UNIVERSITY OF GAZIANTEP

GRADUATE SCHOOL OF

NATURAL AND APPLIED SCIENCES

REHABILITATION OF CONGESTED URBAN ARTERIALS: ERBIL CASE STUDY

M. SC. THESIS

IN

CIVIL ENGINEERING

BY

SAWEEN MOFFAQ ABDULAZIZ

SEPTEMBER 2014

Rehabilitation of Congested Urban Arterials:

Erbil Case Study

M. Sc. Thesis

In

Civil Engineering

University of Gaziantep

Supervisor

Assist. Prof. Dr. Yusuf Kağan DEMİR

By

Saween Moffaq ABDULAZIZ

September 2014

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UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL AND APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Rehabilitation of Congested Urban Arterials: Erbil Case Study

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Exam date: 18.09.2014

Approval of the Graduate School of Natural and Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully citied and referenced all material and results that are not original to this work.

Saween Moffaq ABDULAZIZ

ABSTRACT

REHABILITATION OF CONGESTED URBAN ARTERIALS: ERBIL CASE STUDY

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M.Sc. in Civil Engineering
Supervisor: Assist. Prof. Dr. Yusuf Kağan DEMİR
September 2014
84 Pages

The aim of this study is to reveal status of traffic and assessing potential capacity of Erbil's Urban Network. For this purpose, the most congested segment of the network is selected and traffic surveys are conducted for the segment at peak hours. The data obtained from surveys and road geometry of the segment are entered to microsimulation and modeling of the segments are completed when calibration processes reaches acceptable errors. Some proposals are developed such as traffic signal optimization and roundabout construction for some intersection to improve traffic. The proposals are tested in the microsimulation software. Results show that existence of potential capacity of the segment due to poor signal quality and intersection design. Total delay on the segment can be reduced up to 28% by applying roundabout to some intersections.

Keywords: Traffic congestion, microsimulation, calibration, signalization, roundabout

ÖZET

TIKANIKLIĞA SAHİP KENT ANAYOLLARININ İYİLEŞTİRİLMESİ: ERBİL ÖRNEĞİ

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Aralık 2014
84 Sayfa

Bu çalışmanın amacı Erbil kentine ait trafik trafik durumunu ortaya koymak ve trafik ağındaki atıl kapasitelerin değerlendirmektir. Bu amaçla kentin enyoğun yol kesimi seçilerek bu kesime ait trafik sayımları doruk saatler içinde gerçekleştirilmiştir. Elde edilen veriler ve yol geometrisi mikrosimulayon yazılımına girilerek ilgili kesim için yazılım kalibrasyonu ile ilgili kesim modellenmiştir. Kalibre edilmiş model üzerinde yeni altyapı yatırımları gerektirmeyen düşük maliyetli öneriler geliştirilmiş ve mikrosimulasyon ortamında sınanmıştır. Çalışma sonucunda ilgili çalışma kesiminde, yanlış sinyalizasyon ve kavşak tasarımlarından kaynaklanan atıl kapasitelerin olduğu görülmüştür. Bazı kavşakların dönelkavşağa dönüştürülmesiyle trafikte toplam gecikmelerde %28 varan oranlarda iyileşmeler gözlenmiştir.

Anahtar Kelimeler: tıkanıklık, simulation, kalibrasyon, sinyalizasyon, dönelkavşak

To all my dears, especially:

The soul of my father

My mother

My brothers and sisters

ACKNOWLEDGEMENTS

To begin with I would like to thank the God for implanting the soul of endurance and faith in myself to complete this study.

My thanks and gratitude are extended to Gaziantep University and the deanery of Faculty of Engineering for providing this opportunity to complete my higher study and offering all requirements necessary to prepare this thesis.

I would like to extend my gratitude and sincere thanks to my supervisor Assist. Prof. Dr. Yusuf Kağan DEMİR, for continuous encouragement, valuable guidance and interest throughout the period of the study. In addition, I am obliged to thank PTV- Group for supporting students and providing updated version of the required software program.

I want to express my thanks to The Directorate of Erbil Traffic Police, especially Amanj Mahmoud, for their valuable aid in data collection.

My deepest thanks and respect to all my friends for their unique assistance.
Special thanks to Abdulelah K. A. AL-MASHHADANI for his continuous help.

Words cannot express my thanks and gratitude to my family for their endless assistance to perfect the MSc study.

CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

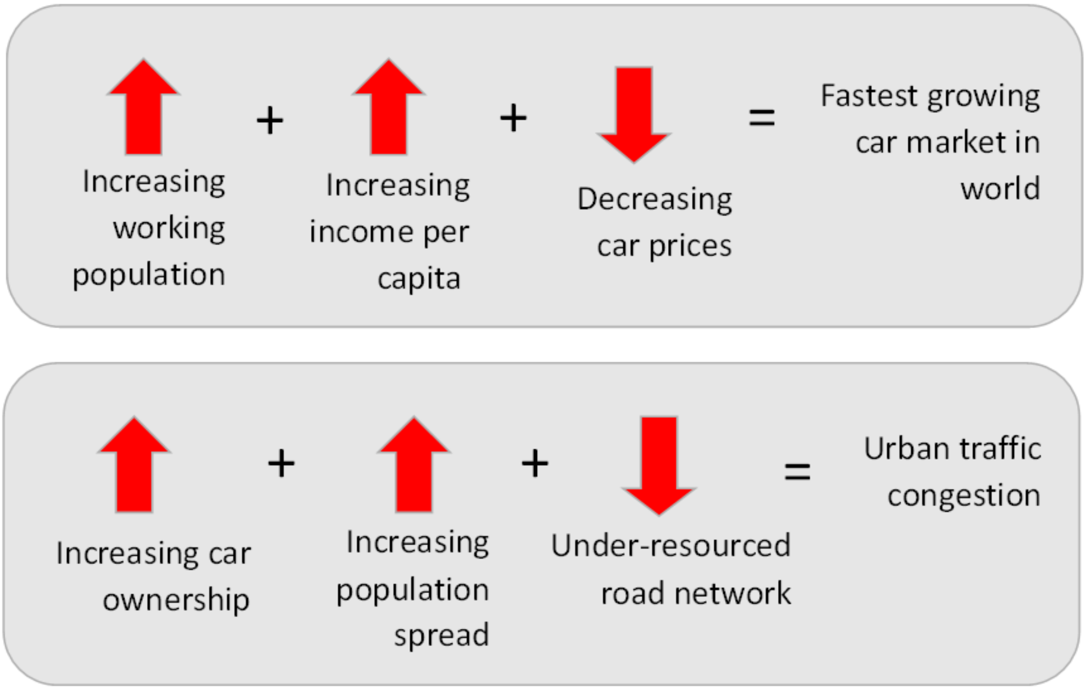
Page

CHAPTER ONE
INTRODUCTION

1.1 GENERAL PEREVIEW

Transportation is important for nation's development and growth in both public and private sector, then good transportation results to great economy. Excellent transportation systems are not enough; there must be excellent transportation services too. Building vast transportation systems requires enormous resources of energy, material, and land. On the other hand, one must know that transportation has other negative effects as well, so that society has indicated willingness to accept some risks and some change of environment to gain the benefits of Transportation Systems. Transportation represents one of the broadest opportunities for employment because it involves many disciplines and modes.

Iraq as it records as one of the largest oil-producing countries in the world. It is considered as an important trading place and increasing mobility of Iraqis and outsiders populous, who needs transportation to manage their daily lives. Like any other oil countries, in Iraq prices of petroleum products, including gasoline, are relatively cheaper than other countries, and also there are not any kind of tax exist on the purchase or sale of cars, additionally, poverty in the public transport made almost everyone has its own car, which led to unusual traffic congestion in almost all the major cities. The diagram below better describes how and why congestion occurs especially in the cities of high population and high working opportunities [1]:



Rehabilitation of urban roads is usually carried out with special restrictions in order to limit traffic congestion and to assure the link between different routes through the urban areas. The rapid growth in urbanization and motorization generally contributes to an urban transportation system that is economically, environmentally and socially unsustainable. The result has been a relentless increase in traffic congestion. Road congestion pricing has been proposed many times as an economic measure to fight congestion in urban traffic, but has not seen widespread use in practice because of Some potential impacts of road pricing remain unknown [2].

The most common measures for reducing the impact of traffic congestion on signalized urban roads are:

1. Provide public transport;
2. Use regulations and traffic engineering to control traffic;
3. Use innovative ideas to reduce traffic impacts on essential roads;
4. Provide an optimum traffic signal cycle time;
5. Provide special lanes for bicycle and pedestrians.

1.2 BACKGROUND OF TRAFFIC IN ERBIL CITY

Erbil is one of the biggest governorates in Iraq, with area of 14,000 square kilometers, after (2003) because of the stable security conditions in this region Erbil has become the most important city in Iraq, accordingly in the last ten years, the city of Erbil made a lot of business, tourism and even daily life progress. The local population has become 1,950,000 (according to statistics from 2011), and in this, city lives in such a quarter or more of this ratio stranger, whether from other cities or other countries. This prosperity is still ongoing and evidence of this Erbil is termed (the capital of the Arab countries for tourism for the year 2014). Because of the existence of opportunities for work, good living situation, the cheap price of gasoline, and re-poverty in public transportation, owning private cars and taxis caused unusual congestion and delays in access, especially in times of starting the official working in the city, as shown in figure (1.1). There are more than one million vehicles on North Iraq Region roads (2009) and %60 of this ratio is existed in Erbil, with the fact that the number is growing as car prices and gasoline charges continue to fall. When this development is not effectively managed, many problems among them, urban transportation system problems are taking place, in this study one of the most congested Erbil's networks named (60-meter street) has been selected as a case study.

Most notorious metropolitan transport problems that can be seen in this case and every signalized urban network are:

• Slower speeds.

• Longer journey times.

• Increased queuing at intersections or bottlenecks.

• Increased stopping and starting.

• More time spent stationary.

• Less predictable journey times.

In addition to these problems, congestion also has both economic and environmental impacts.

Accordingly, the following improvements of traffic control, particularly signal control, are recommended:

1. Optimizing traffic signals.
2. Promote flexible signal controls.
3. Introduce the Urban Traffic Control (UTC) system.
4. Improve maintenance.
5. Better urban road management systems.

6. Round-about some of the signalized intersections.

Figure 1.1 Congested 60-meter street in Erbil city

1.3 DESCRIPTION OF THE STUDY AREA

The study area (60- meter street) represents a two-way network of ten signalized intersections inside Erbil, as shown in figure (1.2). It is the Main-road in the city which connects all the city and most of the main offices of Government and Companies, large-malls, hospitals, hotels even some Colleges are laying on this street. This street is very crowded and has the problems of lane-width, queue in turning-bays and intersections, and delaying in Traffic-lights and LOS. Especially at the morning peak hour because of this congestion the speed does not exceed 40 Km/hr and even this speed many accidents occur. Figure (1.3) describes the network links, depending on the method of single node representation. It also explains the directions of flow for each node and the distance of connection between them.

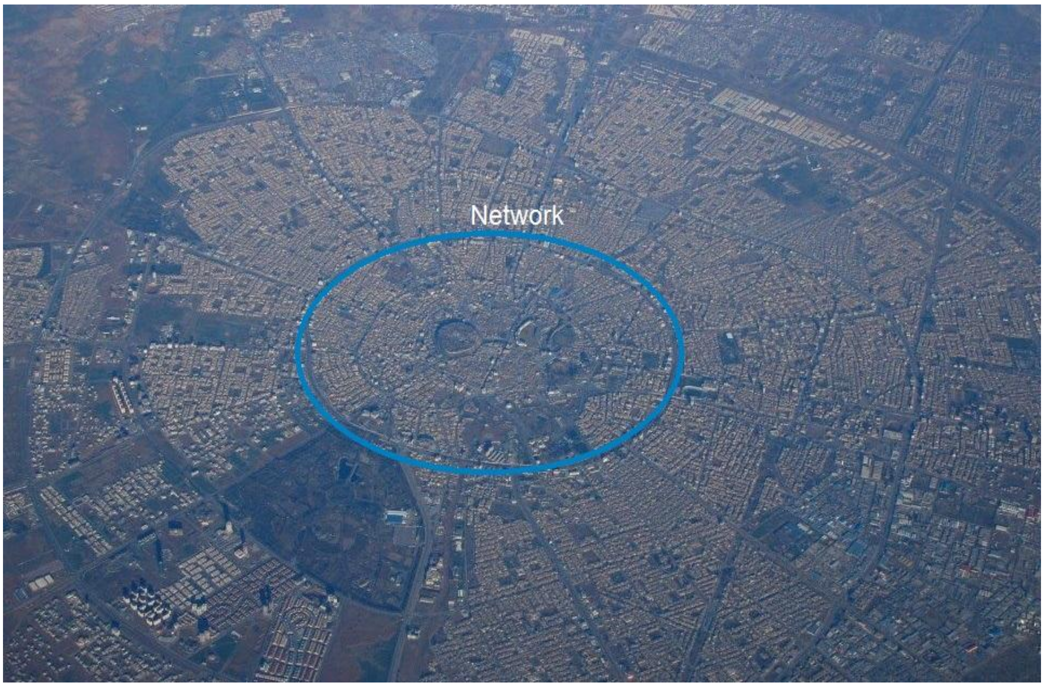


Figure 1.2 Location of the study area in Erbil city

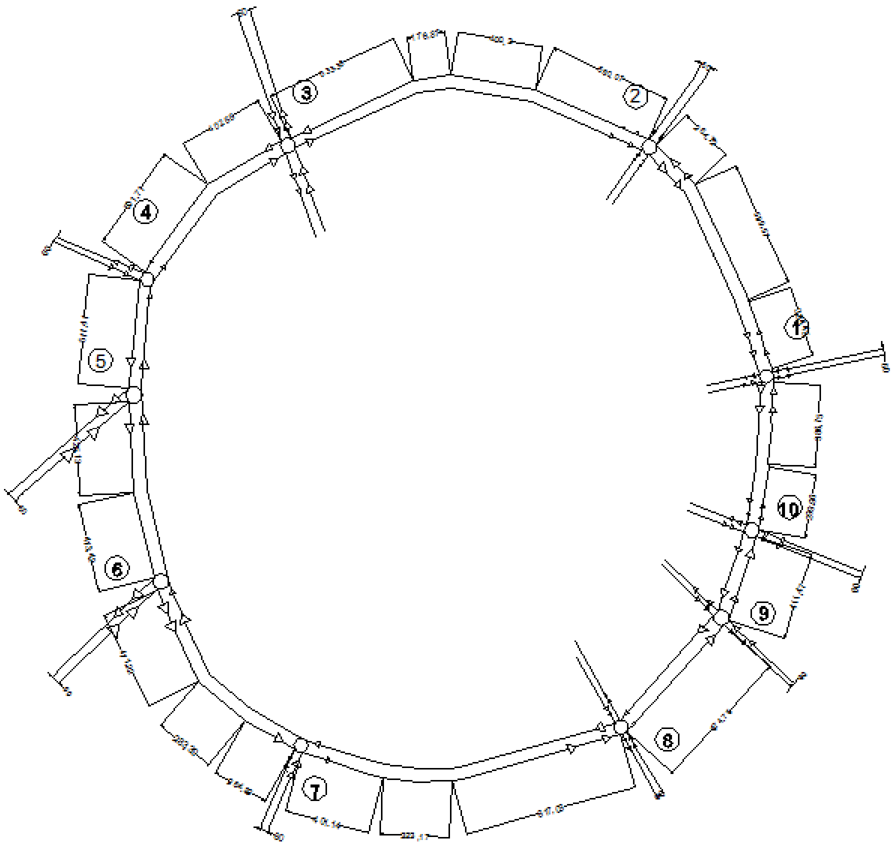


Figure 1.3 Description of the network nodes and links

1.4 TRAFFIC PROBLEMS IN THE STUDY AREA

Growing population and increase in a vehicle number cause traffic and environmental problems in the cities. Even some main arteries do not reach their capacity; drivers are stuck in traffic, especially peak hours. Some of these congestions are can be solved without any infrastructure measurements. Optimization of signal, roundabout, lane-width arrangement, management of traffic and turn-bays can solve these problems in **Short-term** with **Low-cost**.

1.5 STATEMENT OF THE NETWORK

After (2003) Because of the stable security conditions in this region it becomes the most important city in Iraq. There are more than one million vehicles on North Iraq Region roads (2009) and %60 of this ratio is existed in Erbil, with the fact that the number is growing as car prices and gasoline charges continue to fall. The (60-meter street) is the Main-road in the city which connects all the city and most of the main offices of Government and Companies, large-malls, hospitals, hotels even some Colleges are laying on this street. This street is very crowded and has the problems of lane-width, queue in turning-bays and intersections, and delaying in Traffic-lights and LOS. Especially at the morning peak hour because of this congestion the speed does not exceed 40 Km/hr and even this speed many accidents occur.

1.6 OBJECTIVE OF THE STUDY

This study will focus only on North of Iraq Region Urban Road Network. Therefore, this research will be directed to simulate and calibrate the traffic flow data of this network, in order to obtain the results of existing measurements of the network performance. Then, the network is prepared and been ready to try improving its performance by suggesting proposals and testing their results.

1.7 PROCEDURE OF THE WORK

The study was conducted in the following order;

- Collection of current flow data by Laser Traffic Camera.
- Calibration of simulation software.
- Then we can analyze the network flow by using a suitable software program such as (PTV VISSIM, CORSIM, PARAMICS, etc.).

- So that we will suggest some proposals to decrease the congestion and improve the performance of the network.
- By using the adopted program we must test and check the results of the proposals to discuss it and select the recommending one.

1.8 STRUCTURE OF THE THESIS

This thesis consists of five chapters. Chapter one is an introduction chapter where the general preview of transportation in Iraq and background of transportation in Erbil, in particular, is presented. The description of the study area and traffic problems, the work procedure and objective of the study are also stated in this chapter.

The transportation system management, traffic flow theory and performance measurements, as well as software programs of traffic field and the adopted program (PTV-VISSIM 6.0) that used for data simulation are reviewed in chapter two, while the research methodology is addressed in chapter three, which contains the data collection, detailed description of the network and the volume of vehicles in the network. In chapter four, the network results are demonstrated by using the adopted program with some proposals to improve the network performance. Furthermore, another program specialist with intersections named SIDRA INTERSECTION is used for improving cycle time and roundabout some signalized intersections in this chapter. The results of proposals are checked in main program PTV-VISSIM 6.0. Finally, chapter five includes the discussion of results achieved from this study, and some future recommendations are explained.

