%	100.0%	100.0%	100.0%
	% Of Total	29.1%	31.3%	39.6%	100.0%

* Section Type & BI Level: Phi = 0.222, Cramer’s V = 0.157, Sig. = 0.001.

** Day& BI Level: Phi = 0.204, Cramer’s V = 0.144, Sig. = 0.001.

The null hypothesis for this test was: the BI level and section type are independent, while the alternative hypothesis was the BI Level and section type are dependent, at significance level = 5%. Chi-square test p-value was less than the significance level 5% at 95% confidence interval; hence, the null hypothesis was rejected, and the data provide sufficient evidence at a 5% level of significance to conclude that section type and BI Level are dependent. The same test was conducted to investigate the association between Day and BI Level at the same confidence level. The data provide sufficient evidence at a 5% level of significance to conclude that Day and BI Level are dependent. Table 6 confirms the chi-square test's findings between section type and BI Level. Table 6 also indicates that Thursday has BI that falls in the medium and low BI Level, which means reliable trips during this day; this confirms that the reliable route does not mean there is no delay or congestion. Nevertheless, the expected delay is the case in this study; every Thursday has the same time to make the same trip with a slight variation every week. On the other hand, Wednesday has less reliability level; even though it is known that the congestion on Wednesday is lower than Thursday, the travel time on Wednesday varies compared to the same trip and the same day. Figure 3 shows the graphical representation of the total percentages of BI level for Tables 5 and 6.

