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GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

TRAVEL TIME RELIABILITY ANALYSIS OF THREE DIFFERENT ROUTES IN BAGHDAD CITY

MSc THESIS

Makarim Kareem Jebur AL-SARRAY

Department of Civil Engineering

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Thesis Advisor: Assist. Prof. Dr. Hakan ASLAN

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The thesis work titled "Travel Time Reliability Analysis of Three Different Routes in Baghdad City" prepared by Makarım Kareem Jebur AL-SARRAY was accepted by the following jury on …. /…. /……. by majority of votes as a MSc THESIS in Sakarya University Graduate School of Natural and Applied Sciences, Civil Engineering department, Transportation program.

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ABBREVIATIONS

95th	: 95 The Percentile Travel Time
AASHTO	: American Association of State Highway and Transportation Officials
BI	: Buffer Index
CBD	: Central Business District
ERI	: Ecosystem Research Institute
FFS	: Free Flow Speed
FFTT	: Free Flow Travel Time
FHWA	: Federal Highway Administration
GIS	: Geographical Information Systems
GPS	: Global Positioning System
HCM	: Highway Capacity Manual
LOS	: Level of Service
PTI	: Planning Time Index
PV	: Percent Variability
RR	: Reliability Ratio
SD	: Standard Deviation
SHRP	: Strategic Highway Research Program
SPSS	: Statistical Package for the Social Sciences
TTI	: Travel Time Index
VOR	: Value of Reliability

SYMBOLS

q	: Flow rate [passenger car units]
t	: Time [min, sec]
$\boldsymbol{\beta}, \boldsymbol{\gamma}$	: Coefficients
V	: Volume of traffic [c/hr]
C	: Capacity [car/km/hr]

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DEVELOPING MULTI MODAL TRANSPORTATION MODELS AND STRATEGIES FOR BAGDAD

SUMMARY

Transportation is an important aspect of the daily life allowing people to participate in human activities and to obtain basic needs. The rise in population has resulted in an escalation in transportation requirements, leading to an augmented volume of traffic on the roads. Consequently, mobility-related predicaments, such as congestion, have become more prevalent, particularly in city centers where human activities are concentrated. With that sense, transportation networks are to be planned properly to control urban traffic to mitigate mobility problems related to transportation travel time.

Travel time reliability refers to the level of assurance and consistency with which travel times can be predicted on a given transportation system. A reliable transportation system offers a certain level of guarantee that one can reach their intended destination within a reasonable timeframe. A transportation system that lacks reliability is susceptible to unforeseen delays, resulting in higher expenses for its users. Travel time reliability is a metric that evaluates the consistency of time taken to traverse a particular link or segment of a road during various hours of the day, quantified in terms of additional time (buffer) that drivers must allocate to compensate for unexpected delays. Travel time reliability is a crucial measure not only for transportation providers but also for passengers who rely on the system for their daily commuting needs.

In this study data collection process began when the test vehicle was equipped with GPS (moving vehicle technology) to collect data on specified paths. The Statistical Package for the Social Sciences (SPSS) program was utilized to analyze GPS field data collected from 50 running trials conducted in both the South and North directions during morning and evening hours. The aim was to assess the impact of increased traffic volume on flow behavior of the vehicles and reliability in three selected routes.

In the first case, the average travel time for all links in three paths was obtained from the real time GPS vehicle data. After that traffic volumes on each path were estimated using the BPR equation. Following, a simulation was conducted using the PTV Vissim program to increase traffic volumes by 10% for each iteration up to 10 times, and the average travel times for all increments were calculated. The purpose was to compare the simulation results with the initial and realistic case to determine the traffic structure and reliability after the proposed changes.

The results of the buffer time index for three routes (real case), Route1, Route2, and Route3, were obtained as 22%, 12%, and 14%, respectively. In the simulation case, the results for Route1, Route2, and Route3 were obtained as 7%, 8%, and 9%,

respectively. These results showed that the reliability got better for Route1 during the peak period, and the best values in real case was for Route2, and in simulation case for Route1. Extra delay in the real case over the free flow travel time was observed on Route1, Route2, and Route3 in terms of the 95th percentile travel time for the real case, which were 52%, 38%, and 41%, respectively. While in the simulation case, the delays increased to 67%, 42%, and 50% for Route1, Route2, and Route3 after the last iteration, respectively.

BAĞDAT ŞEHİRİNDE ÜÇ FARKLI GÜZERGAHTA SEYAHAT SÜRESİ GÜVENİLİRLİK ANALİZİ

ÖZET

Ulaşım, insanların yaşamsal faaliyetlerine katılmalarını ve temel ihtiyaçlarını elde etmelerini sağlayan günlük hayatın önemli bir yönüdür. Nüfus artışı, ulaşım gereksinimlerinde bir artışa neden olmuş ve bu da yollardaki trafik hacminin artmasına yol açmıştır. Bu nedenle, özellikle insan faaliyetlerinin yoğunlaştığı şehir merkezlerinde, trafik sıkışıklığı gibi mobilite ile ilgili sorunlar daha yaygın hale gelmiştir. Bu nedenle, ulaşım ağları doğru bir şekilde planlanmalıdır, böylece şehir trafiği kontrol altında tutulabilir ve ulaşım seyahati ile ilgili mobilite sorunları azaltılabilir.

Seyahat süresi güvenilirliği, belirli bir ulaşım sisteminde seyahat sürelerinin ne kadar öngörülebilir ve tutarlı olduğuna ilişkin düzeyi ifade eder. Güvenilir bir ulaşım sistemi, kişinin amaçladığı varış noktasına makul bir süre içinde ulaşabilmesine dair belli bir garanti sağlar. Güvenilirliği olmayan bir ulaşım sistemi, öngörülemeyen gecikmelere maruz kalabilir ve kullanıcıları için daha yüksek maliyetlere neden olabilir. Seyahat süresi güvenilirliği, bir yolun belirli bir bağlantısının veya bölümünün günün farklı saatlerinde alınan sürelerinin tutarlılığını ölçen bir ölçüttür ve sürücülerin beklenmedik gecikmeleri telafi etmek için ayırmaları gereken ekstra zaman şeklinde ifade edilir. Seyahat süresi güvenilirliği, sadece ulaşım sağlayıcıları için değil, günlük işe gidip gelme ihtiyaçları için sistemlere güvenen yolcular için de önemli bir ölçüttür.

Sık sık yaşanan gecikmeler, günlük iş veya diğer etkinliklere geç kalınmasına neden olabilen bir durumdur ve insanlar için rahatsızlık ve hayal kırıklığına neden olabilir. Tek bir olay önemli bir sorun olmayabilir, ancak böyle durumlar sık sık ve beklenmedik bir şekilde meydana gelirse, varış noktasına ulaşmak için gereken süre hakkında belirsizlik söz konusu olabilmektedir. Bu belirsizlik, etkilenen kişilerin çocuklarını okula taşımaları veya zamanında yetişmeleri gereken sosyo-kültürel bir etkinliğe katılmaları gerektiği durumlarda daha da önemli olumsuzluklara neden olabilmektedir. Bu durumlarda, insanlar daha erken yola çıkmayı veya trafikten kaçınmak için alternatif yollar bulmayı düşünmek zorunda kalabilmekte, böylece varacakları yere zamanında varacaklarından emin olabilmektedirler.

Aslında, gideceğiniz yere güvenilir bir zaman diliminde ulaşmak için kullandığınız ulaşım sistemine güvenemeyebilirsiniz. Ulaşım sistemlerinin güvenilirliğinin eksikliği, insanların sağlığı, işleri, aile ilişkileri, tüketici mallarının maliyeti, acil müdahale süreleri vb. gibi birçok konuda olumsuz etkiler yaratır. Bu nedenle, seyahat süresi güvenilirliği önemlidir. Bu doğrultuda, güvenilir olmayan seyahat süresinin etkilerinin analiz edilmesi ve olumsuz etkilerinin minimize edilmesi oldukça önemlidir. Karayolu kullanıcıları, toplum taşıma hizmeti sağlayıcıları, taşıyıcılar ve yolcular, seyahat süresindeki farklılıkları hem günlük bazda hem de

aynı gün içinde anlamak için ortak bir ilgiye sahiptirler. Seyahat süresindeki değişkenlik, aynı gün içinde aynı başlangıç ve varış noktaları arasındaki seyahat süresinde farklı zamanlarda oluşan değişiklikleri ortaya çıkarabilir. Genellikle, yoğun olmayan saatlerde seyahat süresi, yoğun saatlere göre daha kısadır, bu da aynı gün içinde seyahat süresinde belirgin bir farklılık yaratır.

Bu çalışmada, Bağdat şehrinde üç güzergâh seçilmiştir. Bu güzergahlar ana arter ve toplayıcı yollar olup, trafiğin iyi koşullarda olduğu ve tüm trafik durumu özelliklerini karşıladığı düşünülmüştür. Seçilen güzergahlar Bayaa-Bab Al-Madaam dora otoyolu (Route1), Bayaa-Bab Al-Madaam alawee caddesi (Route2) ve Bayaa-Bab Al-Moadam al mansur yolu (Route3) olarak belirlenmiştir. Bağdat şehrinin sinyalli kavşaklarında ve önemli kentsel caddelerinde özellikle sabah ve akşam saatlerinde en yoğun trafik sıkışıklığının görülmesi yaygındır. Başkent Bağdat'ta araç sayısındaki dramatik artış ve yol ağı kapasitesindeki pek az iyileşme, gecikmelerin artmasına ve seyahat süresi güvenilirliğini etkileyen hizmet seviyesinin azalmasına neden olarak sistem kullanıcılarının rahatsızlığına yol açmaktadır.

İncelenen güzergahlardaki çoğu kavşaktaki trafik akışı polis tarafından kontrol edilmektedir. Bu nedenle, bu kavşaklarda tahmini kontrol gecikmesini hesaplamak için geliştirilen denklemlerin sonuçları, örneğin karayolu kapasite el kitabında olduğu gibi, gerçek koşullardan uzaktır. Bu nedenle, trafik yoğunluğunun oldukça yüksek olduğu üç arteriyel kentsel yolda, seyahat süresinin tahmin edilmesi önemlidir. Zira, Bayaa - Bab Al-Mutham (otoban güzergahı), Bayaa kavşağı - Bab Al-Mutham (şehir merkezi güzergahı) ve Bayaa - Bab Al-Mutham (Al-Mansoor güzergahı) seçilen güzergahlar, Bağdat şehrindeki yol kullanıcıları için gündelik yaşam kalitelerinde önem arz etmektedir. Trafik sıkışıklığı, belirli bir zamanda yol üzerinde aşırı sayıda aracın bulunması nedeniyle meydana gelir ve "serbest akış" veya hız seviyelerinin normalden daha yavaş olmasıyla sonuçlanır. Trafik sıkışıklıkları sırasında, yüksek araç sayısından dolayı yoldaki uzun kuyruklar nedeniyle araçlar dur-kalk durumuna girerler. Bu durum, araçların sayısı yolun tasarım kapasitesinden daha fazla olması durumunda, yolu kullanan araçların aşırı gecikmeler yaşamasına neden olur. Ayrıca, bu çalışma içeriğinde belirlenen rotalar yoğun kentsel ve ticari alanlara sahip olup, birçok restoran ve alışveriş merkezi bulundurmaktadırlar. Rotalar boyunca düzensiz park alanları, restoran ve mağaza girişleri ile farklı inşaat alanlarının bulunması, darboğaz ve şok dalgası durumlarına neden olmaktadır.

Bahsedildiği gibi güzergahlar, her iki yönde şehir ulaşım ağı için mevcut olan yoğun trafik hareketini temsil ettiği için seçilmişlerdir. Öte yandan, bu güzergahlarda, seyahat sürelerinin, haftanın günlerine göre farklı seyahat süreleriyle başlangıç noktasından bitiş noktasına kadar değişkenlik gösteren, yüksek gecikmelere neden olan birçok kavşak bulunmaktadır. Bu güzergahlar boyunca toplanan veriler, her bir bağlantının uzunluğu, şerit sayısı, genişlikleri gibi geometrik yapılarının yanı sıra test aracının hareketinden elde edilen hız verilerini içeren verilerdir. Veriler, belirli yollarda GPS'li test aracı kullanılarak toplanmıştır. Sabah ve akşam saatlerinde Kuzey ve Güney yönlerinde gerçekleştirilen 50 çalışmadan elde edilen GPS saha verileri, kullanılmadan önce düzenlenerek, istatistiksel analiz için Sosyal Bilimler İstatistik Paketi (SPSS) programı kullanılmıştır. Gerekli noktaların koordinatları, bir GPS cihazı aracılığıyla kaydedilir.

Bu çalışmada, seyahat süresinin güvenilirliğini değerlendirmek için BPR seyahat süresi fonksiyonu benimsenmiştir. BPR bağlantı performans fonksiyonu, ulaşım ağlarındaki bağlantı seyahat süresini tahmin etmek için yaygın olarak kullanılan bir yöntemdir. Seyahat süresi, kuyruk bekleme süresi ve araç gecikmesi gibi belirli ölçütlere dayalı olarak, taşıma sisteminin performansını değerlendirmeyi amaçlayan çalışmada, üç güzergahın da bu anlamda seyahat süresi güvenilirlikleri değerlendirilmiştir.

Bu çalışmada, seyahat süresinin güvenilirliğini değerlendirmek için Vissim simülasyon programı kullanılmıştır. Kavşaklar bir koridor ile birbirine bağlanmış, trafik hacmi ve yolun uzunluğu girilerek yolun sonuna varmak için ne kadar zaman gerektiği hesaplanmıştır. Daha sonra trafik hacmi her adımda, iterasyonda, %10 kadar arttırılmış ve her seferinde program tüm bağlantılar için birleşik seyahat süresini hesaplamıştır. Ek olarak, yolun tasarlanan hızı ve şerit sayısı gibi sabit özellikler de dikkate alınmıştır. Bu yollardaki artan trafik hacminin etkisini simüle etmek için de yine PTV Vissim programı kullanılmıştır. Bu program, yol ağının sanal bir modelinin oluşturulmasını içerir ve farklı trafik koşullarında yolların nasıl performans göstereceğini değerlendirmek için kullanılır. TTI, PTI ve BI dahil olmak üzere üç farklı ölçümün her biri üç farklı rota için Vissim simülasyon yazılımı kullanmadan önce ve sonrası için raporlanmıştır. Ayrıca, bu değerlendirmenin Vissim simülasyonlarından elde edilen sonuçları, SPSS kullanarak yapılan istatistiksel analizden elde edilen ortalama seyahat süresi ile karşılaştırılmıştır.

Sonuç olarak, öncelikli olarak gerçek durum da Route1, Route2 ve Route3 için ortalama seyahat süreleri sırasıyla 43, 34 ve 36 dakika olarak GPS aracı üzerinden belirlenmiştir. Öte yandan, simülasyon durumunda ortalama seyahat süreleri Route1, Rout2 ve Route3 için sırasıyla 57, 39 ve 46 dakika olarak elde edilmiştir. Ayrıca, her bir güzergâh için gözlemlenen verilerde ve Vissim simülasyonunda Buffer Index (BI) değerleri analiz edilmiştir. BI yüzde olarak ifade edilir ve planlanan seyahat süresinin zamanında varışı sağlamak için gereken ek süreyi temsil eder. Genel olarak, daha düşük bir BI, belirli bir rotada daha güvenilir bir seyahat süresini gösterirken, daha yüksek bir BI, seyahat eden kişilerin zamanında varışı sağlamak için daha fazla tampon süresi planlamaları gerekebileceğini önerir.

Her bir güzergâh için BI farklıdır ve bazı güzergahların diğerlerinden daha yüksek BI'ı vardır. Örneğin, gözlemlenen verilere göre, gerçek durumda üç rota için BI sonuçları, Route1, Route2 ve Route3 için sırasıyla %22, %12 ve %14 olarak elde edilmiştir. Simülasyon durumunda ise Route1, Route2 ve Route3 için sırasıyla %7, %8 ve %9 sonuçları elde edilmiştir. Bu sonuçlar, Route1'in yoğun dönemde daha güvenilir hale geldiğini gösterirken, gerçek durumdaki en iyi değerler Route2 için ve simülasyon durumundaki en iyi değerler ise Route1 için elde edilmiştir. Ayrıca, gerçek durumda 95. yüzdelik seyahat süresinde ekstra gecikme değerleri, Route1, Route2 ve Route3 için sırasıyla %52, %38 ve %41 olarak gözlemlenirken, simülasyon durumunda gecikmeler Route1 için %67, Route2 için %42 ve Route3 için %50 artmıştır. Rotalar için TTI değerlerini simülasyondan önce ve sonra karşılaştırarak, üç rota için de trafik hacmi arttıkça TTI'de bir artış olduğu tespit edilmiştir. Bu, trafik sıkışıklığının ve seyahat süresi değişkenliğinin arttığını göstererek, hacim artışının seyahat süresi güvenilirliği üzerinde olumsuz bir etkisi olduğunu ifade etmektedir.

Güzergahlar üzerindeki PTI değerleri, simülasyon öncesi ve sonrası için farklı bir eğilim göstermektedir. Route1i Route2 ve Route3 için, Vissim kullanılarak yapılan simülasyon sonuçlarına göre trafik hacmi arttıkça PTI'da da artış görülmektedir. Bu da seyahat süresinde artış olduğunu göstermektedir. Genel olarak, bu senaryonun PTI üzerindeki etkisi, özellikle belirli güzergâh özelliklerine (her bir bağlantının uzunluğu, hız sınırı ve kesişim) bağlı olarak değişebilir ve simülasyon seyahat süresi bu anlamda güvenilirliğini etkileyen tüm faktörleri temsil etmeyebilir. Bu çalışmada incelenen üç güzergâh, kullanıcılara sunulan tüm hizmetleri ve kavşakları içermektedir. Son yıllarda artan ekonomik faaliyetler ve yaşam kalitesinin iyileşmesi, seyahat süresinin değerini artırdığından, istikrar ulaşım için önemli bir konu haline gelmiştir. Bu nedenle, beklenmedik bir gecikme herhangi bir yol kullanıcısı için büyük kayıplara neden olabilir. En önemli hedef, araçlar arasındaki etkileşim sürecinden kaynaklanabilecek potansiyel riskleri azaltmak için gerekli tüm güvenlik faktörlerini sağlamak ve geçen tüm yolculuklar için uygun bir zaman dilimi ve daha az gecikme ile seyahat kolaylığı sağlamaktır. Güzergahlar ve bağlantılar için güvenilirliği sağlamak adına dikkate alınması gereken birkaç husus vardır; ağdaki linklerin uzunluğu, hız sınırı ve şebekede bulunan şerit sayısı, araçların birbirleriyle etkileşim noktaları, yol tasarım hızının belirlenmesi ve kavşakların kontrol stratejileri, kavşaklarda bulunan hareket yönlerinin karşılıklı kesişimleri, en yüksek hacimli trafik akım yönlerinin tespiti vb.

Sağlam ve güvenilir bir ulaşım sistemi, erişilebilirliği ve ekonomik büyümeyi teşvik ederek insan ve malların güvenli ve verimli bir şekilde hareket etmesine imkân vereceği için herhangi bir bölgenin veya ülkenin ekonomisi için önemli bir rol oynayacaktır. Ayrıca, depremler, sel felaketleri, kasırgalar ve diğer felaketler gibi doğal afetler sırasında da etkilenen bölge ve nüfus için en önemli yaşam hattı fonksiyonunu görecektir.

1. INTRODUCTION

The provision of transportation facilities is crucial in enabling individuals to participate in daily activities and fulfill their basic needs. However, as the population continues to grow, the demand for transportation also increases, leading to mobility-related problems such as traffic congestion, particularly in densely populated urban areas. Therefore, proper planning and management of transportation networks and traffic control are essential to address these challenges. Additionally, the design of transportation infrastructure must be taken into consideration in both urban and suburban areas, as well as public and private transportation networks. This issue has been extensively studied over the past few decades due to its complexity, interdisciplinary nature, practical importance, and theoretical interest, leading to a significant number of relevant publications. Reviews were published by Magnanti and Wong (1984), Friesz (1985), Migdalas (1995), and Desaulniers and Hickman (2007). Several of these reviews are concerned with broader network design issues.

The term "reliability" has diverse interpretations across different fields, including road transportation systems. In the context of this thesis, reliability is defined as the level of certainty and predictability of travel times on a transportation system. A reliable transportation system is characterized by its ability to ensure that travelers can reach their intended destinations within a reasonable timeframe, with travel times closely aligned to the expected duration. Conversely, an unreliable transportation system is prone to unforeseen delays, leading to increased costs for users. With this regard, travel time reliability refers to the consistency of travel times, which can vary due to unexpected delays stemming from different traffic flows at various times of the day. Hence, travel time reliability is a crucial factor for various system users and operators, including passengers, transit passengers, shippers, and other road users, as it enables them to make informed decisions regarding their time utilization. For instance, shipping companies require predictable travel times to ensure timely delivery of goods and services. The unpredictability of travel times due to congestion during rush hours poses a significant challenge for system users as it not only increases travel time but also makes it difficult to estimate the expected travel time for a specific route or segment. Therefore, ensuring travel time reliability is essential to enhance the efficiency and effectiveness of transportation systems and to support the needs of all road users. Travel time reliability can be regarded to provide an environment making it there on time. In recent times, there has been a growing interest in evaluating the reliability of travel time and analyzing transportation projects. This interest is not limited to a specific region or country but is observed globally. In fact, international research projects have been initiated to guide transportation agencies on how to incorporate the value of reliability (VOR) in the cost-benefit analysis. This is particularly important when making investment decisions related to reducing congestion and improving the reliability of travel time. The VOR approach helps decision-makers to consider the economic benefits associated with travel time reliability when evaluating transportation projects. This, in turn, leads to better decision-making and improved efficiency in transportation systems.