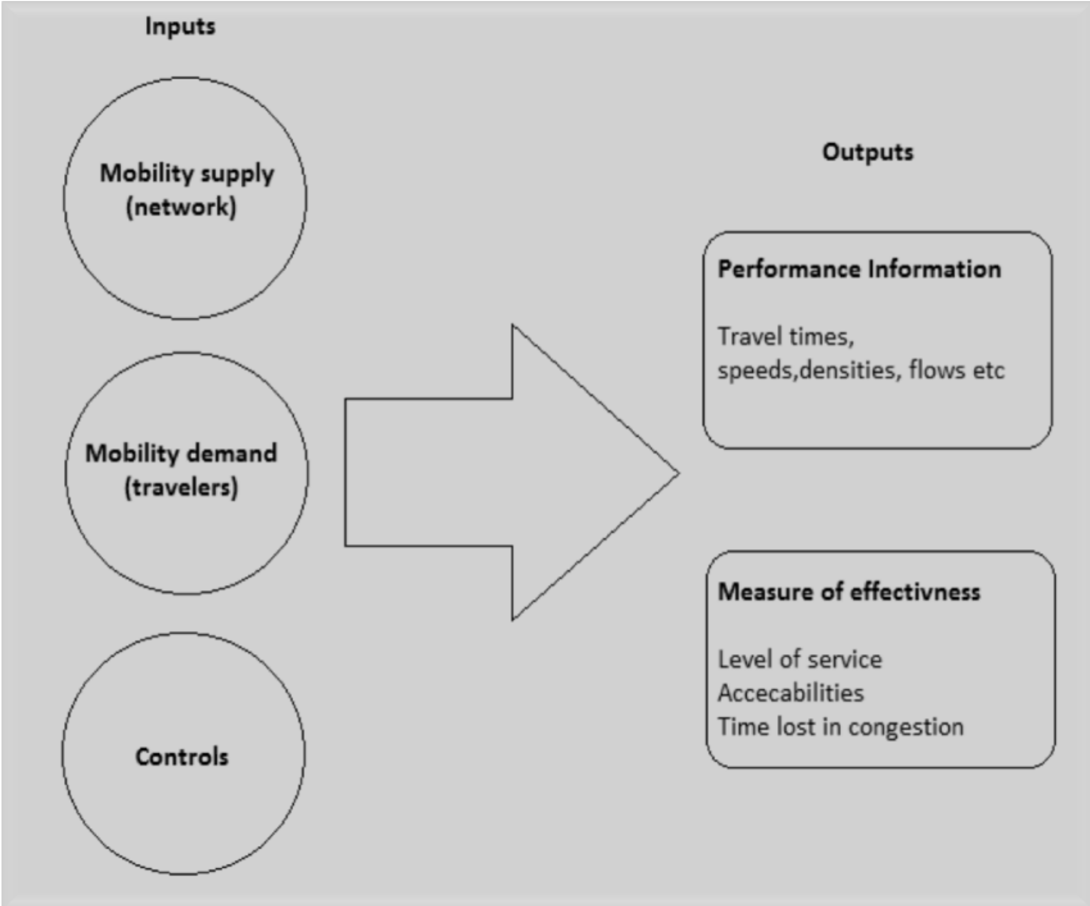
CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Congestion is not a new phenomenon and is not strictly reserved for urban areas. In some form it has been present since the first automobiles traveled the rutted roads of the early 1900s [2]. Urban traffic congestion tends to maintain equilibrium: it increases to the point that delays discourage additional peak-period trips. Under such conditions, roadway expansion usually provides only short-term congestion relief and can exacerbate other transport problems; durable reductions require more systematic solutions [3]. Peak-hour traffic congestion is a result of the way modern societies operate, and of residents' habits that cause them to overload roads and transit systems every day [4]. Over the years congestion has been defined or measured as level of service, speed, travel time, and delays. The amount of congestion and its documented increase is closely related to similar trends in population growth [2].

Traffic simulation models, similar to other simulation models, are designed to mimic the behavior of the real traffic system. A detailed description of the system performance can be obtained by using a properly designed simulation model where separate entities are integrated to simultaneously interact. The model is a mathematical or physical abstraction that describes the actual system intended to promote understanding. A simulation refers to a computerized version of the model which is run over time to study the behavior of the defined interactions. In [5], implementation of traffic simulation models is discussed where areas such as testing new designs, training personal and safety analysis are included. The input and output of traffic simulations are illustrated in the diagram below.



Many researchers prefer to carry out simulation and optimization using simulation experiments by means of noncommercial software packages; whether individually developed or open-source software packages [6, 7, 8, 9]. On the other hand [10] were concerned about the problem of signalization control in isolated intersections. They managed to solve the problem effectively offering promising contributions in optimizing the vehicular flow. However, fewer researchers managed successfully to model an urban traffic control network consisting of several multiple intersections, taking into consideration the interdependency between them [11, 12, 13].

In addition, optimization using simulation has arisen as one of the main solution techniques in the world. [14] Used an evolutionary optimizer, the set of signal timings controlling the road network that consisting of two major signalized intersections in Alexandria, Egypt city, the road network under study has been optimized and simulated. The paper emphasizes on enhancing the traffic performance through adequate management of signalization settings in order to solve the congestion problem that threatens the splendor of the city.

There are also some tries with evaluating the application of traffic simulation on the roundabout. For example, the simulating roundabout with VISSIM has been done by [15]. Additionally, [16] states that at high traffic volume roundabout brings out increase in highway capacity reduction in road accidents, well-coordinated and speedier travel time, the study conducted with the help of VISSIM simulation analysis.

Due to the importance of this network and its special geographical location, it is necessary to analyze the traffic congestion and the suggested proposals for solving this congestion. Simulation is an approach which can be used to model large, complex network systems for forecasting or performance measurement purposes [17, 18, 19]. It is the most common quantitative modeling technique used [17]. The selection of simulation as a modeling tool is usually because it is less restrictive. Other modeling techniques may impose material mathematical restrictions on the process, and also require multiple intrinsic assumptions to be made [18].

VISSIM is traffic microscopic simulation software which has been widely used assessing traffic conditions. It is especially useful to evaluate different traffic management scenarios to choose the best alternative and optimization measures before implementation. This study builds a road network model in VISSIM. This paper uses travel time, travel speed, queue length and delay as evaluation indicators to conduct the comparison [20, 21].

Thus the chapter describes some views of previous studies about estimating traffic network and its analysis, starting with definition of transportation system management (TSM) and explaining its objective. And complement this chapter is to clarify the traffic flow theory, and it’s both microscopic and macroscopic characteristics, describing their variables with equations. As well as, performance indicators which include the peak hour factor, the reliability of travel times, the levels of service, and measure of efficiency of road indicators have been briefly discussed.

In this chapter, it was necessary to describe some of the well-known software programs that used in the network simulating and analyzing in transportation engineering, at the end the adopted software programs have been discussed.

.

2.2 TRANSPORTATION SYSTEM MANAGEMENT (TSM)

Transportation Systems Management (TSM) is a strategy aimed at improving the overall performance of the transportation network without resorting to large-scale, expensive capital improvements. TSM integrates techniques from across disciplines to increase safety, efficiency and capacity for all modes in the transportation system [22, 23]. Urban traffic management system is also an important component which can properly control and guide the distribution of traffic flows on roads.

Transportation systems management strategies are low-cost but effective in nature, which include, but are not limited to:

- Intersection and signal improvements
- Freeway bottleneck removal programs
- Data collection to monitor system performance
- Special events management strategies

2.3 TRAFFIC FLOW THEORY

Traffic flow theories seek to describe in a precise mathematical way the interactions in the interactions between the vehicles and their operators and the infrastructure. The fundamentals of traffic flow and their characteristics have become important and form the foundation for all the theories, techniques and procedures that are being applied in the design, operation, and development of road transportation systems [24].

2.3.1 Microscopic Traffic Flow Characteristics

Road traffic flows are composed of drivers associated with individual vehicles, each of them having their own characteristics. These characteristics are called microscopic when a traffic flow is considered as being composed of such a stream of vehicles. The dynamical aspects of these traffic flows are formed by the underlying interactions between the drivers of the vehicles. This is largely determined by the behavior of each driver, as well as the physical characteristics of the vehicles [25]. In the remainder of this section, we always consider a vehicle-driver combination as a single entity, taking only into account some vehicle related traffic flow characteristics.

2.3.2 Macroscopic Traffic Flow Characteristics

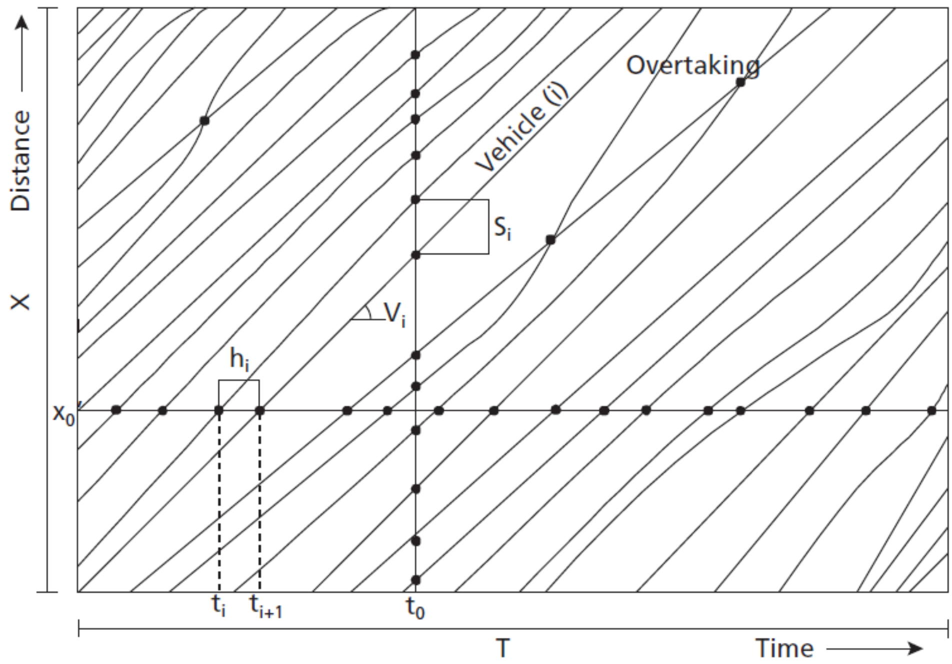


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Figure 2.1 Vehicle trajectories and key microscopic flow characteristics

In general, the flow *q* (also referred to as intensity or volume) is traditionally defined by the 'average number of vehicles (*n*) that pass a cross-section during a unit of time (*T*)'. According to this definition, flow is a local variable (since it is defined at a cross-section) [26]. We have:

Gross and net headways

The (gross) time headway (*h*) is one of the most important microscopic flow variables. It describes the difference between passage times *ti* at a cross section *x* of the rear bumpers of two successive vehicles [26]:

$$h_i(x) = t_i(x) - t_{i-1}(x) \quad (1)$$

Gross and net distance headways

On the contrary, distance headways (oft en denoted by the symbol *s*) are *instantaneous* (measured at one moment in time) microscopic variables, measuring the distance between the rear bumper of the leader and the rear bumper of the follower at time instant *t*:

$$s_i(t) = x_{i-1}(t) - x_i(t) \qquad (2)$$

It should be clear that the time headways and the distance headways are strongly correlated. If *vi*−1 denotes the speed of the leading vehicle, it is easy to see that [26]:

$$s_i = h_i * v_{i-1} \qquad (3)$$

Macroscopic flow variables

So far, we have mainly looked at microscopic traffic flow variables. Macroscopic flow variables, such as flow, density, speed and speed variance, reflect the average state of the traffic flow in contrast to the microscopic traffic flow variables, which focus on individual drivers. Let us take closer look at the most important variables [26].

Traditional definitions of flow, density and speed

In general, the flow *q* (also referred to as intensity or volume) is traditionally defined by the 'average number of vehicles (*n*) that pass a cross-section during a unit of time (*T*)'. According to this definition, flow is a local variable (since it is defined at a cross-section). We have:

This expression shows that the flow can be computed easily by taking the number of vehicles *n* that have passed the measurement location during a period of length *T*. The expression also shows how the flow *q* relates to the average headway *h*, thereby relating the macroscopic flow variable to average microscopic behavior (i.e. time headways) [26].

$$q = \frac{n}{T} = \frac{n}{\sum_{i=1}^{n} hi} = \frac{1}{h'} \qquad (4)$$

In a similar way, the density *k* (or concentration) is defined by the 'number of vehicles per distance unit'. Density is, therefore, a so-called instantaneous variable (i.e. it is computed at a time instance), defined as follows [26]:

$$k = \frac{m}{X} = \frac{m}{\sum_{i=1}^{m} Si} = \frac{1}{\dot{s}} \qquad (5)$$

Similarly to the definitions above, average speeds *u* can be computed in two ways: at a cross-section (time-mean speed, $\overline{v}_{TMS}$), or at a time instant (space-mean speed, $\overline{v}_{SMS}$), as shown in equations 6 and 7 respectively. The difference between these definitions can be very large. Surprisingly, in practice the difference is seldom determined. For instance, the Dutch motorway monitoring systems collect time-mean speeds, while for most applications (e.g. average travel time) the space-mean speeds are more suitable as described in the following subsections [26].

$$Time - Mean\ Speed, \overline{v}_{TMS} = avg.speed = \frac{\sum v_i}{n} = \frac{\sum \frac{d}{t_i}}{n} \qquad (6)$$

$$Space - Mean\ Speed, \overline{v}_{SMS} = \frac{distance\ traveled}{avg.\ travel\ time} = \frac{d}{\frac{\sum t_i}{n}} = \frac{n * d}{\sum t_i} \qquad (7)$$

- **Fundamental Relation of Traffic Flow Theory**

There exists a unique relation between three of the previously discussed macroscopic traffic flow characteristics density *k*, flow *q*, and space-mean speed $\overline{v}_s$ [10]:

$$q = k\, \bar{v}_s \qquad (2.29)$$

This relation is also called the *fundamental relation of traffic flow theory*.

2.4 PERFORMANCE INDICATORS

Performance measures are indicators that enable decision-makers and other stakeholders to monitor changes in system condition and performance against established visions, goals, and objectives. In this section, we will briefly discuss the peak hour factor, the reliability of travel times, the levels of service, and measure of efficiency of road indicators.

2.4.1 Peak Hour Factor

The Peak Hour Factor (PHF) simply can be identified as a measure of short term variations in traffic demand. Past research indicated that PHF has a strong impact on traffic analysis results because it is used to address the effect of traffic flow fluctuations on the highway system. As the traffic volume varies obviously with time and site, every study will get a different (PHF) values depending on time and location of collecting these volumes. Peak Hour Factor (PHF) is used to convert the hourly traffic volume into the flow rate that represents the busiest 15 minutes of the rush hour.

Per the HCM, the peak hour factor (PHF) is a measure of the demand fluctuation or variation within the peak hour period, usually expressed:

$$PHF = \frac{V}{4 * v_p}$$

Where*:*

vp = Peak 15-Minute Volume

V= Peak Hourly Volume

PHF= Peak Hour Factor

The TRB Highway Capacity Manual (HCM) [27] and the AASHTO Policy on Geometric Design of Highways and Intersections [28] recommend evaluating traffic conditions during the worst 15 minutes of either a design hour or a typical weekday rush hour. The existing guidelines provide typical values of PHF and advise using the PHF calculated from vehicle counts at analyzed or similar locations. The HCM recommends a PHF of 0.88 for rural areas and 0.92 for urban areas and presumes that capacity constraints in congested areas reduce the short-term traffic fluctuation. The HCM postulates 0.95 as the typical PHF for congested roadways.

2.4.2 Travel Times and Their Reliability

Travel time reliability is defined as the consistency of a given trip's travel time [29]. Travel time reliability is an important measure of congestion and can serve as a baseline for prioritizing improvements into a region's transportation system. Measures of travel time reliability attempt to quantify both the variability in travel times across different days and months and the variability across several times of a day. Travel time reliability is an alternative to the volume-to-capacity ratio, and can greatly help to determine the adequacy of the service provided by a transportation network [30].

1. Travel Time Definitions

Travel time, or the time required to traverse a route between any two points of interest, is a fundamental measure in transportation. A travel time is Traffic Engineering Staffs' good indicator for comparing present traffic conditions to those in the past, identify congested areas and make adjustments to traffic signal timings as necessary, and to identify overcrowded areas [31].

Travel time can be directly measured by traversing the route(s) that connects any two or more points of interest. Travel time is composed of *running time*, or time in which the mode of transport is in motion, and *stopped delay time*, or time in which the mode of transport is stopped (or moving sufficiently slow as to be stopped, i.e., typically less than 8 kph, or 5 mph). Figure (2.2) illustrates the concepts of running time and stopped delay time [31]:

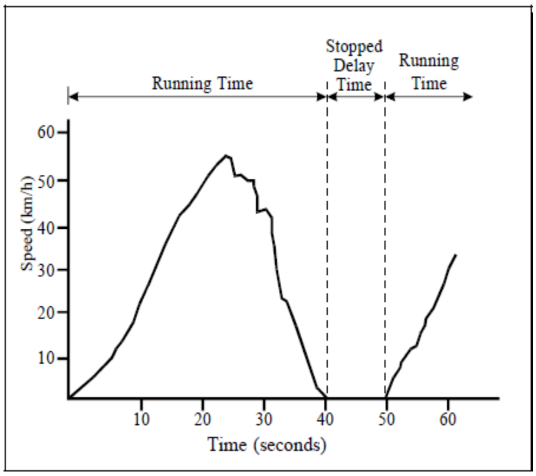


Figure 2.2 Illustration of Running Time and Stopped Delay Time

Travel time can also be estimated in certain cases by assuming the average speed at a particular point (spot speed) is constant for a relatively short distance (typically less than 0.8 kilometer, or 0.5 mile). The assumption of consistent speeds over a short roadway segment is most applicable to uninterrupted flow facilities (e.g., freeways or expressways) with stable traffic flow patterns. The estimated travel time can be computed using the average spot speed, or time-mean speed, and the roadway segment length, described in the equations below:

$$Estimated\ Travel\ Time\ (seconds) = \frac{Segment\ Length\ (km)}{Time - Mean\ Speed\ \left(\frac{km}{h}\right)} * \left(3{,}600\frac{sec}{hour}\right) \quad (1\text{-}1)$$

$$Time - Mean\ Speed, \bar{v}_{TMS} = avg.speed = \frac{\sum v_i}{n} = \frac{\sum \frac{d}{t_i}}{n} \quad (1\text{-}2)$$

$$Space - Mean\ Speed, \bar{v}_{SMS} = \frac{distance\ traveled}{avg.\ travel\ time} = \frac{d}{\frac{\sum t_i}{n}} = \frac{n * d}{\sum t_i} \quad (1\text{-}3)$$

$$Average\ Running\ Speed, \bar{v_r} = \frac{distance\ traveled}{avg.running\ \ time} = \frac{d}{\frac{\sum t_{ri}}{n}} = \frac{n * d}{\sum t_{ri}} \quad (1\text{-}4)$$

Where:
d = distance traveled or length of roadway segment;
n = number of observations;
v_i = speed of the ith vehicle;
t_i = travel time of the ith vehicle; and
t_{ri} = running time of the ith vehicle.

$$\bar{v}_{TMS} \approx \bar{v}_{SMS} + \frac{S^2_{SMS}}{\bar{v}_{SMS}} \quad (1\text{-}5)$$

Where:

$\bar{v}_{TMS}$ = sample time-mean speed;

$\bar{v}_{SMS}$ = sample space-mean speed; and

S^2_{SMS} = sample variance of the space mean speed.

