T.R.
SAKARYA UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

PERFORMANCE ANALYSİS OF ROUNDABOUT JUNCTİON İN DUHOK WİTH PROPOSED SİGNALİZED ONE THROUGH VISSIM SOFTWARE

MSc THESIS

Muhammad Hameed Ahmad ALDOHUKY

Civil Engineering Department

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Thesis Advisor: Prof. Dr. Hakan ASLAN

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The thesis work titled “Performance Analysis of Roundabout Junction in Duhok with Proposed Signalized one Through VISSIM Software” prepared by Muhammad Hameed Ahmed ALDOHUKY was accepted by the following jury on 15/05/2023. by unanimously/majority of votes as a MSc THESIS in Sakarya University Graduate School of Natural and Applied Sciences, Civil Engineering department

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Muhammad Hameed Ahmed ALDOHUKY

To my mother, father, sisters, colleagues and friends

ACKNOWLEDGMENTS

I want to thank a lot of key people who supported me throughout this project, namely, my parents, my supervisor Prof. Dr Hakan ASLAN, Mr Abdulillah OZDEMIR, my colleagues Mustafa and Makarim and my friend Muhammad GHIYATH.

Muhammad ALDOHUKY

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ABBREVIATIONS

AASHTO **:** American Association of State Highway and Transportation Officials

FHA **:** Federal Highway Administration

HCM **:** Highway Capacity Manual

ICD **:** Inscribed Circle Diamater

IIHS **:** Insurance Institute for Highway Safety

LOS **:** Level of Service

TVC **:** Traffic Volume Count

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DUHOK DÖNER KAVŞAĞININ VISSIM YAZILIMI ÜZERİNDEN ÖNERİLEN SİNYALİZELİ BİRLEŞTİRME PERFORMANS ANALİZİ

ÖZET

İlk kez 1966'da Birleşik Krallık'ta tanıtılan modern dönel kavşaklar, ve önceki kavşaklara göre önemli bir gelişme olduğu kanıtlanan uzun yıllar kullanımdan sonra, Amerika Birleşik Devletleri gibi birçok gelişmiş ülke de dahil olmak üzere dünya çapında çok daha yaygın hale gelmeye başladı. Amerika'da ilk olarak sadece 33 yıl önce 1990'da inşa edilen modern dönel kavşaklar, 2023 itibariyle ülkede yaklaşık 9.000 dönel kavşağın var olduğu bir sürecinde başlangıcı olmuş oldu. Pek çok iyileştirmeye rağmen, bu tür kavşaklar kendi eksileri ve kısıtlarını barındırmış olsa da, ülke çapında yapılan birçok anket sonuçlarında, vatandaşlar arasında bu kavşaklara artan bir desteğin olduğunu göstermiştir. Örneğin, 2007'de yapılan bir araştırma, kavşak inşaası öncesi var olan %22 ile %44 arasındaki halk desteğinin inşa sonrası %57-%87'ye yükseldiğini göstermiştir. Genel olarak dönel kavşaklar, araba kazalarının ve dolayısıyla ölümlerin miktarını önemli ölçüde azaltmanın yanı sıra gecikmeyi azaltma ve makul bir kapasite sağlama konusunda da kredilendirilmiştir. Dönel kavşakların kapasitesi, giriş açısı ve şerit genişliği gibi geometrik özelliklerine bağlı olmakla birlikte, tek şeritli dönel kavşaklar genellikle günde 20.000 ila 26.000 araç taşırken, iki şeritli tasarımlar günde 40.000 ila 50.000 araç kapasitelidir.

Göze çarpan iyileştirmelerine rağmen, modern dönel kavşakların da kendi eksileri ve sınırlamaları söz konusudur. Bu sınırlamaların en büyüğü, başlangıçta yalnızca orta düzeyde bir trafik hacmine sahip kavşakları barındıracak şekilde tasarlanmış olmalarıdır. Bu da, dünya çapında son on yılda neden binlercesinin sinyalize kavşaklara dönüştürüldüğünün temelini oluşturmaktadır. Artan kent nüfusu ve araç sahiplik oranları zaman içerisinde kent içi ulaşım şebeke kullanım değerlerini artırmaktadır. Dolayısı ile aynı fiziksel mekanların farklı yönlerden gelen trafik akımları tarafından kullanıldığı kavşak kesimlerinin yönetiminde gecikme, kuyruklanma gibi değerlerin azaltılabilmesi için sinyalize kavşak sistemlerine geçişler söz konusu olmaktadır.

Bu çalışmanın yapıldığı Duhok şehrinde sadece bir kaç dönel kavşak varken, bunlar gerçekten yoğun bir trafik sıkışıklığına konu olmamakla birlikte, kentin doğu bölgesinde bulunan ve 36.8683768 enlem ve 43.0020989 boylam değerlerine sahip Gali dönel kavşağı belki de en fazla sıkışıklığa sahip dönel kavşak olarak öne çıkmaktadır. Bu anlamda bakıldığında Duhok şehrindeki tüm dönel kavşakların artan trafik miktarına bağlı olarak performans analizleri yapılmalı ve gerekli görülen kavşaklarda da sinyalize kavşak dönüşümü sağlanmalıdır.

Bu çalışma kapsamında performans analizi yapılan Gali dönel kavşağı, 2000 yılında inşa edilmiş olup, şehrin en işlek ve turistik yoğunluğun olduğu merkezleri arasında bağlantıyı sağlayan önemli bir role sahiptir. Kavşak göreceli olarak düşük kapasiteli bir kavşak olup, T-kavşak akım kollarına sahip dönel bir kavşak olarak hizmet vermektedir. Geniş kamyon ve tırların oldukça seyrek olarak kullandığı kavşakta, bu taşıtların kavşak içi mobilitelerine imkan verecek geometrik düzenlemeler yapılmıştır.

Kent merkezinden uzak, izole bir lokasyonda iki dağ arasında inşa edilmiş olan kavşak, her biri 5.5 m genişliğe sahip olan 2 şeritli caddelere ve yollara hizmet vermektedir. Bununla beraber, sağ şeritler dominant bir şekilde parklanma içinde kullanılmaktadır. Dağlık coğrafya da inşa edilmiş olması nedeniyle, kapasite artımına gidilmesini sağlayacak geometrik değişikliklerin yapılmasına imkan sağlayacak olanaklar neredeyse yok denecek kadar azdır. Bu durum, kavşak lokasyonun değiştirilmesinin, kavşak yönetim stratejilerinin geliştirilmesinde dikkate alınmasına neden olmaktadır.

Trafik sıkışıklığı, trafik gecikmesinin başlıca kaynaklarından ve nedenlerinden biridir ve her yıl artan araç sayısı ile bu durum daha da karmaşıklaştırmaktadır. Dönel kavşaklar, merkezi ada çevresinde tek yönde trafik akışı sağlayarak ve dolaşımdaki akışa öncelik vererek tıkanıklığın azaltılmasına katkıda bulunma konusunda benzersiz bir avantaj ve kapasiteye sahiptir. Bununla beraber, başlangıçta ılımlı trafik hacimlerine sahip kavşaklar verimli ve istenen sonuçları üretmektedirler. Dolayısı ile artan araç sayısı ve dolayısıyla trafikle birlikte, bu durum kavşakların öngörülebilir gelecekte belirli trafik miktarlarını barındırmak için uygun olup olmayacağı konusunda daha fazla soru ortaya çıkarmaktadır. Örneğin, Birleşik Krallık'ta, araç sayılarının ve nüfusun artması sonucu trafiği barındırmaları zorlaştığı için birçok dönel kavşak son on yılda sinyalize kavşaklara dönüştürülmüştür. Bu çalışmada, Irak'ın Duhok kentindeki Gali Dönel Kavşağı ile ilgili olarak, bu kavşağın sinyalize bir kavşağa dönüştürülmesi veya olduğu gibi kalması gerekip gerekmediğine dönük analizler yapılacaktır.. Bu amaca ulaşmak için, kavşak kullanıcıları olan sürücülerin diikatini dağıtmadan, manuel olarak video kayıt sistemi ile trafik verileri dijital ortamda temin edilmiş ve gerekli çözümlemeler daha sonra yapılarak otomobil eşdeğeri cinsinden kavşak trafik yükü, bir diğer ifade ile trafik hacmi, belirlenmiştir. Otomobil eşdeğerleri, farklı taşıt türleri için geçerli olan dönüşüm katsayıları kullanılarak elde edilmiştir. Dönel kavşağın geometrik özelliklerini de dikkate alarak, saatlik trafik hacim değerleri kullanılarak VISSIM yazılımı aracılığıyla, kavşağın mevcut durumuna ait temel performans ölçütleri olan ortalama kuyruk uzunluğu, seyahat süresi gecikme değerleri gibi çeşitli parametrelere ait sayısal veriler belirlenmiştir. Elde edilen bu VISSIM simülasyon sonuçları, kavşağın aynı tutulması veya farklı bir yönetim stratejisinin belirlenmesinde karşılaştırma verileri olarak kullanılmıştır. Varsayımsal projeksiyon simülasyonları da yine VISSIM'de gerçekleştirilmiş ve gelecekte kavşağı kullanan araç sayısının belli oranlarda artması durumunda, bu yeni trafik akım değerlerine bağlı olarak gerçekleşmesi beklenen kavşak performası mevcut güncel performans ile karşılaştırılmıştır. Böylece dönel kavşak kullanımının sürdürülebilir olup olmayacağı konusunda gerçekçi bir değerlendirilme zemini elde edilmiştir. Kavşak analizinde kullanılan veriler 16 Nisan 2022 tarihinde zirve saat trafiği olarak belirlenen 9:20-10:20 saatleri arasında, 10`ar dakikalık periyotlarla 6 farklı zaman aralığı kapsamında elde edilmiştir. Ekipman ve bütçe yetersizlikleri dikkate alındığında, otomatik sayım yerine manuel sayım yöntemi tercih edilmiştir. Bu yöntem, çalışma bölgesi ve kesitlerinden geçen araçların sayılarının ve tiplerinin dijital olarak kaydedilmesi esasına dayanmaktadır. Sayım bölgesinin dijital olarak görsellenmesinden sonra görseller, gerekmesi durumunda kayıtların tekrar tekrar gözden geçirilmesi ile, son derece dikkatli ve yavaş bir süreç ile çözümlenmiş ve araç sayıları ile kompozisyonları belirlenmiştir.

Kavşak geometrilerinin karşılaştırılmasına imkan vermesi, kapasite analizlerini yapabilmesi, mikroskopik ölçekte inceleme ve dijital görsel sonuçları üretebilme özellikleri,yıllık trafik artışı etkilerini analiz edebilmesi, SIDRA yazılımına göre daha ucuz ve kesin-kapsamlı sonuçlar verebilmesi gibi gerekçelerle VISSIM bu tezin analiz sürecinde kullanılan yazılım olmuştur.

Kavşak yaklaşım akım kollarına ait trafik miktarları, düz hareket edenler, sağa ve sola dönenler olarak ayrı ayrı sisteme dahil edilerek analizler yapılmıştır.

Analiz sonuçlarında gerek mevcut duruma ait akım değerlerine gerekse de artırılmış trafik akım değerlerine bağlı olarak ortaya çıkan duruş gecikme değerleri, araç başına ortalama duruş sayıları, ortalama araç gecikme süreleri elde edilmiş ve karşılaştırılarak değerlendirilmiştir.

Benzer şekilde ortalama ve maksimum kuyruklanma uzunlukları, ortalama seyahat süreleri ve mesafeleri de mevcut ve önerilecek kavşak tipinin değerlendirilmesinde dikkate alınan parametreler olarak öne çıkmaktadır.

Kavşağın sinyalize kavşak olarak dönüştürülmesi durumunda, trafik akım değerlerine bağlı olarak optimum devre sürelerinin, yeşil ve kırmızı sürelerinin de hesabı Webster yöntemine göre yapılmış ve sonuçlar tez içeriğinde ifade edilmiştir.

VISSIM analizi, mevcut dönel kavşağın sinyalize bir kavşağa dönüştürülmesi durumunda daha fazla tıkanıklığa ve artan seyahat süresi gecikmesine neden olacağını öngörmektedir. Bununla birlikte, dönel kavşağın 5 yıl içinde çok daha geniş bir dairesel çapa sahip olmasını da önermektedir. Ancak bir dağın yakınında bulunan kavşağın fiziksel konumu nedeniyle sahip olduğu topografik nedenler, muhtemelen geometrik özelliklerinde herhangi bir değişiklik yapmanın önünde bir engel olacaktır.

PERFORMANCE ANALYSIS OF ROUNDABOUT JUNCTION IN DUHOK WITH PROPOSED SIGNALIZED ONE THROUGH VISSIM SOFTWARE

SUMMARY

Traffic congestion is one of the major sources and reasons of traffic delay, and with increasing number of vehicles annually, this further complicates the situation. While Roundabouts have the unique advantage and capability of contributing to the reduction of congestion by providing traffic flow in one direction around central island and giving priority to the circulating flow, at the same time they were originally designed to accommodate intersections and junctions that had moderate traffic volumes, so with increasing number of vehicles and thus traffic, this situation raises further questions about whether roundabouts will be suitable for accommodating certain junctions in the foreseeable future. In the United Kingdom, for example, after many researches and studies many roundabouts have been converted to signalized junctions over the past decade as the growth of vehicles and population made it overwhelming for them to accommodate traffic. In this research, a decision will be made regarding Gali Roundabout in Duhok, Iraq, whether this junction should be converted to a signalized junction or remain as it is. To reach this aim, several objectives are required to be carried out manually such as obtaining geometrical properties of the Roundabout, obtaining hourly Traffic Volume Count, and via the ever reliable VISSIM software, Average queue length, travel time delay and so on. After triggering some simulations through VISSIM, the software, will aid in the projection. Hypothetic simulations will also be conducted on VISSIM where it is assumed if the number of vehicles entering the roundabout in the future increases by 15%, this will compare with the performance of the roundabout in present time and will thus provide a breakthrough whether the usage of roundabout will be sustainable or not.