An efficient and dependable transportation system is crucial for the economy of any region or country. It ensures safe and smooth movement of goods and people, and plays a critical role in disaster situations; such as floods, earthquakes, and hurricanes. In such events, the transportation system serves as the primary lifeline, facilitating access to affected areas and people by enabling the restoration of other essential services such as water supply, power, and communication networks (Nicholson and Du, 1997). Vehicles cannot be driven to places with poor transportation system causes to hinder not only the recovery process economically but also deaths. A reliable transportation system must also be considered under the permanently changing traffic flows from hour to hour on daily basis. Actual travel requirements and road capacity vary over time, therefore, contributing to the uncertainty of travel times. As the transportation system provides a competitive advantage in the global economy, the importance of the reliability of the transportation system cannot be overemphasized.

1.1. Problem Definition

The experience of being unexpectedly caught in traffic, leading to a delay in daily commutes to work or other events, is a common occurrence that can cause inconvenience and frustration. While a one-time event may not be a significant issue, if such incidents occur frequently and in an unexpected pattern, it can create uncertainty about the necessary amount of time needed to reach the destination. This uncertainty can be exacerbated in cases where the affected individual needs to transport their children to school or attend a special event, such as a game or concert, on time. In such circumstances, individuals may need to consider leaving earlier or identifying alternate routes to avoid traffic and ensure timely arrival at their destination. In fact, you cannot rely on the transportation system you travel to go to your place in a reliable time period. The lack of reliability of the transportation systems affects people`s health, jobs, family relationships along with cost of consumer goods, emergency response times etc. So, travel time reliability does matter. Having said that, it is quite important to analyze the impacts of unreliable travel time and minimize the negative effects of it. Road users, transit service (public transportation) providers, shippers, and travelers all share an interest in understanding the variations in travel time, both on a day-to-day basis and throughout the same day. The variability in travel time within a single day can reveal changes in the time needed to travel between the same origin and destination at different times throughout the day. Typically, travel time during off-peak hours is shorter than during peak hours, which leads to a noticeable variance in travel time during the same day.

It is common to observe traffic congestion at most of the signalized intersections and major urban streets in Baghdad city especially at peak hours of morning and evening periods. The dramatic increase in the number of vehicles and demand for traffic in the capital city of Baghdad without much improvement in road network capacity led to increased delays and decreased level of service (LOS) affecting the travel time reliability causing system user’s discomfort. The traffic flows at most intersections on the arterial streets are controlled by the policeman. Therefore, most of the equations that have been developed for computing the estimated control delay at fixed intersections have their results far from real conditions as in highway capacity manual (HCM). So, it is important to investigate and estimate the travel time for three arterial urban roads (arterials and collectors) where the traffic is under quite dense condition. Bayaa- Bab Al-Mutham (highway route), Bayaa intersection - Bab

Al- Mutham (downtown route), and Bayaa - Bab Al- Mutham (Al-Mansoor route) were the selected routes having crucial importance for the road users in the city of Baghdad. The traffic congestion takes place due to existence of the excessive vehicles on the roadways at certain time leading to slower than usual "free flow" or speed levels. Throughout the traffic congestions, long queues are formed on the roads, causing the vehicles start and stop states because of the fact that the numbers of the vehicles are higher than the road’s design capacity. This leads the vehicles that trying to use the road suffer excessive delays because increasing the volume and the travelers are not capable of moving within the required time.

1.2. The Study Objectives

The major objectives of this thesis are as follows:

1. Estimating and evaluating the travel times for the three selected urban streets located in Baghdad (Bayaa- Bab Al-Madaam (highway - Route1), Bayaa intersection - Bab Al- Madaam (downtown - Route2), and Bayaa - Bab Al-Madaam (Al-Mansoor - Route3).
2. Estimating the reliability indexes (buffer index, travel time index, and 95% percentile travel time) which will help to provide the road users with useful information for planning and managing their trips. This can also help to understand the differences in travel time and assist in the planning of transport system management as far as transportation planning department of the city of Baghdad is concerned.
3. Comparing the three selected routes and find out the most reliable one based on the reliability indexes estimations.
4. Calculate the traffic volume of each link depending on its mean travel time and free flow travel time using the BPR function.
5. Simulating the traffic volume using the PTV Vissim software and perform different traffic scenarios to study the various affects.
6. Comparing the results of time and reliability indicators by the two methods of statistical analysis and simulation through a software.

1.3. Study Area

In this study, three routes have been selected in Baghdad city following the work of Alkaissi1 et al. (2022). These routes shown in Figure 1.1, are arterial roads and collector roads where the traffic is considered to be in good conditions and meet all the characteristics of traffic state. The selected routes are Bayaa - Bab Al-Madaam dora express way (Route1), Bayaa - Bab Al-Madaam alawee street (Route2), and Bayaa - Bab Al-Moadam al mansur way (Route3). Moreover, these routes are heavily urbanized and commercial containing many restaurants and shopping malls. Non-uniform parking areas, entrances of restaurants and shops along with different construction areas exist along the routes causing bottleneck and shock wave situations.

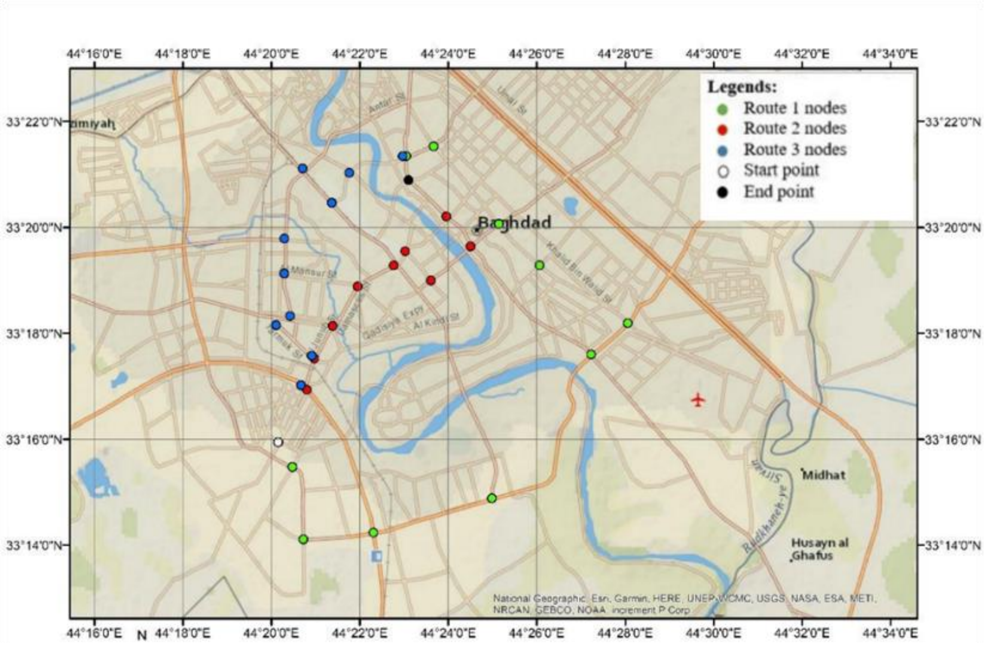


Figure 1.1. Bayaa Intersection - Bab Al-Mutham Intersection (3 routes).

1.4. Study Methodology

In this study, the following steps are utilized to obtain the aimed outcomes of the work:

1. Fieldwork to collect data, which is site selection and description of the intersection and location of each point inside the route.
2. Traffic data for the selected arterials in Baghdad city.

3. Travel time collection and the development and execution of a travel time modelling using the collected data using SPSS software package.
4. Using the manual method, by observant to collect the roadway's geometric features such as the number of lanes, width of roadway and speed, etc.
5. Performing reliability measurement and travel time for each route.
6. Comparison of the results using PTV Vissim software, and changing the traffic scenarios by increasing traffic volume 10, 20, 30, 50, 70, until 100% and observe the simulation via the software. To assess the impact of increased traffic volume on the road behavior and reliability, the average time for all links in three roads was first calculated, and the traffic volumes for these links were estimated using the BPR equation. A simulation was then conducted using the PTV Vissim software, which incorporated various road parameters such as speed limits, lengths of the links, speeds on and through the intersections, and traffic volumes.

As listed in the steps, firstly the routes were selected as they represent a heavy traffic movement available for the transportation network of the city for both directions. On the other hand, these routes have many intersections responsible for heavy delays causing the travel times to fluctuate with various travel times from start to the end point of the journey with the available demand through the days of week. The data collected through these routes are the data consisting of geometric structure of the routes such as the length, number of lanes, widths of each link along with the speed data obtained from the movement of the test car. SPSS software was employed after collecting all the data for the analysis purpose and the results of the travel time reliability. Finally, traffic volumes for these links were estimated using the BPR equation. A simulation was then conducted using the PTV Vissim software, which incorporated various road parameters such as speed limits, link lengths, lengths of the intersections and traffic volumes.

1.5. Thesis Outline

The related contents of this study are summarized as following five chapters:

- Chapter one gives a brief idea about the present work.

- Chapter two reviews the literature related to previous work in transportation network reliability in general and specifically with respect to the travel time reliability along with reliability index, travel time in (GPS device) etc.
- Chapter three describes the study area and the methodology for collecting the data using a test car equipped with a GPS device (vehicle moving technique). This chapter further explains extracting and processing data using EXCEL sheets.
- Chapter four illustrates analytical results regarding the reliability measurements obtained by using the Statistical Package for the Social Sciences (SPSS) for each direction (North and South) of the selected routes. Also, using PTV Vissim software to simulate the traffic volume in different scenarios.
- Chapter five contains conclusions, recommendations, and suggestions for future researches.

2. LITERATURE REVIEW

2.1. Introduction

The reliability of the transportation network is one of the hot-spot researches in the field. Current researches on urban transportation network reliability can be mainly divided into three categories: capacity reliability, travel time and connectivity reliability. Transportation network reliability concept first came into consideration after the huge Kobe earthquake in Japan as it caused dramatic negative effect on the movement of people and vehicles preventing the rescue operations and hindering the people with vital substance required for their daily life (Chang and Nojima, 2001). First limelight studies are related with connectivity reliability analysis in accordance with the immediate problems faced with after the Kobe earthquake. Following, it became one of the most popular and important branches of the transportation network performance analysis by including travel time and capacity reliability of the networks.

Numerous studies have explored the reliability of road networks, taking into account different sources of disruption. While some studies have focused solely on traffic congestion caused by significant increases in demand, such as during holiday weekends, others have examined the impact of exceptional events, such as major natural or manmade disasters, as well as regular events, including vehicle crashes. To enhance the understanding and management of such uncertainty, researchers have analysed the effects of different disruptions on transportation network performance, and how this information can affect the design and economic evaluation of transportation policy measures (Asakura et al., 2001). Previous reliability analyses have primarily focused on the connectivity, travel time, capacity, behavioral and potential reliability (Neumayer and Modiano, 2010).

In general, when transportation network reliability is under consideration the major aspects of reliability are considered as connectivity, capacity, and/or travel time reliability (Chen et al., 1999). In the field of transportation engineering, the term "reliability" refers to the likelihood that components, products, or systems will successfully perform their intended functions without failure for a specific duration of time, under the specified operating conditions, and with a given level of confidence. This definition was outlined by Kececioglu (1991) and is widely accepted in the field of reliability engineering.

The focus of this thesis is on travel time reliability, which can be defined as the likelihood that traffic can reach a designated destination within a specified time frame. For instance, if the travel time reliability for reaching a destination within 20 minutes is 0.5, this indicates that drivers can expect to arrive at the destination within 20 minutes approximately 1time out of 2.

When analysing travel time reliability in transportation networks, it is essential to consider the overall situation on the network. Specifically, a distinction should be made between abnormal and normal situations. In abnormal situations, events such as natural disasters, major accidents, or extensive maintenance work can significantly impact travel time reliability. In such scenarios, certain components of the road network system may fail or become non-functional. In contrast, normal situations arise due to typical variations in traffic demand and road capacity, which can impact network reliability and the ability of traffic to reach a destination within a given time frame.

Connectivity reliability of the transportation networks describes the situation whether one or some of the links cannot be used to let the vehicle continue their movement by using those links. As can be seen from this description, it is related to the Level of Service (LOS) concept of the networks. The functionality of the links in terms of whether they can be used by vehicles can be categorized depending on the specific congestion conditions of urban traffic under which LOS are used to decide whether the links functioning or not. This is used as a measure of the probability that network nodes are connected. Under extreme conditions, i.e., earthquakes, the network might be considered successful and connected if at least one path is operational for a specific O-D pair without taking the LOS into consideration. As far as binary approach is concerned a path consists of a set of links characterized by zero (0) or one (1) to denote the link’s status of whether they are operating or failed. This binary approach has limited applications in everyday situations representing the fluctuations on traffic demand where roadway links operate at certain various levels between O-D pairs of the network (Iida and Wakabayashi, 1989; Asakura et al., 2001; Kurauchi et al., 2004). Wakabayashi (2004) stated that network connectivity reliability could be improved effectively by optimizing the most important primary link (links) on a network. When such an important link (or links) is detected, the connectivity reliability can be efficiently improved and maintained by keeping that link (or links) under operational conditions of certain level. This can reflect the change and improvement of traffic conditions under congestion conditions especially in the morning and evening rush hour periods.

2.2. Urban Street

Arterial roads of urban transportation networks serve both commercial and residential traffic movements, hence, are considered to have high traffic volumes with available relatively high speeds and frequent traffic with other collectors and roads (HCM, 2010). Urban streets with arteries and collectors from the multilateral suburban and local streets are seen in the hierarchy of street transport systems. The function of the streets and the criteria for regulation along with the character of roadside growth (TRB, 2005) are the basic tools to specify the road type, the control conditions, and the roadside development's character (TRB, 2005). The minor urban arteries transport significant amounts of traffic within and across metropolitan centers. Urban arterials may have some connection to abutting properties. However, such an access provision would only be incidental to the arterial's primary role to support broad traffic movement (AASHTO, 2011). In terms of the speed of travel that affects highway capacity, hence, the degree of urban street mobility is calculated by considering the factors (TRB, 2005), as follows:

1. Three primary variables are used to decide on the speed of the street surroundings providing a traffic flow, the facility's geometric properties, the characteristics of roadside service, and the adjacent usage of the zones.
2. The interaction of the vehicles depending on the traffic level, the number of heavy vehicles (such as trucks and buses) and the turning movements.
3. Traffic regulations allowing all traffic to halt or slow down. This also has an impact on the standard of service provided. Some urban arterial road guidelines for the design speeds according to AASHTO (2011) are shown in Table 2.1.

Table 2.1. The road and terrain design speeds.

Type of road	Type of terrain	Design speed/rural roads (mph)	Design speed/urban roads (mph)
Freeway	Level	70	+50
	Rolling	70	+50
	Mountainous	50-60	+50
Arterial	Level	60-75	30-60
	Rolling	50-60	30-60
	Mountainous	40-50	30-60
Collector	Level	40-60	+30
	Rolling	30-50	+30
	Mountainous	20-40	+30
Local	Level	30-50	20-30
	Rolling	20-40	20-30
	Mountainous	20-30	20-30

2.3. Delay Concept in Transportation

One of the most important analytical studies carried out in transportation engineering is related to determination of total amount of time needed to travel from a starting point to a destination point of the travel. To conduct such study, information regarding location, durations and causes of delays may need to be investigated. As the level of service provided by the transportation systems is of vital importance, the improvement of the overall flow of the traffic on the networks can only be managed and sustained through these analytical studies. Thanks to data obtained through this analysis; the ability and efficiency of a route to carry the demand available on it, the locations with high delays, evaluation of the effectiveness of the before - after studies regarding traffic operation improvements, developing congestion indices, determination of travel times on the links of the network and evaluation of traffic operation alternatives to lessen the travel times can be assessed.

As far as transportation engineering analysis process is concerned, delays can be divided into various categories:

- Operational delay: This component of the delay is caused by another impedance to the movement. This impedance may occur either as lateral friction, when the traffic flow is interfered by other traffic (such as parking), or as internal friction, where the disturbance is within the flow of traffic, for example, reduction in the capacity of a highway (Garber and Hoel, 2014).

- Geometric delay: This delay is produced by engineering features forcing cars to slow down while approaching a section of the system (for example, it encounters delay when an arterial road takes a sharp turn, forcing vehicles to slow down or delays caused by the indirect path that vehicles will follow through a roundabout).
- Accident delay: Compared to the case of no accident, the additional travel time might be caused by an accident.
- Traffic delay: This delay arises from vehicles` contact, making drivers to slow down below free-flow traffic speed (HCM, 2010). Traffic delay is one of the important parameters used to evaluate the performance of any roundabout or intersection (signalized or unsignalized).
- Delays caused by signalized intersections: This is the result of delays caused by devices such as traffic lights. This delay relies on how much traffic or impedance may occur (Garber and Hoel, 2014). Delays can be analyzed in different ways as explained below:
    1. Delay stop time: It includes the time the vehicle spends at a traffic stop light from the first second of stopping until the start of movement.
    2. Approach delays include the time the vehicle spends when acceleration increases and decreases before and after stopping as well as stopping time.
    3. Delay Travel time: This type of delay refers to the difference between the actual time and the designed speed time in road.

The delay measurements at the signalized intersections can vary depending on the conditions at the available intersections on the routes. Figure 2.1 shows the stop time, approach and travel time delay of an individual vehicle passing through an intersection with varying signals. The same figure also illustrates the direction of the target and the real progress of the vehicle with regard to desired and actual path including the red stop sign.

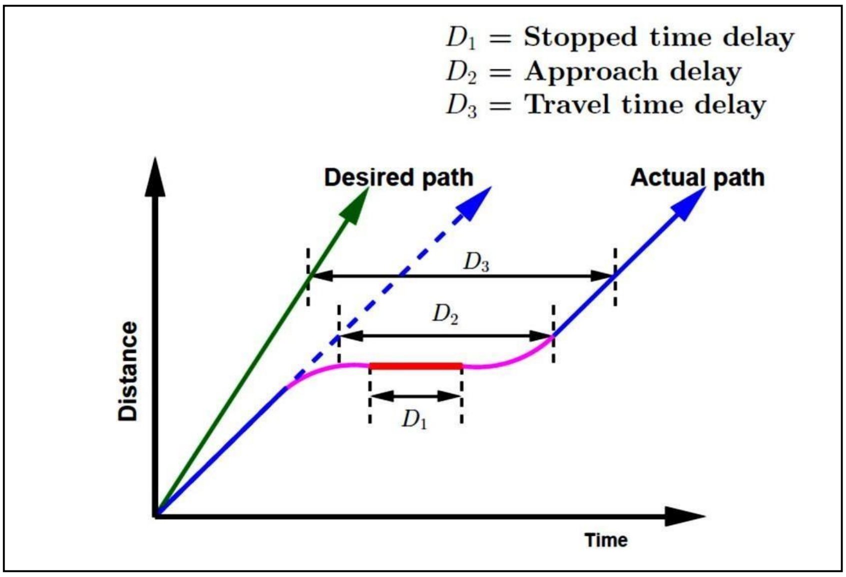


Figure 2.1. An illustration of the delay procedure (Khalil, 2013).

The delay at signal intersections is one of the key parameters used to improve the timing of traffic lights. Moreover, the delay is a key parameter in calculating the level of service provided to motorists at intersections with traffic lights. Table 2.2 shows the level of service standards for the signalized intersections explained in the Highway Capacity Guide (TRB, 2010).

Delay, on the other hand, is a parameter that can be measured with uncertainty because it involves the fluctuating and random arrivals of the vehicles resulting in different aspects of available delay components along with various acceleration rates from the stopping point depending of the composition of the vehicles (Kang, 2010).

Table 2.2. Level of service standards for signalized intersections (Kang, 2010).

Level of Service	Average Control Delay (sec/veh)	General Description (Signalized Intersections)
A	≤ 10	Free Flow
B	> 10 - 20	Stable Flow (slight delays)
C	> 20 - 35	Stable Flow (acceptable delays)
D	> 35-55	reaching unstable traffic flow (There may be a delay, often wait for more than one signal loop)
E	> 55-80	Unstable Flow (intolerable delays)
F	> 80	Forced flow (jammed)

2.3.1. Traffic queue length

The average queue length is an index that measures the adequacy of the geometric characteristics for a roundabout or intersection approach. It can be considered equivalent to either the approach delays per hour or the number of vehicles per hour. This index is highly useful as an evaluation tool for assessing the performance of roundabouts and intersections relative to other types of roundabouts or intersections (FHWA, 2000). Delays in queuing with one vehicle are not easily explained, as it requires getting in and out of queue with multiple vehicles.

2.3.2. Roundabout or intersection level of service (LOS)

LOS is defined as an induction that refers to operational situations in a traffic flow stream, and their perception by system users and/or passengers. The LOS parameter simplifies the traffic criteria such as speed, delay, freedom to maneuver, comfort, travel time and safety into A to F scale, where A refers to ideal traffic situation to system user's perspective, and F refers to the worst situation, (Taylor, 2012). There are six levels of the scale of service properties which are shown in Table 2.2. It should be mentioned that, an acceptable level of service depends on the nature of the intersection or roundabout. In high volume downtown location, level of service "E" may be considered acceptable, but at rural intersections, it could be considered unacceptable with low traffic volume. According to literature, average delay of 25 to 35 seconds level of service "D" is considered acceptable LOS (HCM, 2010; WisDOT, 1982; SORB, 1982).

2.3.3. Categories of urban streets functional and design

Geometry and demand data are required to determine the speed, delay and LOS of an urban/rural road or intersection. The most precise way to obtain parameter values is to take field surveys as research inputs. The classification step is used here for determining the appropriate type of design. The category of design depends on the phase density, the speed limit, the density of driveway/access point and other design characteristics (Mohapatra, 2012). The functional component is divided into the main and minor arterial, according to (HCM, 2010). The design section is classified into four groups: The highway, the suburban, the urban and the intermediate. Four groups of urban streets defined by Latin numerals (I, II, III, and IV) can be seen in Tables 2.3 and 2.4.