2. Queuing Delays

In capacity analysis and simulation there are a number of measures used, among these measurements are average delay per vehicle, average queue length, and number of stops are the most common measurements. Delay is a measure that most directly relates driver's experience and it is measure of excess time consumed in traversing the intersection. Queue length is one of the most crucial performance measures for signalized intersections which is also critical to signal optimization. Length of queue at any time is a useful measure, and is critical in determining when a given intersection will begin to impede the discharge from an adjacent upstream intersection. Among these three, delay is the most frequently used measure of effectiveness for signalized intersections for it is directly perceived by a driver. The delay is measured in terms of flow rate and travel time in excess of the free-flow value. Delay is expressed in vehicle-hours. The estimation of delay is complex due to random arrival of vehicles, lost time due to stopping of vehicles, over saturated flow conditions etc. *Intersection delay* can be characterized by stopped delay, time in queue delay, and approach delay [32, 33].

3. Reliability and Robustness Properties

As travel time reliability considers the distribution of travel time probability and its variation across the road network; the higher the travel time variance is, the lower will be the travel time reliability. It is also true that under ideal conditions travel time reliability would have a variance equal to zero. Indeed, the increase of its variance will therefore significantly reduce its reliability [34].

Travel time reliability can be measure by two ways [34]:

The first measurement is the percent variation which expresses the relationship between the amount of variation and the average travel time in a percentage measure.

$$Percent\ variation = \frac{Standard\ Deviation}{Average\ travel\ time} \times 100\% \qquad (1)$$

The second is travel time buffer which adds the extra travel time of 95per cent trips in order to arrive on time.

$$Buffer\ time = 95th\ percent\ travel\ time\ for\ a\ trip - Average\ travel\ time \quad (2)$$

The planning index is the additional travel time of 95% trips in order to arrive on time which is obtained from the 95th percentile of the actual travel time.

$$Planning\ Index = 95th\ percent\ travel\ time\ for\ a\ trip \quad (4)$$

Travel time reliability measures, though valuable by themselves, can also be used to supplement other congestion measures. Additionally travel time reliability is an important measure of service quality for travelers [24].

Road network robustness is the *insusceptibility* of a road network to disturbing incidents, and could be understood as the opposite of network vulnerability. In other words, road network robustness is the *ability* of a road network to continue to operate correctly across a wide range of operational conditions. Since robustness is a relatively new concept in the road network domain, the existing studies on road network robustness mainly use the methods of network reliability analysis [36, 37].

2.4.3 Level of Service

Level of service (LOS) is a qualitative measure used to relate the quality of traffic service. LOS is used to analyze highways by categorizing traffic flow and assigning quality levels of traffic based on performance measure like speed, density, etc.

The following section pertains to only North American highway LOS standards as in the Highway Capacity Manual (HCM) and AASHTO Geometric Design of Highways and Streets ("Green Book")[24], using letters A through F, with A being the best and F being the worst:

A: free flow. Traffic flows at or above the posted speed limit and motorists have complete mobility between lanes.. LOS A occurs late at night in urban areas.

B: reasonably free flow. LOS A speeds are maintained, maneuverability within the traffic stream is slightly restricted.

C: stable flow, at or near free flow. Ability to maneuver through lanes is noticeably restricted and lane changes require more driver awareness. This is the target LOS for some urban and most rural highways.

D: approaching unstable flow. Speeds slightly decrease as the traffic volume slightly increases. Freedom to maneuver within the traffic stream is much more limited and driver comfort levels decrease. It is a common goal for urban streets during peak hours.

E: unstable flow, operating at capacity. Flow becomes irregular and speed varies rapidly because there are virtually no usable gaps to maneuver in the traffic stream and speeds rarely reach the posted limit. This is a common standard in larger urban areas, where some roadway congestion is inevitable.

F: forced or breakdown flow. Every vehicle moves in lockstep with the vehicle in front of it, with frequent slowing required. Travel time cannot be predicted, with generally more demand than capacity. A road in a constant traffic jam is at this LOS.

As an example, we provide an overview of the different levels of service in Table 2.1 below.

Table 2.1 Level of service (LOS) indicators for a motorway, adopted from [39], in similar form originally published in HCM 1985

LOS	Density (veh/km)	Occupancy (%)	Speed (km/h)
A	0 – 7	0 – 5	≥ 97
B	7 – 12	5 – 8	≥ 92
C	12 – 19	8 – 12	≥ 87
D	19 – 26	12 – 17	≥ 74
E	26 – 42	17 – 28	≥ 48
F	42 – 62 > 62	28 – 42 > 42	< 48

Calculating levels of service can be done using a multitude of methods; some examples include using the density (at motorways), using the space-mean speed (at arterial streets), using the delay (at signalized and un-signalized intersections) [37].

2.4.4 Efficiency

Efficiency is the comparison of what is actually produced or performed with what can be achieved with the same consumption of resources (money, time, labor, etc.) with a minimum amount or quantity of waste, expense, or unnecessary effort. It is an important factor in determination of productivity.

Chen et al. [47] state that the main reason for congestion is not demand exceeding capacity (i.e., the number of travelers who want to use a certain part of the transportation network, exceeds the available infrastructure's capacity), but is in fact the inefficient operation of motorways during periods of high demand. They investigate the speed during periods of very high flows based on the distribution of 5-minute data samples from some 3300 detectors. And this leads to a so-called sustained speed $\overline{v}_{sust}$ = 60 mil/h (which is around to 97 km/h).

They proposed a performance indicator called *efficiency* η and it based on the ratio of the total vehicle miles travelled (VMT), divided by the total vehicle hours travelled (VHT). As the units of VMT and v_{sust} should correspond to each other, some researchers in this subject propose to use the terminology of total vehicle distance travelled (VDT) instead of the VMT, in order to eliminate possible confusion. Both VDT and VHT are defined as follows:

$$\mathbf{VDT} = q\,K \qquad (2.34)$$

$$\mathbf{VHT} = \frac{\mathbf{VDT}}{\overline{v}_s} \qquad (2.35)$$

With, as explained before, q the flow, K the length of the road section, and $\overline{v}_s$ the space-mean speed, and by using the above definitions, we can write the efficiency of a road section as:

$$\eta = \frac{\mathbf{VDT}/\mathbf{VHT}}{\bar{v}_{sust}} \qquad (\mathbf{2.36})$$

The efficiency is expressed as a percentage, and it can rise above 100% when the recorded average speeds surpass the sustained speed $\bar{v}_{sust}$. Also the efficiency can be calculated for a complete road network and an arbitrary time period.

In contrast to the work of Chen et al., Brilon proposed another definition for the efficiency (now denoted with symbol *E*): it is expressed as the number of vehicle kilometers that are produced by a motorway section per unit of time [25]:

$$E = q\ \bar{v}_s\ T_{mp} \qquad (2.37)$$

With now *q* the total flow recorded during the time interval-T_{mp}. Brilon concluded that in order for motorways to operate at maximum efficiency, their hourly flows typically have to remain below the capacity flow [42].

2.5 SOFTWARE PROGRAMS OF TRAFFIC ANALYSIS

There is a large amount of traffic simulation models; in this section I have selected five well-known models, AIMSUN2, PARAMICS, CORISM, INTEGRATION, and VISSIM to be described. Each traffic simulation model has its unique underlying logic. This logic includes a car-following logic, a lane-changing logic, and gap acceptance logic [42].

AIMSUN: is short of Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks. This microscopic traffic simulation software is capable of reproducing various real traffic networks and conditions on a computer platform. The driver behavior models inside AIMSUN such as car-following model, lane changing model and gap-acceptance model provide the behavior of each single vehicle of the entire simulation period [44].

PARAMICS: is a widely used microscopic traffic simulation. The advantages of PARAMICS include the real-time dynamic three-dimensional visible user interface, which is easy to operate and understand; capable of using a large number of functionalities to simulate a traffic network and to "evaluate various policies and control strategies and their effects on the transportation network such as vehicle delays and emissions"; similar to AIMSUN, the model allows for the overriding or extending the default models using API (Application Programming Interface) [45].

CORSIM (CORidor SIMulation): CORSIM is a microscopic simulation model applies time step simulation to model traffic operations, implying that it models individual vehicle movements based on car-following and lane-changing theories on a second-by-second basis for the purpose of assessing the traffic performance of highway and street systems [46].

INTEGRATION: is a trip-based microscopic traffic simulation model. The two most important features of the INTGERATION software are first; it is the first model to attempt to integrate both freeways and arterials; second, it integrates traffic assignment and microscopic simulation within the same model. Furthermore, the model is capable of computing a number of measurements of effectiveness, including vehicle delay, vehicle stops, emissions and fuel consumption as well as the crash risk for 14 crash types [43].

VISSIM: is a time step and behavior based microscopic traffic simulation model. This traffic simulation software is developed to model urban traffic and public transit operations [43]. The detailed description of this program would be in the section 2.6.

2.6 ADOPTED SOFTWARE PROGRAMS

The adopted software programs of this study were PTV-VISSIM 6.0 and SIDRA INTERSECTION 5.1.

VISSIM is a microscopic, behavior-based multi-purpose traffic simulation to analyze and optimize traffic flows. It offers a wide variety of urban and highway applications, integrating public and private transportation. Complex traffic conditions are visualized in high level of detail supported by realistic traffic models [54].

VISSIM was developed by Planng Transport Verkehr (PTV), a German company. Innovative Transportation Concepts (ITC) based in Corvallis, Oregon distributes and supports VISSIM throughout Northern America. VISSIM is one of the latest micro-simulation software programs available and provides significant enhancements in terms of driver behavior, multi-modal transit operations, interface with planning / forecasting models, and 3-D simulation [49]. VISSIM provides animation capabilities similar to PARAMICS, with major enhancements in the 3-D simulation of vehicle types (i.e. from different passenger cars, trucks, transit vehicles, light rail and heavy rail). In addition, movie clips can be recorded within the program, with the ability of dynamically change views and perspectives. Other visual elements, such as trees, building, transit amenities and traffic signs, can be inserted into the 3-D animation [50].

VISSIM has been used now for analyzing all sizes of networks, ranging from single intersections to entire urban areas. Inside any of these transportation networks, we can model all networks functional classifications from freeways (motorways) to driveways by VISSIM. Many prevalent, in addition to unique, geometric and operational conditions present throughout the transportation system that VISSIM can simulate. In this study, we used VISSIM 6.0 for representing and analyzing the network by drawing all links and nodes and connect links with each other, in addition to setup the parameters, input vehicles, signal controllers.

SIDRA INTERSECTION (previously called Sidra and aaSidra) is a software package used for intersection and network capacity, level of service and performance analysis by traffic design, operations and planning professionals. First released in 1984, current version is SIDRA INTERSECTION 5.1 [51, 52]. It is a micro-analytical traffic evaluation tool that employs lane-by-lane and vehicle drive cycle models [52]. This program can be used to compare alternative treatments of individual intersections and networks of intersections involving signalized intersections (fixed-time/pre-timed and actuated). Roundabouts un-signalized, roundabouts with metering signals, fully signalized roundabouts, two-way stop and give-way (yield) sign control, all-way (4-way and 3-way) stop sign control, merging, single-point urban interchanges, traditional diamond and diverging diamond interchanges, basic freeway segments, signalized and un-signalized mid-block crossings for pedestrians, and merging analysis. Sidra Intersection allows modeling of separate Movement Classes (Light Vehicles, Heavy Vehicles, Buses, Bicycles, Large Trucks, Light Rail/Trams and two User Classes) with different vehicle characteristics [52, 53]. SIDRA INTERSECTION 5.1 have been used in this study for optimizing signal controllers of the network and for changing three of the network's signalized intersections by un-signalized roundabout and analyzing them.

CHAPTER THREE
DATA COLLECTION AND PROCESSING

3.1 INTRODUCTION

This chapter explains the study network's signalized intersection details, where the geometric design for each intersection has been expressed with enhancing by AutoCAD plans and Satellite images, as well as intersection's link details such as their names and dimensions are recorded in tables. At the end of this chapter the process of collecting data at the peak hour of the day described, and the volume of vehicles for each link that used in running the adopted software program are listed in a table.

3.2 DETAILED DESCRIPTION OF THE NETWORK

The Network which named 60-meter Street in Erbil city contains of ten nodes signalized intersections, as shown in figure (1.2) and (1.3). Figure (1.2) represents the location of the network according to the city, while Figure (1.3) is a plan shows dimensions between the nodes and flow directions in the network. It is the Main-Road in the city, which connects all the city and most of the main offices of Government and Companies, large-malls, hospitals, hotels even some Colleges are laying on this street, therefore, it is a very crowded road and there are a large number of vehicles passing this street, and it is intersections, especially at A.M. and P.M. peak hours.

Detailed description for each of ten intersections is shown below, in addition to the explanation of geometric characteristics by AutoCAD plans, Satellite images, and detailed tables.

3.2.1 Node Number 1 (Koye Intersection)

This intersection is a four-leg intersection, which connects Koya Road, two sides of 60meter street, and Setaqan Street, as shown in satellite image of figure (3.1). This intersection is crowded at A.M. and P.M. peak hours, because it connects the crowded way coming from *Koye* (Koye is a district east of Erbil city), most of the areas of new housing units laying on this way, therefore, they use this way as their main road for coming to the city center. On the other hand, Setaqan Street connects the 30 meter street to the 60 meter street, so that they use this intersection for going to or coming from 30 meter street also.

The layout of intersection is explained in figure (3.2), and the intersection links details and names are listed in table 3.1 below.

Table 3.1 Link directions and dimensions for node- 1

Node no.	**1**											
Link no.	101	102	103	104	105	106	107	108	109	110	111	112
No. of lanes	1	2	2	1	2	1	1	2	1	1	2	1
Link width (m)	3.5	7	7	3.5	7	3.5	3.5	7	3.5	3.5	7	3.5

Figure 3.1 A satellite image for node-1 (Koye Intersection), with marking the direction of its links

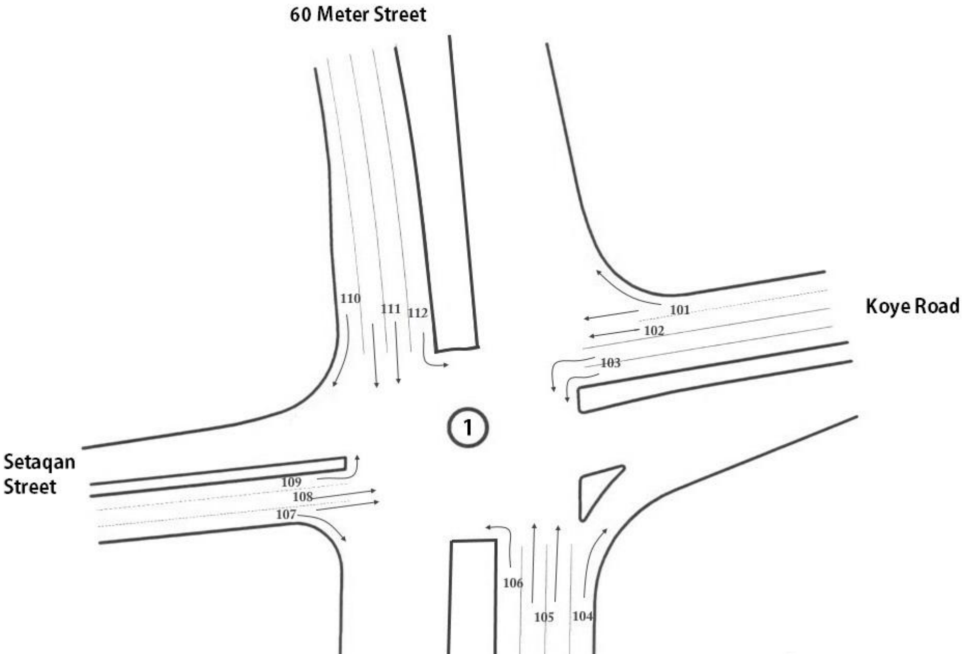


Figure 3.2 The layout of node-1 explaining the details of Koye Intersection

3.2.2 Node Number 2 (Shoresh Intersection)

It is a four leg intersection, which connects the Pirmam (Shorsh) road, two sides of 60 meter street, and Xanzad Road, as shown in satellite image of figure (3.3). This intersection is congested because, Pirmam Road is the main road for coming from and going to Pirmam and Shaqlawa (Districts north east to Erbil City), and additionally there are a number of new residential compounds and foreign villages lying on this road. Another reason for the congestion is reaching to the Khanzad Road, because it connects the 60 meter street to the 30 meter street. There is an overpass named (Shoresh Bridge) passes this intersection through the 60 meter street.

The geometric design of this intersection is shown in figure (3.4), as well as the description of the intersection link details and names shown in table 3.2 below.