VISSIM analysis ultimately projects that this roundabout, if it were to be converted to a signalized junction would cause more congestion and increasing travel time delay. It does however also recommend that the roundabout should have a much wider ICD in 5 years time but due to the roundabouts location, which is being nearby a mountain, topographic reasons will likely be an obstacle of performing any changes to its geometrical properties. So this roundabout may be shifted or displaced 200-300m from its original location and then changes to its geometrical elements and properties can be then applied.

1. INTRODUCTION

1.1. Purpose of This Research

The purpose of this research is to compare the performance or reliability of roundabout junctions, that have somewhat of a reputation for traffic congestion, with signalized junctions (Traffic Lights) in the city of Duhok, Iraq. Based on similar studies, many junctions in Duhok that previously had had a history of traffic problems, have been rectified after moderation.

Hence, indicating the positive affect or influence of this phenomenon. In this study, we have Gali roundabout as a case and based on data obtained such as volume of vehicles, average speed, traffic flow, Level of Service, etc, a decision will be made on whether we should convert this roundabout to a signalized junction, perform some changes to geometric properties of roundabout or leave it as it is. The decision will be analyzed via interpretation from VISSIM.

1.2. Roundabouts

1.2.1. What is a roundabout?

Roundabouts along with Rotaries and neighborhood traffic circles are one of the three types of traffic circles, which is a circular intersection that simultaneously provides a circular traffic pattern and reduces the amount of conflict points [1]. Roundabouts permits flow in a single direction around a central island and prioritize the traffic that is already present in the junction. Roundabouts promote slow and consistent vehicle speeds entering, circulating, and exiting the intersection. They vary from other traffic circles in terms of their size, speeds, and lack of lane changes within the intersection.

1.2.2. Characteristics of roundabouts

Roundabouts have specific defining characteristics that separate them from other circular intersections as enumerated below [2].

- Yield control at each approach

- Separate conflict traffic movements by means of pavement markings or raised islands
- Speed is limited (Should not exceed 50 km/h)
- Parking is usually prohibited or not allowed

1.2.3. Advantages or benefits of roundabout

Roundabouts have plenty of advantages over signalized junctions [3] such as:

- Reduce delays and congestion or queues
- Require less space on approaching roads, thus have a lower cost.
- Roundabouts significantly reduce the amount of points of conflict, particularly for those of left turning vehicles.
- Roundabouts have also been found to be very environmental friendly as they reduce carbon emissions due to their ability to reduce delay and stabilize traffic flow.
- Roundabouts improve traffic flow and capacity of junction by promoting a continuous traffic flow and movement as drivers aren't obligated to stop during a red light like a signalized junction.
- Roundabouts also improve safety in general. According to a research by the IIHS and FHA, roundabouts typically achieve a 37% reduction in overall collisions, 75% reduction in injuries, 90% reduction in fatal collisions and 40% reduction in pedestrian collisions.

1.2.4. Suitability of roundabouts

The usage of roundabouts are appropriate for Intersections that have the following characteristics:

- Large Traffic delays
- Complex Geometry
- Frequent left-turn movements
- Balanced Traffic flows. In other words, when there is equivalent traffic volume approaching from all directions.
- Designed hourly volume does not exceed 3000 veh/hr.

1.2.5. Disadvantages of roundabouts

In the previous section the advantages of Roundabouts over other signalized junctions were highlighted however, there are also many cases where the selection of roundabout may not be suitable [4] such as:

- Intersections that have an unbalanced traffic flow and high traffic volume as increasing queues significantly reduces the possibility of drivers finding gaps. In the UK for example, many congested roundabouts have been converted to signalized junctions in the past couple of years due to annual increase in traffic volume.
- When planned on high speed roads such as freeways, roundabout requires extremely large size.
- Roundabouts are also poor fits for intersections whose angle is too acute as it becomes difficult to provide a sufficient weaving length
- Roundabouts make travel troublesome at close intervals.
- Intersections whose hourly traffic volume exceed 3,000 vehicles.
- Profile grade on entries and the profile being greater than 4%.

1.2.6. Geometric elements of roundabouts

Roundabouts are composed of many features, each of which have their own function [5]. The most important and significant of these features are:

- Splitter Island: Used to separate traffic in opposing directions of travel.
- Central Island: The center of a traffic circle that is circulated by traffic.
- Truck apron: Compensate for off-tracking of larger vehicles.
- Yield lines: Notifies drivers that they are required to prioritize a vehicle at a point of conflict or pedestrian traffic.
- Raised traffic island: Designed to protect pedestrians, enabling refuge for them in the middle of the road.
- Pavement Markings: Direct traffic into a one-way counter-clockwise flow around the central island

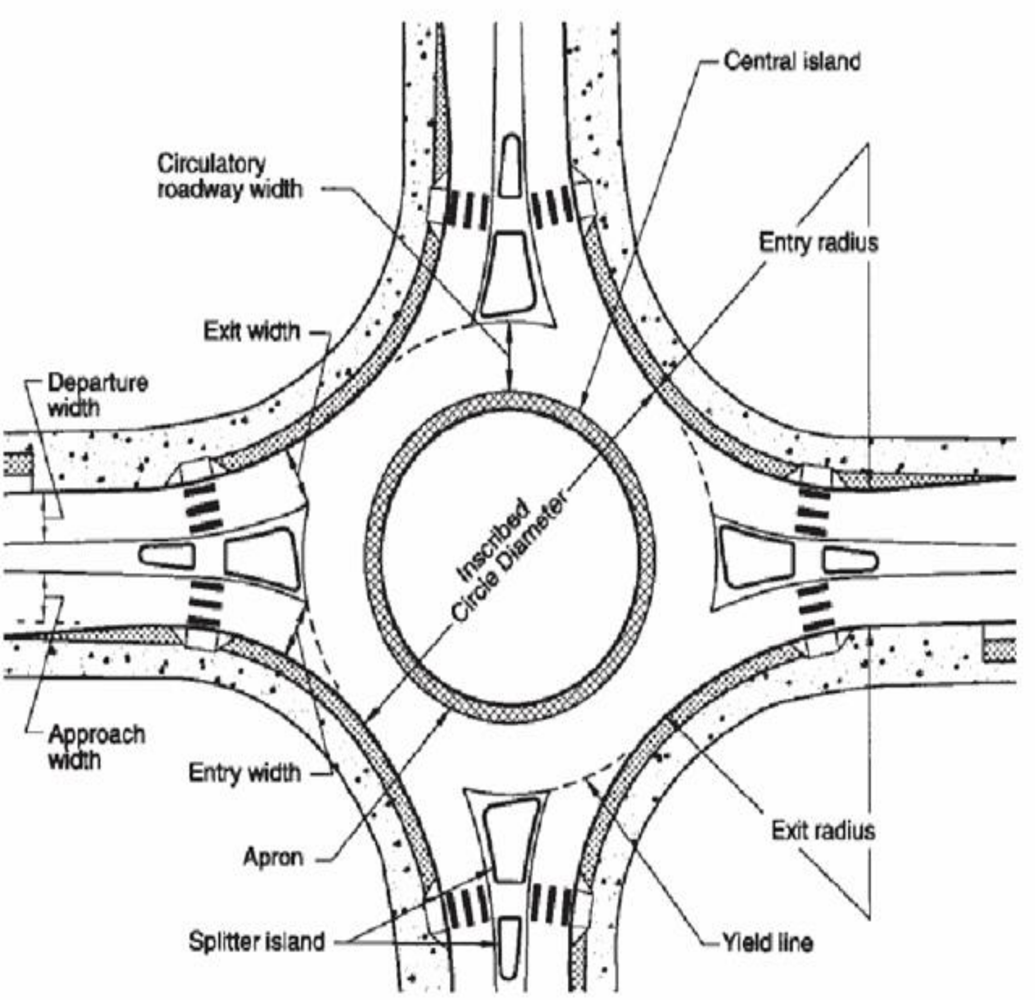
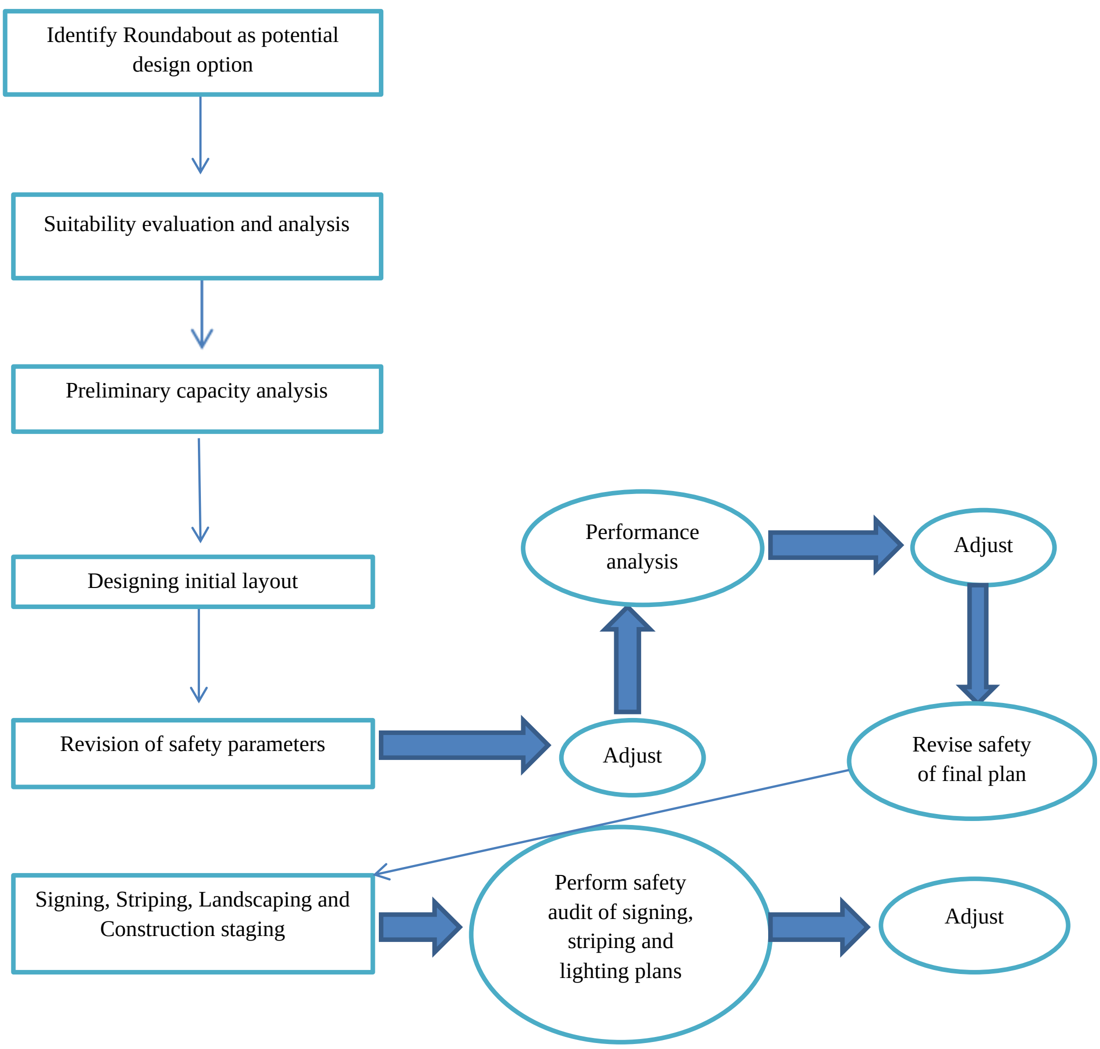


Figure 1.1. Geometric elements of roundabout

1.2.7. Roundabout design process

The process of designing roundabouts is iterative, with that said, it’s very rare for an optimal geometric design to be established after the initial attempt. This is due to the necessity of designer to perform revisions and refinements of the initial layout as minor geometrical adjustments can significantly impact the safety along with the operational performance.

Table 1.1. Roundabout design process



1.2.8. Types of roundabouts

Roundabouts are divided into 3 types. Mini roundabouts, Compact roundabouts and Large roundabouts, all of which vary with each other according to their size, cost, speed and traffic volume count [6].

1.2.8.1. Mini roundabouts

By its name, its clear Mini roundabouts are the smallest types of roundabouts in terms of size, however, because the maximum speed of vehicles in a roundabout is dependent on the diameter of roundabout, mini roundabouts also possess the minimum speed out of all the roundabouts. Mini roundabouts contain center or splitter islands that can be fully traversed by vehicles. They generally have an inscribed circular diameter of 15 to 30 meters. Mini roundabouts are preferably constructed and utilized in places where the speed limit is between 25 and 30 km/h. Mini roundabouts are not ideal nor recommended for areas with high traffic volumes (>15,000 average daily traffic), such as state routes or major highways. In addition to high traffic volumes, mini roundabouts are not suitable either for cross intersections (intersections that contain 4 legs). In general, mini roundabouts are widely regarded as the least effective of these types.

Figure 1.2. Mini roundabout

1.2.8.2. Compact roundabouts

Compact roundabouts generally have an inscribed circular diameter between 30 and 35 meters and have a combination of attributes found in both mini and single lane roundabouts. Compact roundabouts requires very little additional pavement space and may have center islands that can make room for turning large trucks without the necessity of a large overall size. A typical urban compact roundabout allows speeds between 35 and 65 km/h. Because of their larger size, compact roundabouts are suitable for high traffic volume and can serve average daily traffics of 20,000 to 25,000. In general, Compact Roundabouts are extremely similar to Mini Roundabouts except for the fact they are larger in size, more suitable for high speed approach, have the capability of accommodating high traffic volume and don’t contain central islands that are fully traversable.

Figure 1.3. Compact roundabout

1.2.8.3. Large roundabouts

Large Roundabouts have inscribed circle diameters of up to more than 75 meters and therefore allow speeds of up to 70 km/h. The main responsibility of a Large Roundabout is to simultaneously accommodate larger vehicles and maintaining low speeds for normal passenger vehicles. Judging by their geometric properties, they require very large land, therefore could prove to be pretty expensive. While mini and compact roundabouts are widely believed to better for overall safety due to the low speeds they allow, in high speed environments, such as a major highway, the design of approach geometry has a more significant basis and roundabouts with larger diameters generally enable the supply of a better approach, which aids in decreasing the speed of approaching vehicles. In addition to this, Roundabouts with larger inscribed diameters also reduce the angle formed between entering and circulating vehicle paths.