Table 2.3. Criteria of Urban Arterial LOS (HCM, 2010).

The Average Travel Time Speed by Class (mph)					
Class		I	II	III	IV
Free-flow speeds Ranges (FFS)		55 - 45	45 - 35	35 - 30	35 - 25
Ideal (FFS)		50	40	35	30
LOS	A	> 42	> 35	> 30	> 25
	B	> 34 - 42	> 28 - 35	> 24 - 30	> 19 - 25
	C	> 27 - 34	> 22 - 28	> 18 - 24	> 13 - 19
	D	> 21 - 27	> 17 - 22	> 14 - 18	> 9 - 13
	E	> 16 - 21	> 13 - 17	> 10 - 14	> 7 - 9
	F	≤ 16	≤ 13	≤ 10	≤ 7

Table 2.4. Arterial Roads LOS table (HCM, 2010).

The Average Travel Time Speed by Class (km/h)					
Class		I	II	III	IV
Free-flow speeds Ranges (FFS)		90 - 70	70 - 55	55 - 50	55 - 40
Ideal (FFS)		50	40	35	30
LOS	A	> 72	> 59	> 50	> 41
	B	> 56-72	> 46-59	> 39-50	> 32-41
	C	> 40-56	> 33-46	> 28-39	> 23-32
	D	> 32-40	> 26-33	> 22-28	> 18-23
	E	> 26-32	> 21-26	> 17-22	> 14-18
	F	< 26	< 21	< 17	<14

2.4. Estimating the Measurements of the Reliability of Travel Time

Transportation network reliability is regarded as one of the critical procedures for assessing the performance of transportation system, especially under unexpected events (Lei et al., 2014). Scientists have developed different types of reliability indicators with a variety of considerations. The available indicators of traffic reliability include travel time reliability, connection reliability, travel cost reliability, capacity reliability, traffic demand reliability, slack traffic reliability, user satisfaction reliability (Hojati et al., 2016). The reliability of the travel time was characterized in several ways based on the FHWA (2010). This measure has been described as the dependability or the consistency in the travel times, as it has been evaluated from the day-to-day and/or over various day times. As can be seen from

Figure 2-2, the majority of the travelers remember and experience something that considerably differs from a simple averaging over one year of the commutes. Their times of travel are considerably varying from one day to another, and they consider these few bad days that they had endured over the unpredicted delay times. The reliability of the travel time quantifies the travel time variability on a route throughout the day, month or year. The reliability of the travel time is significant from the users of the road as well as the road management viewpoints.

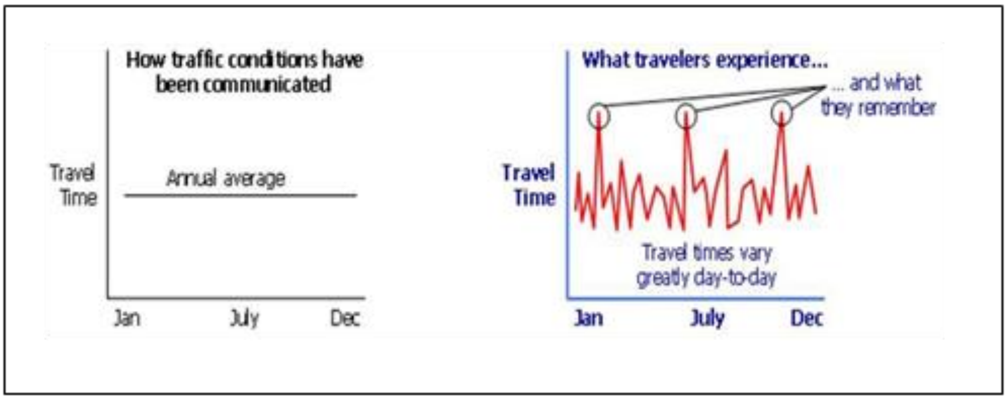


Figure 2.2. Travel time reliability (Pu, 2011).

2.5. Indices of the Travel Time Reliability

The standard deviation (SD) is a statistical measure used to quantify the amount of variation in a dataset. It can also be used to measure the reliability of travel time. However, this measure is not commonly used as it may be difficult for the general public to understand the reliability of travel time based on the SD values, which can be represented by using equation 2.1.

$$SD = \frac{\sum(\text{Travel time on specific segment} - \text{Average travel time for certain dataset})^2}{\text{Total datasets number}} \quad (2.1)$$

The normalized standard deviation, expressed as a percentage, is commonly used to measure the degree of variation in a dataset. This metric is calculated by dividing the standard deviation of the dataset by its mean traveling time, and is particularly useful when comparing the variability of multiple datasets. This concept is described by equation 2.2.

$$\text{Percent Variability} = \frac{SD}{\text{Average travel time}} * 100 \quad (2.2)$$

Measuring the reliability of travel time can be achieved through a simple approach of using the 90th or 95th percentile travel time. This method estimates the extent of traffic delay that can be expected on specific routes, providing road users with a better understanding of potential traffic congestion. The percentile travel times are typically expressed in minutes, allowing users to plan their trips accordingly.

To ensure on-time arrival, travelers can add extra time, referred to as buffer time (BI), to their mean travel time when planning their trips. Buffer time represents the time cushion that allows for potential traffic delays. This concept can be expressed mathematically by using equation 2.3.

$$\text{Buffer Time Index} = \frac{\text{95 percentile travle time} - \text{Average travel time}}{\text{Average travel time in minutes}} \quad (2.3)$$

The Travel Time Index (TTI) is a metric used to evaluate the level of congestion on a roadway. It is calculated as the ratio of the mean travel time over the course of a year to the travel time during free-flow conditions. This concept can be expressed mathematically by using equation 2.4.

$$\text{Travel Time Index} = \frac{\text{Avg. travel time}}{\text{Free flow travel time}} \quad (2.4)$$

The Planning Time Index (PTI) is a metric used to determine the amount of time that a traveler must allocate to ensure on-time arrival. This index takes into account the variability of travel time due to congestion and other factors. The PTI is calculated as the ratio of the 95th percentile travel time to the mean travel time. This calculation is expressed mathematically by using equation 2.5.

$$\text{Planning Time Index} = \frac{\text{95 percentile travle time}}{\text{Free flow travel time}} \quad (2.5)$$

The distinction between the buffer time and the schedule time index lies in their respective interpretations. The buffer time represents an additional time period added to the mean travel time to ensure on-time arrival, while the schedule time index represents the total travel time needed to ensure that 95% of trips arrive on time.

Both the Travel Time Index and the Planning Time Index utilize similar numerical metrics. However, the Travel Time Index is specific to peak hours, while the Planning Time Index applies to travel at any time of the day. There is a number of the available indices for the travel time reliability in order to estimate the reliability of the travel times on the roadways. The FHWA (2010) recommended four measures for the estimation of the reliability of the travel time, 95th percentile, Standard Deviation (SD) travel time, planning time index, buffer index, and frequency exceeding a certain threshold of congestion. Those indices were suggested and utilized for years for the measurement of the reliability of the travel time. There are several statistical measures utilized for quantifying the reliability of the travel time. The Strategic Highway Research Program (SHRP) describes the measures for the estimation of the reliability of the travel time as shown in Figure 2.3.

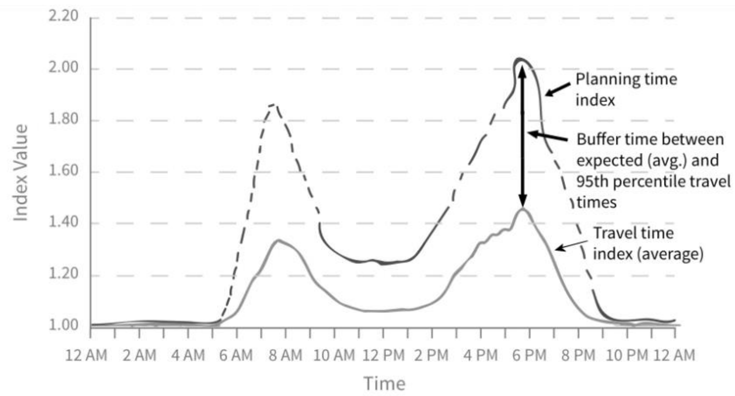


Figure 2.3. Relationship between travel time index, buffer index, and planning time index. (Office of Operations, 2006)

2.6. Travel Time Reliability Performance of the Transportation Networks

Travel time is a critical measure of transportation system performance that is closely linked to reliability and consistency. The degree of certainty and predictability in travel times on a transportation system is directly related to its reliability. A reliable system offers users a reasonable expectation of arriving at their intended destination within a predictable range of travel time. The delays increasing travel costs for users mean additional time for the system users. Hence, the users make new travel choices because they allow them to make better decision regarding the use of time. The concern is not just that excessive travel time due to rush hour congestion being lower than desired level, it is also that travel time is unpredictable as a function of time or road segment (Iida et al., 2000). Ability to get to a regular destination in the same amount of time on every trip affect everyday life related to time, money, events, families, friends, etc. Moreover, spending a lot of hours stuck in traffic causes losing money and fuel. So, in order to create a reliable transportation system, one should understand who plays what role in improving travel time reliability.

Strategic and operational efforts should be performed to implement satisfactory transportation systems management and operation strategies by improving travel time reliability if services are unreliable. However, and since the users are not interested whether the problems are caused by the traffic load or poor operator behaviors, the responsible agencies should identify the source of the problem and implement solutions to fix it.

The following points should be considered to improving travel time reliability:

1. Operate the system efficiently, communicate with travelers and operators, and measure the performance of the transport agencies compare to contracted service expectations.
2. Response swiftly, handling the accident site and removing symptoms quickly and safely.
3. A road user should drive responsibly and be aware of the travel options.

On the other hand, Chen et al. (1999) suggested the following solutions to improve transportation systems:

1. Control accidents and arrange special events proactively to prevent traffic congestion and work areas.
2. Control the redirection of traffic to entry and exit points on traffic roads.
3. Add temporary capacity.
4. Add the ability to make traffic smarter, flag weak points, remove obstacles continuously, and manage traffic based on a combination of historical time, real time, and predicted traffic conditions.
5. Adjust the timing of the signal at the intersections.
6. Apply diversion of traffic in cases of accident on a parallel lane using the sides or middle of the road.

7. Manage travel demand by influencing passengers' choice of mode, direction and departure time, thus reducing the number of vehicles on the road at times of congestion.
8. Re-lay lanes or use the shoulders as a lane during peak hours to increase capacity.

It should be noted that these strategies can make a huge difference of up to 50% in reducing unexpected delays that can really mean to regular commute.

The negative impacts of delays on travel time include increased costs for users in terms of time and other resources. This often prompts users to seek alternative modes of transportation or to adjust their travel behavior in order to improve their use of time. Furthermore, it is not just excessive travel time during rush hour congestion that is problematic; unpredictable travel time as a function of time or road segment can also be a concern. This can lead to mobility levels that are below the desired level of service, which is not acceptable for users of the transportation system. The use of technological advancements, improving communications among the agencies that train first responders, and changing travel data to intelligent data is the strategy that can improve the reliability of travel time.

2.7. Factors Having Effect on Reliability

Even minor disruptions in traffic flow can have a significant impact on travel time in areas with high levels of traffic congestion. Such disruptions may cause excessive delay and take longer to clear compared to non-congested areas. Thus, lack of reliability in travel time is closely associated with delays caused by congestion, particularly those resulting from infrequent events. In congested areas, traffic tends to be dense and the roadway capacity is limited, making it more susceptible to disruptions caused by incidents such as accidents, construction, and weather-related events. As minor incidents can lead to significant delays, resulting in an unreliable transportation system, efforts to improve travel time reliability must address congestion and other factors that contribute to travel delays in these areas. Congestion and reliability closely related can improve travel time reliability when improvements in congestion are made. Many sources of traffic congestion that affect reliability are discussed below (Cambridge Systematics Inc., 2013; Kittelson and Associates, 2013).

2.7.1. Bottlenecks

Traffic jams refer to sections of a road that experience reduced traffic capacity when compared to the capacity of the source road segments. Common bottlenecks include lane drops, changes in road alignment (such as horizontal curves), merging and weaving sections, changes in physical road properties (such as tunnels), intersections, hills, geometric changes, and access points to residential or commercial developments.

Strategies to mitigate the impact of bottlenecks include upstream demand management, such as managing traffic flows before it reaches the bottleneck location. This can be achieved through the use of effective signage treatments, providing timely traffic information to travelers, and offering alternative routes for travelers to avoid the bottleneck altogether. Other strategies may include increasing the capacity of the road network through widening or adding additional lanes, improving the geometric design of the roadway, and implementing traffic management and control measures such as traffic signals and roundabouts. By mitigating the impact of bottlenecks, transportation systems can improve travel time reliability and reduce delays for users (Office of Operations, 2006).

2.7.2. Traffic crashes

Traffic accidents are unpredictable events that can disrupt the regular flow of traffic, leading to a reduction in road capacity. These events include accidents, vehicle breakdowns, and spillages of loads and debris. The reduction in road capacity due to the blockage of the lanes because of an accident can cause significant delays tending drivers to slow down near the accident site to observe the situation, which can exacerbate the delay caused by the incident. The duration of the delay due to accidents depends on several factors, including the number of closed lanes, the magnitude of the accident, and the level of travel demand at the time of the incident. On average, during a multi-lane accident, travel time can increase by 205% compared to traffic conditions without accidents. Strategies to mitigate the impact of accidents include providing timely traffic information to travelers, implementing traffic control measures to redirect traffic away from the accident site, and emergency response measures to clear the accident scene as quickly as possible. By reducing the impact of accidents on traffic flow, travel time reliability can be improved, and delays for road users can be minimized (Wright et al., 2015).

2.7.3. Weather

Weather can have an impact on the roadway itself, causing damage and resulting in lane closures with accompanied reduced capacity. This is particularly true during winter weather conditions when roads may become icy or snow-covered. In such cases, strategies to reduce the impact of weather on travel time may include increased plowing and salting, use of anti-icing materials, and implementation of reduced speed limits to increase safety. Additionally, effective communication of weather-related information to travelers, such as through message boards or mobile applications, can also help to mitigate the impact of weather on travel time by allowing drivers to make more informed decisions about their route and travel plans.

2.7.4. Construction area

Work areas are the locations where road related activities may lead to temporary physical changes on the highway environment. Effective communication with road users, providing advance warning and real-time traffic information can help to minimize the disruption caused by working areas. Furthermore, effective planning of work schedules and locations can also minimize the impact on traffic flow. Strategies such as scheduling work during off-peak periods or at night can help reducing the impact on traffic during peak hours. Finally, implementing temporary traffic management systems such as temporary traffic signals, mobile barriers, and lane reversal schemes can also help alleviate congestion in working areas.

2.7.5. Traffic control

Proper maintenance and use of traffic control devices can help reduce the delay caused by congestion related to ineffective or malfunctioning devices. It is important to regularly inspect and maintain traffic control devices, including traffic signals, signs, and pavement markings, to ensure they are functioning properly and effectively guiding traffic flow. Additionally, proper placement and timing of traffic control devices can help prevent congestion and improve the overall efficiency of the transportation system.

2.7.6. Special occurrences

Special occurrences refer to unique events that affect traffic flow, such as sporting events, concerts, parades or construction projects. These events can cause localized congestion and delays, as well as divert traffic to alternative routes. Strategies to mitigate the impact of special occurrences include effective communication with travelers regarding event schedules, temporary changes to traffic control devices and signal timings with provided alternative routes and use of public transportation. Planning and coordination between event organizers and transportation authorities can also help to minimize disruptions to traffic flow. Special events can lead to sudden changes in travel demand, resulting in greatly altered traffic conditions that differ from normal traffic patterns and cause unexpected delays. Infrequent congestion due to special events occurs near arenas, convention centers, stadiums, and other gathering places due to sudden increases in demand during a short period of time (usually shortly before the event starts and ends). Strategies to mitigate this type of congestion include temporarily diverting non-event related traffic, increasing capacity in the main direction of travel, and controlling entry and exit ramps to limit incoming or outgoing traffic on the highway.

2.7.7. Demand changes for travel

As demand fluctuations can have a significant impact on traffic congestion, implementing demand management strategies can help mitigate the effects of increased travel demand. Some additional strategies that can be used include adjusting work schedules to spread out peak travel times, promoting car-pooling and other forms of ride sharing, and incentivizing the use of alternative modes of transportation such as bicycles or public transit. By reducing the number of single-occupancy vehicles on the road during times of peak demand, congestion can be alleviated and travel times can become more reliable.

2.8. Network Connectivity Reliability

The reliability of a network's connectivity is a critical metric for assessing its effectiveness. This is particularly true for transportation systems, where reliability is essential for ensuring efficient and timely travel. Achieving this reliability requires a combination of strategies that can manage both traffic and demand, while also responding effectively to any disruptions that may arise. In the context of transportation networks, connectivity reliability refers to the likelihood that the various nodes within the network will remain connected and capable of accommodating a specific level of traffic. This metric is crucial for ensuring that road users can reliably predict travel times and reach their destinations on schedule. Effective management of connectivity reliability is therefore essential for maintaining the overall performance and efficiency of transportation systems.

The network is considered successful if at least one path is operational if connectivity between the OD pair is 0.4, then the user can reach from origin to the destination point without congestion 4 times out of 10. Connectivity reliability is defined as the probability of maintaining the connected nodes in the transport network. The concept of connectivity reliability was first introduced to assess the probability of maintaining connectivity between any two nodes in a transportation network. Originally, this metric focused on the binary states of the links or nodes, i.e., connected or disconnected, without considering the time-varying capacity of the links. The final reliability of a transportation network is a special case of connectivity reliability that also takes into account the paths between origin-destination (OD) pairs. This terminal reliability metric reflects the availability of a road network in which alternative routes are used when the functionality of certain links is disrupted.

In functional terms, the connectivity reliability of a given link can be expressed as a binary variable (0,1) that indicates whether the related nodes are physically connected within a specified time. The concept of connectivity reliability is particularly relevant for transportation networks and is based on the level of service (LOS) the network provides. The specific traffic congestion conditions in urban areas determine a certain level that serves as a limit for assessing the performance of the transportation network. The ability of the network to meet this level of service (LOS) at a given time determines whether or not the road functions as intended. In this sense, as expressed, connectivity reliability is often used as a measure of the probability that nodes in the network will remain connected.

The success of a transportation network is typically defined by the presence of at least one operational path that connects the origin and destination nodes. A path is comprised of a set of links, each of which can be characterized by a binary variable indicating its status as either operating or failing. While this binary approach may be suitable for extreme situations such as earthquakes, it has limited applications in everyday situations where roadway links typically operate between two opposite ends (Iida and Wakabayashi, 1989).

2.9. Methods for Measuring Travel Time

The calculation of travel time reliability requires accurate and comprehensive travel time data. Travel time, the time taken for a vehicle to travel between an origin and destination point, can be measured directly by noting the start and end times of the journey, or by dividing the distance between the two points by the average speed. It includes both runtime, which is the time taken while the vehicle is in motion, and delay time due to traffic control devices and other operational delays.

Several methods are available to measure travel time, including GPS-equipped vehicles, aerial photogrammetry, GPS vehicle detectors, cellular devices, license plate matching, and road user experience surveys. To accurately capture daily and seasonal changes and calculate travel time reliability metrics, travel time data must be collected over long periods of time. Additionally, travel time data can be used to estimate other traffic variables such as total delays.

Two primary data capture techniques used to calculate travel time reliability include field data collection and simulation. Field data collection involves surveying traffic volume, speed, occupancy, capacity, links, and vehicle classification data, which can be used to define different measures of travel time reliability for various vehicle classes. Sensor data collected from GPS and cell phone-equipped vehicles has also become increasingly popular for deriving reliability measures. Simulation, on the other hand, involves computer-based products that simulate the movement of vehicles and pedestrians along with their interactions with each other and traffic controls. Simulation models can simulate traffic at micro, intermediate, and macro levels and are used to capture changes in behavioral responses to different travel and infrastructure options.

It is important to note that each type of data capture technique has its own advantages and limitations that must be considered when designing any reliability study. The reliability of travel time estimates and calculations is heavily dependent on the quality and accuracy of the data source used (Office of Operations, 2006).

2.10. Vissim Simulation

Vissim is a microscopic multi-modal traffic flow simulation software package developed by the German traffic engineering software company PTV. This software can model many details of the transportation system and provides the user with great flexibility in modelling and testing different traffic scenarios before their realization. The user can control the junction geometry, the location of the stop line, as well as gap acceptance and driver behavior-type parameters among several other measures (Kimber, 1989). It allows transportation engineers and planners to model traffic flows and simulate various scenarios to evaluate the performance of transportation systems. The software uses microscopic simulation techniques to model individual vehicles and their interactions with other vehicles, pedestrians, and infrastructure.

Vissim can be used to model a wide range of transportation systems, from small intersections to entire cities. It includes a variety of tools and features to allow users to customize their simulations and analyze the results. Some of the key features of Vissim include:

1. Network building: Vissim allows users to build complex transportation networks using a variety of road types, intersections, and other alternatives.
2. Vehicle modelling: The software models individual vehicles and their movements through the network, including acceleration, deceleration, and lane changings.
3. Pedestrian modelling: Vissim also includes tools to model pedestrian movements, including crossing behaviors and interactions with vehicles.

4. Traffic control: Vissim allows users to model a variety of traffic control devices, including traffic signals, stop signs, and roundabouts.
5. Performance measures: The software provides a variety of performance measures to evaluate the efficiency of the transportation system, including travel times, vehicle delay, and queue lengths.