Table 3.2 Link directions and dimensions for node- 2

Node no.						**2**						
Link no.	201	202	203	204	205	206	207	208	209	210	211	212
No. of lanes	1	2	1	1	1	2	1	2	1	1	1	2
Link width (m)	3.5	7	3.5	3.5	3.5	7	3.5	7	3.5	3.5	3.5	7

Figure 3.3 A satellite image for node-4 (Shoresh Intersection), with marking the direction of its links

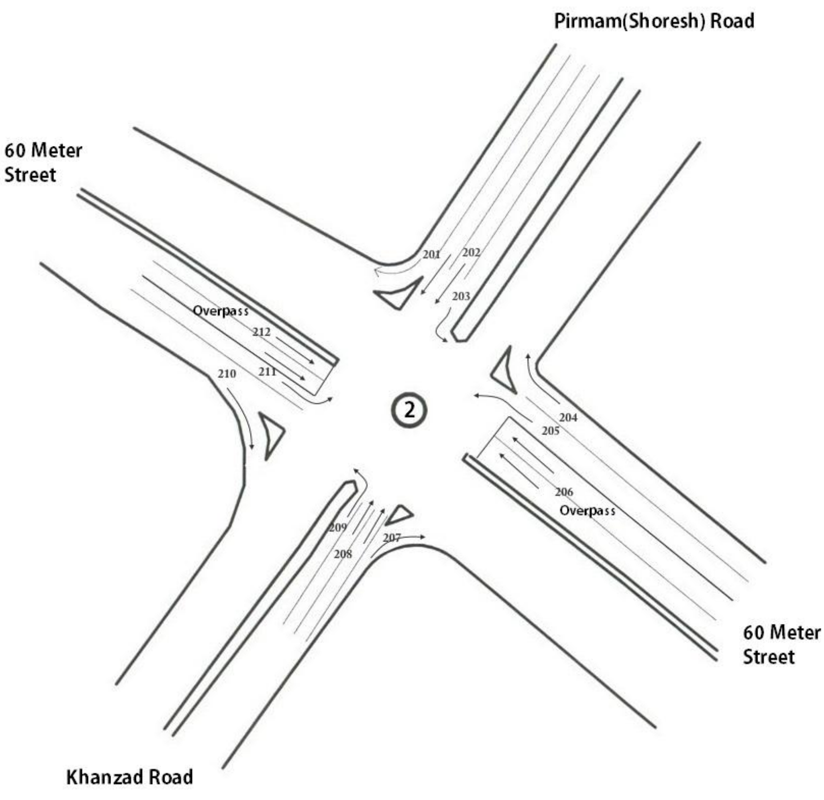


Figure 3.4 The layout of node-2 explaining the details of Shoresh Intersection

3.2.3 Node Number 3 (Ainkawa Intersection)

It is also a four leg intersection. This intersection connects Ainkawa Road, two sides of 60 meter street, and Pzishkan Road, as shown in satellite image of figure 3.5. There is also an overpass called (Franso Metran Bridge) passes this intersection through the 60 meter street. The Ainkawa and Pzishkan Roads are the main reasons for congesting this intersection, because there is a large number of vehicles coming from 40 meter street, 100 meter street, and from Ainkawa through Ainkawa road passing this intersection to 60 meter street, as well as Pzishkan Road is also congested because it connects the 60 meter street to the 30 meter street.

The details of geometric design of the intersection are shown in figure (3.6), while the intersection characteristics described in table 3.3 below.

Table 3.3 Link directions and dimensions for node- 3

Node no.	**3**											
Link no.	301	302	303	304	305	306	307	308	309	310	311	312
No. of lanes	1	2	1	1	1	2	1	2	1	1	1	2
Link width (m)	3.5	7	3.5	3.5	3.5	7	3.5	7	3.5	3.5	3.5	7

Figure 3.5 A satellite image for node-4 (Ainkawa Intersection), with marking the direction of its links

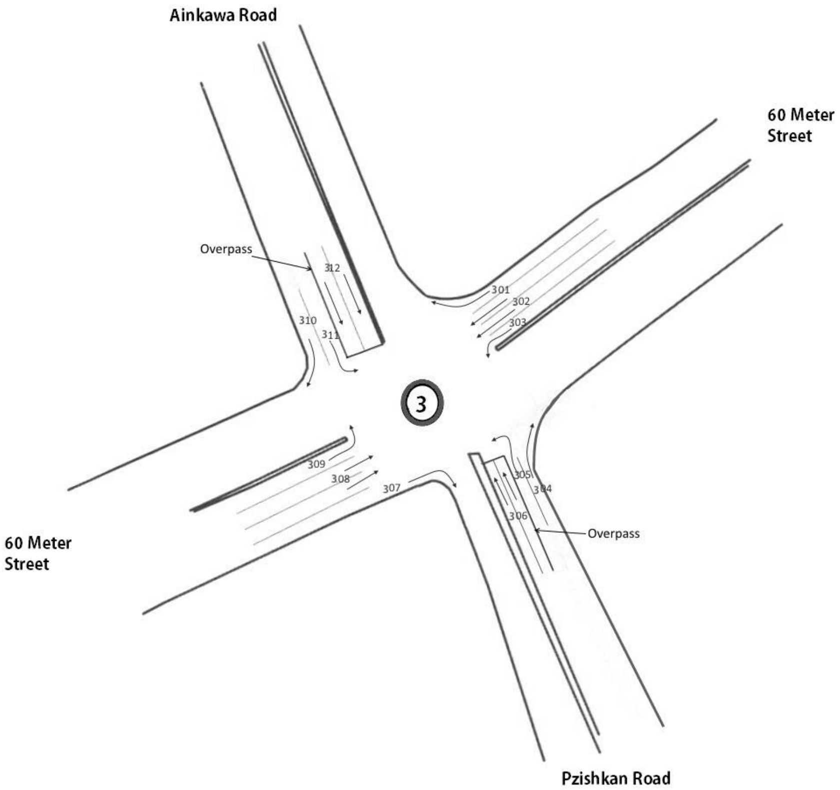


Figure 3.6 The layout of node-3 explaining the details of Ainkawa Intersection

3.2.4 Node Number 4 (Park Intersection)

This intersection is a three-leg (T) intersection, which connects the Zagros (Park) Road and two sides of 60 meter street, as shown in satellite image of figure (3.7). This intersection is congested at the A.M. and P.M. peak hours, because it is located near Parliament, Council of Ministers, and Ministry of Religious Endowments.

Details of intersection's geometric design shown in figure (3.8), and the intersection link names and other characteristics described in table 3.4 below.

Table 3.4 Link directions and dimensions for node- 4

Node no.			**4**			
Link no.	401	402	403	404	405	406
No. of lanes	1	2	1	4	2	2
Link width(m)	3.5	7	3.5	14	7	7

Figure 3.7 A satellite image for node-4 (Park Intersection), with marking the direction of its links

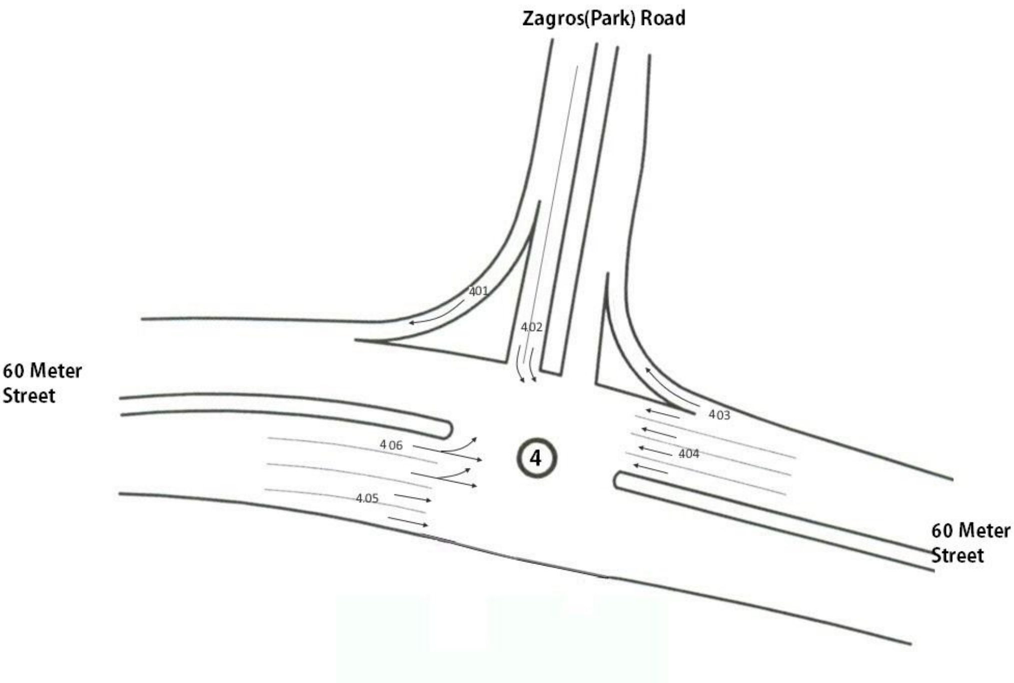


Figure 3.8 The layout of node-4 explaining the details of Park Intersection

3.2.5 Node Number 5 (Mosul Intersection)

This intersection is three-leg (T) intersection, which connects the Mosul Road and two sides of 60 meter street, as shown in satellite image of figure (3.9). There is an underpass named (Parliament Underpass) passes this intersection through 60 meter street.

This intersection is congested at the A.M. and P.M. peak hours not only because it is located near the Municipality of Finance and Economy, but there is a large number of vehicles want to flow from 60 meter street (505) to Mosul Road which they must stop at the traffic signal for more than one time because of inadequate in traffic signal timing and lane number because the underpass made the lane number smaller than it's required, explained in figure 3.10 below.

The geometric design of the intersection is shown in figure (3.10), while the intersection link details described in table 3.5 below.

Table 3.5 Link directions and dimensions for node- 5

Node no.			**5**			
Link no.	501	502	503	504	505	506
No. of lanes	1	2	2	2	2	2
Link width(m)	3.5	7	7	7	7	7

Figure 3.9 A satellite image for node-5 (Mosul Intersection), with marking the direction of its links

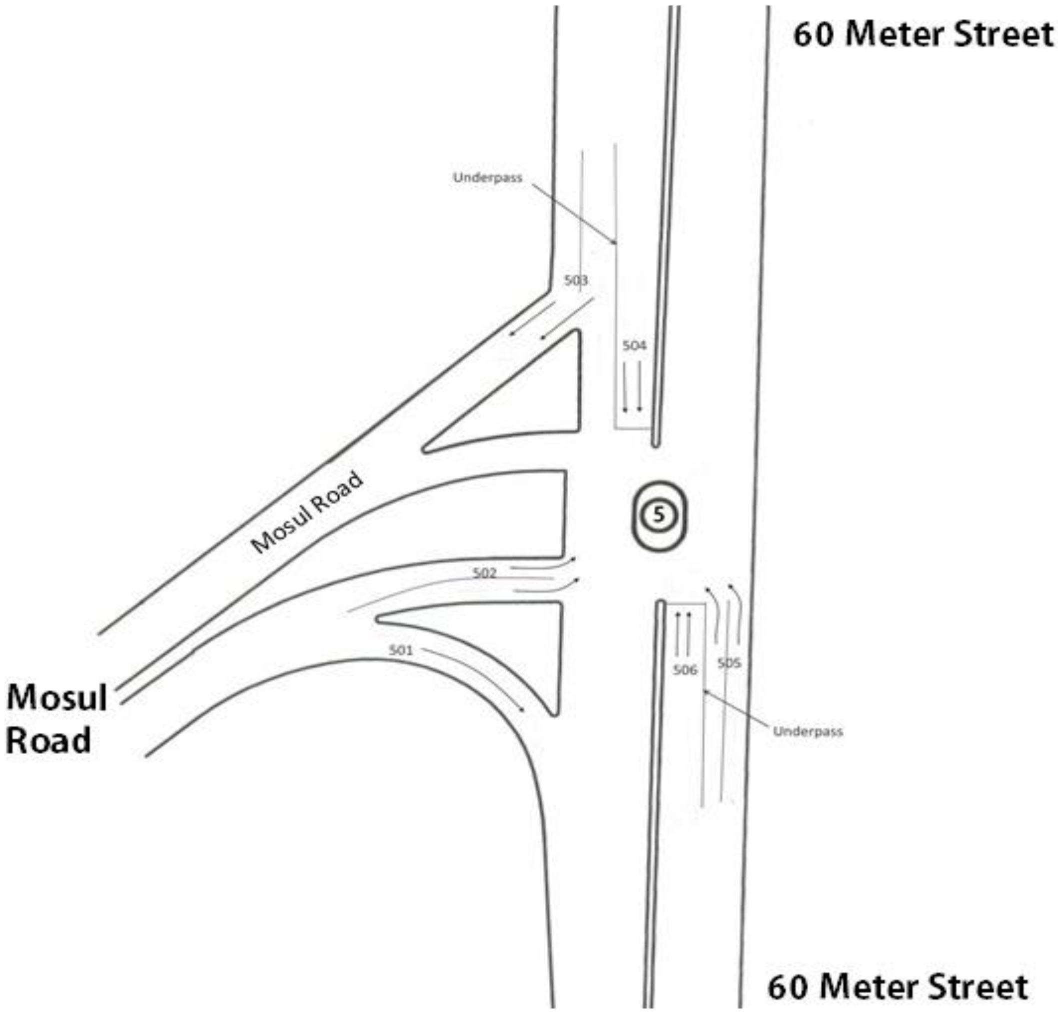


Figure 3.10 The layout of node-5 explaining the details of Mosul Intersection

3.2.6 Node Number 6 (Newroz Intersection)

This intersection is also a three leg intersection, which connects the Newroz Road with the two sides of 60 meter street, as shown in satellite image of figure (3.11).

Newroz Road passes through a wide range of residential areas, which is considered one of the most densely populated areas in the city of Erbil. For these areas the Newroz Road is considered as the main road for arriving to the 60 meter street, thus they have to cross this intersection, which causes congestion in the intersection.

The intersection’s geometric layout is shown in Figure (3.12), while the other links' characteristics are listed in Table 3.6.

Table 3.6 Link directions and dimensions for node- 6

Node no.			**6**			
Link no.	601	602	603	604	605	606
No. of lanes	1	2	1	3	2	2
Link width(m)	3.5	7	3.5	10.5	7	7

Figure 3.11 A satellite image for node-6 (Newroz Intersection), with marking the direction of its links

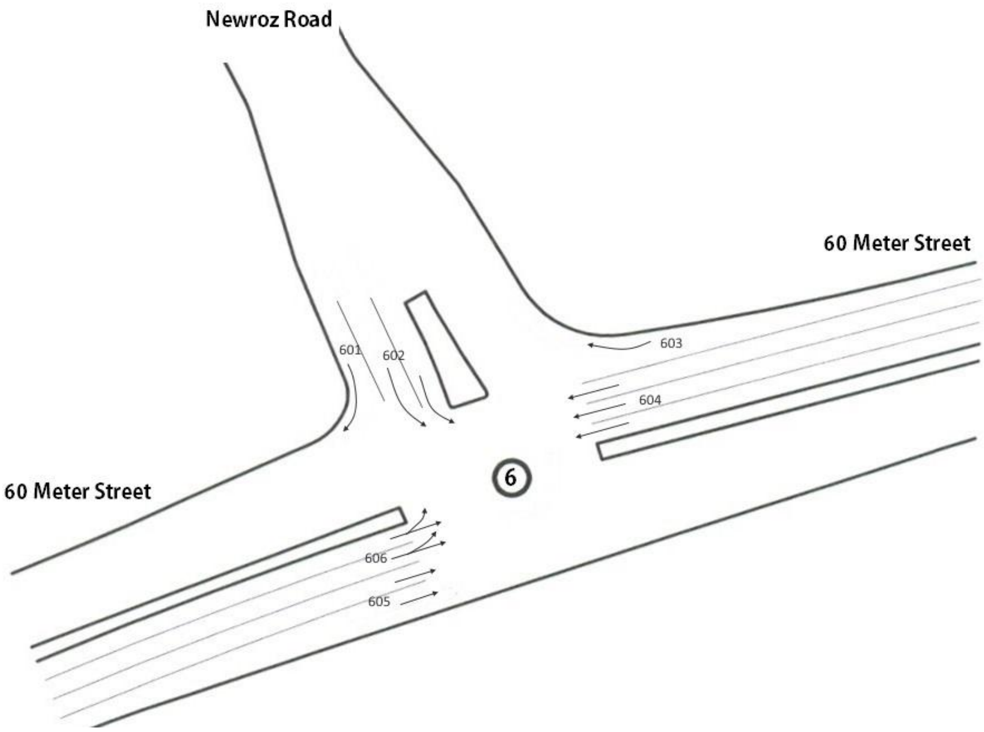


Figure 3.12 The layout of node-6 explaining the details of Newroz Intersection

3.2.7 Node Number 7 (Kuran Intersection)

It is a three leg intersection which connects the Makhmur (Kuran) Road and the two sides of 60 meter street, as shown in satellite image of figure (3.13).

This intersection is also a congested one, because Kuran is the name of Popular Old Market, which lays on Makhmur Road, there is as well a large number of big factories and auto maintenance and repair units laying on this road. In addition to these, Makhmur is a large village so that this road is the main road of this village to come toward the city center.

The details of geometric design and intersection link characteristics are shown in figure (3.14) and in table 3.7 respectively.

Note: There was the process of renewal of part of this intersection while the data have been taken.