Figure 1.4. Large roundabout

Table 1.2. Summary of roundabout types

Roundabout Type	Diameter Range (m)	Speed Range (km/h)	Traffic Volume Range (Veh/day)	Notes
Mini Roundabout	15-30	25-30	<15,000	widely regarded as the least effective type of roundabout
Compact Roundabout	30-35	35-65	20,000-25,000	similar to Mini Roundabouts but larger in size
Large Roundabout	>75	>70	>30,000	Require very large land, therefore could be expensive

1.3. Aims And Objectives

The aim of this research is to make a decision regarding Gali roundabout whether this roundabout should be converted roundabout to a signalized junction like traffic, perform some moderations regarding the geometric properties of the roundabout or leave it as it is. To determine this, the following objectives must be met:

- Count the number of vehicles (traffic volume) that enter the roundabout from each direction in 1 hour and break it down into 6 intervals with duration of each interval being 10 minutes long.
- Determine whether traffic flow from each direction is equal/balanced or not
- Obtain geometrical and traffic properties of the roundabout (Diameter, Average Speed, number of accidents annually, etc.).
- Analyze all the data collected through VISSIM software and come to a conclusion.

2. LITERATURE REVIEW

This chapter will briefly talk about the traffic parameters upon which VISSIM software will analyze the results from.

2.1. Level Of Service

Level of service (LOS) describes the real time operating conditions of a roadway depending on some factors such as speed, travel time, delay and safety. The Level of service of a roadway or any facility is designated or ranged from letters A to F, with A denoting excellent or best possible service and F denoting worst possible service. Perhaps the most important aspect of LOS is that it is the main parameter that needs to be known in order to determine delay of each approach and delay itself is an important parameter to measure the efficiency of intersections.

The level of service at a roundabout is determined by carrying out the control delay of each maneuver on the minor street. Due to various conditions and driver's perception, level of service at the signalized and unsignalized intersections differ from one another. The level of service, depending on the control delay according to the standards of the HCM and AASHTO is given in Table 2.1.

Table 2.1. Level of service for roundabouts

Level of service	Control delay (s/veh)
A	0-10
B	>10-15
C	>15-25
D	>25-35
E	>35-50
F	>50

2.2. Travel Time Delay

2.2.1. Travel time studies

Travel time studies in general indicates the duration that is needed to travel from one location to the other in a specified route. For these studies to be conducted, several information on potential delays such as its location, duration and cause must be determined [7]. When obtained ultimately, a decent indication of the level of service of a study area will be provided which will aid significantly in the identification of problem locations which could prove to be a catalyst in improving the overall flow of traffic in any given route.

2.2.2. Applications of travel time and delay data

The following applications of travel time and delay data could be very useful in traffic engineering:

- Determination of efficiency of a route compared to how its able to serve traffic
- Identifying locations with lengthy delays and the reasons of those delays.
- Assessing the impact of traffic operation improvements by conducting before-and-after studies.
- Determining efficiency of a route through innovation of congestion indices.
- Evaluate and provide possible alternatives that aid in reducing delay.

2.2.3. Delay categories

Delays can be divided into several categories:

- Operational delay: Portion of the delay caused by the impedance of other traffic.
- Stopped time delay: Part of delay during which the vehicle is stationary.
- Accident delay: The duration added to a travel time due to the occurrence of an accident.
- Travel time delay: Refers to the difference between the actual time and design speed time in the road.
- Geometric delay: Delay caused by engineering features that force vehicles to decelerate while approaching a particular system.

2.3. Queue Length

Queue length along with delay is the major parameter that is utilized to quantify and describe the performance of an intersection as they can provide projections and predictions regarding intersection delays, travel times and level of service at intersections. This information might be then provided to drivers in the future so they can travel to an alternative route thus avoiding delay [8]. Queue lengths can also determine the spacing or separation between consecutive intersections so that a queue does not repeatedly spill over the upstream intersection.

As in queues in signalized intersections, the lengths of queues in roundabouts depends on several factors including traffic volume, priority given to straight and right turning vehicles, number of conflict points, pedestrians crossing and the overall traffic flow. However, another factor is the geometrical properties of roundabouts. According to a statewide study conducted in Oregon regarding single lane roundabouts, it was concluded that roundabouts with wide splitter islands appeared to have improved operation and reduced queue lengths.

2.4. Similar Study

In 2019, Marcin Jacek Klos and Aleksander Sobota evaluated the performance of a roundabout in Gdansk, Poland through the utilization of microscopic simulation models via VISSIM. The authors in the research examined the microscopic model, which provides a description regarding affect that individual vehicles have on each other in a junction. The research problem was related to theory or hypothesis of performing changes or moderations to the geometrical properties, such as Inscribed Circle Diameter, Splitter Island width, Entry radius, etc, of the roundabout in Gdansk. Obviously, these potential changes that ought to be applied will depend on the traffic volume and thus, the analysis of the road traffic indicates an increase an increase in traffic volume and overall traffic flow in subsequent years. The aim of solving the problem was to obtain comparison of traffic conditions, which rely on the magnitude of the traffic flow in the proposed variants of roundabout design. With traffic flow projected to increase worldwide, amid increase number of vehicles innovated annually, the suitability and therefore level of service of certain current time roundabouts may not be sustainable in the future years. This characteristic increases the likelihood of converting roundabouts to signalized junctions or performing changes to geometrical properties. The solution to research's problem required the validation of the current state, where the procedure of handling traffic was mapped. Secondly, validation was also imperative for the changes proposed on geometrical properties in all traffic flow prognostic years. The microscopic traffic simulation models were ultimately developed through road traffic measurement data. Furthermore, the percentage shares of peak hours in both morning and afternoon in the daily traffic flow were determined based on the traffic flow obtained. In their case, the morning peak hour was chosen for the purpose of more in detail interpretation, due to the intensity of traffic being greater during this period, which allows for the mapping of the worst traffic conditions. After applying simulations through VISSIM software, the level of service for the roundabout in Gdansk, based on the average values of time losses in s/veh, which was determined by VISSIM, will be III in 2030, denoting an average roundabout but will be furthermore downgraded to IV in 2034 as the delay time exceeds 50 seconds per vehicle. However, VISSIM simulation showed that the addition of a second lane at the inlet will reduce the average delay or the time lost at the intersection, therefore improving the level of service of roundabout from III to II for the year 2030. While the level of service of the roundabout did not improve or remain unchanged for the other prognostic years with increasing traffic flow with respect to the current state with the proposed changes to geometrical properties, the delay or average time lost did actually decrease. Table 2.2 below shows all of the results.

Table 2.2. Delay and Level of service of roundabout at existing state and after proposed changes

Technical variants	Prognostic years	Delay (s/veh)	Level of Service
Existing state	2018	5.23	I
	2030	30.19	III
	2034	108.69	IV
	2035	110.43	IV
	2040	154.27	IV
	2050	155.26	IV
proposals to change the geometry of the intersection on one of it's inlets (Addition of second lane)	2018	4.70	I
	2030	18.24	II
	2034	89.36	IV
	2035	101.54	IV
	2040	143.29	IV
	2050	175.22	IV

The following conclusions were distinguished for the analyzed case:

- The geometrical change of the inlet had a positive outcome regarding traffic conditions at the inlet because delay was reduced in each of the corresponding prognostic years by about 20 s/veh, however this does not solve all of the communication problems occurring at the roundabout as the level of service improved for only the prognostic year of 2030.
- The improvement of traffic conditions following the addition of the lane at the inlet will actually increase the average values of time losses for relations on other inlets. This event was caused by the uptick in the traffic volume on the roundabout envelope, which reduces the average duration between vehicles. The increase in traffic is a consequence of both the prognostic variation in traffic potentials in the immediate vicinity of the intersection along with the whole landscape of socio-economic changes manifesting, an increase in the motorization index and an increase in the population's mobility

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3. STUDY AREA AND DATA OBTAINED

3.1. Study Area

This section will highlight information regarding study area roundabout such as geographic location, topography, approaches, design, etc.

3.1.1. Geographic location

The area of research, in this case Gali Roundabout, is located in the Eastern portion of Duhok, Iraq with coordinates of latitude of 36.8683768 and longitude of 43.0020989 and altitude of 554.6495742m. The Roundabout, exported from Google Earth is shown in the figure below.

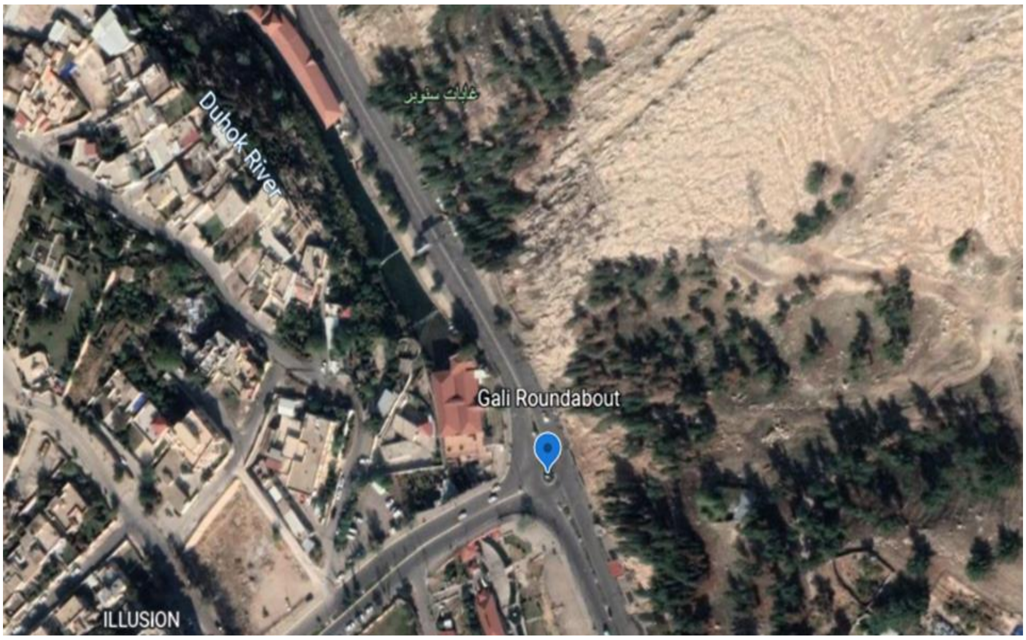


Figure 3.1. Geographic location of Gali roundabout

3.1.2. Gali roundabout

3.1.2.1. History of gali roundabout

Gali Roundabout was developed in the year 2000 by the Dohuk Municipality Directorate. It was constructed for the purpose of providing a link or pathway between the city center, which is one of the busiest and most crowded places in Duhok, and

Duhok Dam a hot site for tourists, while simultaneously maintaining a mobile traffic flow. Usually its peak are during Friday evenings, which is when most people in Duhok go on trips.

According to the archive files obtained by the Duhok Traffic Directorate, only 8 accidents have occurred since its implementation, however in recent years, due to a surge in the number of vehicles and the areas attraction to tourists following renovation, it has been subjected to heavy traffic congestion, which has led to many debates being sparked whether or not this roundabout should remain as it is or convert it to a traffic light junction or perform changes regarding its position and geometric properties. There have been efforts to reduce congestion by the recommendation of Duhok Traffic Police, many times particularly on Fridays and federal holidays, cones are placed in way of approach A, blocking access to that approach.

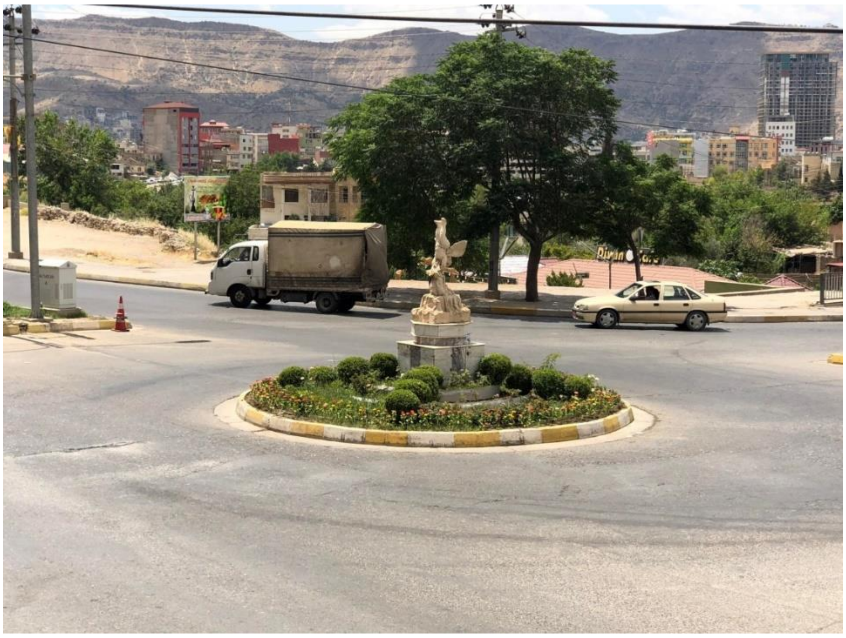


Figure 3.2. Gali roundabout

3.1.2.2. Gali roundabout design

The roundabout is small in size and serves a T-leg or three leg intersection and has three approaches (Denoted as A,B,C in the figure below). The roundabout's truck apron can also be fully mountable by large vehicles, although very rarely do large trucks enter this roundabout. The roundabout is located in an area that is somewhat isolated, since it's near the Duhok Dam which is clustered between two mountains. In addition to being isolated by mountain, it also serves a narrow 2 lane street with each lane having a width of 5.5 meters but most of the right lane in particular is dominated by parking vehicles, therefore effectively reducing the width of the street to about 7 meters. With that being said, this constraint along with geographic constraint, as mentioned earlier being located nearby a mountain, might make it extremely difficult to moderate or perform changes to its geometric properties.