Overall, PTV Vissim is a powerful tool for transportation planning and analysis. By allowing users to simulate various scenarios and evaluate the performance of transportation systems, it can help to identify areas for improvement and inform decision-makers for transportation infrastructure and policy.

3. METHODOLOGY AND DATA COLLECTION

Travel time estimation and reliability measurement have been identified as critical issues for providing better performance and safe networks. This thesis aims to estimate the total travel time, analyze the collected data, and estimate the reliability through the paths selected in city of Baghdad.

This chapter describes the methodology used to collect data and the tools employed. The field data was collected using a vehicle equipped with a GPS (vehicle moving technology). The data set collected by GPS consists of time, date, longitude, latitude, travel time, and the speed at which the note was taken. Finally, this chapter will introduce the computer programs used to analyze traffic data.

3.1. Data Collection

3.1.1. Fieldwork involves data collection

The coordinate data is extracted from the two GPS traffic devices logged into a server that is accessed using the username and password that were registered by engineers in the local company. Following, the data was saved in Excel files. Before collecting field data by a GPS device, several important steps had been taken which consist of: preparing the test vehicle, determining routes on which travel times are to be measured, creating a framework with instructions for the driver (data collector), determining the necessary sample size depend on conducting the study. The coordinates of all intersections start of link and end for north and south direction (go & return) as seen in Figure 3.1.

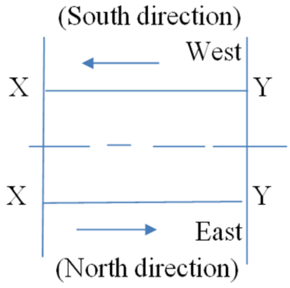


Figure 3.1. Test position for Moving-Vehicle Method (Garber and Hoel, 2014).

3.1.2. Geometric data

The free flow speeds were obtained from field measurement during the free flow conditions for each link of the specified arterial streets on the selected paths. They were measured for each link as shown in Figure 3.2 by driving the vehicle in free-flow conditions in order to obtain the most accurate measurements. It should be mentioned that the free flow speeds were obtained under the constraints of not exceeding the speed limits.

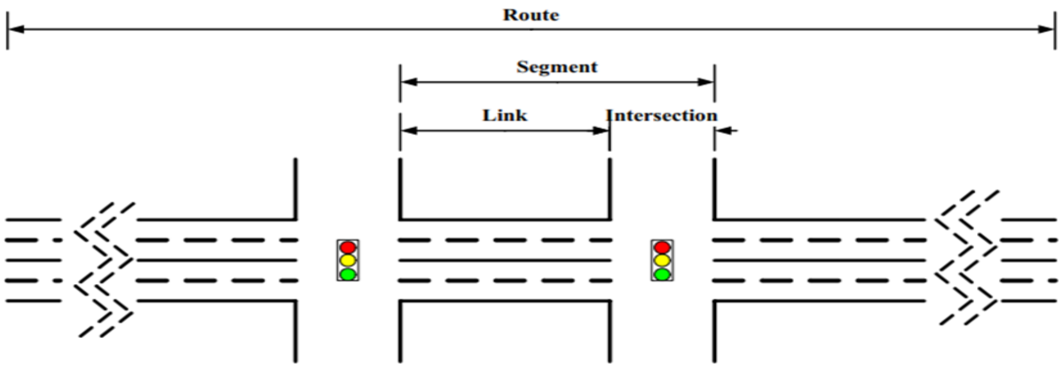


Figure 3.2. Scheme overview and basic elements of a standard urban route (Van Lint, 2004).

3.2. Study Area-Field Work

In this study, a locally manufactured tool is installed through the car's lighter to obtain power while the car is running. The data collection process begins when the test vehicle is equipped with GPS before travelling the specified path. The tool consists of a GPS device and a control button connected to the device via a cable, as shown in Figure 3.3.

Travel time data was obtained from WENK GPS at 10-second intervals at the (7–9 a.m.) and (1-3 p.m.) peak hours of the morning and evening periods for each route to determine the trip time for each link based on the data acquired from the station. We concern to obtain data during good weather to minimize the disturbance in the estimated travel times due to the bad weather effect. The statistics on travel time was estimated for a single day (January 1st, 2021 to February 28th, 2021). Data were obtained and analyzed for all the week-days, except for the holidays and weekends. Later, they were combined to a sample sheet as illustrated in Table 3.1.

Figure 3.3. The manufactured GPS device.

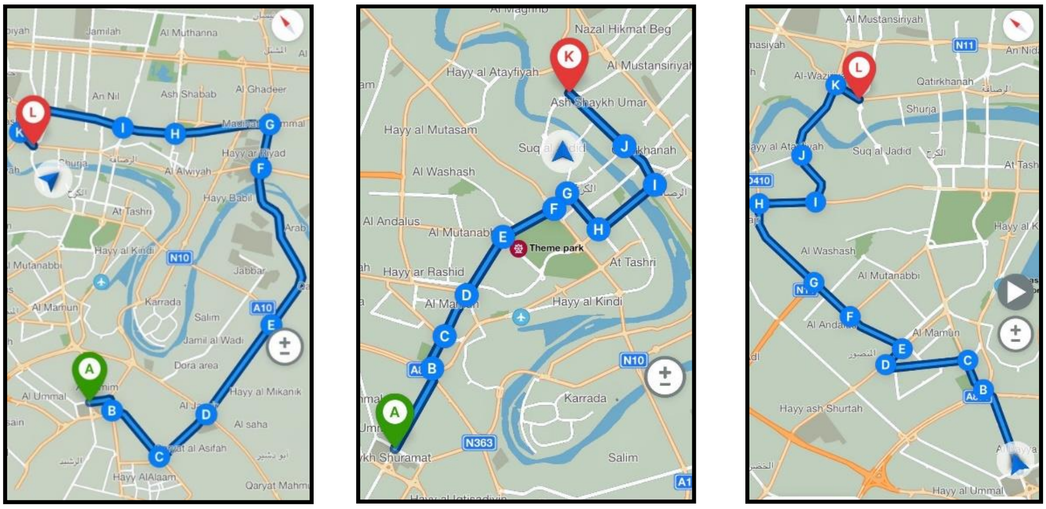
Table 3.1. Sample of data sheet from server of GPS device.

No	Speed	Coordinates	Location	Sensor	Value	Time
100	10	33.299908, 44.354892	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:12
101	4	33.300090, 44.355027	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:22
102	0	33.300117, 44.355047	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:32
103	5	33.300158, 44.355077	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:42
104	16	33.300368, 44.355215	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:50
105	5	33.300530, 44.355333	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:06:55
106	16	33.300597, 44.355382	Dimashq Street, Baghdad, Iraq	SOS	1	2021-01-04 pm 01:07:00

All the selected routes are shown in Figure 3-4 to 3-6. Each table from 3-2 to 3-7 presents data forms for two directions of north and south to each route. The free flow speeds (FFS) of the selected streets were collected by field measurement under normal traffic conditions.

3.2.1. The first route: Route1

The figures below illustrate all the paths chosen for the analysis. Figure 3.4.a shows the Route 1 with the total number of 50 runs for both directions. Each direction, north and south, has 25 runs. The route consists of eleven links for the north and south direction, as shown in Tables 3.2 and 3.3.



a) b) c)

Figure 3.4. a) Route1, b) Route2, and c) Route3 stations with the selected intersections of North and South directions.

Table 3.2. Route1 North direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bayaa Sq.	…	33.266022 - 44.336543	…
2	Saydiaa - Bayaa Intersection	60	33.258149 - 44.341235	1.4
3	Addarwesh In.	40	33.235311 - 44.345189	3.0
4	Doraa Expressway	100	33.237172 - 44.371493	6.6
5	Alkarrada Exit	60	33.247738 - 44.416491	4.7
6	Baghdad University	40	33.293190 - 44.453884	2.3
7	Mohammed Alqasim	60	33.303230 - 44.467921	9.5
8	Alshaab Stadium	60	33.321249 - 44.434697	2.0
9	Neurology Hospital	40	33.334523 - 44.419203	5.0
10	Almustansirya	60	33.359142 - 44.394094	2.0
11	Art College	40	33.355409 - 44.383792	1.0
12	Bab Almuaddam	40	33.348769 - 44.385141	0.75

Table 3.3. Route1 South direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bab al muaddam	40	33.348769 - 44.385141	0.75
2	Art College	40	33.355409 - 44.383792	1.0
3	Almustansirya	60	33.359142 - 44.394094	2.0
4	Neurology Hospital	40	33.334523 - 44.419203	5.0
5	Alshaab Stadium	60	33.321249 - 44.434697	2.0
6	Mohammed Alqasim	60	33.303230 - 44.467921	9.5
7	Baghdad University	40	33.293190 - 44.453884	2.3
8	Alkarrada Exit	60	33.247738 - 44.416491	4.7
9	Doraa Expressway	100	33.237172 - 44.371493	6.6
10	Addarwesh In.	40	33.235311 - 44.345189	3.0
11	Saydiaa - Bayaa Intersection	60	33.258149 - 44.341235	1.4
12	Bayaa Sq.	…..	33.266022 - 44.336543	

3.2.2. The second route: Route2

Figure 3.4.b, shows the Route 2 with the total number of 50 runs for both directions. Each direction, north and south, has 25 runs. The route consists of ten links for the north and south direction, as shown in Tables 3.4 and 3.5.

Table 3.4. Route2 North direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bayaa Sq.	…..	33.266022 - 44.336543	……
2	Um Altubol	60	33.285215 - 44.346748	2.41
3	Qahtan Sq.	40	33.291398 - 44.350088	0.8
4	Alnusur Sq.	40	33.301866 - 44.356623	1.28
5	Baghdad Gallery	60	33.314801 - 44.366000	1.77
6	Alawee	60	33.321692 - 44.380468	1.6
7	Iraqi museum	40	33.325344 - 44.383909	0.48
8	Yafa st.	40	33.317049 - 44.393231	1.28
9	Liberation Sq.	40	33.327113 - 44.407958	1.77
10	Wathba Sq.	40	33.336586 - 44.400361	1.44
11	Bab Almuaddam Sq.	40	33.348769 - 44.385141	1.93

Table 3.5. Route2 South direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bab Almuaddam Sq.	40	33.348769 - 44.385141	1.93
2	Wathba Sq.	40	33.336586 - 44.400361	1.44
3	Liberation Sq.	40	33.327113 - 44.407958	1.77
4	Yafa st.	40	33.317049 - 44.393231	1.28
5	Iraqi museum	40	33.325344 - 44.383909	0.48
6	Alawee	60	33.321692 - 44.380468	1.6
7	Baghdad Gallery	60	33.314801 - 44.366000	1.77
8	Alnusur Sq.	40	33.301866 - 44.356623	1.28
9	Qahtan Sq.	40	33.291398 - 44.350088	0.8
10	Um Altubol	60	33.285215 - 44.346748	2.41
11	Bayaa Sq.	…..	33.266022 - 44.336543	…..

3.2.3. The third route: Route3

Figure 3.4.c, illustrates the Route 3 with the total number of 50 runs for both directions. Each direction, north and south, has 25 runs. The route consists of eleven links for the north and south direction, as shown in Tables 3.6 and 3.7.

Table 3.6. Route3 North direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bayaa Sq.	…..	33.266022 - 44.336543	….
2	Um Altubol	60	33.285215 - 44.346748	2.41
3	Qahtan Sq.	40	33.291398 - 44.350088	0.8
4	Jorden Sq.	40	33.305017 - 44.334803	2.25
5	Sayed Alhaleeb	40	33.304480 - 44.340882	0.64
6	Almansur	60	33.318282 - 44.338243	1.6
7	Alleqaa Sq.	60	33.329260 - 44.338810	1.28
8	Adamya Bridge	60	33.350730 - 44.345478	2.57
9	Almuthanna airport	100	33.341168 - 44.355747	1.44
10	Utaifeya	60	33.350445 - 44.362790	1.44
11	Sarafiaa bridge	60	33.355134 - 44.383456	1.6
12	Bab almuddam	40	33.348769 - 44.385141	0.8

Table 3.7. Route3 South direction.

link	Intersections	Free-flow speed km/h	location	Length of links km
1	Bab almuddam	40	33.348769 - 44.385141	0.8
2	Sarafiaa bridge	60	33.355134 - 44.383456	1.6
3	Utaifeya	60	33.350445 - 44.362790	1.44
4	Almuthanna airport	100	33.341168 - 44.355747	1.44
5	Adamya Bridge	60	33.350730 - 44.345478	2.57
6	Alleqaa Sq.	60	33.329260 - 44.338810	1.28
7	Almansur	60	33.318282 - 44.338243	1.6
8	Sayed Alhaleeb	40	33.304480 - 44.340882	0.64
9	Jorden Sq.	40	33.305017 - 44.334803	2.25
10	Qahtan Sq.	40	33.291398 - 44.350088	0.8
11	Um Altubol	60	33.285215 - 44.346748	2.41
12	Bayaa Sq.	….	33.266022 - 44.336543	….

3.3. Moving Vehicle Technique Method

Since the late 1920s, vehicle testing technology has been used to collect travel time data. This method traditionally involves the use of a data collection method in which the analyst monitors the accumulated driving time at predetermined checkpoints along the route. After that this data is translated into travel time, speed, and delay for each segment along the survey arterials. The sample size must be chosen to achieve a high degree of accuracy in the results of the study. With regard to this research, sample size of 25 runs for each direction of the paths was selected. This sample size is more than sufficient recommended in the Travel Time Data Collection Handbook shown in Table 3.8 (Turner et al., 1998). Moreover, the vehicle-moving method technique involves steering the test vehicle by an observer in the flow of traffic to collect the required data during the day. A GPS sensor was fitted in the vehicle selected for testing used in this study. The device is installed through the car's lighter to obtain power when the car is running. The data collection process begins when the GPS-equipped test vehicle reaches the specified route.

Table 3.8. Demonstrative sample size of test vehicle on arterial street.

Traffic Signal Density (Signals per mile)	Average Coefficient of Variation (%)	Sample Sizes		
		90% Confidence, ± 10 % Error	95% Confidence, ± 10 % Error	95% Confidence, ± 5 % Error
Less than 3	9	5	6	15
3 to 6	12	6	8	25
Greater than 6	15	9	12	37

3.4. Statistical Program (SPSS)

The Statistical Package for the Social Sciences (SPSS) user program is the most widely used statistical data analysis software in many fields of research; such as engineering, economics, medicine, social sciences, etc., and is available in the majority of higher education institutions worldwide. It is also very easy to use and performs all the functions. Various simple and complex statistical analyses can also be performed through SPSS, starting with descriptive statistics to modelling. This does not necessarily mean that it is a "much better" package than any of the other options available.

SPSS 22.0 statistical package was used to analyze the data obtained within the concept of this research. In addition to statistical analysis, text analytics, data mining, collaboration and publishing (including aggregate services and automated logging), SPSS Statistics also includes a number of other features. to achieve the objectives of the study. SPSS software package was employed to perform descriptive statistics for three main routes studied in this research available in city of Baghdad.

3.5. Queue Delay

In transportation, queue delay refers to the amount of time that vehicles are delayed while waiting in a queue, such as a line of cars waiting at a traffic signal or in a congested section of a highway. This delay can be caused by a variety of factors, including high traffic volume, limited capacity of the roadway, and traffic control devices such as traffic signals or stop signs. Queue delay is an important performance measure for transportation systems, as it can have impact on the reliability of travel times, fuel consumption, and air quality, as well as the safety of drivers and pedestrians. Transportation engineers and planners use queue delay analysis to identify congested locations, evaluate the effectiveness of traffic management strategies, and design improvements to reduce delay and improve mobility.

3.6. Vehicle Delay

Vehicle delay refers to the additional time that a vehicle spends on its journey compared to the ideal travel time under free-flow conditions. This delay can be caused by a variety of factors, including traffic congestion, traffic control devices, and adverse weather conditions. Vehicle delay is an important performance measure for transportation systems, as it can have impact on the reliability of travel times, fuel consumption, and air quality, as well as the safety of drivers and pedestrians. Transportation engineers and planners use vehicle delay analysis to identify congested locations, evaluate the effectiveness of traffic management strategies, and design improvements to reduce delay and improve mobility. Common techniques used to measure vehicle delay include travel time studies, queue length measurements, and delay-based performance measures such as the Travel Time Index (TTI) and the Planning Time Index (PTI). These measures are used to understand the extent and causes of vehicle delay, and to develop strategies for mitigating delay and improving travel efficiency.

4. RESULTS AND DISCUSSION

This chapter describes methods for analyzing data collected from three selected urban arterial paths. It is preferable to investigate the differences in the total travel time of each link of the selected paths and the estimated speed of each signal intersection along the three urban arterial streets based on GPS field data collected during 50 running trials in the south and north directions during morning and evening hours. The evaluation criteria of the performance of the transportation system are travel time, queue delay and vehicle delay obtained by using PTV Vissim simulation software. The input data for program includes the road network, traffic demand, and other relevant data used as input to the simulation. This data was obtained from the moving test car and traffic volume assumptions that travel time on a road network is affected by traffic supply and demand. The function used to estimate travel times is the BPR link performance function, which is commonly used in the transportation field. BPR function is employed in this study to evaluate the accuracy of the travel times in the network. Basically, the BPR function is used to calculate the time taken to travel along a single road or route. The simulation settings include the time period simulated, the traffic control devices used (e.g., traffic signals), and other simulation parameters such as vehicle types and driver behavior to ensure that the simulation accurately represents real-case conditions.

4.1. Data Processing

Data collected using GPS fitted vehicle must be processed before it can be used. The coordinates of the required points are recorded via the GPS device, and a special server is used to save these coordinates through a dedicated account and password from the service provider. Data downloaded into a text file as raw data. Data processing began by converting the text file into an excel file for each street. The data consists of coordinates (latitude and longitude), date, time, speed in km/h and point identifier. Coordinates (latitude and longitude) are processed and transformed to determine the distance between data points and the link length or direction for reliability analysis. Two methods used to evaluate the travel time. First one is due to normal changes in the routes like increase in traffic volume during the day. The second simulation in Vissim used the travel data obtained from the first method and increased 10 percent at each step until it reaches 100% increase confirming the results of the two conditions. The back-and-forth iteration showed a high accuracy of the results. Then comparison was made with regard to the results to show the most reliable route and whether the results reflect the reality or simulation.

Data about the reliability of travel time were required to estimate various congestion level and travel time reliability indicators. Calculation of road traffic flow and congestion factors (speed, travel time, delay and stops) need to be carried out with this respect. Travel time estimation is an important issue to improve the operational efficiency and safety of the traffic road network. The research investigates the estimation of travel times on some selected paths in the Baghdad city transportation networks. These estimations include travel and running time along with delays obtained by GPS fitted vehicle. This study involves the data acquired by over 45 days of transportation survey of passenger cars in the city of Baghdad using the Global Positioning System (GPS) for all days of the week except holidays to estimate the traffic performance indicators.

4.2. Details of the Selected Intersections Along the Routes

Route1 has eleven links starting from the origin intersection point to the end of the route destination point. For all the paths, the distance is measured for each link from the previous intersection to the next intersection. Route1 has a cumulative distance of 38.25 km, where Route2 and Route3 have 14.76 km and 16.83 km, respectively. As can be seen, Route2 has the shortest overall total distance that GPS fitted car travelled to collect the data. The details of the selected intersections for the three selected routes are presented in Tables from 4.1 to 4.6.

4.3. Analysis of the Travel Time During Working Days of the Week

This analysis may be useful for individuals planning to travel through these intersections in Baghdad and want to estimate their travel time all days of the week.

Table 4.1. Details of the selected intersections in Route1 North direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bayaa Sq.	Sun	Mon	Tues	Wed	Thu			
Saydiaa - Bayaa Intersection	38	41	33	38	35	24	1400	1400
Addarwesh In.	167	269	169	194	280	140	3000	4400
Doraa Expressway	110	118	122	209	138	90	6600	11000
Alkarrada Exit	245	274	167	379	171	159	4700	15700
Baghdad University	349	369	314	380	386	251	2300	18000
Mohammed Alqasim	102	138	66	127	94	62	9500	27500
Alshaab Stadium	311	600	344	600	331	258	2000	29500
Neurology Hospital	122	216	111	179	139	93	5000	34500
Almustansirya	259	457	216	233	269	210	2000	36500
Art College	550	206	73	84	83	66	1000	37500
Bab Almuaddam	102	183	86	244	80	44	750	38250

Table 4.2. Details of the selected intersections in Route1 South direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bab al muaddam	Sun	Mon	Tues	Wed	Thu			
Art College	733	550	629	400	733	44	750	750
Almustansirya	236	508	413	140	75	66	1000	1750
Neurology Hospital	583	875	1050	1167	328	210	2000	3750
Alshaab Stadium	152	127	139	238	101	93	5000	8750
Mohammed Alqasim	311	339	327	363	327	258	2000	10750
Baghdad University	113	117	102	102	344	62	9500	20250
Alkarrada Exit	261	256	369	295	285	251	2300	22550
Doraa Expressway	199	209	171	185	196	159	4700	27250
Addarwesh In.	132	155	96	123	100	90	6600	33850
Saydiaa - Bayaa Intersection	151	378	368	304	636	140	3000	36850
Bayaa Sq.	33	40	44	42	60	24	1400	38250

Table 4.3. Details of the selected intersections in Route2 North direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bayaa Sq.	Sun	Mon	Tues	Wed	Thu			
Um Altubol	344	217	163	167	129	117	2410	2410
Qahtan Sq.	486	217	170	150	150	102	800	3210
Alnusur Sq.	122	70	71	85	98	60	1280	4490
Baghdad Gallery	108	151	88	79	98	65	1770	6260
Alawee	200	538	130	90	101	70	1600	7860
Iraqi museum	83	63	60	63	67	40	480	8340
Yafa st.	220	117	152	144	180	108	1280	9620
Liberation Sq.	84	120	57	117	55	42	1770	11390
Wathba Sq.	224	153	145	143	116	110	1440	12830
Bab Almuaddam Sq.	282	151	228	151	167	107	1930	14760

Table 4.4. Details of the selected intersections in Route2 South direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bab Almuadam Sq.	Sun	Mon	Tues	Wed	Thu			
Wathba Sq.	170	563	181	334	233	107	1930	1930
Liberation Sq.	122	186	126	159	147	110	1440	3370
Yafa st.	382	88	84	65	62	42	1770	5140
Iraqi museum	127	171	360	220	166	108	1280	6420
Alawee	85	138	125	129	129	40	480	6900
Baghdad Gallery	280	99	226	318	101	70	1600	8500
Alnusur Sq.	107	325	310	224	71	65	1770	10270
Qahtan Sq.	67	231	125	113	109	60	1280	11550
Um Altubol	319	167	173	110	142	102	800	12350
Bayaa Sq.	225	557	266	334	234	117	2410	14760

Table 4.5. Details of the selected intersections in Route3 North direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bayaa Sq.	Sun	Mon	Tues	Wed	Thu			
Um Altubol	300	325	234	249	156	117	2410	2410
Qahtan Sq.	340	268	204	232	152	102	800	3210
Jorden Sq.	29	27	31	36	24	20	2250	5460
Sayed Alhaleeb	94	113	97	80	67	60	640	6100
Almansur	185	190	185	174	160	120	1600	7700
Alleqaa Sq.	259	309	269	250	221	210	1280	8980
Adamya Bridge	190	179	174	190	145	120	2570	11550
Almuthanna airport	85	119	79	89	60	50	1440	12990
Utaifeya	120	110	120	141	110	90	1440	14430
Sarafiaa bridge	279	353	211	273	140	120	1600	16030
Bab almuddam	314	268	289	220	159	110	800	16830

Table 4.6. Details of the selected intersections in Route3 South direction.