Table 3.7 Link directions and dimensions for node- 7

Node no.			**7**			
Link no.	701	702	703	704	705	406
No. of lanes	1	2	1	3	2	2
Link width(m)	3.5	7	3.5	10.5	7	7

Figure 3.13 A satellite image for node-7 (Kuran Intersection), with marking the direction of its links

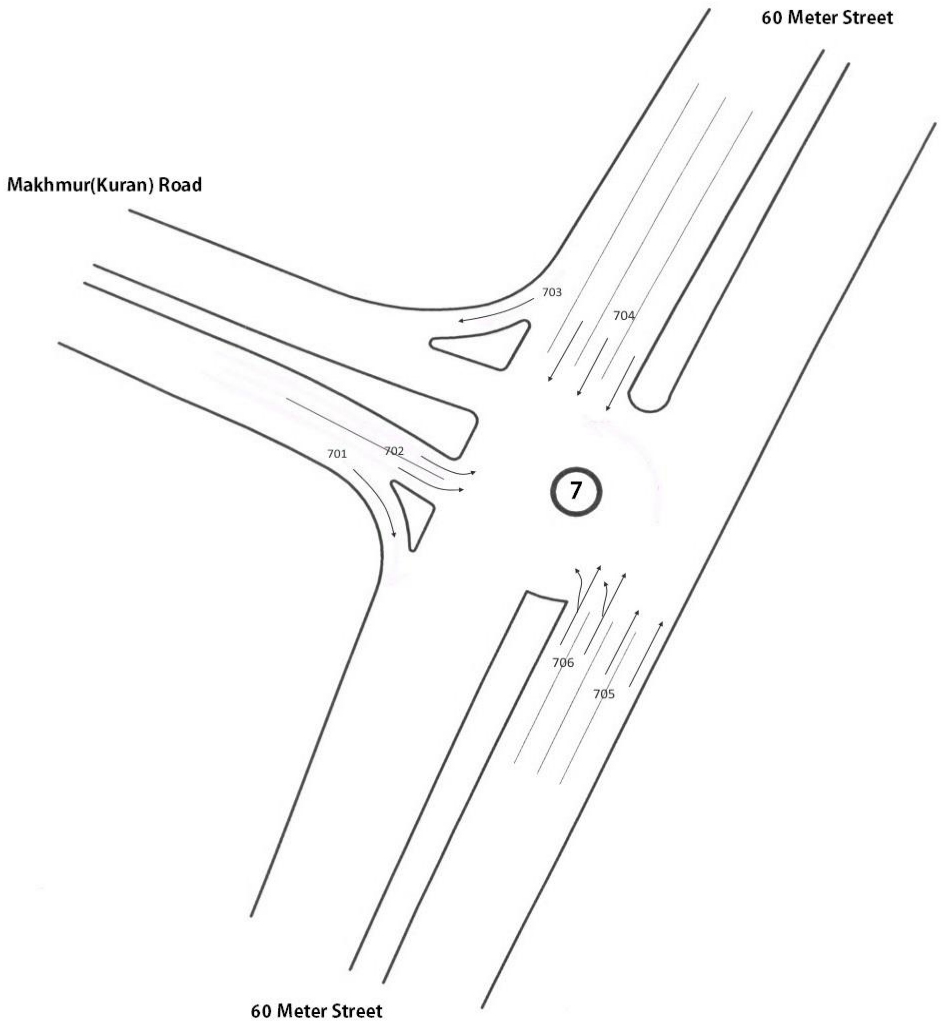


Figure 3.14 The layout of node-7 explaining the details of Kuran Intersection

3.2.8 Node Number 8 (Azadi Intersection)

This intersection is a four-leg intersection, which connects the two sides of Azadi Road and the two sides of 60 meter street, as shown in satellite image of figure (3.15). There are an overpass and underpass named (Martyr Akram Mantik Overpass) and (Martyr Akram Mantik Underpass) respectively in this intersection. The overpass passes through the two sides of 60 meter street, and the underpass passes through the two sides of Azadi Road.

This intersection is located in a very important area in the city, and it is crowded almost all the peak hour periods, because the first side of the Azadi Road as indicated in figure 3.16 is the main road for reaching number of Colleges, and the other side of the road is the chief road for a part of City-Center Market, explained in figure 3.16 below.

The geometric design of the intersection is shown in figure (3.16), as well as the intersection's link details shown in table 3.8.

Table 3.8 Link directions and dimensions for node- 8

Node no.						**8**						
Link no.	801	802	803	804	805	806	807	808	809	810	811	812
No. of lanes	1	2	1	1	1	2	1	2	1	1	1	2
Link width (m)	3.5	7	3.5	3.5	3.5	7	3.5	7	3.5	3.5	3.5	7

Figure 3.15 A satellite image for node-8 (Azadi Intersection), with marking the direction of its links

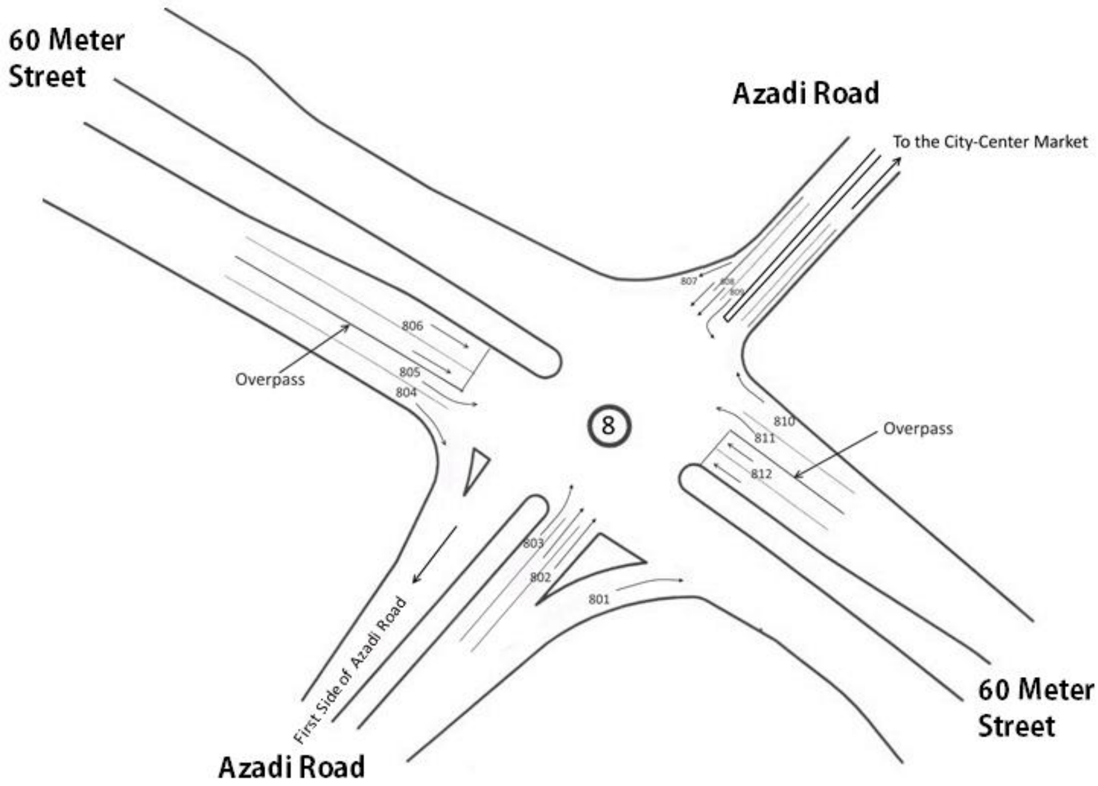


Figure 3.16 The layout of node-8 explaining the details of Azadi Intersection

3.2.9 Node Number 9 (Karkuk Intersection)

This intersection is also a four-leg intersection, which connects the Karkuk Road, the Sharawani Road, and the two sides of 60 meter street, as shown in satellite image of figure (3.17).

There are an underpass and overpass passing this intersection, they are also named (Martyr Akram Mantik Underpass) and (Martyr Akram Mantik Overpass) respectively. The underpass passes through Karkuk - Sharawani Roads, while the overpass is the same overpass that described in Node Number 8, which passes these two intersections.

Karkuk is another governorate in Iraq, and they use the Karkuk Road as the main road for coming to the center of Erbil city, additionally, there are also a number of Colleges, Institutes, Ministries, government departments, and in addition General Directorate of Traffic laying on this way. On the other hand, Sharawani Road leads to Ministry of Municipality of North of Iraq, Castle of Erbil, and Caesarea Market of the city. Therefore, it’s logical that these two roads loading a very large number of vehicles passing this intersection at A.M. and P.M. peak hours on the working days.

The description of the geometric layout of the intersection is shown in figure (3.18), while the link details explained in table 3.9 below.

Table 3.9 Link directions and dimensions for node- 9

Node no.						**9**						
Link no.	901	902	903	904	905	906	907	908	909	910	911	912
No. of lanes	1	2	1	1	1	2	1	2	1	1	1	2
Link width (m)	3.5	7	3.5	3.5	3.5	7	3.5	7	3.5	3.5	3.5	7

Figure 3.17 A satellite image for node-9 (Karkuk Intersection), with marking the direction of its links

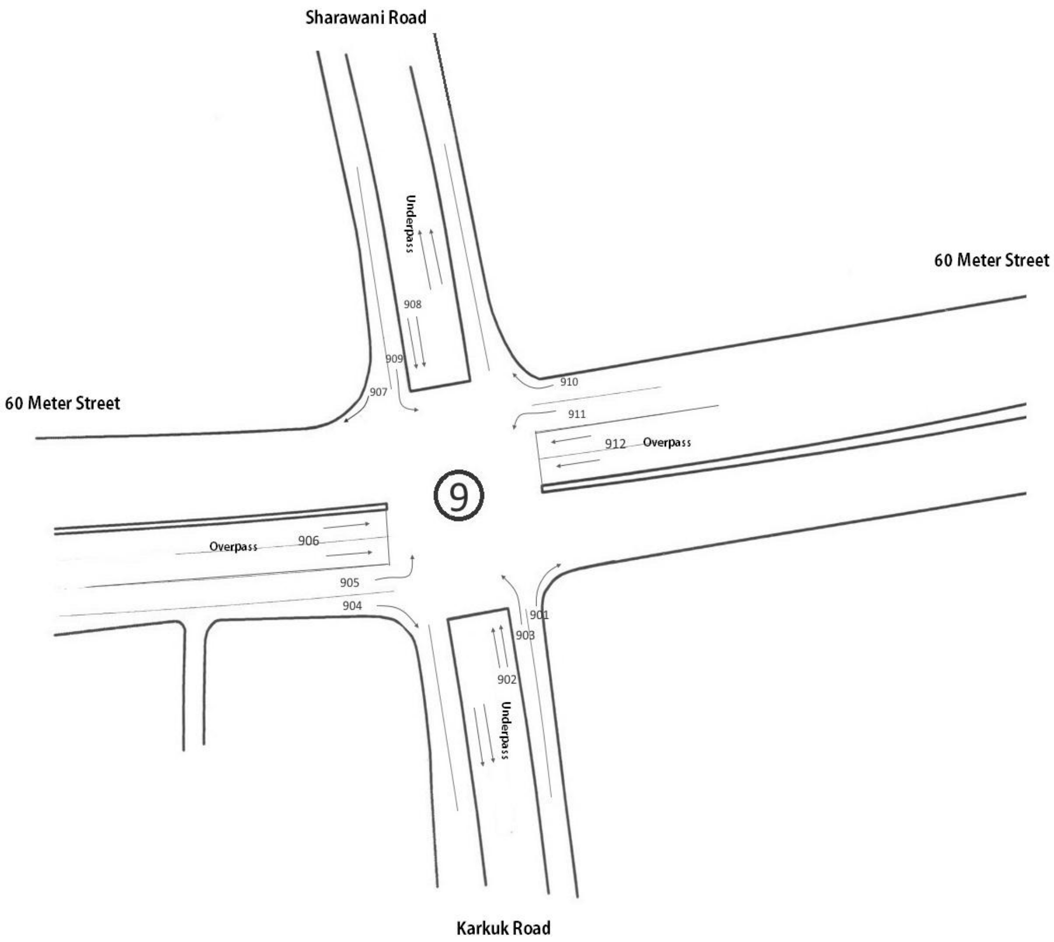


Figure 3.18 The layout of node-9 explaining the details of Karkuk Intersection

3.2.10 Node Number 10 (Iskan Intersection)

The last intersection is also a four-leg intersection, which connects the Ronaki Road, the Iskan Road, and the two sides of 60 meter street, as shown in satellite image of figure (3.19). There is an underpass called (Iskan Underpass) passes this intersection through the two sides of 60 meter street.

This intersection is always congested as it is an important connection between 30 meter street and 40 meter street, because Ronaki Road is connecting between 40 meter street and 60 meter street, while Iskan Road is connecting between 60 meter street and 30 meter street.

The intersection's geometric design is shown in figure (3.20), while the intersection characteristics listed in table 3.10 below.

Table 3.10 Link directions and dimensions for node- 10

Node no.						**10**						
Link no.	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012
No. of lanes	1	1	1	1	1	2	1	1	1	1	1	2
Link width (m)	3.5	3.5	3.5	3.5	3.5	7	3.5	3.5	3.5	3.5	3.5	7

Figure 3.19 A satellite image for node-10 (Iskan Intersection), with marking the direction of its links

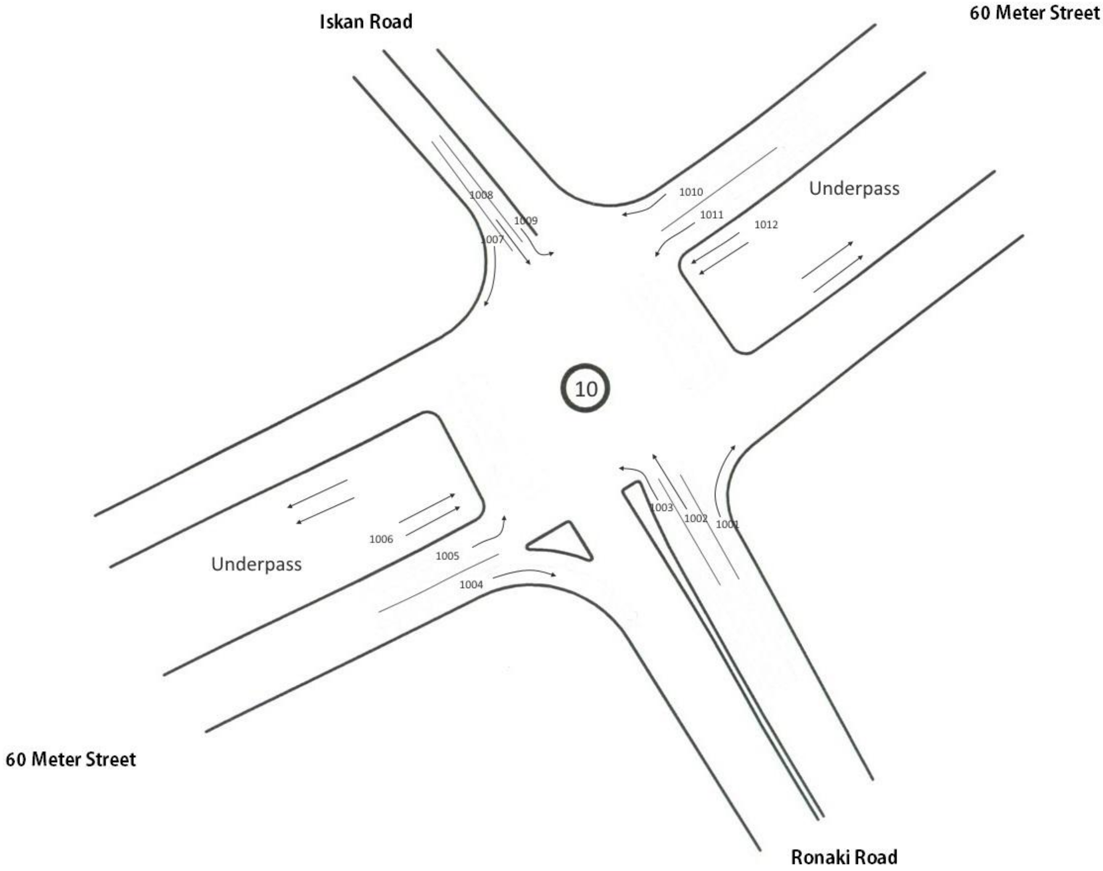


Figure 3.20 The layout of node-10 explaining the details of Iskan Intersection

3.3 VOLUME OF THE NETWORK

After fixing the location and counting the links of the network and calculating their geometric parameters, now it is important to determine the peak hour period consequently, the volume at peak hour.

3.3.1 Determination of peak hour period

For the highest capacity requirements, capacity delay and other traffic analyses concentrate on the traffic volume at the peak hour, because it represents the most critical period for operations. The peak hour volume, however, depending on the type of route and facility under study, it is not a constant value from day to day or from season to season. If the highest hourly volumes for a given location were listed in descending order, a large variation in the data would be observed.

Rural and recreational routes often show a wide variation in peak-hour volumes. Several extremely high volumes occur on a few selected weekends or other peak periods, and traffic during the rest of the year is at much lower volumes, even during the peak hour. This occurs because the traffic stream consists of few daily or frequent users; the major component of traffic is generated by seasonal recreational activities and special events. Urban routes, on the other hand, show little variation in peak-hour, because, for example, it's in all the days of the official working the same roads at the same times almost become crowded [54].

In order to represent the best time to collect data of peak volumes, volumes must be calculated for twelve hours continually for each intersection within a selected network by taking the average volumes of working days a week (from Sunday to Thursday). However, really the peak hour of this study is selected by putting the traffic camera on each road, and the results showed that this time which is 8:00-9:00 o'clock at the morning was the most crowded time of the day, because it's the time of the official working, University starting even the starting time of private schools too. On the other hand, personal discussions were made with traffic policemen and some users of the road. From all of these considerations, it was found that the peak hour of the network is at 8:00-9:00 A.M.

3.3.2 Counting traffic volume at peak hour

Because of continuous increasing traffic volume and complexity, traffic managers worldwide are faced with an increasing demand for state-of-the-art intelligent traffic information, mainly for traffic management and for safety issues [55].

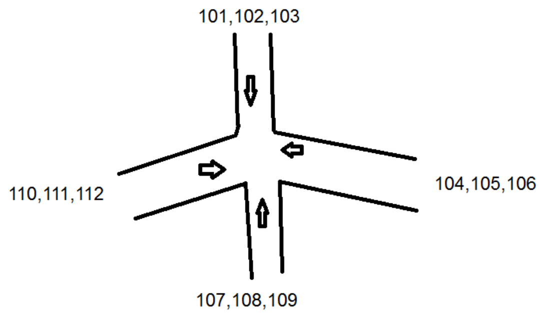
Video detection now is earning acceptance as a more effective technology than the classical technologies, and it has been available commercially for several decades. Traffic data collection using video image detection can offer a set of standard traffic data information about traffic flow at this point and the largest control of areas. In this study, the data collection, a very sensitive type of camera used, which is a special traffic Laser's camera which records the time, speed and the number of vehicles passed this way at the specified time by itself and sending the information to it's the specific laptop. Figure (3.21) and (3.22) below shows, the camera and an example of data recorded by this camera during my data collection.

Figure 3.21 Laser Traffic Camera

Figure 3.22 Sample of recorded data by Laser Traffic Camera
from (8:00-9:00) a.m.

The following table shows the volume, direction and name of links at a peak hour period. The operation of collecting data for all the links of intersections was at five working days in a week (from Sunday to Thursday) during A.M peak hour (v/h). It is started in October 2013 for three weeks. Volume counting was divided into 15-minute periods, as shown in the table 3.11 below.