Figure 3.3. Gali roundabout approaches

3.1.2.3. Gali roundabout geometrical properties

The roundabout's central island has a *diameter of 6.6 meters* (radius of 3.3m) and *an inscribed circle diameter (ICD) of 32.3 meters*. The roundabout's truck apron, which as mentioned earlier can be fully mountable by large vehicles has a thickness of 30 cm. In addition to these elements, the geometric properties of each approach such as Entry and Exit widths as well as the width of the Splitter Island as were obtained manually shown in the table below.

Table 3.1. Geomtrical properties of Gali roundabout

Approach	Splitter Island width (m)	Entry Radius (m)	Entry width (m)	Exit width (m)
A	5.5		9	9
B	4.1	27.1	13.7	11
C	3.2	18.9	13.3	12.9

3.1.2.4. Gali Roundabout approaches

Since Gali Roundabout serves a T-leg intersection, it has 3 approaches, all of which will be discussed briefly in this sub section.

- Approach A

The first approach in Gali roundabout provides access to Duhok Dam which is one of the most attractive tourist sites in the city of Duhok and usually is subjected to heavy traffic congestion, although not many accidents have occurred. As mentioned earlier, in an effort to reduce this congestion, on many occassions, especially on Fridays, the access of this approach from approaches B (Green) and C (blue) is blocked by cones, preventing vehicles from entering the roundabout instantly. Therefore, vehicles from approaches B and C turn right and go straight respectively instead to the nearest junction (Rasheed), which is about 740m away from the roundabout to make a U-turn for the purpose of entering the approach. Although this stradegy increases the travel time delay of vehicles in the roundabout, at the same time it balances flow and therefore reduces the congestion. The links to approach A are shown in the figure below with B being denoted in blue and C being denoted in Green.

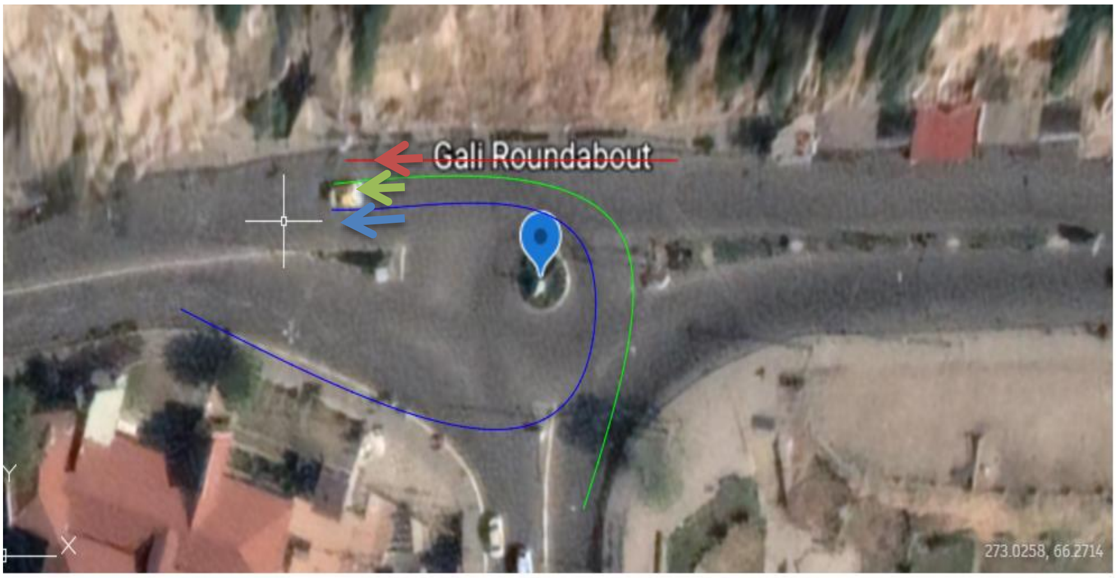


Figure 3.4. Approach A and its links

Rasheed Junction as mentioned earlier, is the nearest junction to Gali Roundabout. Vehicles that have the desire of entering approach A from approaches B and C are forced to enter this junction and make a U-turn for the purpose of entering approach A, whenever cones are placed to block access to the approach. This scheme occurs occiasionally though rather than usually, especially on Fridays and federal holidays, as mentioned earlier.

Figure 3.5. Aerial photo of Rasheed junction

Figure 3.6. Close up of Rasheed junction

- Approach B

Approach B provides access to the city center (Carsi) of Duhok, one of the busiest places in the city during the day that is also subjected to heavy traffic congestion and in some occassions moderate car accidents. Because access to Approach A from B is blocked on occasions, many vehicles as mentioned earlier, undeseriably make a right turn (Shown in green) and make a U-turn at the nearest junction (Rasheed) to enter approach A. At the mean time, vehicles who have the desire to enter approach A from approach C (Red) also undeseribly enter approach B where they will head to Rasheed junction to make a U-turn. This makes approach B, in most cases where cones block access to A, to have the highest traffic volume count out of all the approaches in the roundabout.

Figure 3.7. Approach B and its links

- Approach C

Approach C provides access for vehicles exiting Duhok Dam or City Center.

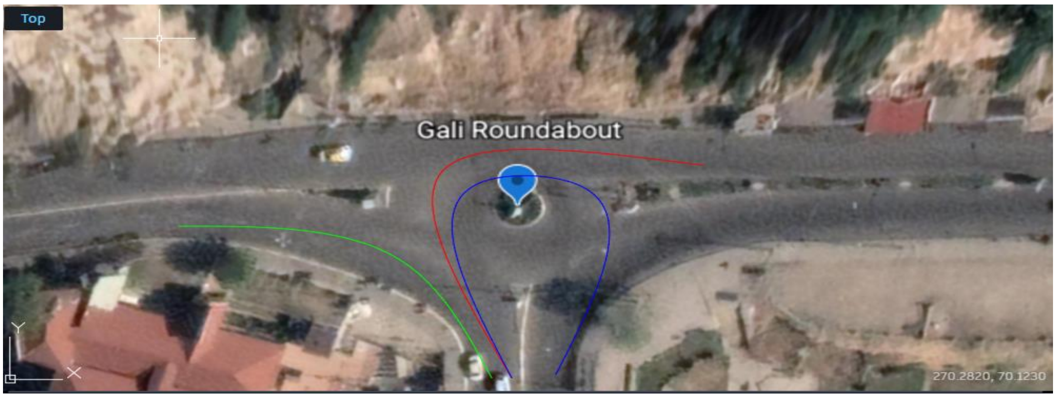


Figure 3.8. Approach C and its links

3.2. Data Obtained

VISSIM requires users some traffic related data in order to be a bedrock in the decision making of converting unsignalized junctions to signalized ones and vise versa. Traffic data includes TVC, LOS, etc..

3.2.1. Manual traffic volume count

The following table below shows the number of vehicles that entered Duhok Roundabout from each approach between 9:20 and 10:20 PM on April 16. The traffic volumes have been divided or broken down by 6 intervals with each interval being 10 minutes long.

Table 3.2. Traffic volume in terms of manual TVC

	Traffic volume								
	Approach A			Approach B			Approach C		
Time	Straight	Left turn	U-turn	Straight	Right Turn	U-turn	Right Turn	Left Turn	U-turn
9:20-9:30	88	-	-	36	137	11	68	81	-
9:30-9:40	112	-	-	28	160	13	49	75	-
9:40-9:50	111	-	-	36	148	11	43	68	-
9:50-10:00	95	-	-	31	131	18	69	60	-
10:00-10:10	99	-	-	35	126	12	55	64	-
10:10-10:20	97	-	-	30	140	15	50	66	-
Total Number of Vehicles from each direction	602			196	842	80	334	414	
Total Number of Vehicles entering each approach	602			1,118			748		
Total Number of Vehicles	**2,468**								

3.2.2. Volume in terms of passenger car unit (PCU)

A total of 2,468 vehicles entered Gali Roundabout within an hour. However, this figure only represents vehicles in general without being specific by indicating the type of vehicles. Although the amount of vehicles apart from passenger vehicles and taxis entering this roundabout is very sparse, it nevertheless has an impact on the traffic flow rate, which is assessed by the PCU. Therefore, it is better to also determine the total volume of this roundabout in terms of Passenger Car Equivalent (PCE), which is calculated by multiplying the total number of vehicles entering the roundabout in 1 hour with the PCU factor, whose value varies for each type of vehicle.

The Table below shows the calculation of traffic volume in terms of PCU.

Table 3.3. Traffic volume in terms of PCU

Vehicle type	Approach A	Approach B	Approach C	Passenger Car Equivalent (PCE) Factor	PCU (N*PCE)
Car, taxi	581	1,055	704	1	2,340
2-wheeler	12	53	35	0.1	10
Minibus	5	6	5	1.5	24
Bus	0	1	1	3	6
Truck	4	3	3	2	20
Total Volume in PCU					2,400

According to the data, it is quite clear that Cars and taxis make up an overwhelming majority of the vehicle composition for this roundabout at about 94%, while minibuses, busses and trucks make up only about 6% of the roundabouts composition.

Although on most occasions, the normal Traffic Volume Count (TVC) is usually less than the volume in terms of Passenger Car Units (PCU) this case was an exception as the normal TVC had a net volume of +68 vehicles. This is due to the roundabout serving a decent amount of motorcycles and 2-wheeled vehicles in general with 100 and given its PCE factor is 0.1, this will reduce the volume of that category to just 10, which is exactly one-tenth of its normal TVC. In the mean time, the roundabout did not serve as near amount of busses, trucks and other large vehicles in general. As mentioned, those 2 vehicles types combined made up only 6% of the total vehicle composition of the roundabout. Therefore, the lack of access to this roundabout by large vehicles led to the PCU being less than the normal TVC, which is usually not the case.

Table 3.4. Vehicle composition of Gali roundabout

Vehicle type	Approac h A	Approa ch B	Approa ch C	Total	Total volume of roundabout	Vehicle composition (volume of vehicle type/Total volume of roundabout)
Car, taxi	581	1,055	704	2,340	2,468	0.948
2-wheeler	12	53	35	100		0.041
Minibus	5	6	5	16		0.011
Bus	0	1	1	2		0
Truck	4	3	3	10		0
Total						1

4. METHODOLOGY AND PROCEDURES

4.1. Methodology

To analyze the performance of Gali Roundabout, several data is required which need to be obtained through some methodology. This section will highlight the philosophies applied.

4.1.1. Traffic data collection

The methodology that was implemented to obtain the data is known as Traffic Volume Count.

Traffic Data Collection in general, is basic requirements for transport planning. Traffic Data integrates some economic aspects of a particular nation and such knowledge is critical in drawing a rational policy for movement of passengers and goods by both government and the private sectors [9].

4.1.2. What is traffic volume count?

Traffic Volume Count (TVC) is basically the process of counting the amount of vehicles passing through a junction whether signalized or not, over a specific period of time. It is often expressed as Passenger Car Unit (PCU) and is measured to calculate the Level of Service, and other similar attributes such as congestion, carrying capacity, V/C Ratio, determination of peak hour, etc. Many instruments can be used to obtain TVC including:

- Bending Plates
- Capacitive Strip and Capacitive Mat
- Piezo-electric Cable
- Video Camera

TVC can be done manually or automatically. In this study, due to the lack of equipment and instruments mentioned above which are required for Automatic TVC, data was collected manually by video camera

4.1.3. Manual traffic volume count

As mentioned, due to a lack of equipment and budget, the manual traffic volume count is much more commonly used than Automatic TVC. It's implementation simply involves an individual(s) recording the number of vehicles passing by on a particular study area. Raw data obtained from this method is then collected and organized for the purpose of further analysis.

This method however, may be complex as the data collector has to be extremely precise in counting vehicles when rewatching the record and not miscount the number of vehicles and therefore may require several of revisions, in addition to possible inaccurate counting, process also may be slow. However, with lack of availability of infrastructure required to implement Automatic TVC, this is the best possible method and very effective.

When analyzing the traffic, it is also very important to be aware of the manner in which the traffic composition varies as dealing with tidal flow is key.

Hourly patterns generally show a number of peaks that are very comparable or their stark contrast being very noticeable. For example, peaks in the morning can be followed by a big decline in traffic volume especially after working hours before reaching another peak at the night, etc.

Daily patterns shows the difference in traffic volume between some specific days. They likely show that traffic volume on working days (Monday and Friday) significantly differ from the traffic volume during the weekend.

4.1.4. Factors to be considered while performing TVC

It is extremely essential to take a couple of factors into consideration before counting traffic volume of a junction. Without the proper consideration of the following, there are likely to be some anomalies in the procedure.

- Making sure that the surveyor or data collector should have no effect on traffic flow
- Since the visibility of all approaches and directions of roundabouts are crucial for TVC, video camera must be stationed in the most suitable position possible.

- Safety of surveyor should also be given priority. So, selecting a safe location is very important particularly in areas where carriageways may not be well defined
- The most important task for driver is that he/she watches their way. With that said, it is important to set equipment in a location that doesn't distract the driver.