Locations	Travel time (sec.)					Run. Time (sec.)	Length (m)	Cum. dis. (m)
Bab almuddam	Sun	Mon	Tues	Wed	Thu			
Sarafiaa bridge	175	297	333	234	229	110	800	800
Utaifeya	141	462	152	286	197	120	1600	2400
Almuthanna airport	150	231	155	196	180	90	1440	3840
Adamya Bridge	455	104	100	77	74	50	1440	5280
Alleqaa Sq.	141	190	400	245	185	120	2570	7850
Almansur	447	724	656	677	677	210	1280	9130
Sayed Alhaleeb	480	169	387	545	174	120	1600	10730
Jorden Sq.	98	300	286	207	66	60	640	11370
Qahtan Sq.	22	77	42	38	36	20	2250	13620
Um Altubol	162	173	204	182	112	102	800	14420
Bayaa Sq.	403	209	217	136	175	117	2410	16830

Two sets of data for each intersection provide the cumulative distance in meter and the average travel time and running time for both North and South directions. The "average time north" and "average time south" in seconds seem to indicate the time to travel the distances in that particular direction.

4.3.1. Route1

The Figures 4.1-5 presents the cumulative distance and travel times for different locations in Route1, in terms of the average travel and running times for each of North and South direction. The locations are listed with the order of increasing cumulative distances. Moreover, the figures clearly demonstrate the differences between travel times for traveling North versus South directions. It appears that on average, travel times for traveling South are longer than those for traveling North. Furthermore, close results are seen in average travel time for both directions on Monday and Wednesday. In addition, traveling in the South direction on Tuesday takes 3708 seconds (1.03 hours) representing the highest value for average travel time in Route1. On the other hand, for the North direction it takes 1700 seconds (0.47 hours) for the same day which represents the smallest value for travel time.

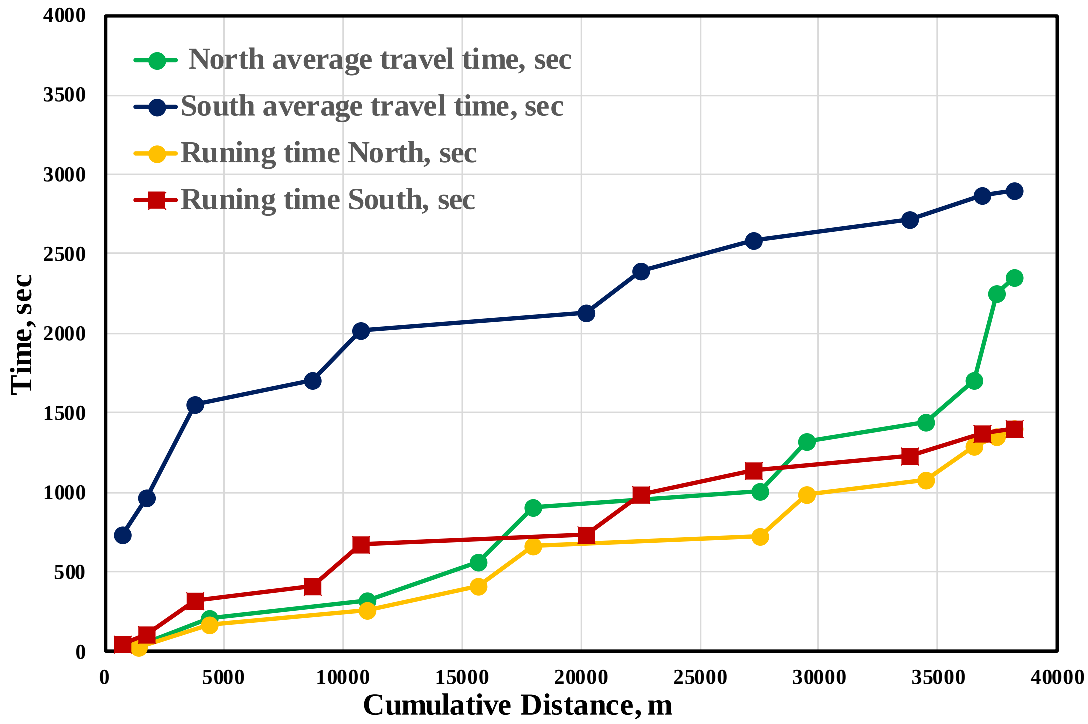


Figure 4.1. Travel and running time vs. cumulative distance for Rout1 North and South directions for Sunday.

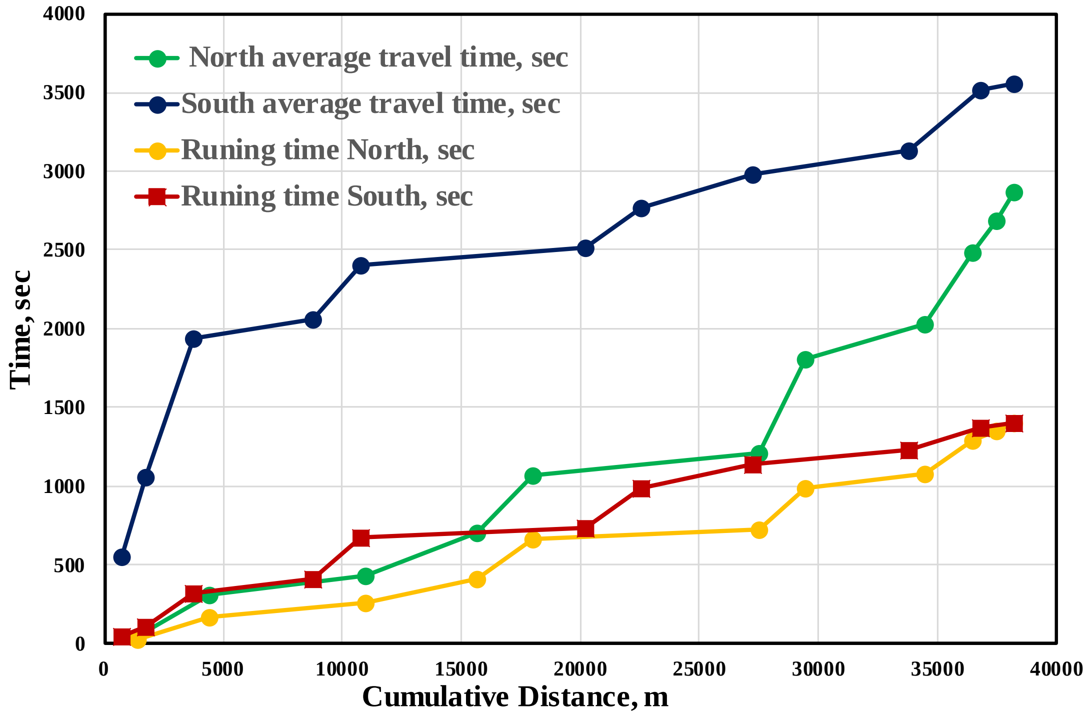


Figure 4.2. Travel and running time vs. cumulative distance for Rout1 North and South directions for Monday.

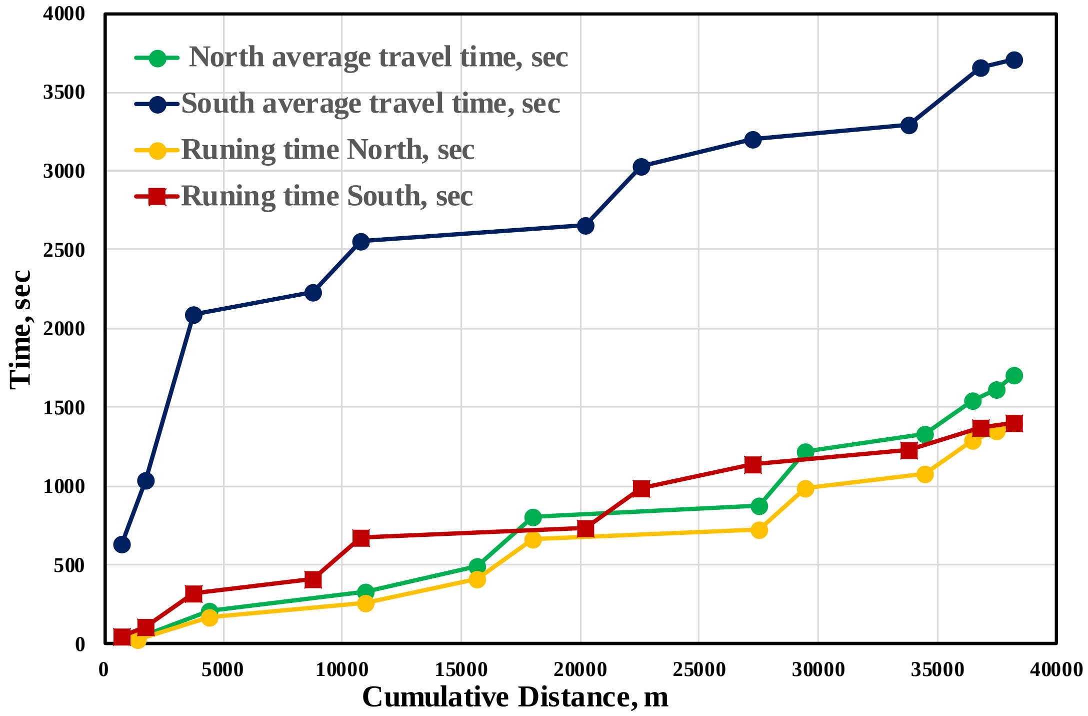


Figure 4.3. Travel and running time vs. cumulative distance for Rout1 North and South directions for Tuesday.

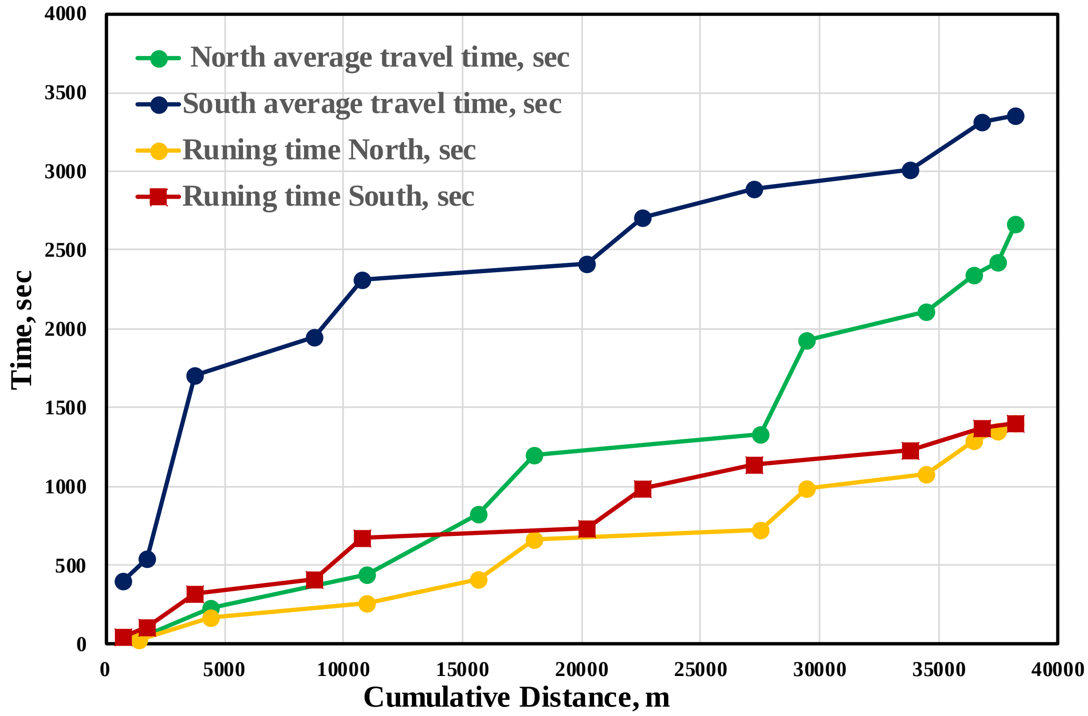


Figure 4.4. Travel and running time vs. cumulative distance for Rout1 North and South directions for Wednesday.

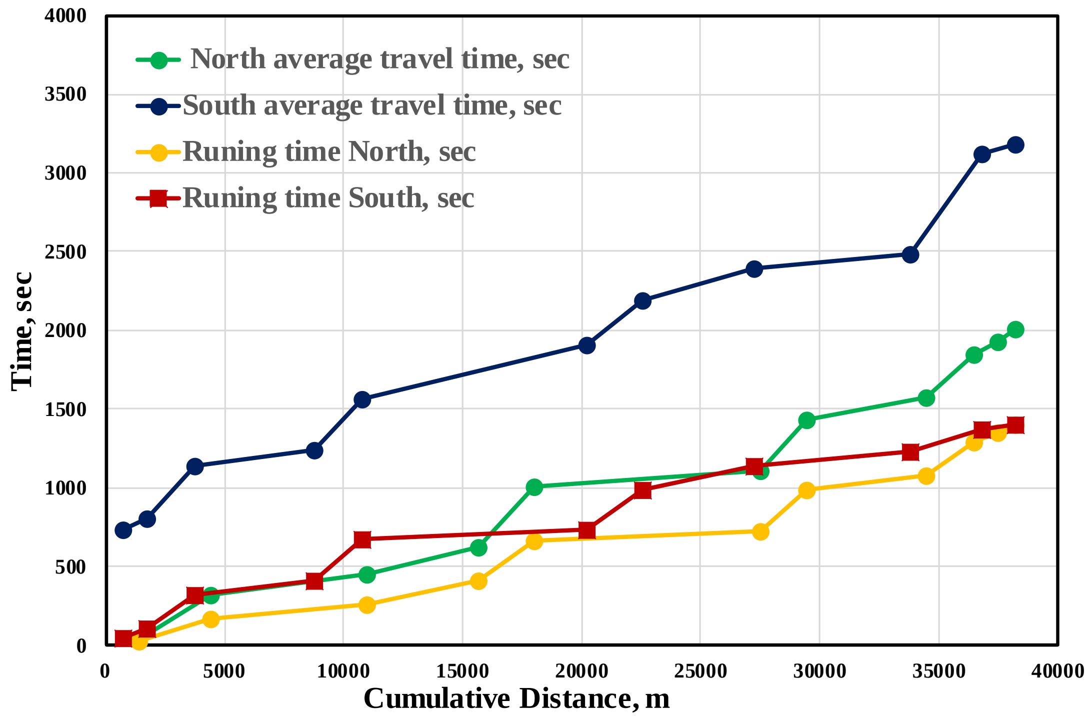


Figure 4.5. Travel and running time vs. cumulative distance for Rout1 North and South directions for Thursday.

4.3.2. Route2

The Figures 4.6-10 shows the cumulative distance and average travel times and the running times for different locations in Route 2 for traveling North and South directions. The locations are listed in the order of increasing cumulative distances. Furthermore, an analysis of the differences between travel times for traveling North versus South was conducted. The results indicate that, on average, travel times for traveling south are longer than those for north travels. However, the average travel times for both directions were found to be similar on Tuesday and Wednesday. Notably, the highest value for average travel time on Route2 was observed on Mondays when traveling in the South direction, taking almost 2500 seconds (0.69 hours). Finally, Thursday was found to be the optimal day for traveling along Route2, with the shortest travel time observed for both North and South directions at 576 (0.16 hours) and 737 seconds (0.21 hours), respectively.

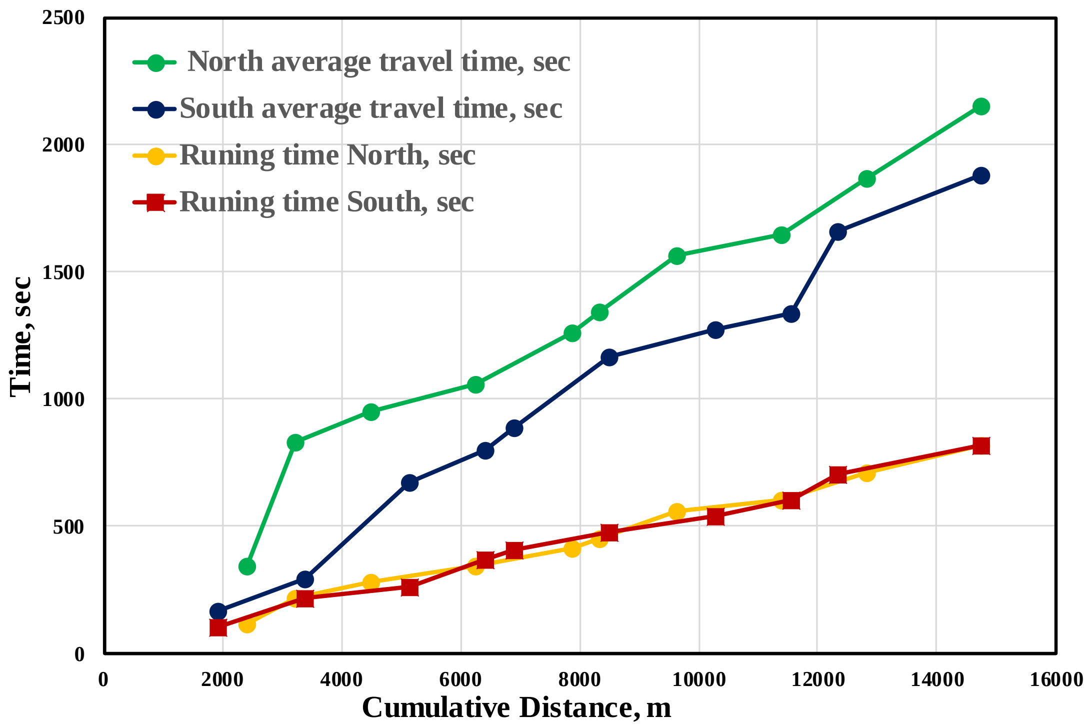


Figure 4.6. Travel and running time vs. cumulative distance for Rout2 North and South directions for Sunday.

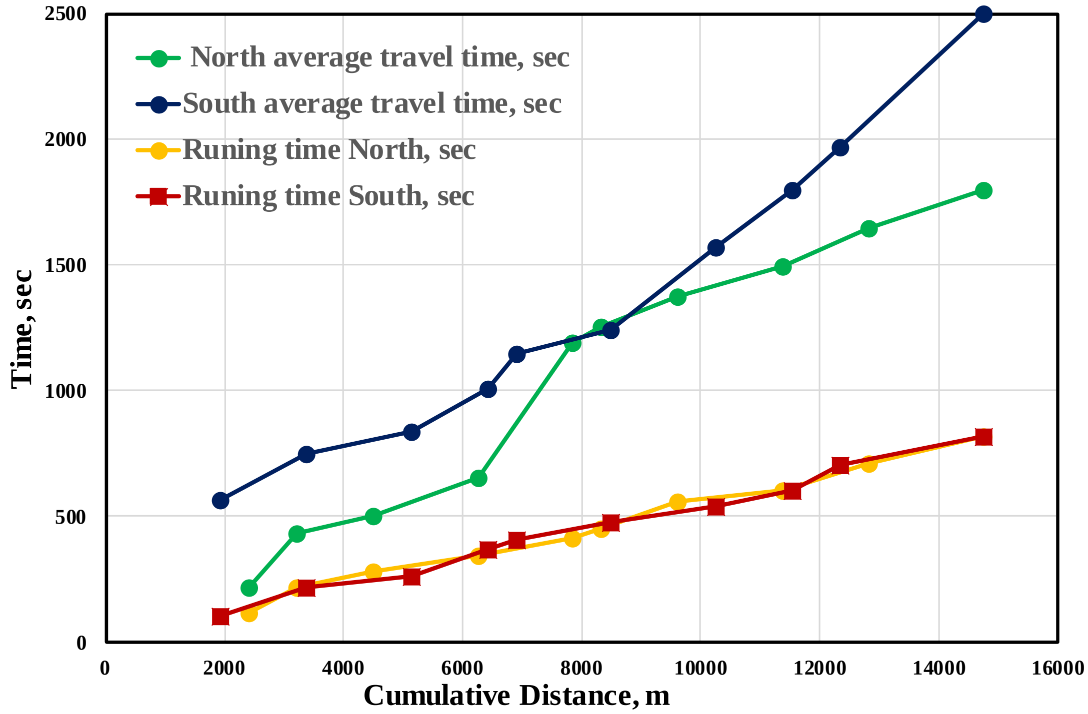


Figure 4.7. Travel and running time vs. cumulative distance for Rout2 North and South directions for Monday.