Table 3.11 Volume (v/h) and direction of links at a peak hour period for all nodes of network (Links named in clock wise direction, started from outside of the network)



Node No.						**N**						
Link No.	N01	N02	N03	N04	N05	N06	N07	N08	N09	N10	N11	N12
Node No.						**1**						
Link No.	101	102	103	104	105	106	107	108	109	110	111	112
Volume	683	683	911	462	826	489	478	504	409	416	566	481
Node No.						**2**						
Link No.	201	202	203	204	205	206	207	208	209	210	211	212
Volume	788	567	907	368	346	1023	340	476	544	266	385	842
Node No.						**3**						
Link No.	301	302	303	304	305	306	307	308	309	310	311	312
Volume	562	578	648	288	400	1013	464	399	463	252	328	573
Node No.						**4**						
Link No.	401	402	403	404	405	406	407	408	409	410	411	412
Volume	655	160	---	479	1057	---	---	---	---	1284	161	---
Node No.						**5**						
Link No.	501	502	503	504	505	506	507	508	509	510	511	512
Volume	600	900	---	640	1203	---	---	---	---	782	743	---
Node No.						**6**						
Link No.	601	602	603	604	605	606	607	608	609	610	611	612
Volume	576	693	---	471	1485	---	---	---	---	740	436	---
Node No.						**7**						
Link No.	701	702	703	704	705	706	707	708	709	710	711	712
Volume	436	655	---	1210	917	---	---	---	---	376	608	---
Node No.						**8**						
Link No.	801	802	803	804	805	806	807	808	809	810	811	812
Volume	412	590	577	173	407	391	247	347	396	264	353	331
Node No.						**9**						
Link No.	901	902	903	904	905	906	907	908	909	910	911	912
Volume	419	419	349	147	384	561	310	319	384	263	356	537
Node No.						**10**						
Link No.	1001	1002	1003	1004	1005	1006	1007	1008	1009	1010	1011	1012
Volume	747	537	555	343	447	347	377	400	380	315	339	359

CHAPTER FOUR

SIMULATION AND CALIBRATION OF CASE STUDY

4.1 INTRODUCTION

This chapter represents the results obtained from simulation, which begins with showing a simulation, then the calibration made between existing and simulated volume's data dependent on Theil's-U, after that the measure of performance of the existing traffic network system has been described and showed by tables, in order to apply some proposals for improving the network performance such as optimizing the signals' cycle time and roundabouts some of the signalized intersections, later comparing the new results with the existing.

4.2 SIMULATION

Traffic simulation is increasingly being used to assess traffic operations along many different types of roadway networks. From highways to arterial streets, traffic simulation enables the engineer as well as the public to visualize traffic operations.

Microscopic simulation models have been widely used in both transportation operations and management analyses because simulation is safer, less expensive, and faster than field implementation and testing [20]. With the increase of traffic simulation as a tool for comparing one roadway alternative to another, one should understand the complexities in simulating the whole network. One benefit that simulation adds to an analysis is the ability to determine impacts of closely spaced intersections and their effects on each other. On the other hand, as traffic simulation proves to be a viable tool for analyzing traffic operations along proposed roadway networks, it is becoming important to be able to simulate "non-traditional" alternatives that may be proposed [21].

Test site and simulation model

Test Site

An urban arterial street network in *Erbil*, Iraq, was chosen for the test site. The site, presented in Figure 1, consists of an arterial, and 10 coordinated actuated signals. The 10 intersections contained coordinated actuated signal control.

Simulation Model: VISSIM

The simulation model used in this research was VISSIM, version 6.0. VISSIM is a microscopic, time step, and behavior-based simulation model. Essential to the accuracy of a traffic simulation model is the quality of the actual modeling of vehicles or the methodology of moving vehicles through the network. VISSIM uses the psychophysical driver behavior model developed by Weidman [21, 49].

To reduce stochastic variability, multiple runs must be conducted for each scenario from the experimental design. The average performance measure and standard deviation should be recorded for each of the runs.

4.3 DATA INPUT

The first task in the calibrating the VISSIM model was creating the study network for each mission. For the purpose of simulating traffic operations, it is necessary to replicate the modeled infrastructure network to scale. To attain this, base maps in a bit map format were imported and used to exactly trace a network in VISSIM.

Study networks were built based on the road geometry and infrastructure maps. Street networks are created in VISSIM through a series of links and connectors. Links are generally straight or follow the curvature of the road. Connectors, which are used to connect links, are typically used to model turning areas and lane expansions and contractions. In VISSIM, the creation of street networks is fairly simple through the use of a graphical interface and an aerial photograph in the background.

However, in VISSIM, two intersecting links does not automatically create a full intersection. The links only represent through traffic, and all left-tum and right-tum maneuvers need to be coded separately by connectors, which follow the path of the desired maneuver. To model a typical four-legged intersection in VISSIM, two links plus eight connectors need to be coded.

The vehicle population in VISSIM is categorized into *vehicles types*. A single type gathers vehicles that share common vehicle performance attributes. These attributes include model, minimum and maximum acceleration, minimum and maximum deceleration, weight, power, and length. All of these, except for model and length, are defined in VISSIM with probabilistic distributions (as opposed to scalars). Since no trucks were found on the study networks only one vehicle type called CAR was created to model the networks. Therefore traffic composition proportion was defined as 100% CAR. The vehicle specification for this type is identical to that of the default CAR type in VISSIM.

Traffic volume data, which includes input flow rates, turning movements at intersections, and traffic composition, were provided from the field.

A typical VISSIM run of the existing conditions model used for this study took an average 20 to 30 minutes to simulate a 1 hour and 15 minute simulation. The first 15 minutes were used to initialize the model. Statistics were gathered for the VISSIM runs only after the initial 15-minute period had elapsed. Pictures of two intersections (Node 8 and Node 9) of the study network in three different modes are shown below in Figures 4.1, 4.2, 4.3. Additionally, figure 4.4 shows the whole study network in VISSIM.

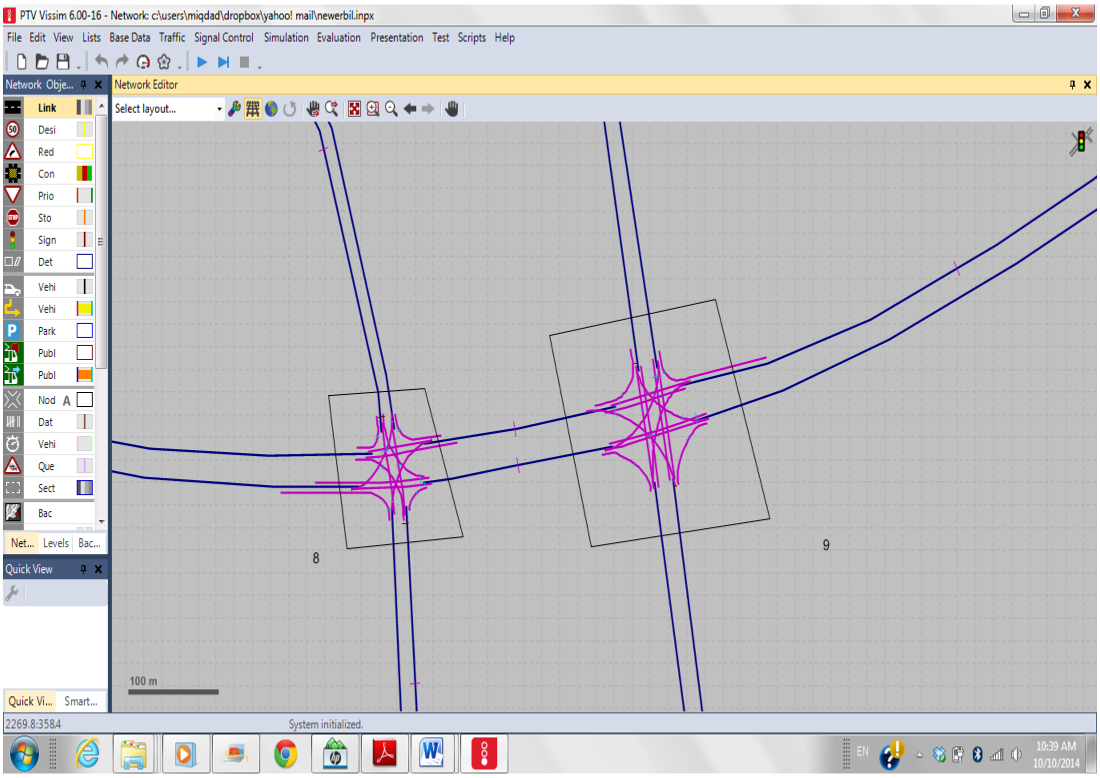


Figure 4.1 Node 8 and Node 9 links and connectors

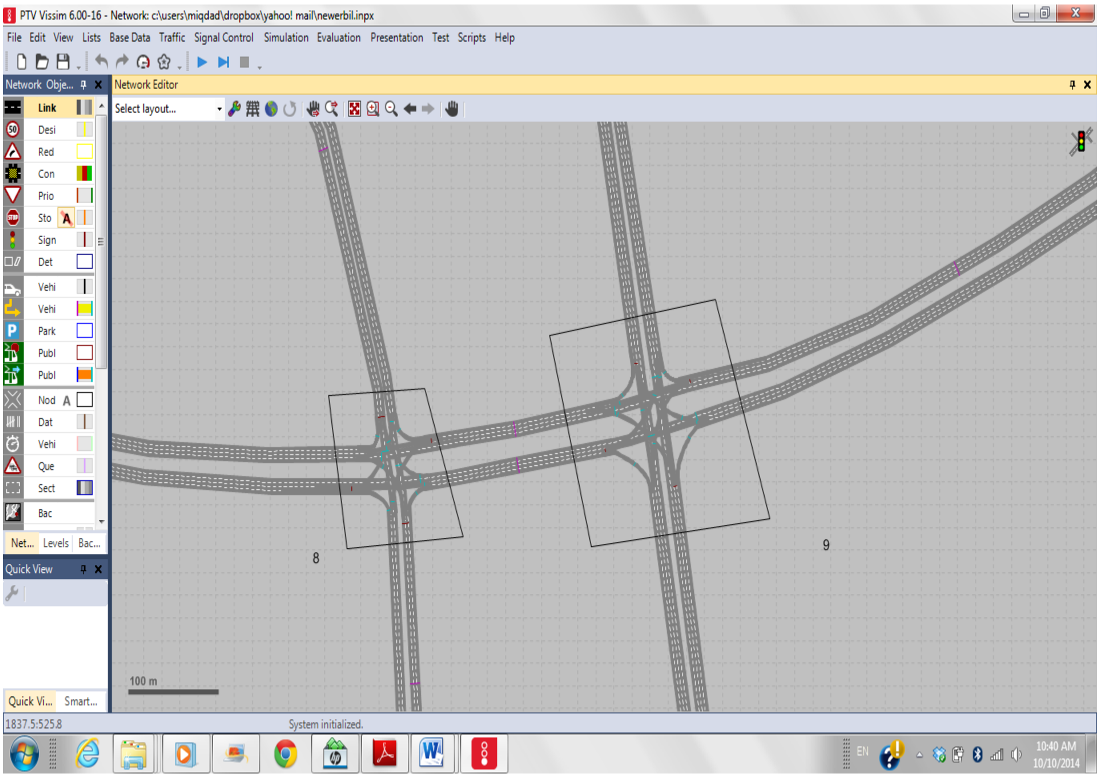


Figure 4.2 Node 8 and Node 9 with street drawings

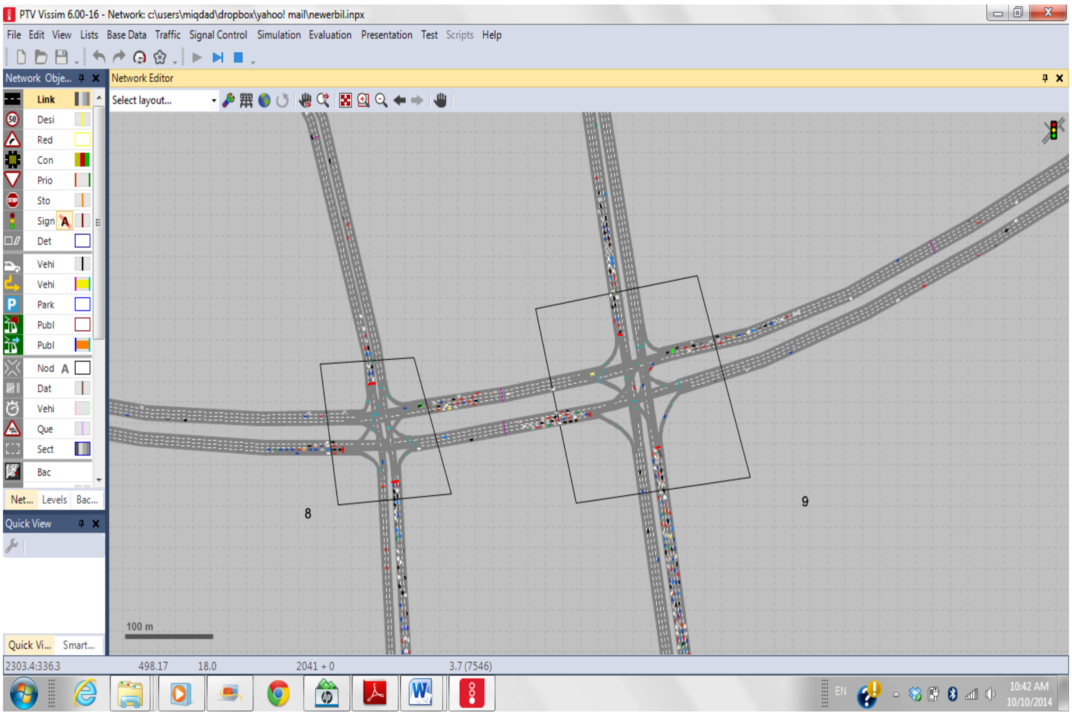


Figure 4.3 Node 8 and Node 9 during Simulation

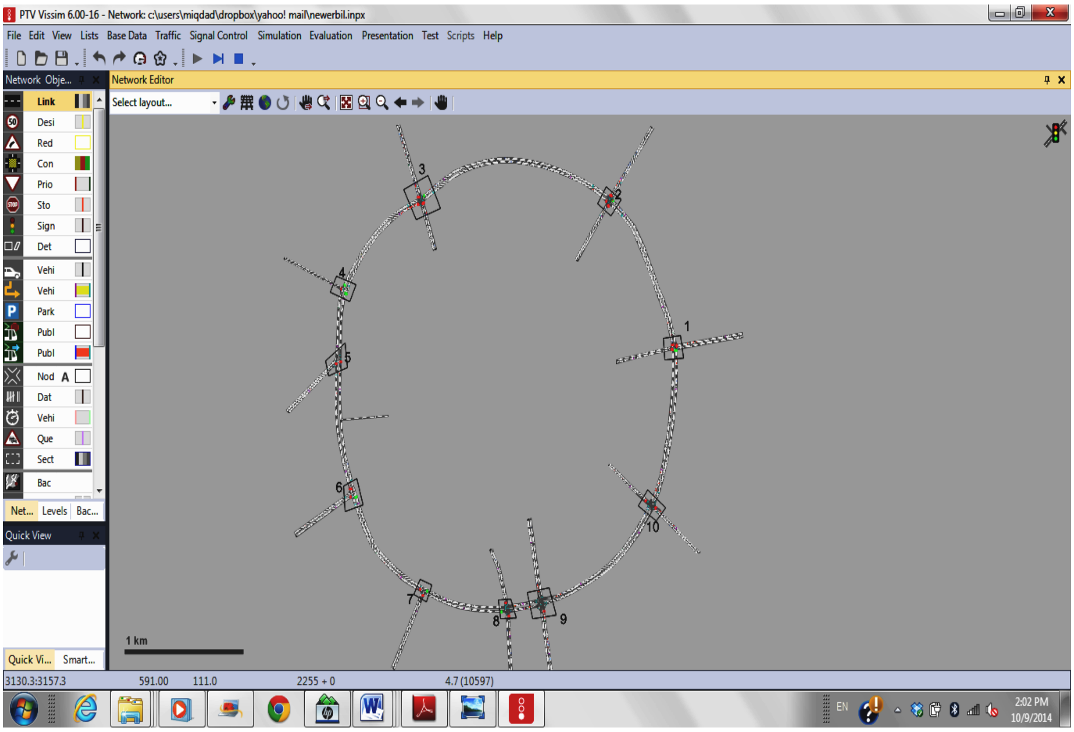


Figure 4.4 The Study Network in VISSIM

4.4 CALIBRATION

While analyzing network problems as well as attempting to solve them Calibration between observed (actual) volumes and simulated volumes is the most important stage in the study, in order to depend on this representation of the network and check the proposals of improving the performance of network, simulated flow must represent the indeed flow closely as it is possible.

After representing the network in adopted program and setting up all required data and parameters for simulation, this calibration can be done by using "***Theil's U***" a formula which contains both actual and simulated data as shown below in equation 4.1 [37, 20].

$$U = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - x_i)^2}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i)^2} + \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i)^2}} \tag{4.1}$$

Where:

n is the number of observations,

yi is the ground truth value for observation, *i*, and

xi is the simulated or detector reported value for observation *i*.

The results of U value will be between or equal to 0 to 1. The best values are the closest of 0, and the bad values are those closest of 1. There is no exactly trustworthy value of U, but often less than or equal 0.2 values give good forecasted results. The following classification of U, as shown in Table 4.1, is dependent by some specialists in simulation and forecasting data by interpreting the value (1 - Theil's U) [57].

Table 4.1 Interpreting Theil's U value

1 – Theil's U	**Classification (interpretation)**
From 1.00 to 0.80	Strong high forecasting power
From 0.80 to 0.60	Moderately high forecasting power
From 0.60 to 0.40	Moderate forecasting power
From 0.40 to 0.20	Weak forecasting power
From 0.20 to 0.00	Very weak forecasting power

Determination of dependent limits of values related with the accuracy required in the work. In this work, high accuracy is required, so that we will ratify the first and second classes shown in table- (strong high and moderately high) especially with main links that affect the flow inside the network. In other hands, we can adopt the third class (moderate) for the links that have less effectiveness on the network flow. After making simulation to the network by using adopted program (PTV-VISSIM) several times and checking the simulated volumes with the observed by Theil's U, the result was obtained of current cases. Table 4.2 shows calibration and U results for the ten nodes of the network (Appendix).