4.1.5. Need of TVC

TVC is an essential part of town planning and can be effective in the design of future master plans. Its study is to understand the factors that form the basis of:

- Assessing the saturation of road network by comparing present traffic volume with calculated capacity or by determining level of service
- Institutionalize the networks accessed by vehicles of different categories.
- Necessity of median shifting, road widening or in the case of roundabouts, change in geometrical properties, like the one in this research

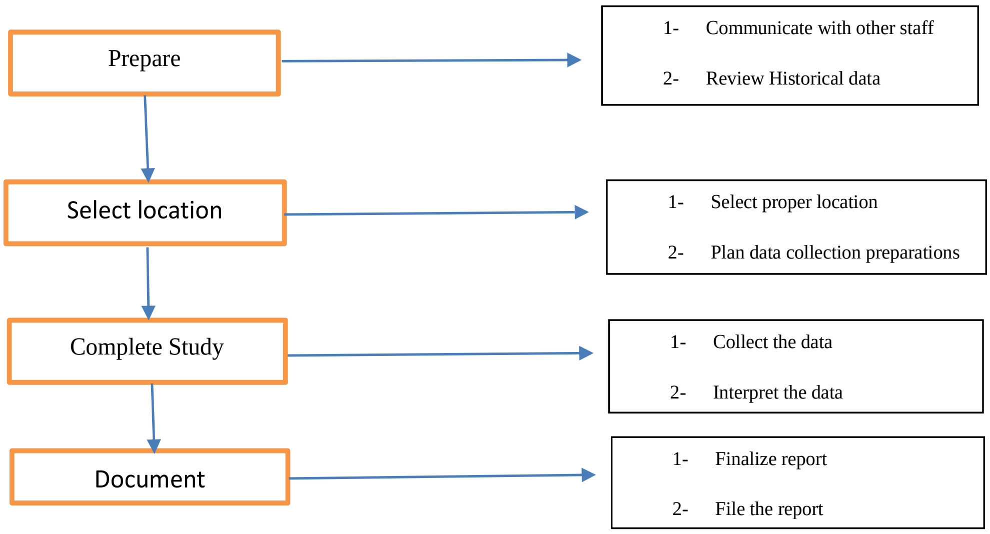
4.1.6. Process of TVC design

The procedure of performing TVC somewhat requires the approval of many local authorities and officials, especially in a country like Iraq where setting up video cameras that do not belong to local law enforcement, near the side of any road is usually a sign of suspiciousness. In addition to this, for the purpose of assessing the performance of the junction, obtaining archive data such as number of accidents annually, was also essential and that also needed approval from the head of the Duhok Traffic Directorate and in many times, this permission is not granted.

Location selection is very important also as mentioned earlier, it's one of the factors that needs to be taken seriously as it is imperative that video cameras or any other equipment used for counting traffic volume doesn't distract the drivers entering junction.

Concluding the procedure of TVC obviously involves interpretation of data collected in the field. In the case of Manual TVC, the methodology used in this study, the surveyor or data collector must be very rigorous in counting number of vehicles entering a junction when rewatching the entire footage of camera recording the activity of roundabout in a one-hour interval. For the purpose of clarification, it is important that the surveyor revises the video at least twice.

Table 4.1. TVC design process



4.2. VISSIM Software

VISSIM simulation system enable district and microscopic simulation, random traffic flow, junction and network analysis. VISSIM is composed of two large program states, traffic simulator and signal generator. Since roundabouts in urbanized environment are intersections whose research scope is relatively small, VISSIM simulations can be effective in describing the interaction behavior between vehicles [10].

4.2.1. Introduction to VISSIM

VISSIM is a widely used unique software in traffic engineering which provides a number of traffic stimulations and scenarios based on the real life data collected and imported. These parameters include vehicle composition, type of vehicle, priority rules, conflict areas, etc… VISSIM is abbreviated from "Verkehr In Städten - SIMulationsmodell" which in german means “Traffic in cities – simulation model”

VISSIM also has the capability to interpret simulations based on traffic parameters such as queue length, travel time, delay and speed in a junction. This characteristic makes this software even more valuable as those elements indicate the traffic flow of a particular junction.

4.2.2. VISSIM applications

VISSIM aids in mastering various traffic-related challenges. The following use cases cover several fields of applications:

- Comparing junction layout (Roundabout vs signal control)
- Transport development planning
- Capacity analysis
- Public Transport simulation
- Investigate and visualize traffic microscopically

4.2.3. Why VISSIM?

With the annual increase of traffic volume, congestions in intersections have also increased. As a response, many traffic simulation softwares have been developed for the purpose of helping to solve these problems. 2 very notable and widely used of these softwares are VISSIM and SIDRA. Both of these softwares are extremely reliable for comparing the performances of signalized junctions with unsignalized junctions but both usually provide slightly different results.

While it has been believed through many case studies that the usage of SIDRA is more simple/less complex, the data provided by VISSIM is more accurate, hence why it was used for this research. Furthermore, the usage of SIDRA software in Iraq is extremely rare, as the software denies temporary licenses for students and the permanent license is very costly at $80k.

Because VISSIM has the ability to generate virtual models of both signalized and unsignalized intersections, the performances of both intersections thus can be compared under different traffic demand conditions. This can assist in making a more informed decision whether or not to convert between junctions.

The factors that may be needed to take into consideration when comparing the performance of a roundabout with signalized junctions include:

- Capacity: How well each type of intersection handles high traffic volume.
- Delay: The duration that vehicles spend waiting to enter the intersection.
- Safety: The probability of collisions or accidents occurring at the intersection.
- Energy consumption: The level of fuel consumption by vehicles passing through the intersection.

- Environmental impacts: The emissions generated by vehicles and the overall impact on air quality.

Via simulations with various traffic demand levels and result interpretation, it can be better understood as to how well each type of intersection performs under different conditions and make a decision about which type of intersection is most appropriate for a given location.

4.2.4. Advantages of VISSIM

According to a study, in which VISSIM was used to simulate traffic data in San Diego, California, it's advantages include the following [11].:

- Integrates freeways and surface streets with simplicity
- Enables pre-timed and actuated signals and ramp meters
- Adjusts driver behavior parameters and thus provide flexible calibration and validation
- Limitless number of nodes, links and vehicles on any simulation
- Capable of utilizing GIS layers and/or photos to define inputs and reference animation output
- VISSIM can model complicated facilities, such as major freeway interchanges with ramp metering.

4.3. Procedure

The procedure of the study is listed below. This involves 2 types of procedure, with the first being operation on field (Traffic data collection) and the other being software usage (VISSIM).

4.3.1. Manual procedure

- Obtained geometrical properties of Roundabout manually such as Circle Island Diameter, Inscribed Circle Diameter, Entry radius, Splitter Island width, truck apron thickness, entry and exit width.
- Set Video Camera in a predetermined area where the vehicles entering and exiting from all directions is visible without drawing the attention of the drivers
- Record the number of vehicles from each direction in the duration of 1 hour

- Trim the video by 6 parts where each video is 10 minutes long and count the number of vehicles in each interval in each approach

The figure below shows precisely the location of where the equipment was set, in this case video camera, for the purpose of counting Traffic Volume.

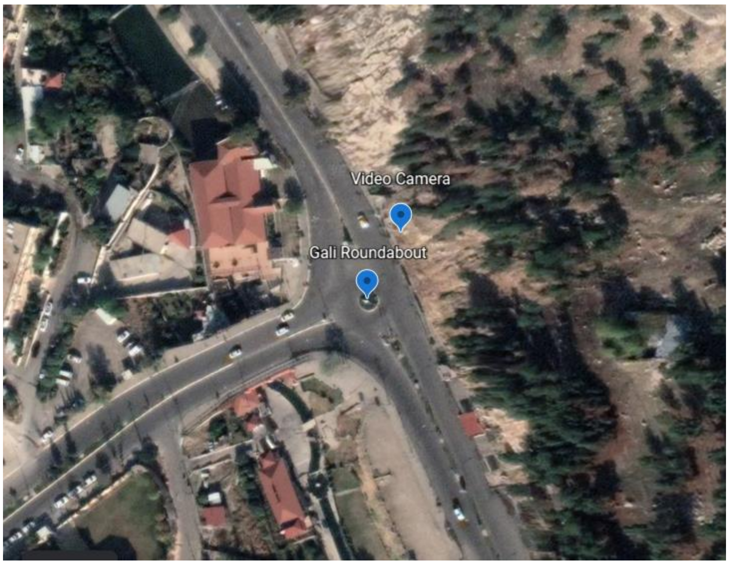


Figure 4.1. Location of video camera

4.3.2. VISSIM procedure

- Open VISSIM software and zoom in on Gali Roundabout which is located in Duhok, Iraq and having geographic coordinates of latitude of 36.8683768 and longitude of 43.0020989.
- After having a clear shot at the roundabout, links are generated as shown in Figure 4.2. Since the roundabout serves a T-leg intersection, therefore 3 nodes are generated along with its opposing direction

Figure 4.2. Links A,B,C generated through VISSIM

- After the links are generated, connectors will be defined. Connectors in the roundabout are the following:
    1. A-A: straight moving vehicles approaching A (Figure 4.3).
    2. B-B: straight vehicles approaching B (Figure 4.4).
    3. C-B: right turning vehicles approaching B from C (Figure 4.5).
    4. A-B: u-turning vehicles approaching B from A (Figure 4.6).
    5. B-C: right turning vehicles approaching C from B (Figure 4.7).
    6. A-C: left turning vehicles approaching C from A (Figure 4.8).

Figure 4.3. Connector A-A

Figure 4.4. Connector B-B

Figure 4.5. Connector C-B

Figure 4.6. Connector A-B

Figure 4.7. Connector B-C

Figure 4.8. Connector A-C

By activating the toggle framework mode, in order to avoid any confusion a better understand visually regarding the links and connectors is obtained as shown in Figure 4.9 with the blue lines denoting the links and the purple lines denoting the connectors.

Figure 4.9. Links and connectors in Toggle framework mode

- After links and connectors are generated, volume of vehicles will be imported on each node (approach) and these inputs are based on the data from table 2.2 with approaches A, B, and C having volumes of 602, 1118 and 748 respectively.
- After inputting the volume of vehicles for each link, simulations could be displayed by clicking the play button in the upper menu bar. Figures 4.10 shows a screenshot of the simulation taken at random.

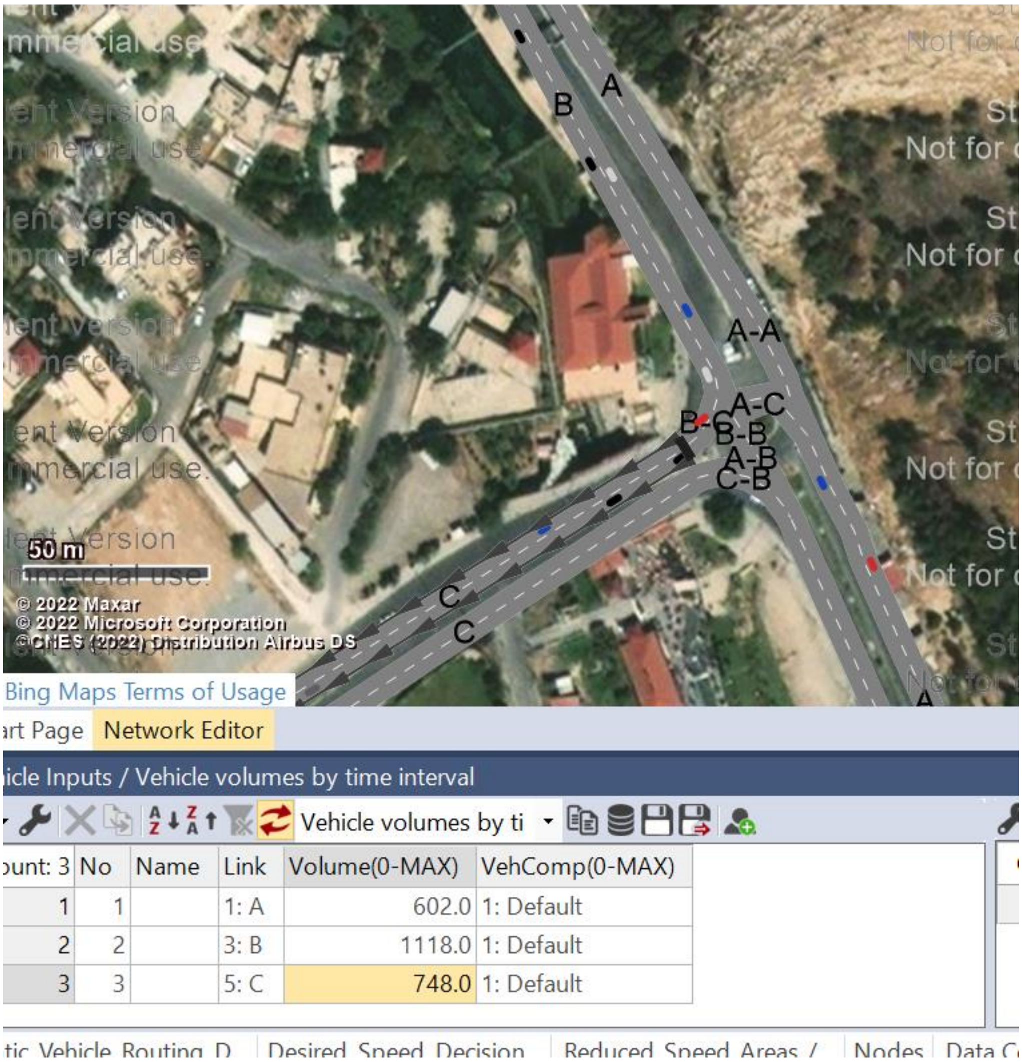


Figure 4.10. Screenshot of the simulation

- After running the simulation, no delay results were displayed, this was due to the vehicles not having any routes and most importantly no priority given to right turning vehicles and vehicles moving straight. So both of these must be done. Firstly, priority vehicles were added to the system, as shown in figure 4.11, the green shaded region denotes vehicles given priority (zero delay), while the red shaded region denotes the vehicles that will be waiting for which particular vehicle incoming from a link.

Figure 4.11. Conflict rules

- After applying conflict rules, static vehicle routes, must be provided. The purple bar denotes the starting point of the first vehicle route, while the turquoise bar denotes the ending or terminal point of the corresponding route. Figure 4.12 shows all routes to link A, Figures 4.13, 4.14 and 4.15 shows all the routes to link B and figures 4.16 and 4.17 shows all the routes to link C. In total, 6 routes were generated.