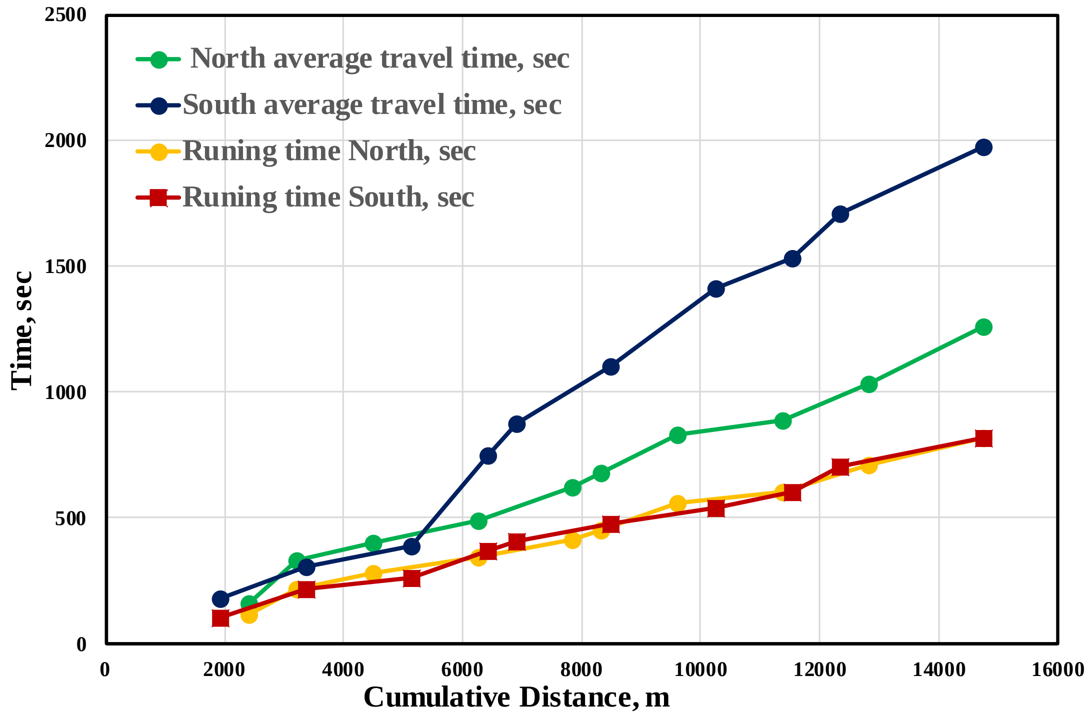


Figure 4.8. Travel and running time vs. cumulative distance for Rout2 North and South directions for Tuesday.

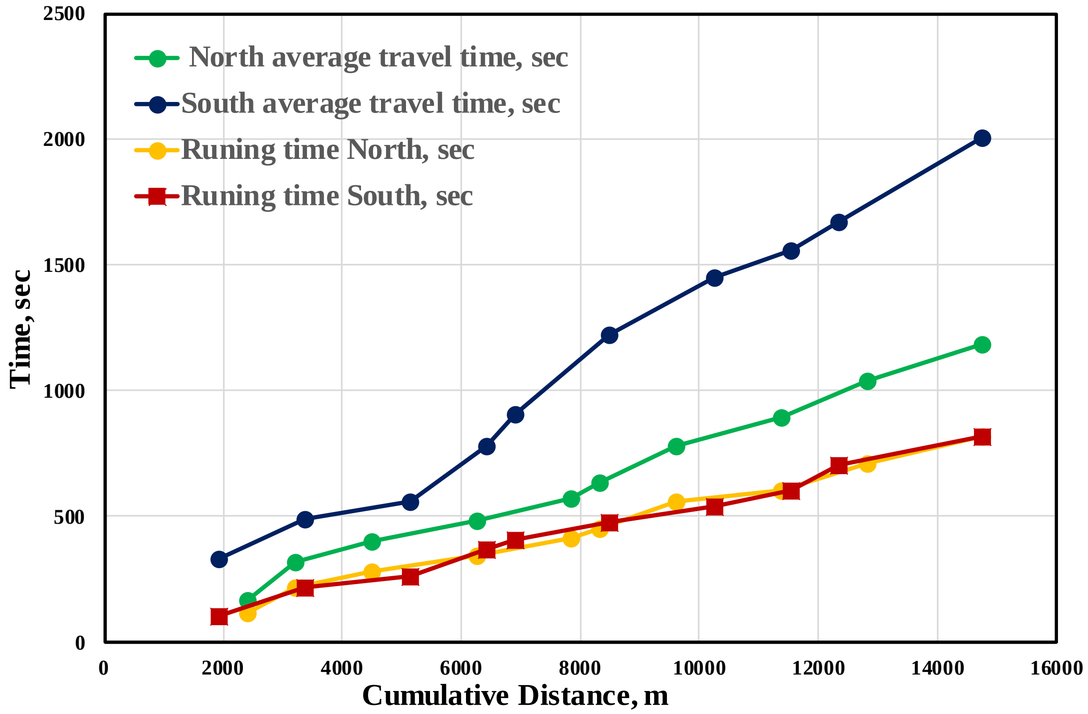


Figure 4.9. Travel and running time vs. cumulative distance for Rout2 North and South directions for Wednesday.

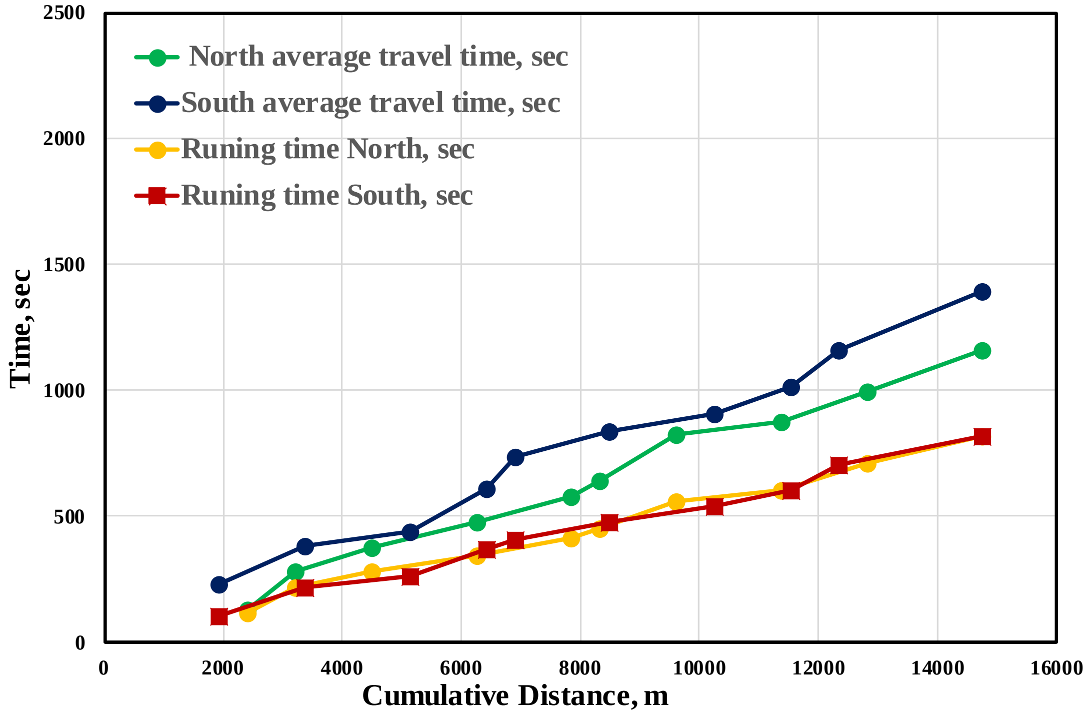


Figure 4.10. Travel and running time vs. cumulative distance for Rout2 North and South directions for Thursday.

4.3.3. Route3

The Figures 4.11-15, represent the cumulative distance along with average travel times and running times for different locations in Route3 for traveling North and South directions. The locations are presented in ascending order of cumulative distance. Further analysis was conducted to determine the differences in travel times for traveling North versus South. The findings indicate that, on average, travel times for traveling South are longer than those for traveling North. The results also show that there were similar average travel times for both directions on Tuesday and Wednesday. Finally, it was observed that less travel time was required on Thursday for both directions. Notably, traveling in the North direction on any given day took approximately more than 1000 seconds (0.28 hour).

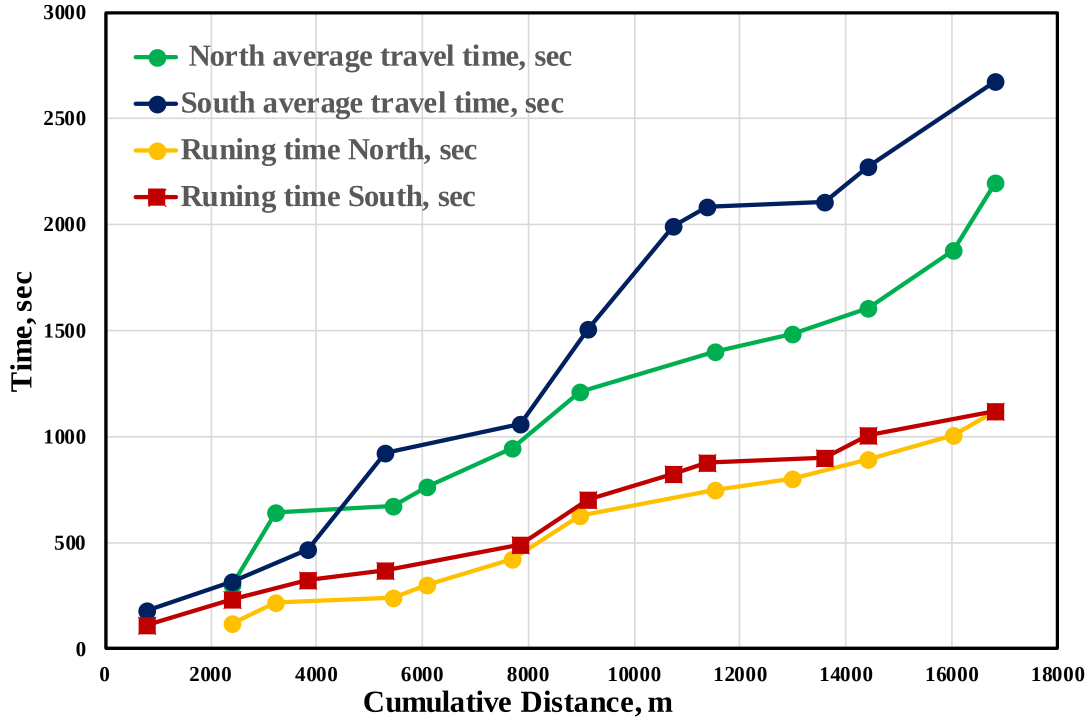


Figure 4.11. Travel and running time vs. cumulative distance for Rout3 North and South directions for Sunday.

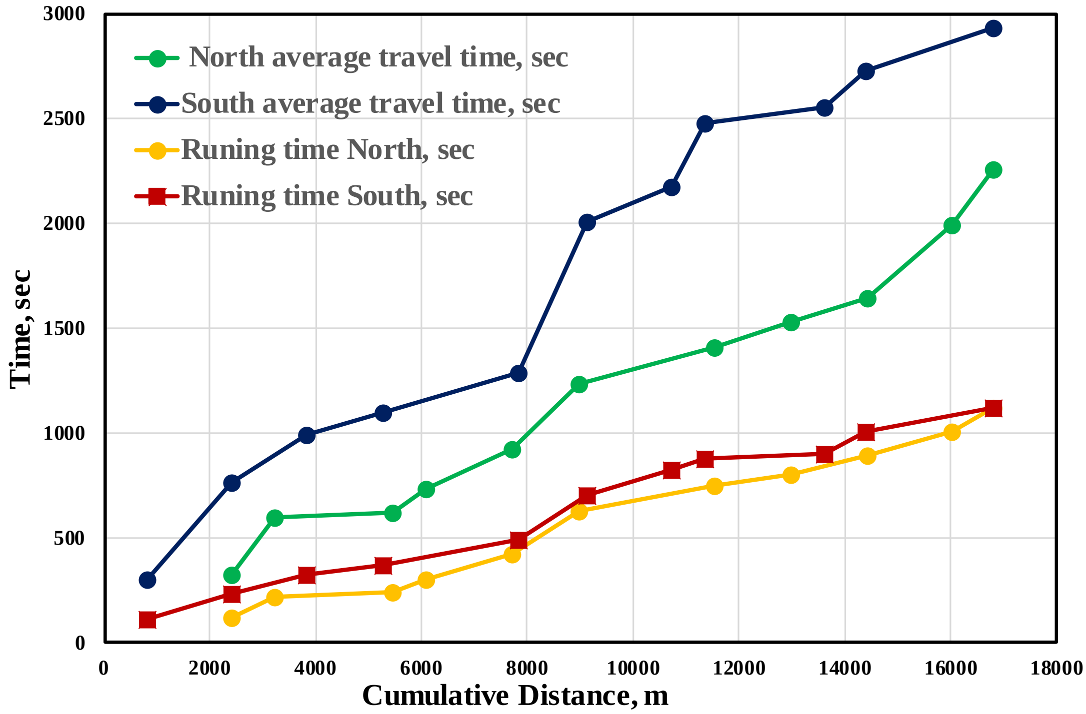


Figure 4.12. Travel and running time vs. cumulative distance for Rout3 North and South directions for Monday.

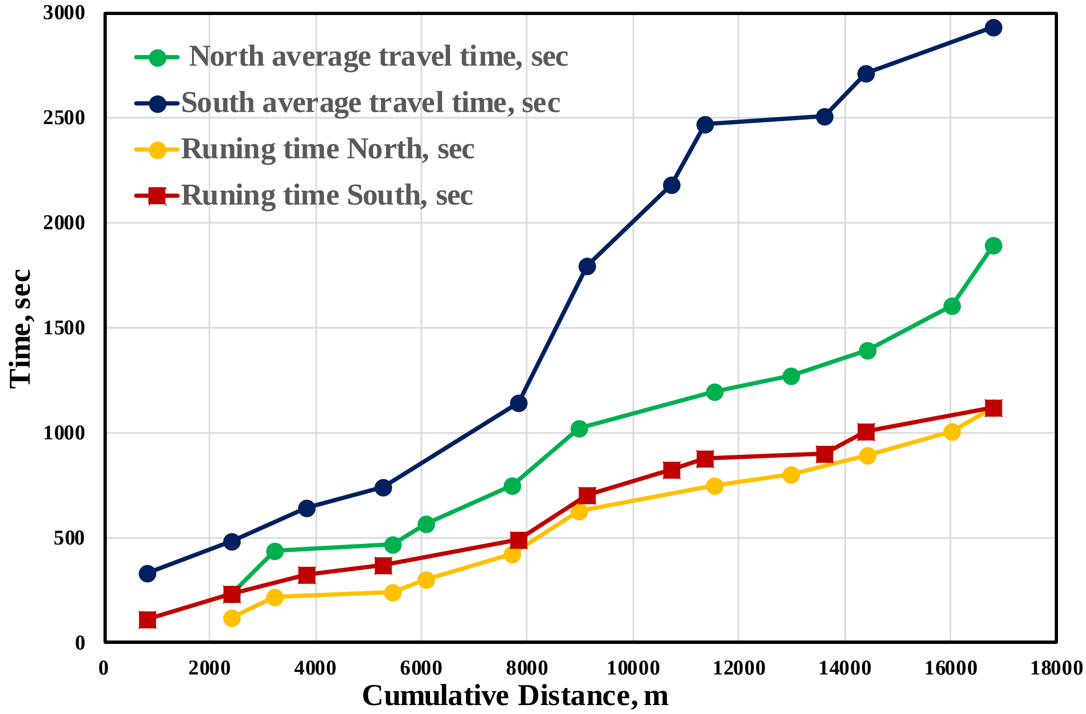


Figure 4.13. Travel and running time vs. cumulative distance for Rout3 North and South directions for Tuesday.

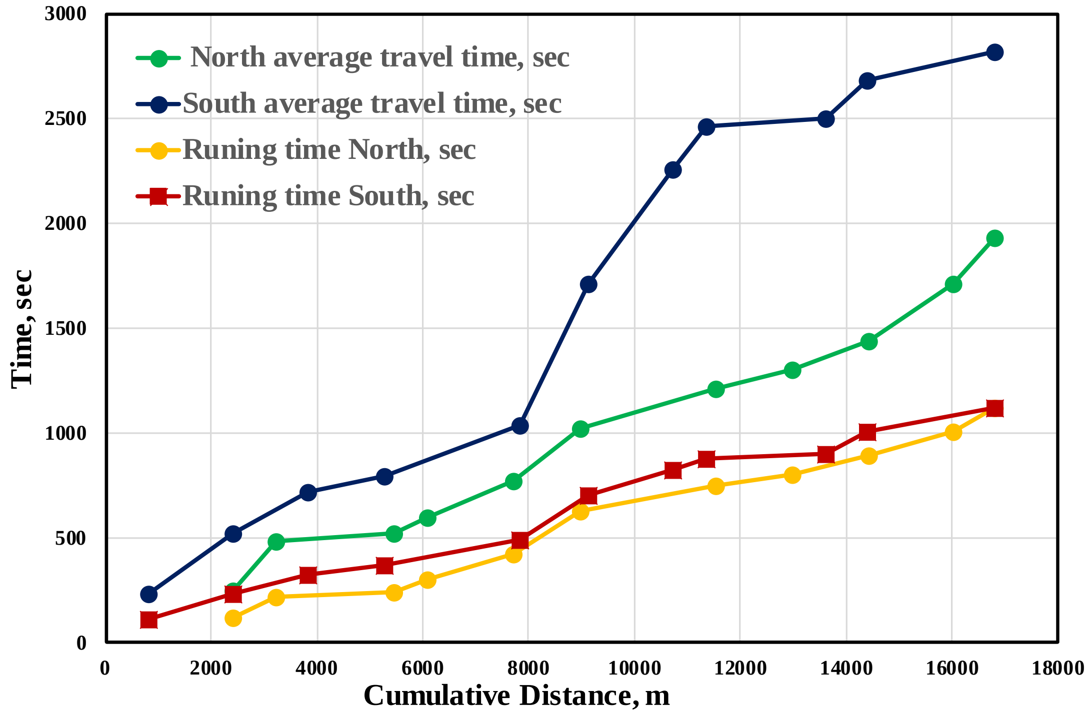


Figure 4.14. Travel and running time vs. cumulative distance for Rout3 North and South directions for Wednesday.

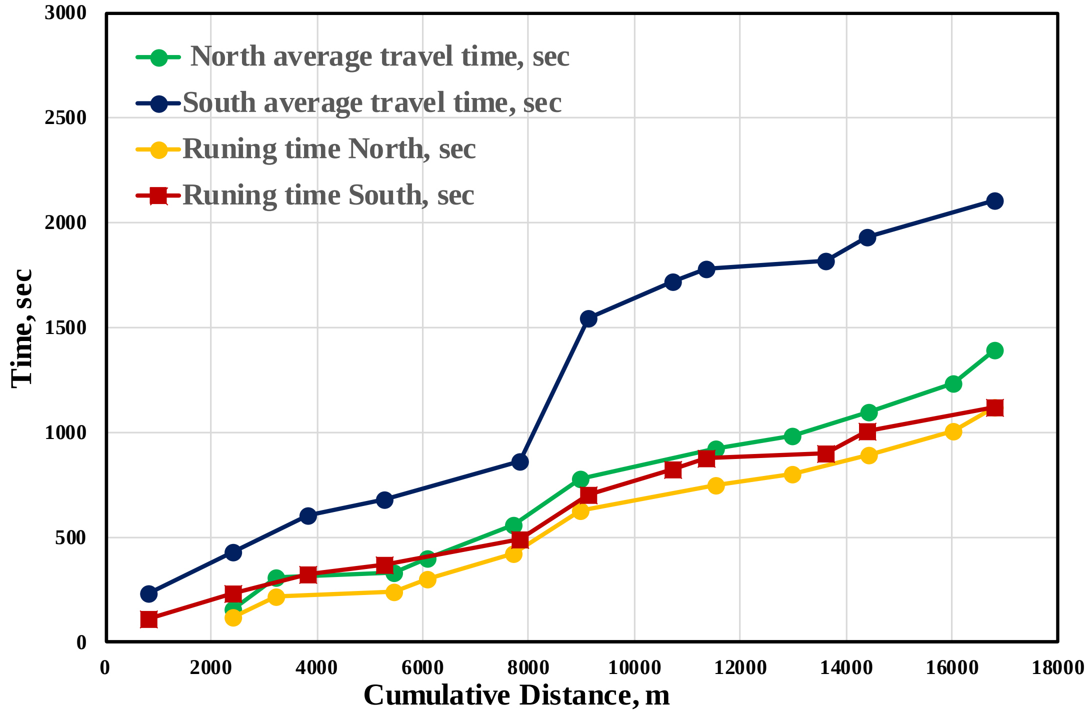


Figure 4.15. Travel and running time vs. cumulative distance for Rout3 North and South directions for Thursday.