4.5 EVALUATION OF EXISTING TRAFFIC NETWORK RESULTS

The method used to evaluate the performance of the existing traffic network system is by simulating the patterns of this network. The simulation runs performed using the PTV-VISSIM6.0 program. Tables 4.3 and 4.4 below are showing results that evaluated for selected links, vehicle Speed average and network performance for the time interval of 300 seconds in the program, it means each 5 minutes of the peak hour. The nodes and zones are shown in figure 1.3.

Note: Link numbers in Table 4.3 are according to VISSIM program.

Table 4.3 Link segment results for important links selected in an existing network

Between nodes	VISSIM Link no.	No. of lanes	Link length (m)	Av. density (v/km)	Av. speed (km/h)	Av. loss time (s)	Av. volume (v/h)
1-2	1	4	1167.492	136.366	31.013	40.5	1280.349
2-1	12	4	1128.793	119.751	20.54	60.7	1135.397
2-3	9	4	1681.504	199.313	16.51	68.4	1331.650
3-2	11	4	1668.226	24.076	49.45	5.4	1102.244
3-4	19	4	918.017	20.299	51.41	1.6	1043.379
4-3	10	4	895.032	394.144	2.65	94.9	1028.491
4-5	8	4	498.484	25.432	47.02	6.1	1230.353
5-4	20	4	467.138	291.456	5.30	89.9	1208.337
5-6	7	4	839.810	30.261	48.93	6.5	1373.225
6-5	55	4	852.274	250.540	4.81	90.8	950.326
	56	4	631.936	29.250	51.22	1.9	1498.630
6-7	6	4	181.312	67.355	22.58	33.1	841.570
	57	4	625.329	36.846	43.89	16.0	883.360
7-6	17	4	203.331	9.755	51.88	1.2	503.115
7-8	5	4	668.264	250.540	4.81	90.8	950.330
8-7	50	4	664.609	15.044	50.46	3.8	758.643
8-9	49	4	210.267	384.468	2.04	91.6	775.676
9-8	16	4	213.141	32.373	31.32	39.9	309.397
9-10	4	4	1133.094	25.315	41.79	20.6	683.147
10-9	15	4	1125.096	219.525	11.29	78.3	925.687
	3	4	412.411	22.098	50.50	1.1	1143.186
10-1	2	4	668.714	39.803	44.55	13.2	1189.573
	13	4	654.250	302.347	4.12	92.4	1142.113
1-10	14	4	405.822	300.230	2.31	95.6	737.772

Table 4.4 Evaluation of network performance results

Avg of five runs	Time interval	Delay avg	Stop avg	Speed avg	Delay stop avg	Delay tot	Stop tot	Delay stop tot
	S	S		Km/hr	S	s		s
AVG	900-1200	166.43	15.3	11.52	122.28	794815.38	73086	583954.57
AVG	1200-1500	176.54	18.08	10.26	127.41	937893.03	96054	676946.88
AVG	1500-1800	188.54	20.61	8.93	135.3	1082781.59	118377	776974.69
AVG	1800-2100	197.71	21.77	7.98	143.27	1212399.86	133517	878574.42
AVG	2100-2400	204.26	22.75	7.38	148.62	1325549.08	147597	964527.73
AVG	2400-2700	210.72	23.58	6.79	154.54	1439254.36	161051	1055511.9
AVG	2700-3000	219.85	23.75	6.02	164.83	1538132.13	166157	1153210.85
AVG	3000-3300	222.93	23.62	5.71	168.38	1605416.6	170072	1212609.58
AVG	3300-3600	225.76	24.76	5.4	169.5	1673464.59	183537	1256403.1
AVG	3600-3900	229.93	24.58	5.02	175	1750638.76	187205	1332281.95
AVG	3900-4200	233.19	24.2	4.76	178.91	1824537.92	189367	1399774.36
AVG	4200-4500	233.49	26.3	4.71	175.04	1878606.74	211610	1408383.04
AVG		**209.11**	**24.12**	**7.02**	**155.62**	**1447309**	**164671.4**	**1087175**

The results in two tables above showed that the flow in the network is bad, and the average speed for most selected links is very slow, which leads to increasing the density and lost time, as indicated in Table 4.3. Furthermore, Table 4.4 illustrates a set of performance measurements of the network which is clearly showing a big delay and stops, in addition to slow average speed.

So that most of the network links are sorted with a level of service LOS F due to large density and slow speed according to Table 2.1 that shown in Chapter two above, and that positions the network under congestion conditions.

The following figure (4.5) better presents the congestion problem in one of the studied signalized intersections (Node 10), and this confirms that the flow in this intersection is bad and the problems of delay and queue could be seen easily. As a consequence, each car needs two or three traffic signal cycles for passing the intersection.

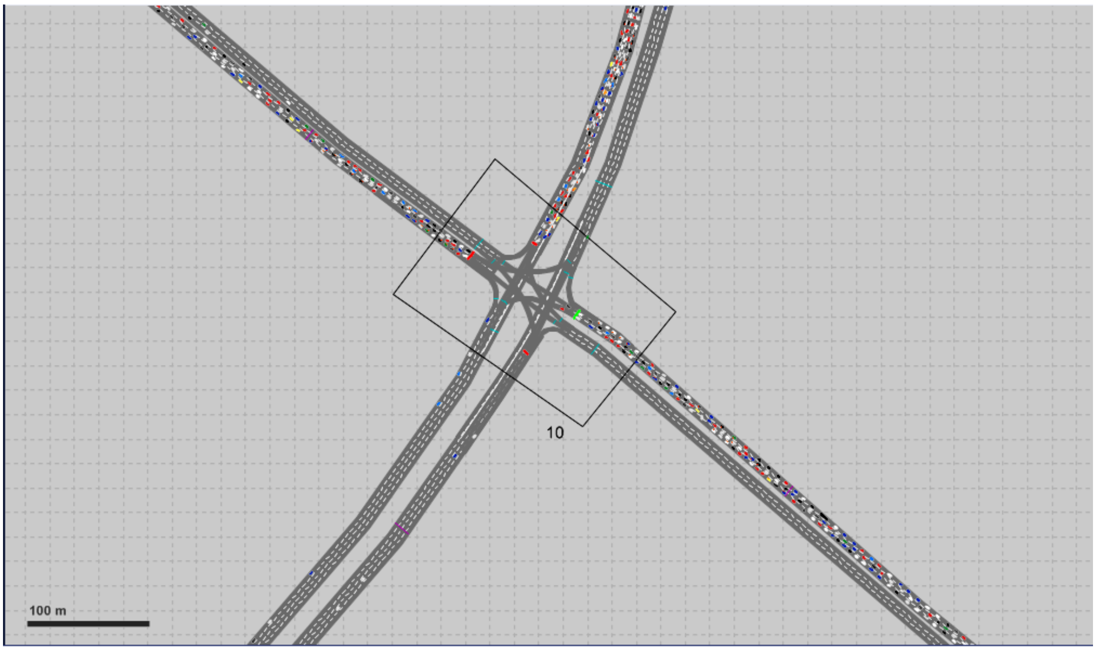


Figure 4.5 Node 10 represented by VISSIM 6.0 Program

4.6 PROPOSALS FOR IMPROVING NETWORK PERFORMANCE

Since the network is congested and having extremely bad results of performance measurements, improving the flow in this network will be needed by trying to decrease both delay and stops and increase the average speed, which will decrease the travel time in the network. For that aim, in the next section some proposals to solve the main reasons that cause the problems in the network have been suggested.

The first proposal to improve the congested networks is optimizing the signal time of the network intersections. The second proposal is installing roundabouts to improve safety and reduce congestion in certain intersections. After that other proposals for geometric design and dimensions will be explained.

4.4.1 Signal Optimization of the Network

In this network, all the intersections are signalized; therefore, for each intersection, the signal timing must be optimized. Then the results would be tested by simulating and running the changes in the Vissim6.0 program, after that we can compare the new outputs with the existing one. . Signal optimization can be done by using intersection expert software program SIDRA INTERSECTION, as explained in Chapter Two Section 2.6. SIDRA is a suitable program for calculating the time of the signal cycle. There are two parameters we must determine: 1) the cycle time and 2) green time distribution.

In first trial, the cycle time will be determined manually for each node by using equation 4.2 below [58], next calculating the green time distribution will be by SIDRA software program, later simulate the new signal time in the main program "VISSIM" to check the new results with the existing.

$$C_{min} = \frac{N t_L}{\left(1 - \frac{V_c}{3600/h}\right)} \qquad (4.2)$$

Where,

N = number of phases in the cycle

t_L = total lost time/ phase (start-up lost time + clearance lost time)

V_c = maximum sum of critical volumes

h = saturation headway

In second trail both cycle time and green distribution will be obtained from SIDRA, then the new results by VISSIM must compare with the existing results, as previous trail.

Trail- 1: (Manually cycle time & SIDRA's green time distribution)

The minimum cycle times that obtained from implementation Equation 4.1 for each node of the network are as shown in Table 4.5 below. Notice that we can use an increment value about 5 seconds up C_{min}.

Table 4.5 Values of length of cycle time for the network nodes

Node no.	1	2	3	4	5	6	7	8	9	10
C_{min} (s)	123	125	109	76	56	72	69	127	102	120
$C_{adopted}$ (s)	125	128	111	79	58	74	74	130	105	122

After representing these values and other data collection of the network in SIDRA software and processing the program, we will obtain the green time distribution of each cycle of nodes, as shown in Table 4.6.

Table 4.6 The green time distribution obtained from SIDRA for all nodes of the network

Node 1	**Cycle time: 125 s**			
Phases Direction from	**A**	**B**	**C**	**D**
Green time (s)	22	29	35	27
Green time + 3	25	32	38	30
Node 2	**Cycle time: 128 s**			
Phases Direction from	**A**	**B**	**C**	**D**
Green time (s)	16	25	43	32
Green time + 3	19	28	46	35
Node 3	**Cycle time: 111 s**			
Phases Direction from	**A**	**B**	**C**	**D**
Green time (s)	28	22	27	22
Green time + 3	31	25	30	25
Node 4	**Cycle time: 79 s**			
Phases Direction from	**A**	**B**	**C**	**---**
Green time (s)	27	16	27	---
Green time + 3	30	19	30	---
Node 5	**Cycle time: 58 s**			
Phases Direction from	**A**	**B**	**C**	**---**
Green time (s)	11	22	17	---
Green time + 3	14	25	19	---
Node 6	**Cycle time: 74 s**			
Phases Direction from	**A**	**B**	**C**	**---**
Green time (s)	27	16	22	---
Green time + 3	30	19	25	---
Node 7	**Cycle time: 74 s**			
Phases Direction from	**A**	**B**	**C**	**---**
Green time (s)	27	16	22	---
Green time + 3	30	19	25	---
Node 8	**Cycle time: 130 s**			
Phases Direction from	**A**	**B**	**C**	**D**

Green time (s)	36	32	28	22
Green time + 3	3	35	31	25
Node 9	**Cycle time: 105 s**			
Phases Direction from	**A**	**B**	**C**	**D**
Green time (s)	38	22	16	17
Green time + 3	41	25	19	20
Node 10	**Cycle time: 122 s**			
Phases Direction from	**A**	**B**	**C**	**D**
Green time (s)	32	25	36	17
Green time + 3	35	28	39	20

Note: 1) The cycle times of this table are calculated manually. 2) The 3 seconds that added represent the yellow time for each phase.

Now all values of cycle time and green time must be simulated in VISSIM program. Then, after running the simulation several times we will obtain the performance measurements of the network as shown in Table 4.7 below.

Table 4.7 The results of network performance measurements for trail- 1 (Manually cycle time & SIDRA's green time distribution)

Performance Measurements	Total delay (s)	Average delay (s)	Average speed (km/h)	Total stops	Average stops	Delay tot. stops (s)	Delay av. stops (s)
Average of 5 runs	1421957	207.63	7.04	155137	22.44	1058262	155.25

Trail- 2: (Both cycle time & green time distribution are by SIDRA)

The results of both cycle time and green time distribution are obtained from SIDRA INTERSECTION software program for all nodes of the network are as shown in Table 4.8 below.

As previously passed, all values of cycle times and green times will be simulated in VISSIM6.0 software program in order to calculate the new results of this trail. Table 4.9 below shows the results of the performance measurements of the network that obtained after running the simulation several times in the VISSIM6.0 program.

Now, to select which of the two trails is better we will compare the results of these two trails with the existing results of performance measurements of the network, in order to see the improvement degree for each of them. Table 4.10 below explains this comparison.

Table 4.8 Cycle time and green time distribution obtained by SIDRA for all nodes of the network

Node 1	**Cycle time: 115 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	22	27	30	24
Green time + 3	25	30	33	27
Node 2	**Cycle time: 100 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	16	22	28	22
Green time + 3	19	25	31	25
Node 3	**Cycle time: 105 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	25	22	24	22
Green time + 3	28	25	27	25
Node 4	**Cycle time: 120 s**			
Phases	**A**	**B**	**C**	**---**
Green time (s)	27	57	27	---
Green time + 3	30	60	30	---
Node 5	**Cycle time: 105 s**			
Phases	**A**	**B**	**C**	**---**
Green time (s)	47	22	27	---
Green time + 3	50	25	30	---
Node 6	**Cycle time: 80 s**			
Phases	**A**	**B**	**C**	**---**
Green time (s)	27	22	22	---
Green time + 3	30	25	25	---
Node 7	**Cycle time: 75 s**			
Phases	**A**	**B**	**C**	**---**
Green time (s)	27	17	22	---

Green time + 3	30	20	25	---
Node 8	**Cycle time: 95 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	22	22	17	22
Green time + 3	25	25	20	25
Node 9	**Cycle time: 90 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	29	17	16	16
Green time + 3	32	20	19	19
Node 10	**Cycle time: 80 s**			
Phases	**A**	**B**	**C**	**D**
Green time (s)	17	16	19	16
Green time + 3	20	19	22	19

Table 4.9 The results of network performance measurements for trail- 2 (Both cycle time & green time distribution are by SIDRA)

Performance Measurements	**Total delay (s)**	**Average delay (s)**	**Average speed (km/h)**	**Total stops**	**Average stops**	**Delay tot. stops (s)**	**Delay av. stops (s)**
Average of 5 runs	1407063	206.64	7.12	153135	22.16	1030051	150.9

Table 4.10 Comparing the degree of improvement for new results of signal optimization with existing

Performance Measurements	Total delay (s)	Average delay (s)	Average speed (km/h)	Total stops	Average stops	Delay tot. stops (s)	Delay av. stops (s)
The existing							
Average	1447309	209.11	7.02	164671.4	24.12	1087175	155.62
Trail- 1							
Average	1421957	207.63	7.04	155137	22.44	1058262	155.25
Improvement Degree %	-1.783	-0.708	0.284	-5.789	-7.131	-2.659	-0.238
Trail- 2							
Average	1407063	206.64	7.12	153135	22.16	1030051	150.9
Improvement Degree %	-2.781	-1.167	-1.425	7.001	-8.126	-5.254	-3.033

Clearly, trail-2 is better than trail-1 in improvement for all performance measurements of the network, hence the results of trail-2 can be taken by adoption as a proposal for signal optimization of the network.

4.4.2 Roundabout without Traffic Lights

Roundabout can effectively service traffic with decreased delay and greater efficiency than traffic signals, since there is no sequential assignment of right-of-way and thus no wasted time. Left turns are not subordinated to through traffic. Vehicles enter under yield control instead of stop control therefore have lower headways and higher capacities.

For applying this proposal, we used SIDRA INTERSECTION program for determining the geometric properties of the roundabouts and finding the level of service for each lane after roundabouts each intersection.

Table 4.11 below shows the performance measurement results of the network, these outputs have been achieved by running the Vissim6.0 program after changing three of intersections (Node 10,7,6) from traffic signal to round about without traffic lights as its shown in the figure (4.2) lower which is Node 10.

Table 4.11 Network performance measurement results after installing Roundabouts

Avg of five runs	Time interval	Delay avg	Stop avg	Speed average	Delay stop avg	Delay tot	Stop tot	Delay Stop tot
	S	S		Km/hr	s	s		S
AVG	900-1200	140.12	14.46	14.76	100.04	590527.6	60942	421612.59
AVG	1200-1500	156.81	16.84	12.51	113.39	707851.13	76004	511840.86
AVG	1500-1800	165.15	18.45	11.47	118.09	796202.33	88916	569400.79
AVG	1800-2100	174.04	19.72	10.37	125.01	886373.68	100439	636719.64
AVG	2100-2400	181.97	20.46	9.46	132.45	985996.25	110817	717730.34
AVG	2400-2700	193.09	21.35	8.28	143.17	1083914.09	119822	803717.87
AVG	2700-3000	198.65	21.83	7.89	148.44	1141587.9	125471	853095.84
AVG	3000-3300	201.49	21.91	7.59	150.67	1178692.44	128155	881427.73
AVG	3300-3600	205.21	22.75	7.1	154.14	1220596.97	135382	916790.36
AVG	3600-3900	206.21	22.46	7.25	154.99	1241928.78	135311	933420.57
AVG	3900-4200	207.46	23.41	7.06	154.54	1271518.48	143450	947240.51
AVG	4200-4500	208.38	23.71	6.86	155.23	1290721.7	146854	961456.65
AVG		**186.55**	**20.61**	**9.22**	**137.51**	**1032992.61**	**114296.91**	**762871.14**

Now the new performance results can be compared to the existing one, as in table 4.12 below, for approving the fact the signalization intersections waste more time because the “lost time” associated with startup and termination of green phase detracts further from the amount time that is available for moving traffic and Heavy left turns, even from exclusive lanes, require dedicated phases that rob time from the major movements and increase the total time lost due to startup and termination of traffic movements.