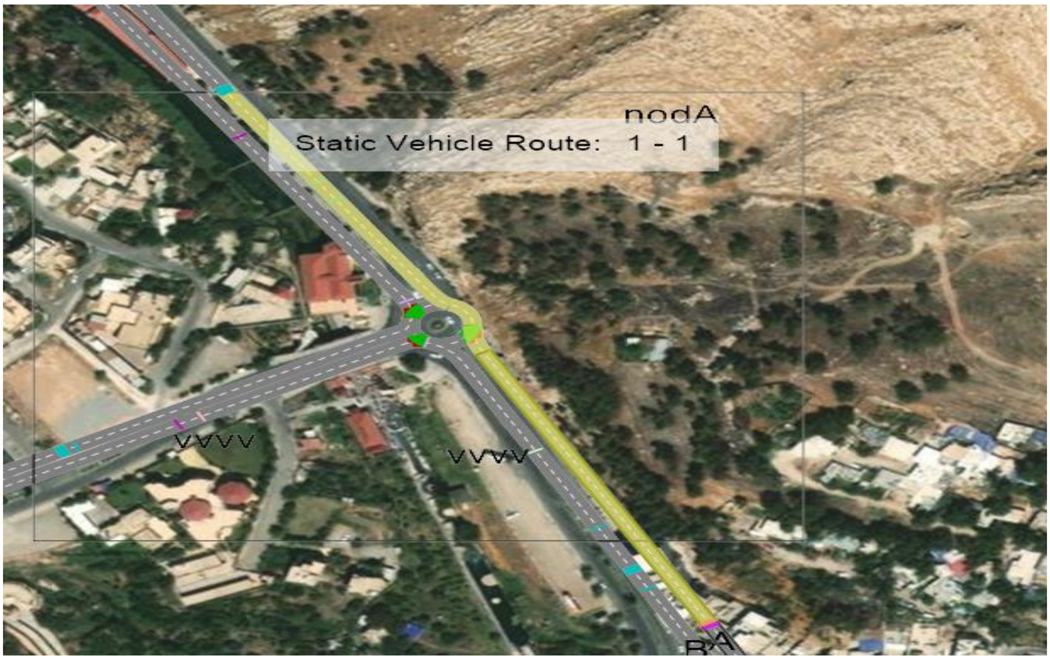


Figure 4.12. Route A-A

Figure 4.13. Route B-B

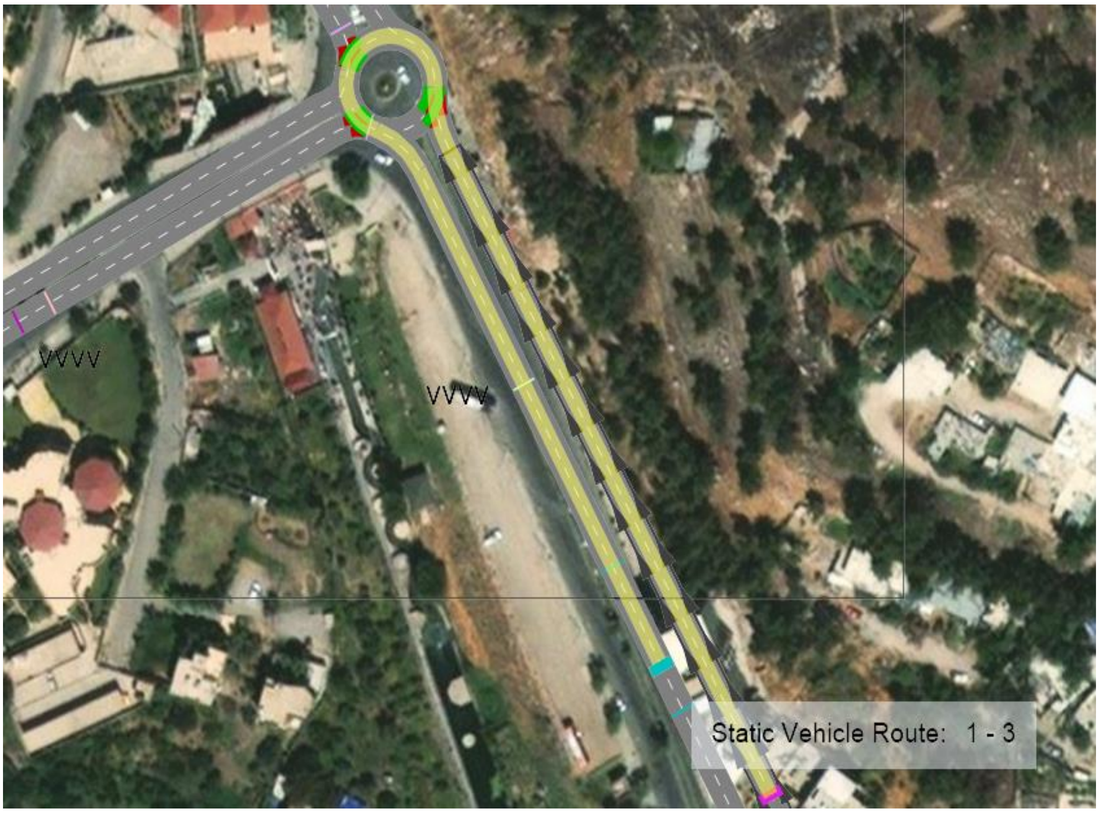


Figure 4.14. Route A-B

Figure 4.15. Route C-B

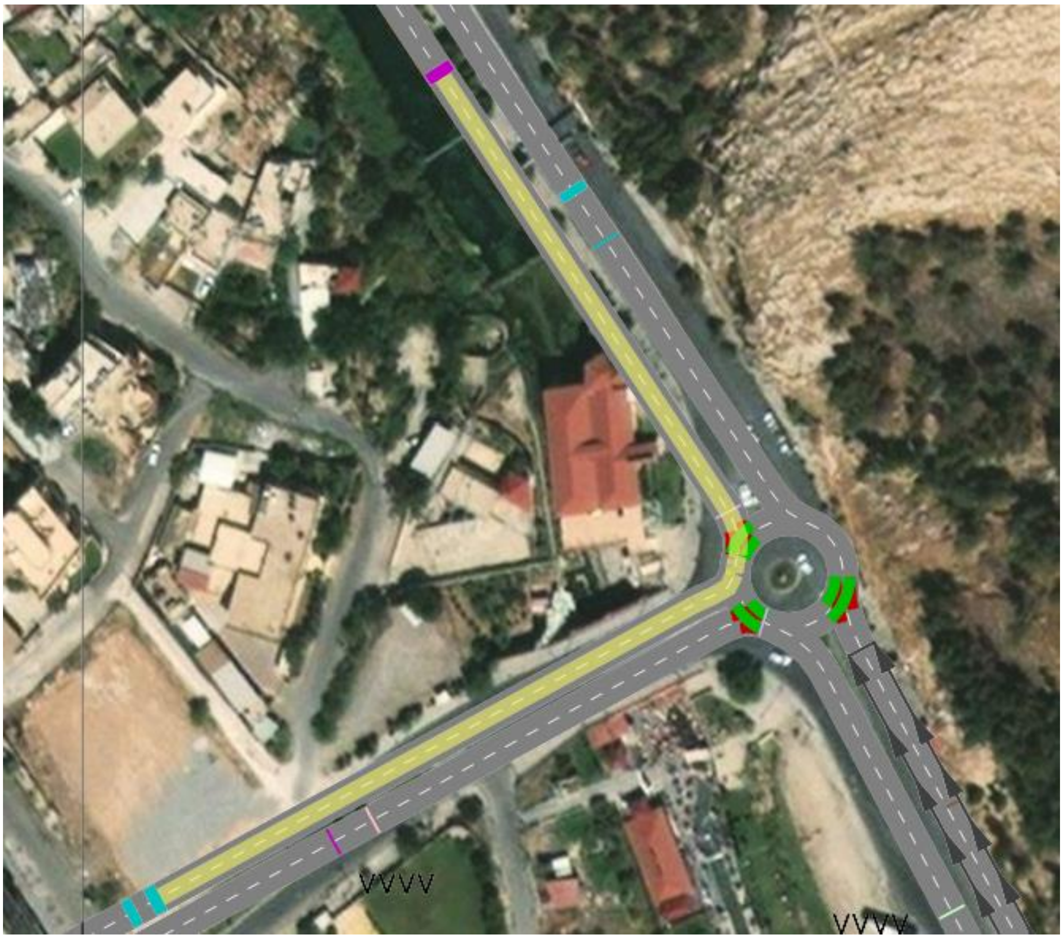


Figure 4.16. Route B-C

Figure 4.17. Route A-C

- After the static vehicle routes were generated, the number of vehicles or vehicle input will be provided for each route. (Data shown in table 3.2).
- After providing the number of vehicles for each static route, the simulation is rerun and this time delay time along with other traffic parameters should be provided.

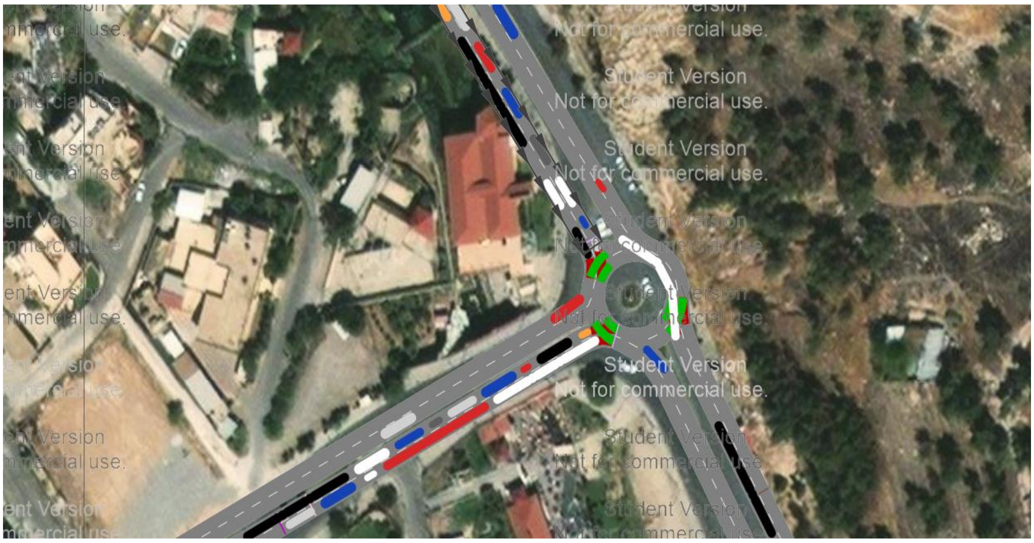


Figure 4.18. Rerun

- After the simulation was reran, file is saved as 'Simulation1' and another file will be opened where it is assumed the vehicle input (number of vehicles) in each direction or link is increased by 15% in the next several years. The new vehicle input is calculated by multiplying 1.15 with the original TVC. After the simulation is run, it will be compared with the previous file that contained the original TVC and see by how much traffic parameters such as delay and queue length changed.

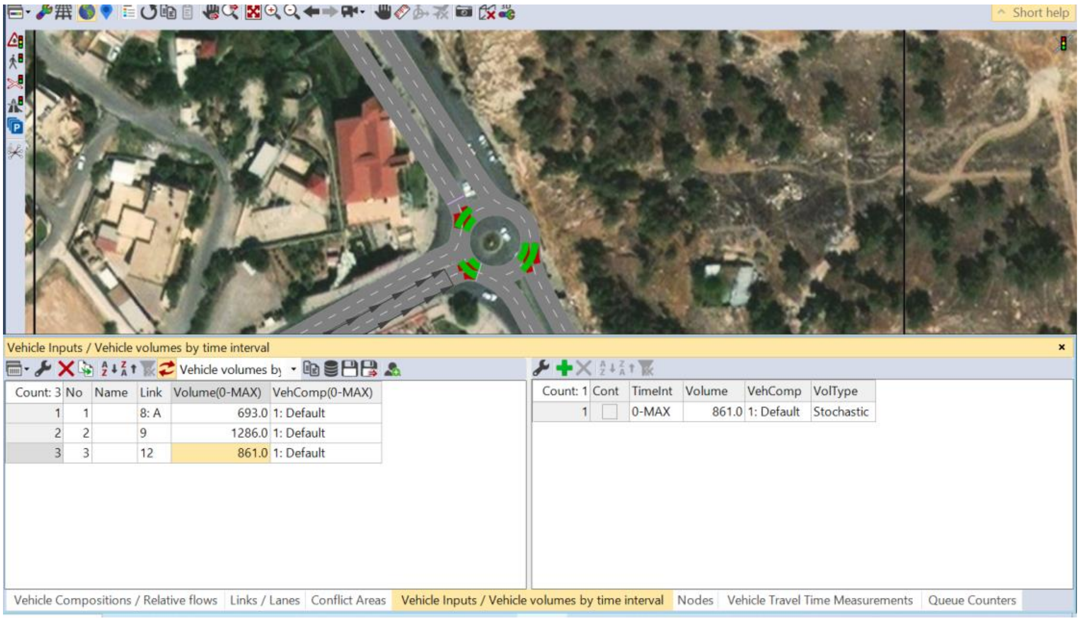


Figure 4.19. New vehicle inputs increased by 15%

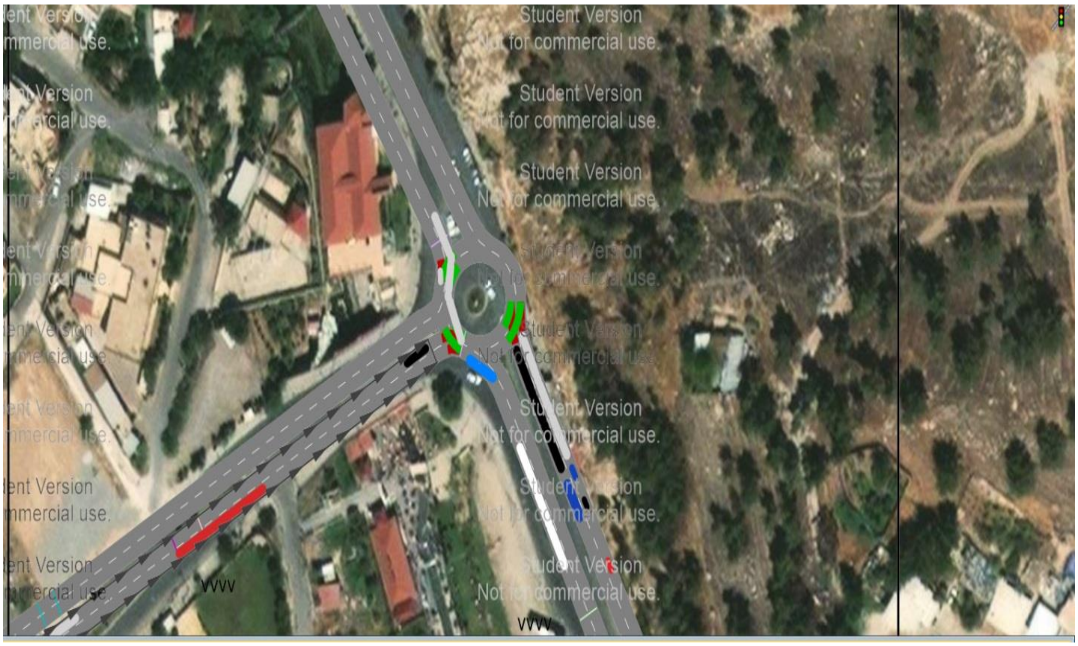


Figure 4.20. Simulation of new vehicle input

- After running simulation of prognostic increasing traffic flow, the circular intersection is deleted and a signalized junction will be generated. With that said, new connectors will be required to be generated. Figure 4.21 below illustrates this step.