4.4. Analysis of Average Travel Times

The average travel time in minutes for all routes in all weekdays are summarized in Table 4.7. Moreover, Figures 4.16-18 compare the free flow time for each route with the travel times in two peak periods, morning 7-9 a.m. and afternoon 1-3 p.m., for both direction of the related route. Overall, travel times are much higher than free flow travel times for all routes as shown in Table 4.7.

For Route1 in the morning, the average travel time for Monday is 72 minutes, which is the longest time during the week and is 49 minutes longer than the free-flow travel time. In the evening commute, the highest time is on Tuesday, with an average of 99 minutes and 76 minutes longer than the free-flow travel time. These values indicate that Route1 is particularly congested during peak times, with significant delays compared to the free-flow travel time.

For Route2 in the morning commute, the average travel time on Sunday is 60 minutes, which is 45 minutes longer than the free-flow travel time. On Thursday morning, the average travel time is the lowest at 27 minutes. In the evening commute, the longest average travel time on Monday is 75 minutes, which is 60 minutes longer than the free-flow travel time. Route2 generally experiences less congestion compared to Route1, with shorter delays during peak times.

For Route3 in the morning commute, the average travel time on Monday is 56 minutes, which is 37 minutes longer than the free-flow travel time. The lowest average travel time is on Thursday morning as 28 minutes. In the evening commute, the highest average travel time is recorded on Monday and Tuesday as 79 minutes, which is 60 minutes longer than the free-flow travel time. Compared to Routes1 and 2, Route3 has relatively consistent travel times throughout the week, with only modest delays during peak times.

Overall, the table shows that the travel time for each route varies by day and time, with some days having longer travel times than others. All three routes experience delays during peak times, with Route1 being the most congested and Route2 being the least congested. Comparing the average travel times with the free-flow travel time highlights the impact of congestion on each route, with Route1 experiencing the greatest delays compared to its free-flow travel time.

Accordingly, these results provide valuable information about the average travel time for different routes on weekdays, where it could be useful for people who commute regularly and need to plan their travel time accordingly.

Table 4.7. Average travel time in minutes for all routes in weekdays.

Route / Time	Weekdays (min)					Free flow travel time (min)
	Sun.	Mon.	Tus.	Wed.	Thur.	
Route1 / AM	54	72	33	65	43	23
Route1 / PM	73	94	99	88	82	23
Route2 / AM	60	48	30	28	27	15
Route2 / PM	52	75	58	57	36	15
Route3 / AM	54	56	44	46	28	19
Route3 / PM	70	79	79	75	51	19

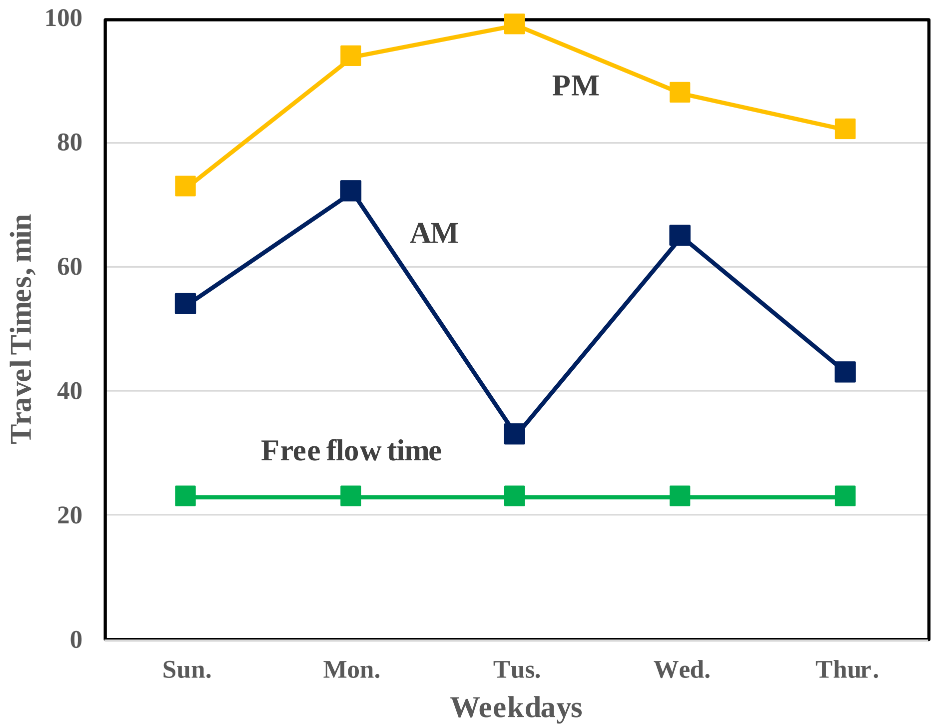


Figure 4.16. Average travel time through the weekdays for Route1 in two periods, morning 7-9 a.m. and afternoon 1-3 p.m.

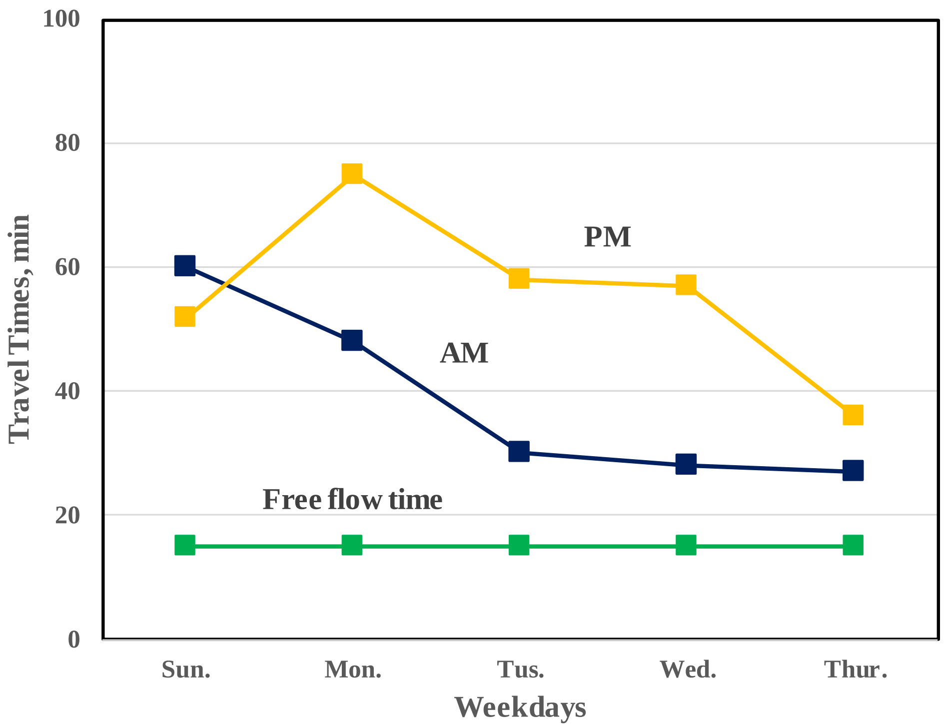


Figure 4.17. Average travel time through the weekdays for Route2 in two periods, morning 7-9 a.m. and afternoon 1-3 p.m.

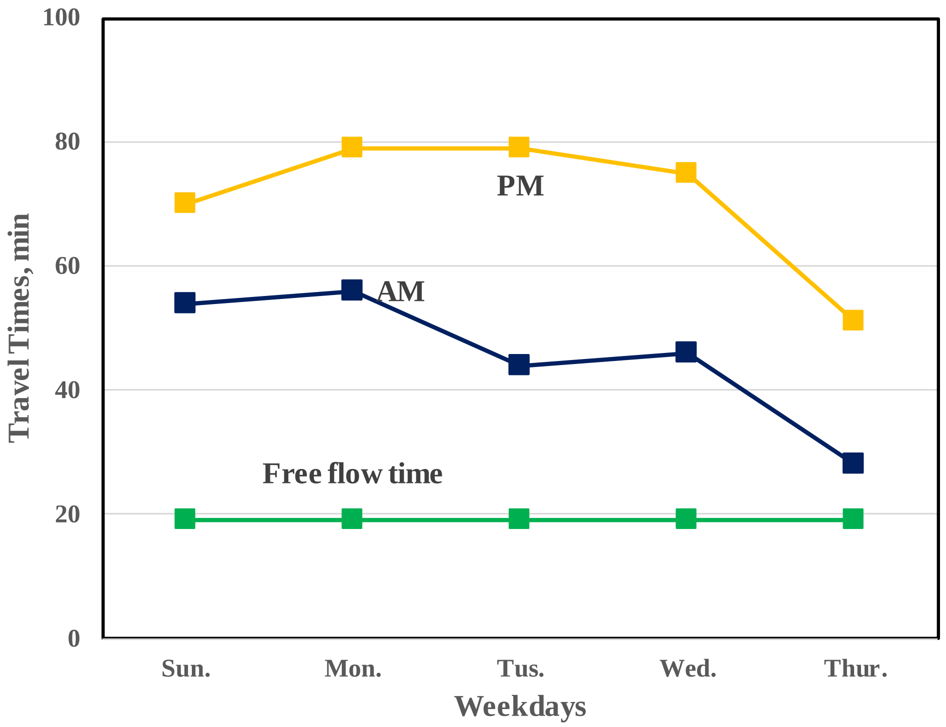


Figure 4.18. Average travel time through the weekdays for Route3 in two periods, morning 7-9 a.m. and afternoon 1-3 p.m.

4.5. Evaluation of Traffic Volume

The travel time in a transportation network is influenced by various factors, such as traffic supply and demand. To describe the relationship among these factors, conventional road impedance functions are commonly used, including the link performance function of the Bureau of Public Roads (BPR), Davidson's road impedance function, and linear and regression road impedance models used by Germany and Japan, respectively. Among these functions, the BPR link performance function has been widely adopted in the traffic field to estimate link travel time in road networks.

In this study, the BPR function is adopted to assess the reliability of travel time in the transportation network. The BPR link performance function is a widely used method for predicting link travel time in transportation networks. It provides a mathematical expression for the relationship between travel time, traffic supply and demand, and capacity, based on empirical coefficients and traffic flow data. Moreover, The BPR function expresses the travel time of a single link or corridor as a function of traffic flow. Specifically, the mean travel time T is a function of the flow rate q, with t_0 which represents the minimum free travel time under zero flow conditions. The BPR function expressed in equation 4.1 is given by Zhang et al. (2019), where β and γ are empirical coefficients with values given as 4 and 0.15, respectively. V is the traffic volume or flow, The capacity C of the link is a $3/4$ saturation flow and depends on the number of lanes (for one lane $C = 1350$).

$$T = t_0 \left[1 + \gamma \left(\frac{V}{C} \right)^{\beta} \right] \tag{4.1}$$

This function is used to calculate the traffic flows on the links according to the travel times recorded by the GPS vehicles during the test drives. Afterwards, the analysis in Vissim was carried out by employing these flows.

4.6. Calculation of Travel Times Using PTV Vissim

For further investigation of the reliability of the routes and their links, after calculating the traffic volumes based on the real travel time, the routes were simulated using the PTV Vissim program with the same selected paths and links. Each link was entered through its location, which starts from the former intersection to the next intersection. Through the simulation, the program provided the duration of the trips, delays, and queue lengths. It should be noted that the routes were divided into links and the same data extracted from the tracking device in the car was used. The results are shown in the Tables 4.8-10. These tables demonstrate the performance metrics for traffic flows at the intersections. The metrics recorded for each link are volume, queue delay, vehicle delay, and travel time. Here, the volume indicates the number of cars that passed through each link within one hour in terms of car equivalency. The queue delays the amount of time that vehicles had to wait in line at the link before proceeding and the vehicle delay the average time that each vehicle was delayed while traveling through the link were also stated. In addition, the travel times the total time that took for each vehicle to traverse the link, including any delays were specified. The tables indicate that the first route, including all its intersections, took 57.50 minutes to reach the end point. The second route, which was determined to be the most reliable through statistical analysis and simulation, confirmed that the travel time from start to finish was 34.47 minutes. The third route was completed in 38.47 minutes.

Table 4.8. Traffic performance metrics for Route1 from Vissim.

Intersections	Volume (c/h)	Queue delay (min)	Vehicle delay (min)	Travel time (min)
1	1926	0.46	1.76	3.28
2	1984	1.06	4.50	6.41
3	1676	0.41	2.64	6.54
4	1830	1.06	5.01	7.86
5	1786	0.62	2.45	4.81
6	1672	0.70	3.75	9.26
7	1442	0.03	0.41	1.80
8	1749	1.17	5.42	8.63
9	1986	0.58	3.03	4.39
10	1876	0.32	1.36	2.51
11	1884	0.24	0.76	2.00
	sum	6.65	31.08	57.50

Table 4.9. Traffic performance metrics for Route2 from Vissim.

Intersections	Volume (c/h)	Queue delay (min)	Vehicle delay (min)	Travel time (min)
1	1138	0.00	0.14	2.71
2	1347	0.01	0.11	2.67
3	1872	0.44	1.31	3.79
4	1752	0.60	2.14	4.15
5	2315	0.55	2.03	3.73
6	1983	0.17	0.64	2.04
7	1642	0.41	1.26	3.47
8	1982	0.44	1.30	4.00
9	1982	0.50	1.40	3.70
10	1577	0.41	1.24	4.20
	sum	3.53	11.57	34.46

Table 4.10. Traffic performance metrics for Route3 from Vissim.

Intersections	Volume (c/h)	Queue delay (min)	Vehicle delay (min)	Travel time (min)
1	1655	0.39	1.57	4.02
2	1877	0.29	1.37	2.03
3	1760	0.50	2.81	4.26
4	1851	0.19	1.15	1.78
5	1858	0.55	2.10	3.87
6	1883	0.44	2.22	3.37
7	1974	0.79	3.64	5.29
8	1652	0.33	1.78	2.81
9	1789	0.43	2.13	3.15
10	1686	0.48	1.93	3.66
11	1944	0.60	1.61	4.23
	sum	4.97	22.31	38.47

Furthermore, as seen from the previous tables, the queue delay for Route1 is 6.65, Route2 3.53 min, and for Route3 is 4.97 minutes. On the other hand, vehicle delays, respectively, are 31.08, 11.57, 22.3 minutes, which help to conclude that the highest delay values are derived from the first route (Route1).

4.7. Comparing Simulated and Real Results

To meet the objectives of the study that include evaluating the performance of the transportation system using specific measures, such as travel time, queue delay, and vehicle delay, the reliability of the three routes were assessed. For this purpose, he results of obtained from Vissim simulations were compared to the findings attained from the statistical analysis conducted by using SPSS.

Figure 4.19 illustrates the vertical representation of the travel times, vehicle delays, and queue delays calculated at each intersection for route 1. The analysis reveals that the 8th intersection causes the highest vehicle delay with 325.0 seconds and queue delay as 70.2 seconds. The maximum travel time of 555.7 seconds was observed at the 6th intersection. Furthermore, after computing the travel time values for each intersection, it was found to be in close agreement with the travel time obtained from Vissim on this route when the expected intersection volume and other parameters like link length, intersection shape etc. were entered (Figure 4.20). It should be noted that the maximum traffic volume was observed at intersection 2. The SPSS analysis shows that the total travel time for all links was 43 minutes. However, Vissim showed an increase of 12 minutes in the total travel time, resulting in a total travel time of 55 minutes. Additionally, Figure 4.20 represents the free-flow travel time at each intersection and the total free-flow travel time of 23 minutes.

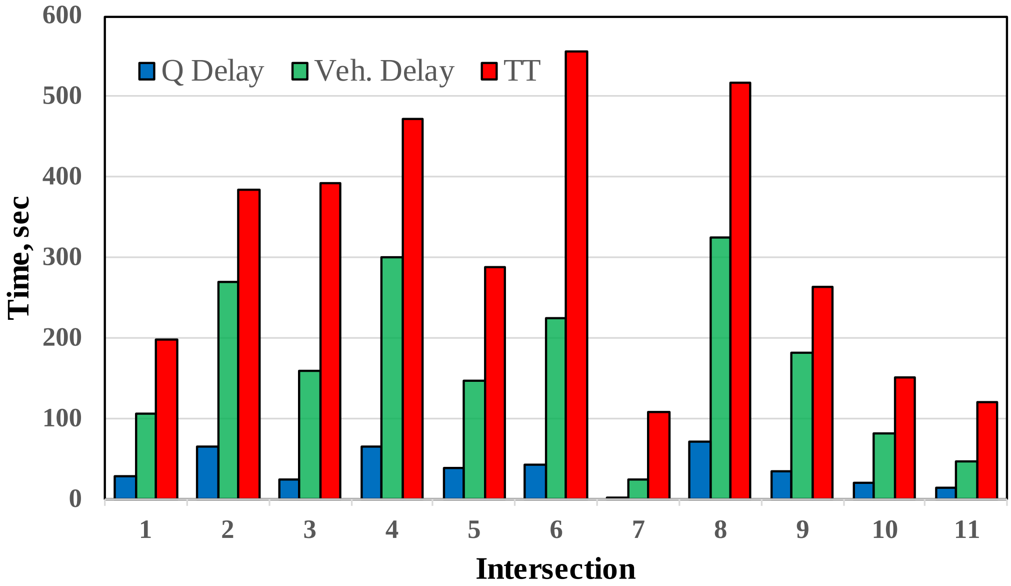


Figure 4.19. Traffic performance metrics for Route1 from Vissim.

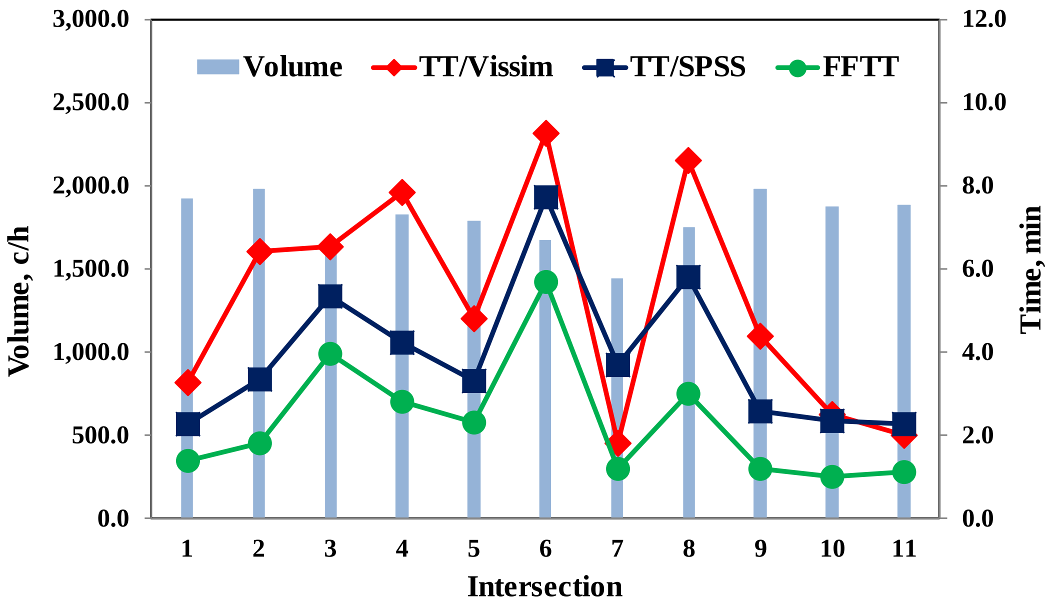


Figure 4.20. Comparing travel time for Route1 along all intersections from SPSS and Vissim.

Figure 4.21 shows the calculated travel time, vehicle delay, and queue delay at each intersection of Route 2. It is evident that the fourth intersection experienced the highest delay in terms of both vehicle and queue delay at 128.3 seconds and 35.8 seconds, respectively. The longest travel time of 249.0 seconds was recorded at intersection 4, while the maximum travel time was observed at intersection 10 as 251.8 seconds. Furthermore, Figure 4.22 indicates that after computing the travel time value for the intersections on the second route, there was a close agreement with the travel time obtained from Vissim in some intersections (3, 4, and 5), provided that the expected intersection volume and other parameters like link length, intersection shape, and length were entered. It is noteworthy that intersection 5 represents the highest traffic volume. The total travel time for all links using SPSS was 34 minutes, but there was an increase of 0.5 minutes, leading to a total travel time of 34.5 minutes in Vissim. Additionally, Figure 4.22 represents the free flow travel times at each intersection, with a total free flow travel time of 15 minutes.

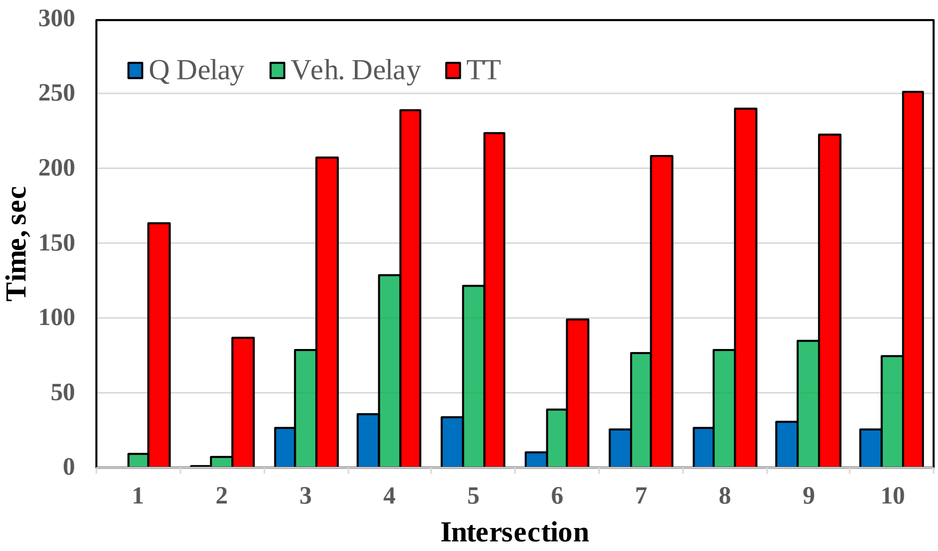


Figure 4.21. Traffic performance metrics for Route2 from Vissim.