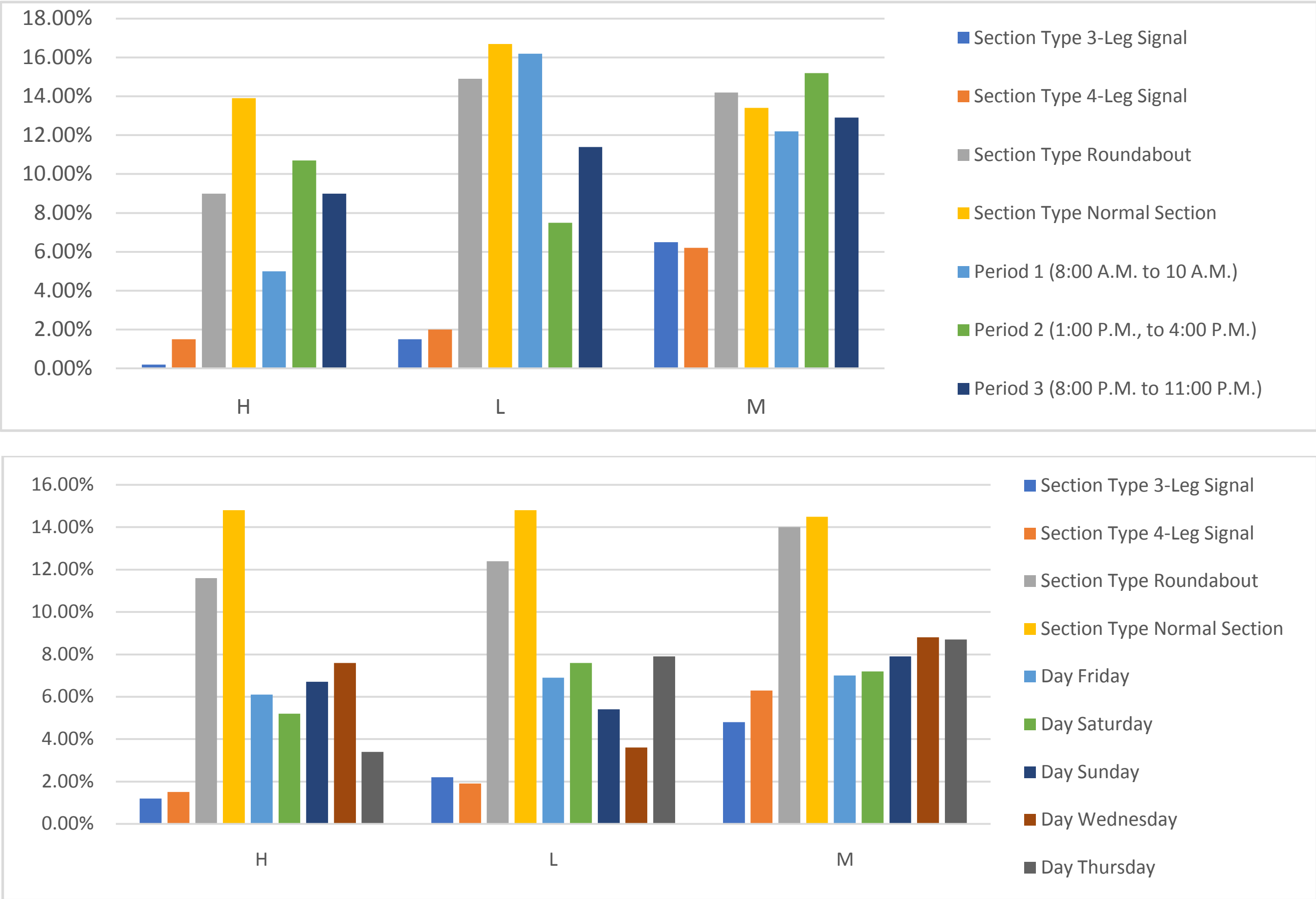

Fig. 3. Graphical Representation of the Total Percentages of BI Level for Tables 5 and 6.

4 CONCLUSIONS

This study aimed to evaluate TTR for urban areas in Irbid city, Jordan. As mentioned in the previous chapters, TTR is very crucial to both travellers and agencies. Many travellers are risk-averse; therefore, they tend to choose a longer route if it is more reliable than the shorter one if they can be confident that they will arrive at their destinations on time. Thus, incorporating GPS technology and tracking devices to study and evaluate travel time for routes is valuable. This study covers two levels of investigation; data were collected through trained drivers to achieve the goals of this study, using Ultra GPS Logger, which retained the vehicle's speed every three seconds. Several reliability measures are based on OD data, which include a general view about each trip regardless of the day and the period of the trips. These measures were computed for OD pairs and the day of the week, OD pairs, and the period of the day.

From the statistical analysis and the discussion presented in this study, the following conclusions could be drawn:

- The reliability studies at the OD level showed that 12 OD out of 17 showed a big difference between the minimum travel time and the maximum travel time. For all trips, Period 1 (8:00 A.M. to 10 A.M.) recorded the lowest travel time when compared to Period 2 (1:00 P.M., to 4:00 P.M.) and Period 3 (8:00 P.M. to 11:00 P.M.).
- The longest OD had several types of traffic control, including signalized intersections, roundabouts, and normal sections. The normal sections had a significant effect on TTR compared with 3-Leg intersections, 4-Leg intersections, and roundabouts.
- On-street parking and pedestrian crossing had a slight effect on travel time.
- The OD 6, which is from Greater Irbid Municipality to Sameh Mall, recorded almost the highest travel time during periods 2 and 3. The 97.5 percentile travel time, which represents the worst scenario, was found to be 36 minutes. Also, OD 17, which is from Princess Basma Hospital to McDonald's intersection, had a 97.5 percentile equal to 27.34 minutes.
- The ODs in the city center had higher travel time during period 2 than during other periods 1 and 3. Also, the ODs located in the city center had higher values of BI, buffer time, PTT, and misery index in comparison with other ODs. Moreover, The OD 6 and OD 7, near the shopping mall (Arabella Mall, Irbid City Center Mall, and Sameh Mall), had high-reliability measures that indicate lower reliability and a significant variation in travel time among the three periods of the day.

- Thursday had BI that falls in the medium and low BI Level, which means reliable trips during this day. This confirms that the reliable route does not say there is no delay or congestion but delay and congestion should be expected.
- Section 5-7 had a misery index equal to 16.9, which represents the worst travel time (97.5 percentile) to the free-flow travel time (15 percentile) and a buffer time two times and half the mean travel time, which indicates low reliability in this section in Al-Hashmi street (in the city center) between a roundabout and a 3-leg intersection.
- For 3-Leg intersections and 4-Leg intersections, the majority of segments had medium (M) BI Level.

This research methodology can be used as a practical note to represent the technique that can be applied broadly to cities in the region with similar socioeconomic demographics. The step-by-step analysis can be used in future studies to investigate several factors that may affect TRR, such as incidents, weather, planned lane closures, and special events. Applying TTR results and adapting them as a measure is recommended for evaluating the traffic networks in Jordan and countries in the region. Refining programming codes are needed to speed up the processing of the prepared data. It took extensive time and effort to prepare the data for this study from Ultra GPS Logger and ArcMap. Also, there is a shortage of available travel time data in this area, where getting them from communication agencies and navigation applications can provide more accurate estimated arrival times. It can also make collecting data more accessible and affordable throughout the year. Evaluating the TTR throughout the year is required to show the difference in travel time across the twelve months based on seasonal variation, work zones, and weather conditions. The study's findings have important implications for travel time applications and programs such as changeable message signs (CMS), Highway Advisory Radio (HAR), shipping and delivery companies, and navigation applications such as Google Maps, Apple Maps, Waze, HERE, TomTom, and Garmin.

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