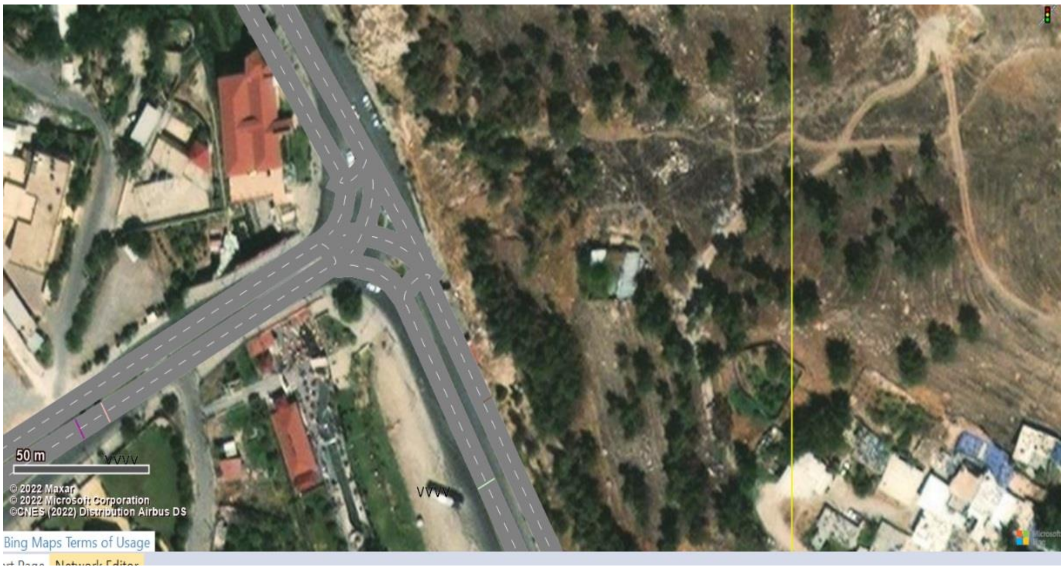


Figure 4.21. New connectors prior to signal heads being generated

- Toggle framework is activated to obtain a better visualization for the links and connectors as shown in figure 4.22.

Figure 4.22. Toggle framework for new connectors

- The first step to creating a signalized junction is to add a signal control which is done by clicking on the 'signal control' button on the menu bar then click add. A new signal controller is displayed as shown in figure 4.23.

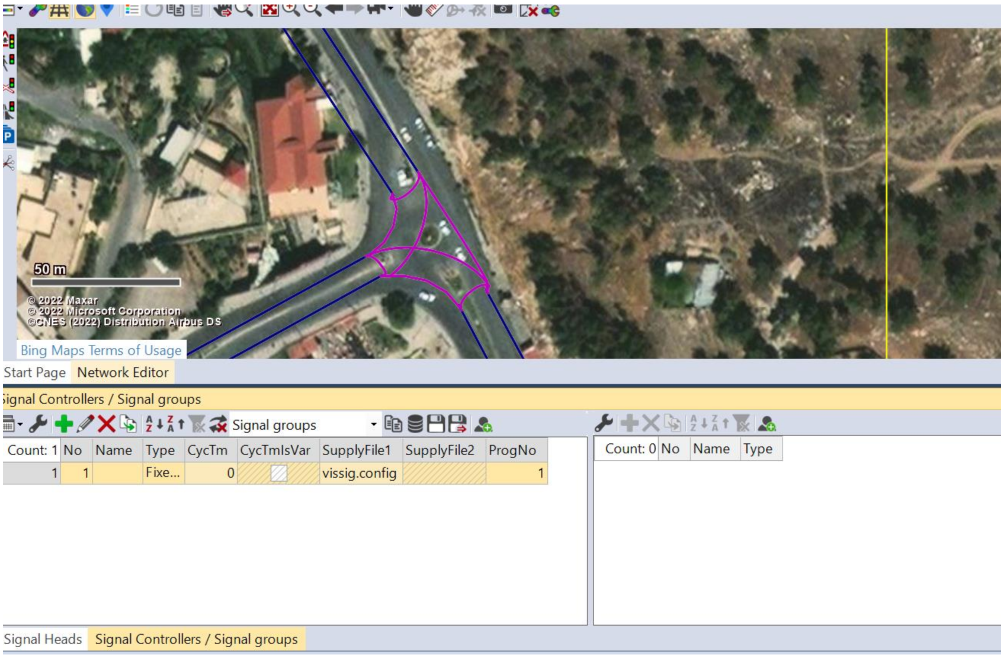


Figure 4.23. New signal controller

- After creating signal controller, signal groups are created. In this case, since there are 3 approaches, there will be 3 signal groups, each of which will be denoted or name after its directions, in this case, Westbound (vehicles entering C), Northbound (vehicles entering A) and Southbound (vehicles entering B).

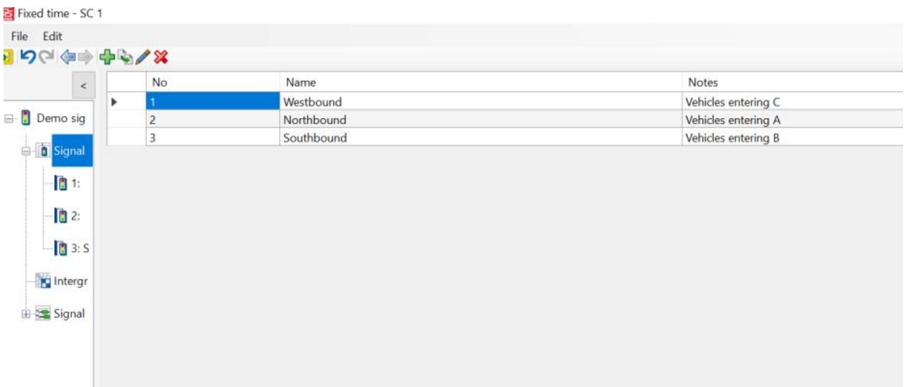


Figure 4.24. Signal groups

- Like in most countries, Iraq adopts the sequence of Red-Green-Amber, so that will be specified as the default sequence of the signal program as shown in the figure below.

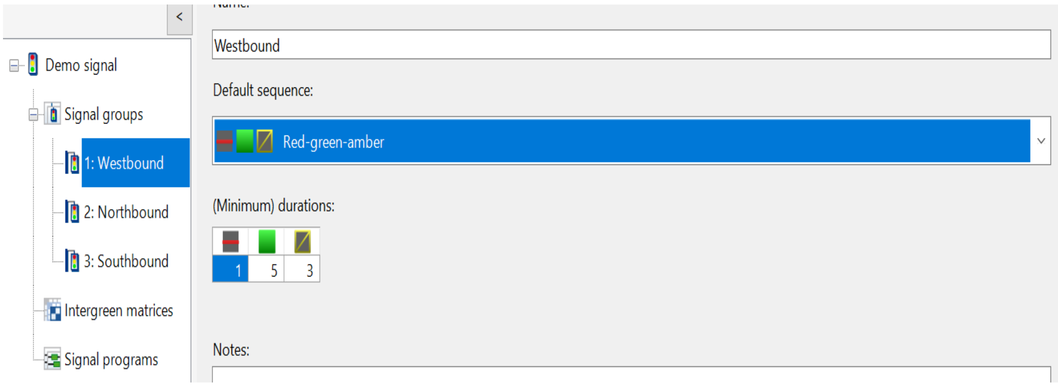


Figure 4.25. Sequence of signal phase

- After creating the signal groups, signal program will be generated. In this catalog, the optimum cycle time, which was obtained through webster's method, which will be discussed in the results chapter in detail, will be specified, along with the Green, Red and Amber time of each of the signal groups or directions, which was also obtained through webster method. According to the calculations, the total optimum cycle time for this junction was 52.6 seconds. The optimum cycle time is basically the combination of the Green, Red and Amber times.

5. RESULTS

5.1. Delay Results For Original TVC

Table 5.1 below shows the Delay results for the simulation run with original traffic volume

Table 5.1. Average, minimum and maximum delay results for original simulation

Attribute	Stopped Delay	Number of stops per vehicle	Average delay time for all vehicles	Number of vehicles
Average	22.0	2.4	45.88	41
Minimum	18.46	2.26	38.84	0
Max	25.54	2.57	52.93	79

5.2. Queue Results For Original TVC

Table 5.2 below shows the queue counters and results for the original simulation.

Table 5.2. Queue results for original simulation

Attribute	Average queue length	Maximum queue length	Number of queue stops
Average	51.53	248.20	107
Minimum	0	0	0
Max	126.74	479.69	258

5.3. Vehicle Travel Time Results For Original TVC

Table 5.3 below illustrates the travel time data obtained through VISSIM.

Table 5.3. Vehicle travel time results for original simulation

Attribute	Number of vehicles recorded	Average travel time of vehicle	Distance travelled
Average	41	59.25	194.69
Minimum	0	52.20	194.69
Max	79	66.29	194.69

5.4. Delay Results For New Vehicle Input (+15%)

Table 5.4 illustrates the delay results for the new simulation where the number of vehicles of each link was increased by 15%.

Table 5.4. Delay results for new vehicle input

Attribute	Stopped Delay	Number of stops per vehicle	Average delay time for all vehicles	Number of vehicles
Average	25.23	2.86	51.54	47
Minimum	18.46	2.26	38.84	0
Max	31.70	3.77	62.86	79

5.5. Queue Results For New Vehicle Input (+15%)

Table 5.5 below displays the queue results obtained for the new simulation.

Table 5.5. Queue results for new vehicle input

Attribute	Average queue length	Maximum queue length	Number of queue stops
Average	92.62	311.18	175
Minimum	0	0	0
Max	215.90	500.11	379

5.6. Vehicle Travel Time Results For New Vehicle Input (+15%)

Table 5.6 below illustrates vehicle travel time results obtained for the new simulation.

Table 5.6. Vehicle travel time results for new vehicle input

Attribute	Number of vehicles recorded	Average travel time of vehicle	Distance travelled
Average	47	64.90	194.69
Minimum	0	52.20	194.69
Max	79	76.21	194.69

5.7. Delay Results For New Vehicle Input (+25%)

Table 5.7. Delay results for +25% traffic volume

Attribute	Stopped Delay	Number of stops/veh	Average delay time for all vehicles	Number of vehicles
Average	27.18	3.47	54.60	55
Minimum	21.13	2.87	42.04	0
Maximum	34.22	4.06	67.15	88

5.8. Queue Results For New Vehicle Input (+25%)

Table 5.8. Queue results for +25% traffic volume

Attribute	Average queue length	Maximum queue length	Number of queue stops
Average	123.66	399.65	206
Minimum	0	0	0
Maximum	279.18	574.82	445

5.9. Vehicle Travel Time Results For New Vehicle Input (+25%)

Table 5.9. Vehicle travel time for +25% traffic volume

Attribute	Number of Vehicles	Average travel time of vehicle	Distance travelled
Average	55	74.5	194.69
Minimum	0	65.3	194.69
Maximum	88	83.7	194.69

5.10. Delay Results For New Vehicle Input (+50%)

Table 5.10. Delay results for +50% traffic volume

Attribute	Stopped Delay	Number of stops/veh	Average delay time for all vehicles	Number of vehicles
Average	35.13	4.43	64.94	62
Minimum	27.81	3.72	50.21	0
Maximum	42.39	5.13	79.66	113

5.11. Queue Results For New Vehicle Input (+50%)

Table 5.11. Queue results for +50% traffic volume

Attribute	Average queue length	Maximum queue length	Number of queue stops
Average	186.97	503.55	233
Minimum	0	0	0
Maximum	418.20	661.75	489

5.12. Vehicle Travel time Results For New Vehicle Input (+50%)

Table 5.12. Vehicle travel time results for +50% traffic volume

Attribute	Number of Vehicles	Average travel time of vehicle	Distance travelled
Average	62	83.7	194.69
Minimum	0	71.7	194.69
Maximum	113	95.6	194.69

5.13. Delay Results For New Vehicle Input (+100%)

Table 5.13. Delay results for +100% traffic volume

Attribute	Stopped Delay	Number of stops/veh	Average delay time for all vehicles	Number of vehicles
Average	44.10	5.48	75.52	68
Minimum	33.38	4.69	59.64	0
Maximum	54.84	6.20	91.49	121

5.14. Queue Results For New Vehicle Input (+100%)

Table 5.14. Queue results for +100% traffic volume

Attribute	Average queue length	Maximum queue length	Number of queue stops
Average	213.66	543.62	255
Minimum	0	0	0
Maximum	488.74	733.14	534

5.15. Vehicle Travel Time Results For New Vehicle Input (+100%)

Table 5.15. Vehicle travel time results for +100% traffic volume

Attribute	Number of Vehicles	Average travel time of vehicle	Distance travelled
Average	68	102.1	194.69
Minimum	0	83.0	194.69
Maximum	121	121.2	194.69

6. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

Traffic parameters such as delay, queue length and level of service were obtained through simulations via VISSIM software. 2 simulations were performed in this study, the first one involving the number of vehicles record manually and the other simulation was a hypothetical one where it is assumed in the future time the vehicle input increases by 15%. According to VISSIM, the average stopped delay per vehicle in seconds excluding stops at PT spots or parking lots was 22.00 for the first simulation and 25.54 for the second. According to table 5.1, the first simulation, based on this delay time has a level of service of C, which denotes an average roundabout. The 2nd one however, since it slightly exceeds 25 seconds, will downgrade the level of service of Gali roundabout to D which denotes not a bad roundabout but rather a below average one. It is important to remember that vehicles from one of the approaches (approach A) were almost completely free of delay as they were given priority from vehicles in other direction according to the conflict rules, which were applied prior to simulation.