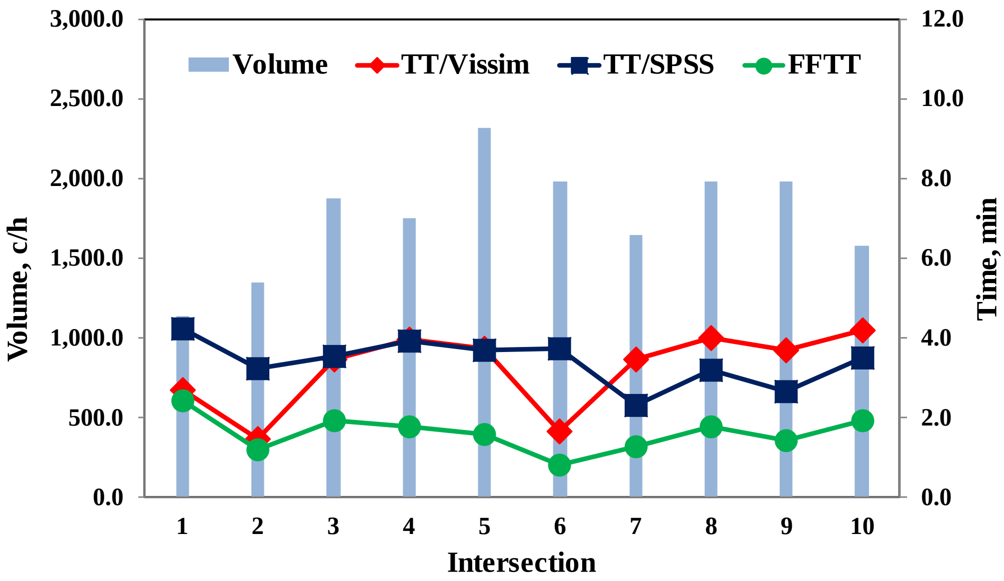


Figure 4.22. Comparing travel time for Route2 along all intersections from SPSS and Vissim.

Figure 4.23 shows the travel time, vehicle and queue delay calculated at each intersection on route 3. The results indicate that drivers experience the highest delay at seventh intersection, with a vehicle delay of 218.5 seconds and a queue delay of 47.1 seconds. The travel time at this intersection is also high, 317.6 seconds. With regard to the travel time values for each intersection on this route, it was found that they are in close agreement with the travel time obtained from Vissim (Figure 4.24), given that the expected intersection volume and other parameters like link length, intersection shape, and length were entered. The intersection with the maximum traffic volume is intersection 7. The SPSS analysis shows that the total travel time for all links was 36 minutes. However, there has been an increase of 2.5 minutes in the total travel time, resulting in a total travel time of 38.5 minutes in Vissim. Additionally, the figure represents the free flow travel time at each intersection and the total free flow travel time of 19 minutes.

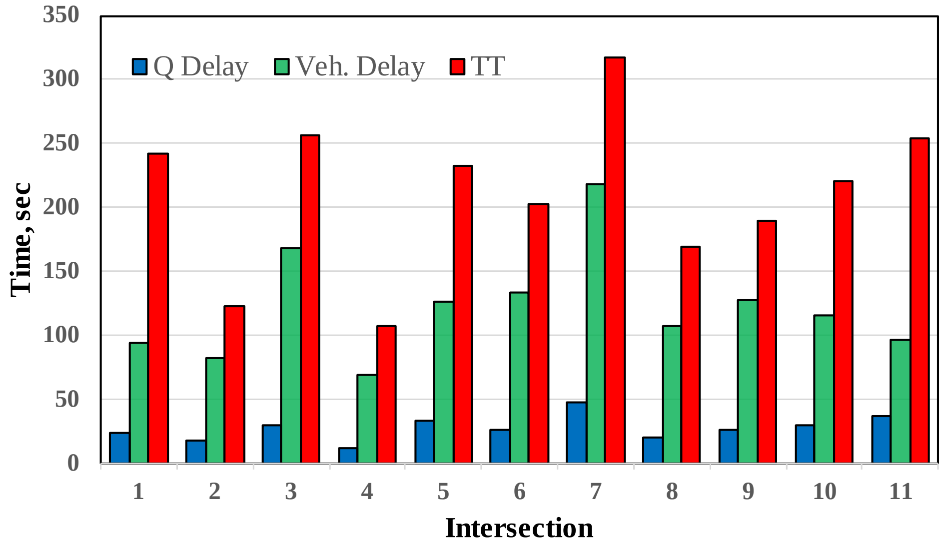


Figure 4.23. Traffic performance metrics for Route3 from Vissim.

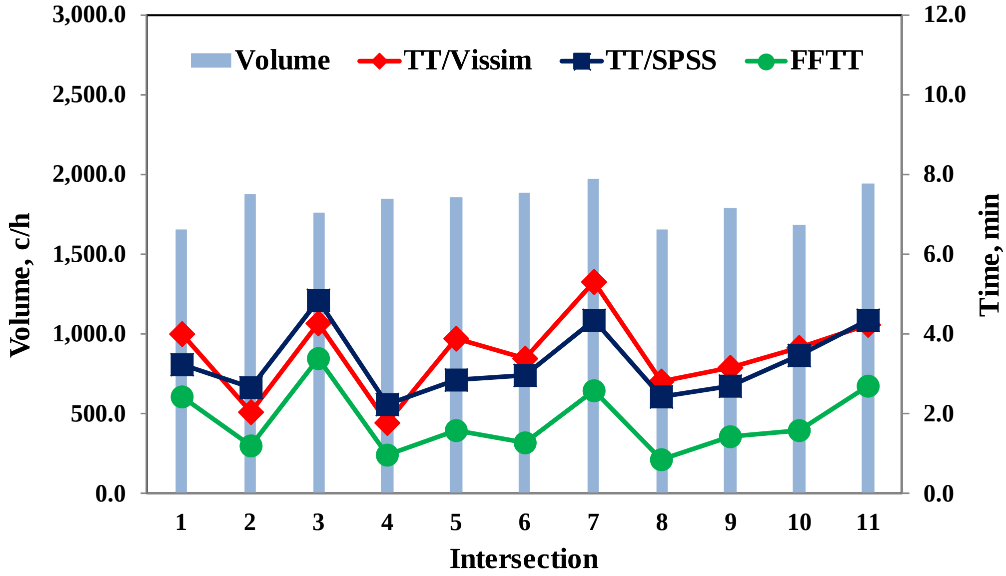


Figure 4.24. Comparing travel time for Route3 along all intersections from SPSS and Vissim.

4.8. Estimation of Travel Time Reliability

Reliability rating using the simulation program Vissim is used to estimate the travel time reliability. Travel time values were obtained through entering the traffic volume and the length of the links for each case in which traffic volumes were increased 10% at each iteration until 100% increase was reached. Figures 4.25-27 shows travel times obtained at each intersection point along Route1, Route2, and Route3, respectively. Also, Buffer Indices were calculated for each link and presented in the figures.

As seen from Figure 4.25, in Route1 links characterized by long distances and high speeds, the impact of increased traffic volume on travel time is relatively limited, resulting in a slight observed increase in time or, in some cases, no discernible change. This outcome is influenced by various factors, including the shape and length of intersections. Specifically, in the first, second, third, and fourth links, a minor time increase was observed after surpassing approximately 60% of the traffic volume. In contrast, the fifth link, distinguished by lower speed, medium distance, and shorter intersections, exhibits a consequent increase in travel time starting from a traffic volume increase of 10%, and this trend persists as traffic volume continues to rise. In the case of the sixth and eighth links, there was a noticeable increase in travel time at a traffic volume of 60%. In contrast, for the seventh, ninth, and tenth links, a direct relationship was observed between traffic volume and travel time, with consistent increments in time as the traffic volume increased from 10% to 100%. As for link 11, there is a slight rise in travel time within the 10-30% range of traffic volume, but subsequently, travel time stabilizes, indicating that further increases in traffic volume have minimal effect on travel duration within that particular link. Among the analyzed links, the fifth link exhibited the highest value of Buffer Index, indicating lower reliability compared to the other links. The travel time in this link showed significant variations when traffic volume was altered, with a recorded value of 16.1%. Notably, in Vissim simulations, the observed results indicate a higher level of reliability for Route1 in comparison to the other two routes.

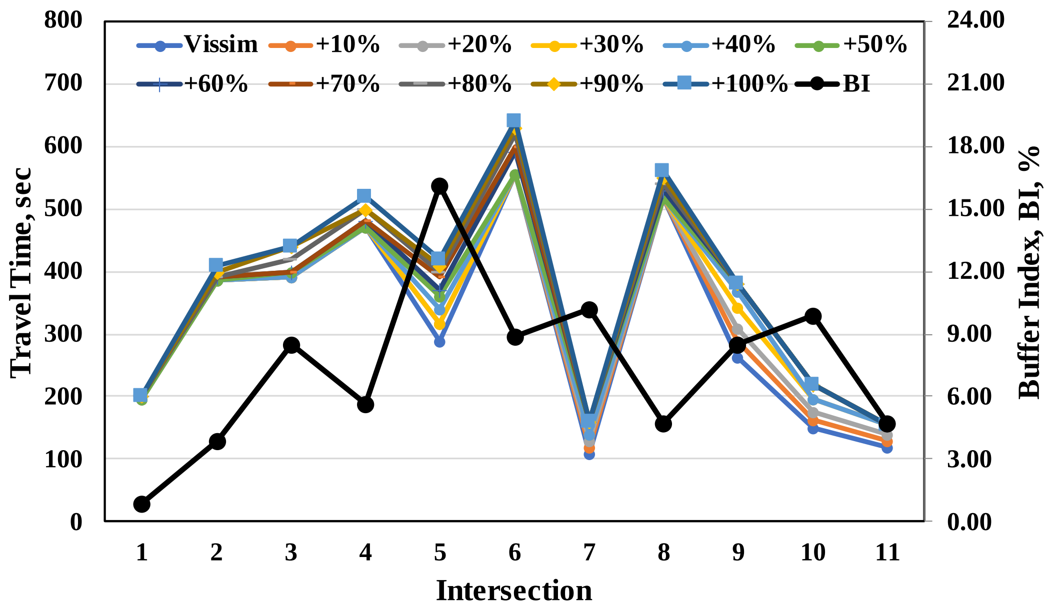


Figure 4.25. Travel times and BI changes for each link along Route1, with increasing the traffic volume using Vissim simulation.

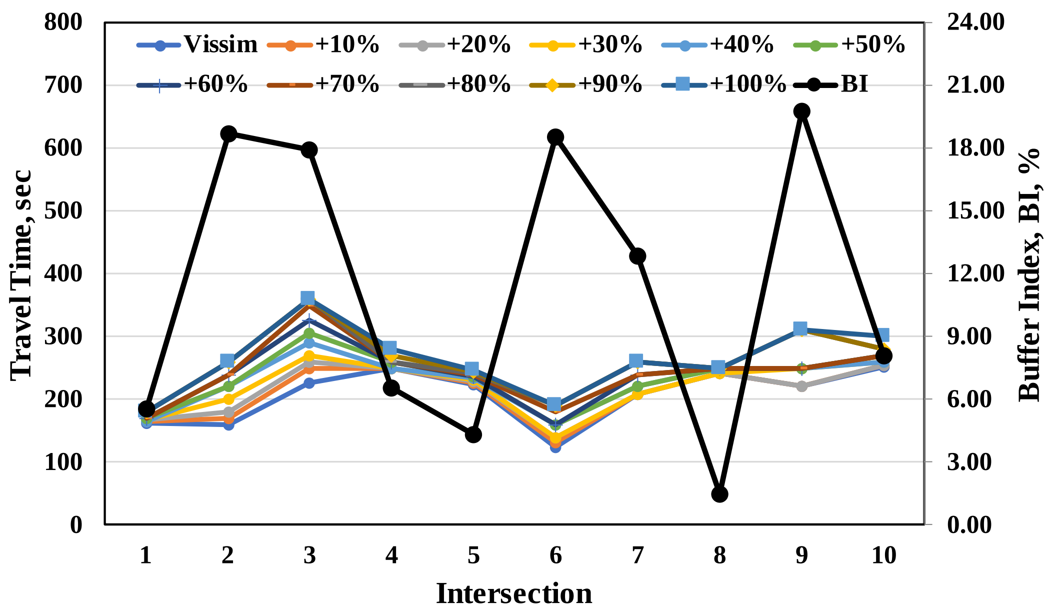


Figure 4.26. Travel times and BI changes for each link along Route2, with increasing the traffic volume using Vissim simulation.

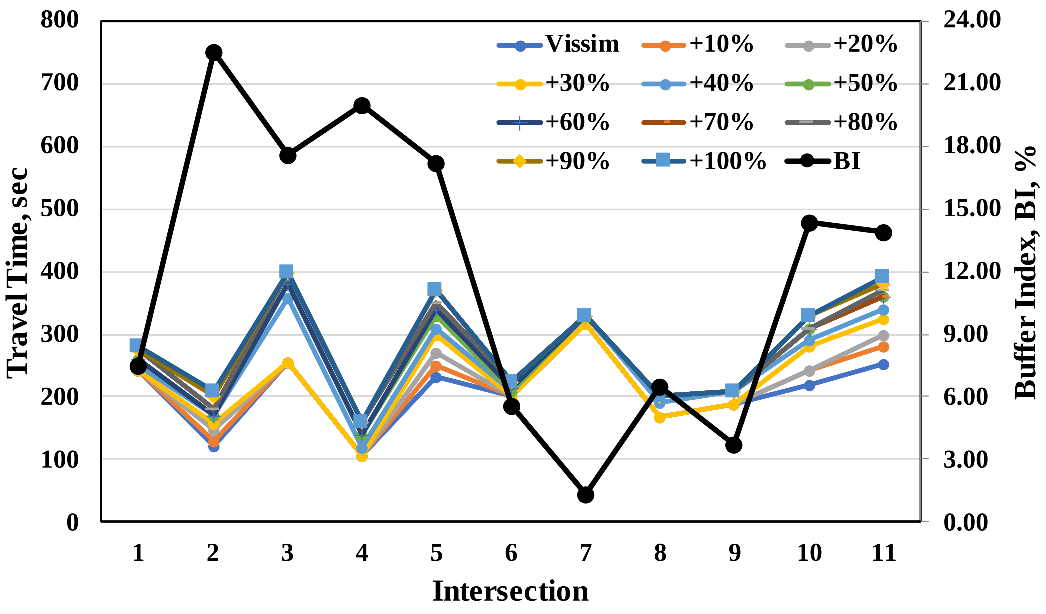


Figure 4.27. Travel times and BI changes for each link along Route3, with increasing the traffic volume using Vissim simulation.

In the case of Route2 (Figure 4.26), which exhibited high reliability in real-world scenarios, the simulation results indicated a loss of reliability due to various factors across all road links. These factors encompassed the length of the link, traffic volume, intersection type and shape, as well as speed. Notably, when the traffic volume was increased by 10% increments, the second, third, sixth, seventh, and ninth links, displayed high BI values of 18.7, 18.0, 18.6, and 19.8%, respectively. The second and third links experienced a significant increase in travel time with each 10% increment in traffic volume. Conversely, the eighth link (BI = 1.4%) remained unaffected by the volume increase, while the ninth link exhibited a noteworthy increase in travel time for every 10% increment.

In the simulation scenario of Route3, the second link exhibited lower reliability with a BI value of 22.5%. The travel time in this link showed significant variation when traffic volume changed. Similarly, the third link had a BI value of 17.6%, where the time increase remained consistent at 10% increments up to 60%, and then further increased up to 100%. The fourth link also displayed relatively low reliability with a BI value of 20.0%. Conversely, the sixth, seventh, eighth, and ninth links demonstrated high reliability, as indicated by their BI values of 5.5, 1.4, 6.5, and

3.7%, respectively. In these links, the travel time remained stable despite significant changes in traffic volume, further enhancing the overall reliability of the road.

Tables 4.11-12. provides the combined trip times for all links for the intersections connected to each other by a corridor (link). As seen from the tables, the average travel time for Route1, Route2, and Route3 for the real case are 43, 34, and 36 minutes, respectively. On the other hand, the simulation case showed that the average travel times are 62, 39, and 46 minutes for Route1, Route2, and Route3, respectively. Moreover, the Buffer Index (BI) is included for each route in both the observed data and the Vissim simulation cases.

The BI is expressed as a percentage and represents the additional time required beyond the scheduled travel time to ensure on-time arrival. In general, a lower BI indicates a more reliable travel time for a given route, while a higher BI suggests that travelers may need to plan for more buffer time to ensure on-time arrival.

Based on the tables, the BI is noted to vary for each route, with some routes having a higher BI than others. For example, in the observed data, Route1 has the highest BI of 22%, while Route2 has the lowest BI of 12%. In contrast, the Vissim simulation showed that Route1 has the lowest BI of 7%, while Route3 has the highest BI of 9%.

Table 4.11. Travel time reliability measurements from the real case.

Routes	Avg. TT (min.)	FFTT (min.)	SD (min.)	95^{th} (%)	PV (%)	BI (%)	PTI	TTI
Route1	43	23	10	52	23	22	2.26	1.87
Route2	34	15	7	38	21	12	2.53	2.27
Route3	36	19	8	41	22	14	2.16	1.89

Table 4.12. Travel time reliability measurements from simulation case.

Routes	Avg. TT (min.)	FFTT (min.)	SD (min.)	95^{th} (%)	PV (%)	BI (%)	PTI	TTI
Route1	62	23	3	67	5	7	2.91	2.71
Route2	39	15	3	42	7	8	2.79	2.57
Route3	46	19	4	50	9	9	2.62	2.40

5. CONCLUSION

The growing demand for transportation in urban areas has necessitated the expansion of the urban transportation network. However, this expansion has led to increased challenges in ensuring the reliability of the network. One of the key factors contributing to this challenge is the variation in the effects of different links on reliability. This variation is due to the diverse locations of the links and intersections across the entire network and the rate of traffic sharing among them. As a result, maintaining the reliability of the urban transportation network requires a comprehensive understanding of the network's characteristics, including the spatial distribution of links and the traffic flow dynamics across the network.

The aim of this study is to assess the travel time reliability of three important arterial urban routes in city of Baghdad by considering their real- case characteristics of them and then incorporating the assumed increased traffic volumes for testing different scenarios through Vissim. For this purpose, fixed features such as the design speed of the routes (links) and the number of lanes were taken into account. To simulate the impact of increased traffic volume on these routes, a PTV Vissim program was utilized. This involved creating a virtual model of the network to evaluate how the links (routes) would perform under different traffic conditions (scenarios). The assessment and evaluation have been carried out through TTI, PTI, and BI reported for three different routes, each under two different scenarios: before and after using the Vissim simulation software.

Comparing the TTI values for the routes before and after simulation, it can be seen that for all three routes, there is an increase in TTI after increasing traffic volume, indicating an increase in congestion and travel time variability. This suggests that the representation of an increase in volume has had a negative impact on travel time reliability.

The PTI values for the routes before and after simulation show a mixed trend. For Route1 and 3, The rise in PTI after increasing traffic volume 10 times and carrying out simulation by Vissim indicates an increase in travel time. Overall, the impact degree of this scenario on PTI seems to vary depending on the specific route features (length of each link, speed limit etc.).

The reliability of three real case routes (Route1, Route2, and Route3) was evaluated using the buffer time index, and during peak hours, the indices were found to be 22%, 12%, and 14%, respectively. However, in the simulation, Route1's reliability declined to 7%, while Route2 had a buffer index of 8% and Route3 had 9%. Route2 exhibited the highest level of reliability in the real case, while in simulation results Route1 has the highest level of reliability. The simulation results also showed that Route1 experienced the highest increase in delays, while Route2 had the lowest delay values in both. Furthermore, the 95th percentile travel time for the real case showed that all three routes experienced additional delays, with Route1 having the highest at 52%, followed by Route2 at 38%, and Route3 at 41%. In the simulation case, the delays for all three routes increased, with Route1 experiencing the highest at 67%, followed by Route2 at 42%, and Route3 at 50%.

The three studied routes in this work included all the services, facilities and the intersections experienced by the system users. Increased economic activities and improved quality of life have increased the value of travel time in recent years making stability to become an important issue in transportation networks. Therefore, any unexpected delay could lead to great loss for network users. The most important goal is to provide all the necessary safety factors to reduce potential risks from the process of interference between vehicles and to ensure ease, smooth and reliable trips with less delay. There are several principles that must be taken into account to ensure reliability for routes and links; the length of the link, speed limit and number of lanes, interference points between vehicles and their handling, speed controlling devices, control of changing the direction of movement to pass through the intersection, the direction that carries the highest traffic etc.

A robust and dependable transportation system is essential for the economy of any region or country, as it facilitates safe and efficient movement of people and goods, promoting accessibility and economic growth. In addition, during natural disasters such as earthquakes, floods, hurricanes, and other calamities, the transportation system becomes the most crucial lifeline for the affected population. According to Nicholson and Du (1997), a weak transportation system can hinder the recovery process, leading to severe losses and fatalities. Moreover, even in normal circumstances, daily disruptions such as traffic congestion, accidents, and unexpected delays can have adverse economic and social impacts, further highlighting the importance of a reliable transportation system. Therefore, ensuring the reliability of the transportation system is critical to promote sustainable economic growth, social well-being, and safety. Actual travel requirements and road capacity vary over time, thus contributing to travel time uncertainty. With increased time value, significant loss is incurred by drivers due to unexpected schedules (either early or late). A well-functioning transportation system will provide a competitive advantage in the global economy.

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