6.2. Webster's Method

As mentioned earlier, the optimum cycle length or period of this junction was determined via Websters method. Webster's method has been widely described as a rational approach for signal design. It is used to determine the optimum cycle period of a traffic signal involving a scattering of data including traffic flow in PCU, total saturation, number of traffic phases, etc. Webster's method also determines the Real green time and red time of a signal control, both of which combined along with amber time basically makes up the total optimum cycle length. The process of calculating these parameters is shown below.

The optimum cycle length is calculated using the equation below

$$C\ opt = \frac{(1.5 * L) + 5}{1 - Y} \tag{6.1}$$

Where:

L: The total time lost in seconds which can be assumed as 5 multiplied by number of phases

Y: The ratio of the maximum flow in PCU for each phase to the total saturation flow (qi/Mi)

After calculating the optimum cycle time, the total effective green time of the cycle can be determined using the equation below. The effective green time refers to the time during which a given traffic movement is set to proceed. It is basically the total cycle time subtracted with the effective red time.

$$EGT = C\ opt - (L + A) - 1 \tag{6.2}$$

Where:

L: is the Lost time which is usually 5

A: Amber time, which is 4 seconds in most countries and 3 in handful. (4 in Iraq)

Equation 6.2 denotes the total effective green time of the entire cycle. To determine it for each specified phase the following equation below is utilized.

$$EGTi = EGT \left(\frac{yi}{Y}\right) \tag{6.3}$$

Where:

EGTi: The effective green time for i phase

EGT: The total effective green time of entire cycle (from Eq 6.2)

yi: Maximum flow for I phase

Y: The summation of the maximum flow of each phase

The effective green time does not represent the real or actual green time of a junction however as many drivers nowadays have the tendency to carry on even when the traffic is red. Hence, the real green time always more than the effective green time as drivers tend to prolong the segment.

The real or actual green time for each phase is calculated using the equation 6.4 below.

$$RGTi = EGTi + (L - A) \tag{6.4}$$

After calculating the real green time for each phase, the actual red time for each phase can also be obtained by basically subtracting the total optimum cycle length with the real green time for i phase and the amber time as shown in equation 6.5 below.

$$Red\ time = C\ opt - RGTi - A \tag{6.5}$$

It can be then checked whether the optimum cycle period is correct by simply combining or adding the red time, real green time of each phase and the amber time.

6.3. Results Obtained From Webster's Method

In the following section, the procedure as to how the data related traffic signal parameters using Webster's method will be detailed.

1. Identifying phases. Since the flow in terms of PCU is an input of obtaining the cycle period, it is essential to define phases and have knowledge as to which direction is involved in that phase. Phase 1 shown in the figure below was defined and it involves the directions A1 (straight), A2 (left turning), B1 (straight) and B2 (right turning). The flow in PCU which was obtained earlier will also be used here rather than the original version.

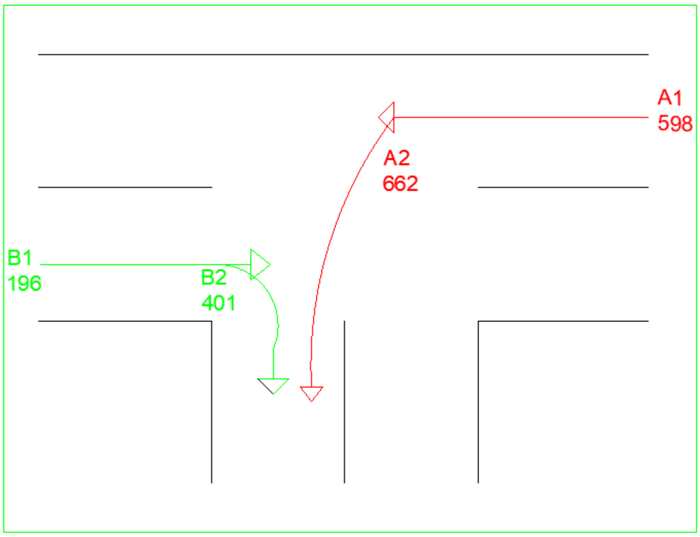


Figure 6.1. Phase 1

As seen in the figure, the original flow of A2 was actually 414 but since the coefficient of left turning vehicles is 1.6, 414 was multiplied by that value to obtain the total flow for A2. Likewise for B2, whose original flow was 334 but was then multiplied by the right turn coefficient of 1.2 hence it became 401. Flows for straight turning vehicles however, will remain the same or unchanged as they have a coefficient of 1, hence why A1 and B1 have the same total flows as the original ones.

The same procedure will be done for Phase 2, which is shown in the figure below. Phase 2 only involves C1 (right turning) and C2 (left turning).

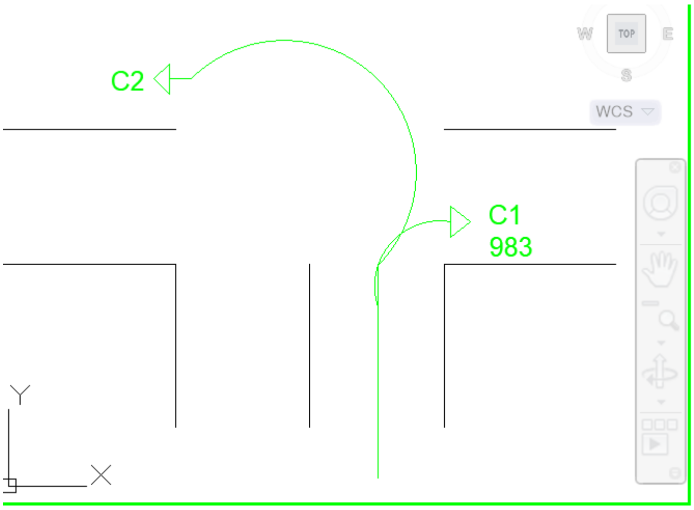


Figure 6.2. Phase 2

As mentioned earlier in the roundabout case, the access to Approach A was blocked for left turning and u turning vehicles in an effort by traffic police to reduce congestion as the day in which the operation was carried out was a weekend where traffic hits peak levels. Hence why there is no flow for C2. For C1 however, the original flow was 819 multiplied by the right turning coefficient of 1.2 and 983 was obtained.

2. Now that phases have been identified, the maximum flow of each phase (yi) can be determined. yi is as mentioned earlier is the ratio of the total flow of a direction to the total saturation flow. Table 6.1 shows the results.

Table 6.1. Maximum flow of each phase

Direction	Total flow in PCU (q)	Saturation flow (S)	Total saturation flow (M=S*number of lane)	Yi= q/M	Phase
A	A1+A2=1260	1800	3600	0.35	1
B	B1+B2=597	1800	3600	0.17	1
C	C1+C2=983	1800	3600	0.27	2

After determining the maximum flow for each phase, the parameter Y can then be determined by adding up the maximum flow of all phases. As seen in the table, the maximum y for phase 1 is 0.35 and for phase 2 is 0.27, so adding them will give 0.62.

Y= y1+y2= 0.35 + 0.27= 0.62

3. Then optimum cycle length was determined using equation 6.1.

$$C\ opt = \frac{\big(1.5 * (5 * 2)\big) + 5}{1 - 0.62} = 52.6\ seconds$$

4. The effective green time was then determined using equation 6.2

$$EGT = 52.6 - (5 + 4) - 1 = 42.6\ seconds$$

5. The effective green time for each phase was then determined.

$$EGT\ for\ phase\ 1 = 52.6 * \left(\frac{0.35}{0.62}\right) = 29.7\ seconds$$

$$EGT\ for\ phase\ 2 = 52.6 * \left(\frac{0.27}{0.62}\right) = 22.9\ seconds$$

6. The real or actual green time was then calculated.

$$Real\ green\ time\ for\ phase\ 1 = 29.7 + (5 - 4) = 30.7\ seconds$$

$$Real\ green\ time\ for\ phase\ 2 = 22.9 + (5 - 4) = 23.9\ seconds$$

7. The actual red time for each phase can then be determined.

$$Red\ time\ for\ phase\ 1 = 52.6 - 30.7 - 4 = 17.9\ seconds$$

$$Red\ time\ for\ phase\ 2 = 52.6 - 23.9 - 4 = 24.7\ seconds$$

Table 6.2 illustrates a summary of the results of each phase

Table 6.2. Optimum cycle time of each phase

Phase	Real green time	Actual red time	Amber time	Optimum cycle time (Real green time + Actual red time + Amber time)
1	30.7	17.9	4	52.6
2	23.9	24.7	4	52.6

Figures 6.3 and 6.4 below details the signal control parameters for phase 1 and 2 respectively.

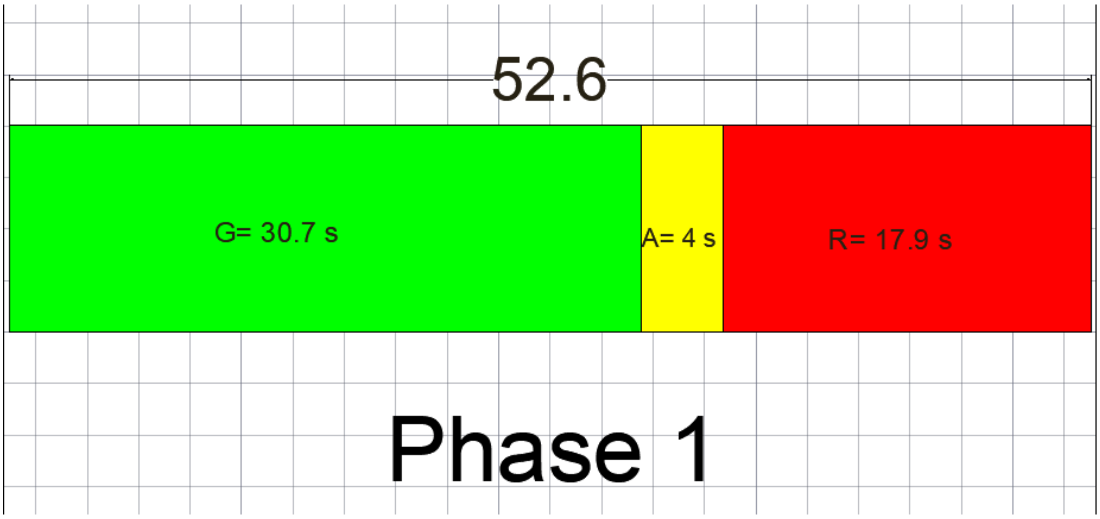


Figure 6.3. Phase 1 signal control parameters

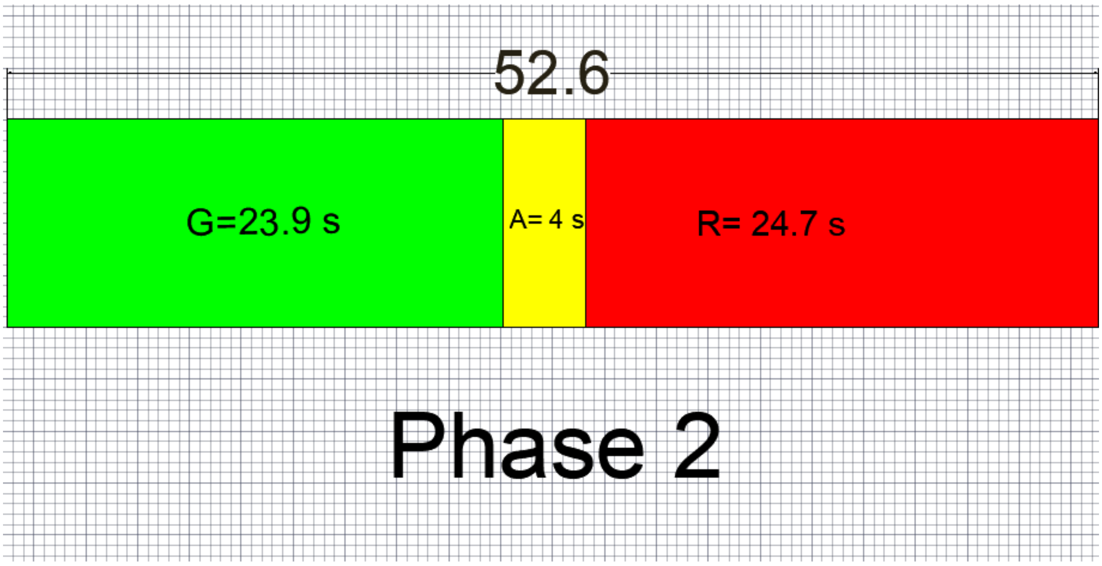


Figure 6.4. Phase 2 signal control parameters

6.4. Recommendations

Based on analysis and results obtained from VISSIM, the roundabout present at the moment is suitable for the junction in Gali Duhok and thus can be relied or persisted on for the next couple of years but with increase in traffic volume, it's fate and it's capability to compensate such volume is under jeopardy. In the mean time, as mentioned earlier, due to topographic reasons, it is extremely difficult to also increase the inscribed circle diameter of the roundabout, which would perhaps help in reducing traffic volume as the roundabout is situated near a mountain and would thus be very costly. Therefore, as of this moment, there are no plans to perform specific moderations or changes to the roundabout. One recommendation would perhaps to displace the roundabout from its original location and change the location nearby where a much bigger inscribed circle diameter would be much more suitable and more affordable as it will have no topographic restrictions like it does now. The recommendation is shown in figure 6.5.

Figure 6.5. Recommendation of new roundabout

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