Table 4.12 Comparing degree of improvement for new results of the roundabout without traffic-lights with existing and signal optimization results

Performance Measurements	Total delay (s)	Average delay (s)	Average speed (km/h)	Total stops	Average stops	Delay tot. stops (s)	Delay av. stops (s)
The existing							
Average	1447309	209.11	7.02	164671.4	24.12	1087175	155.62
Trail- 1							
Average	1421957	207.63	7.04	155137	22.44	1058262	155.25
Improvement Degree %	-1.783	-0.708	-0.284	5.789	-7.131	-2.659	-0.238
Trail- 2							
Average	1407063	206.64	7.12	153135	22.16	1030051	150.9
Improvement Degree %	-2.781	-1.167	1.425	-7.001	-8.126	-5.254	-3.033
Roundabout result							
Average	1032992.61	186.55	9.22	114296.91	20.61	762871.14	137.51
Improvement Degree %	-28.627	-10.789	31.339	-30.591	-14.552	-29.829	-11.637

Figure (4.6) below represents Node 10 in Vissim6.0 at the time of 4121.00 seconds which means nearly at the end of one hour(4500 seconds), and that means approximately all the counted volume of vehicles has entered the network and there is no queue at any lane or any link. On the other hand, this proposal changed the Level Of Service LOS of this intersection from (D, E) which are the worst operating condition of network flow to (A, B) as a result of (SIDRA INTERSECTION program) as its shown in figure (4.7-a) and (4.7-b) lower.

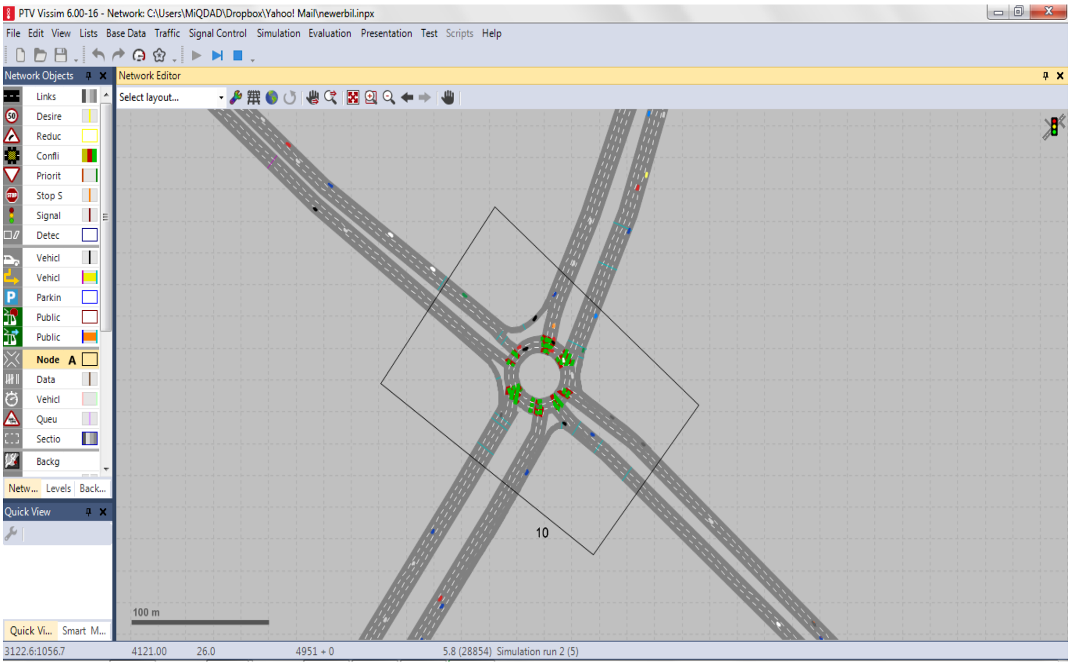


Figure 4.6 Node 10 with roundabout solution represented by VISSIM 6.0 Program

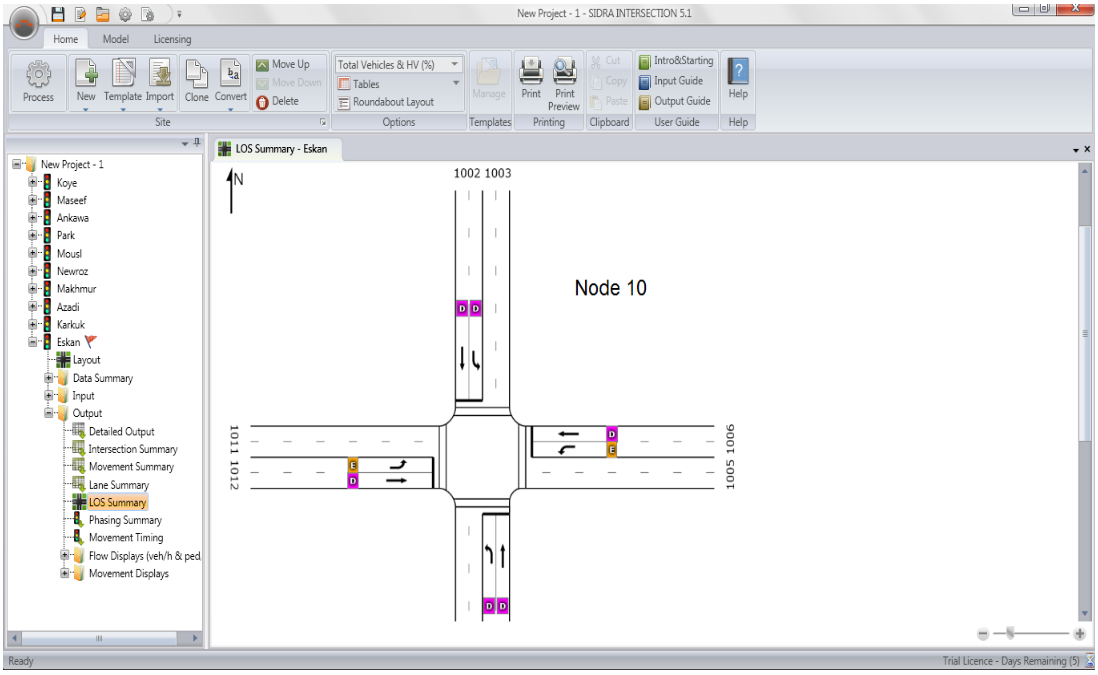


Figure 4.7-a Node-10 LOS results in SIDRA INTERSECTION program with traffic signals

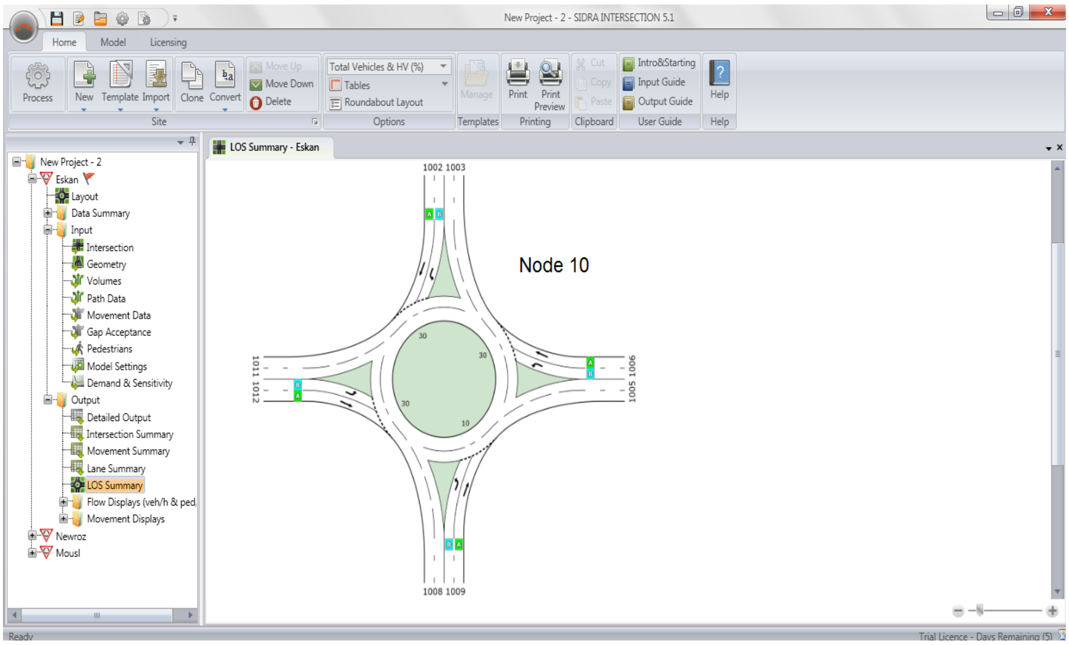


Figure 4.7-b Node-10 LOS results in SIDRA INTERSECTION program with roundabout

4.4.3 Geometric Proposals

The geometric design of any network is an important parameter to optimize efficiency and safety while minimizing cost and environmental damage. In addition to the two previous mentioned proposals, some changes and additions to the network geometric design with low-cost and in short-term will improve the performance of the network.

Geometrically 60 meter street is a good street to a large extend. However, because of the large volume of vehicles that entering this street it still includes the problems of congestion, even after the process of renewing that covered expansion of the street and building a number of overpasses and underpasses through the street and at the intersections to reduce congestion and facilitate the flow through the street.

Among the geometric proposals that we can offer for better performance of the street is widening, as this street has a wide *median* reaches to 9-meters in some parts of the street that can be used to expand the street on both sides. Additionally, there are *sidewalks* sometimes reaching to 7-meters along the sides of street, except near the intersections, that can also be used for generating additional lanes. Definitely, this will positively affect the speed and volume of traffic on the network.

Conclusion

This study has outlined a complete methodology for simulating and calibrating a congested urban network in Iraq named 60 meter street. The methodology included gathering and processing on field data from the traffic laser's camera and microscopic simulation with VISSIM. A successful calibration of the VISSIM model was carried out on the basis of this observation. It can be seen from the study's' analysis that the congestion in the selected network is serious. In an overall view, if we want to solve the pain of 60 meter street congestion, the general principle is making a public transport. Then the other proposals such as signal optimization, roundabout, and geometric proposals can solve this congestion without new infrastructures. In this study two proposals has been tested, optimizing signals' of the network and roundabout without traffic lights of the three of the network's intersections, with the fact that, the latter was most dependable and having better improvement results than the former.

CHAPTER FIVE

DISCUSSION AND RECOMMENDATIONS

5.1 DISCUSSION

This study dealt with the most usable and essential signalized network in a city, in an oil country with cheap price of gasoline and no tax on vehicle purchasing, in addition to poor public transport system.

The good thing in this study was the way of the data collection, that have been collected by a very advanced laser traffic camera which records the data on its special laptop as it's in the real time counting at the peak hour of the day.

Congestions of these types could not be solved easily by a normal signalized network's solutions like changing existing traffic signal cycle time by using the optimum cycle time. It needs another solution for solving the queue and delay problems at all signalized intersections. The other important point of this study is using and combining two significant traffic programs, such as *Sim-Traffic VISSIM6.0*, which has the possibility of assigning the flow, velocity , time and other parameters for making the simulation near the real-life conditions as it's possible. The other is *SIDRA INTERSECTION5.1* for finding the optimum cycle time and representing the effects of applied solutions on the LOS of each intersection. This program lets us to know which solution is better for solving your network problems such as the queue at traffic signals and delay and others by showing the outputs directly with all used data.

In urban areas it is very difficult and costly to increase road infrastructure capacity or rebuild the network, because of the limited space or right-of-way. Such a solution would not be fully sustainable anyway. Therefore, some regulations, policies and innovative technologies may be implemented in urban highway networks in order to ease congestion and to mitigate the undesirable side effects. However, every city's traffic conditions and possible solutions may be unique. Some solutions may work in one city but not in others [43].

Finally, traffic signal optimization is an effective way for improving urban network mobility but for the studied network with this heavy congestion the best solution without new infrastructure was found to be the roundabout without traffic signals at all intersections instead of using signalized intersections. This solution solved the queue at all intersections as shown in figure 4.1 (Node 10). Furthermore, the total delay in the network has been improved by -28.627% after changing the three intersections, Nodes 6, 7, 10, from signalized to roundabout intersections as indicated in table 4.12. On the other hand the roundabout solution has changed the LOS for the three tested intersections from "D, F" which are the worst operating conditions of network flow, depending on HCM to "A, B", as presented in figures 4.2-a and 4.2-b respectively.

It remains that the most suitable solutions for most of the congested urban networks are providing a good and modern public transport system like tramway or metro if the geometric designs of this existing network allow and the support from the administration of this country to provide the easier life for the citizens is existed.

5.2 FUTURE RECOMMENDATIONS

- As the type of camera mentioned in section 3.3 has become available and in use daily in Erbil now, we recommend the reported data to be used in future studies, because "Historical data" provides a graph report showing the historical traffic flow volumes and traffic speed of the transportation network during a selected time period. This information is useful for analyzing the performance of the transportation network and implementing proactive measures to improve the flow of traffic.

- It is better to consider driver's behavior and vehicle characteristics while analyzing in future studies.
- Conducting roadside surveys with drivers to understand origin and destination of trips and developing some measurements to reroute some of the demand transferring congested area
- Wider area network optimization and signal coordination to improve traffic

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APPENDIX

Table 4.2 Calibration results between observed and simulated volumes of nodes

Node Number	Link Number	Time Interval	Observed Volume	Simulated Volume	theil's U	1- theil's U
		8:00-8:15	136	115		
	101	8:15-8:30	240	117	0.317	0.683
		8:30-8:45	205	82		
		8:45-9:00	101	77		
		8:00-8:15	137	108		
	102	8:15-8:30	239	122	0.324	0.676
		8:30-8:45	205	76		
		8:45-9:00	102	72		
		8:00-8:15	183	147		
	103	8:15-8:30	319	135	0.373	0.627
		8:30-8:45	274	88		
		8:45-9:00	135	93		
		8:00-8:15	134	90		
	104	8:15-8:30	133	93	0.145	0.855
		8:30-8:45	95	87		
		8:45-9:00	100	92		
		8:00-8:15	232	126		
	105	8:15-8:30	200	111	0.290	0.710
		8:30-8:45	250	123		
		8:45-9:00	144	111		
		8:00-8:15	115	93		
	106	8:15-8:30	117	83	0.176	0.824
		8:30-8:45	133	92		
1		8:45-9:00	124	78		
		8:00-8:15	96	123		
	107	8:15-8:30	168	104	0.230	0.770
		8:30-8:45	143	69		
		8:45-9:00	71	73		
		8:00-8:15	122	109		
	108	8:15-8:30	168	83	0.257	0.743
		8:30-8:45	141	74		
		8:45-9:00	73	57		
		8:00-8:15	82	123		
	109	8:15-8:30	144	111	0.150	0.850
		8:30-8:45	121	88		
		8:45-9:00	62	61		
		8:00-8:15	109	84		
		8:15-8:30	100	85		

	110	8:30-8:45	143	44	0.302	0.698
		8:45-9:00	64	41		
	111	8:00-8:15	178	136	0.177	0.823
		8:15-8:30	187	121		
		8:30-8:45	98	67		
		8:45-9:00	103	74		
	112	8:00-8:15	158	91	0.247	0.753
		8:15-8:30	156	104		
		8:30-8:45	89	47		
		8:45-9:00	78	45		
2	201	8:00-8:15	159	96	0.375	0.625
		8:15-8:30	250	101		
		8:30-8:45	238	88		
		8:45-9:00	141	100		
	202	8:00-8:15	114	60	0.386	0.614
		8:15-8:30	188	74		
		8:30-8:45	170	64		
		8:45-9:00	95	74		
	203	8:00-8:15	197	94	0.393	0.607
		8:15-8:30	260	109		
		8:30-8:45	258	94		
		8:45-9:00	192	107		
	204	8:00-8:15	76	47	0.391	0.609
		8:15-8:30	115	44		
		8:30-8:45	110	40		
		8:45-9:00	67	40		
	205	8:00-8:15	112	61	0.230	0.770
		8:15-8:30	100	59		
		8:30-8:45	65	58		
		8:45-9:00	69	53		
	206	8:00-8:15	241	188	0.149	0.851
		8:15-8:30	300	198		
		8:30-8:45	239	191		
		8:45-9:00	243	192		
	207	8:00-8:15	68	71	0.223	0.777
		8:15-8:30	119	60		
		8:30-8:45	102	68		
		8:45-9:00	51	52		
	208	8:00-8:15	96	92	0.227	0.773
		8:15-8:30	167	83		
		8:30-8:45	142	95		
		8:45-9:00	71	82		
	209	8:00-8:15	109	101	0.254	0.746
		8:15-8:30	190	86		
		8:30-8:45	164	104		
		8:45-9:00	81	84		
	210	8:00-8:15	69	42	0.243	0.757
		8:15-8:30	80	44		
		8:30-8:45	54	39		
		8:45-9:00	63	40		

	211	8:00-8:15	99	65	0.159	0.841
		8:15-8:30	113	78		
		8:30-8:45	73	69		
		8:45-9:00	100	77		
	212	8:00-8:15	195	153	0.114	0.886
		8:15-8:30	199	175		
		8:30-8:45	213	173		
		8:45-9:00	235	175		
3	301	8:00-8:15	154	61	0.391	0.609
		8:15-8:30	179	71		
		8:30-8:45	150	63		
		8:45-9:00	79	76		
	302	8:00-8:15	134	62	0.388	0.612
		8:15-8:30	177	74		
		8:30-8:45	169	60		
		8:45-9:00	98	76		
	303	8:00-8:15	143	81	0.320	0.680
		8:15-8:30	198	92		
		8:30-8:45	174	79		
		8:45-9:00	133	93		
	304	8:00-8:15	64	48	0.259	0.741
		8:15-8:30	64	46		
		8:30-8:45	89	42		
		8:45-9:00	71	41		
	305	8:00-8:15	100	48	0.385	0.615
		8:15-8:30	98	44		
		8:30-8:45	113	43		
		8:45-9:00	89	44		
	306	8:00-8:15	299	126	0.318	0.682
		8:15-8:30	301	149		
		8:30-8:45	240	139		
		8:45-9:00	173	141		
	307	8:00-8:15	94	90	0.241	0.759
		8:15-8:30	162	78		
		8:30-8:45	139	88		
		8:45-9:00	69	72		
	308	8:00-8:15	81	76	0.238	0.762
		8:15-8:30	139	68		
		8:30-8:45	120	76		
		8:45-9:00	59	68		
	309	8:00-8:15	93	87	0.263	0.737
		8:15-8:30	162	72		
		8:30-8:45	139	84		
		8:45-9:00	69	75		
	310	8:00-8:15	59	38	0.255	0.745
		8:15-8:30	61	38		
		8:30-8:45	78	41		
		8:45-9:00	54	35		
		8:00-8:15	99	39		

	311	8:15-8:30	100	38	0.384	0.616
		8:30-8:45	72	39		
		8:45-9:00	57	38		
	312	8:00-8:15	127	109	0.100	0.900
		8:15-8:30	149	122		
		8:30-8:45	154	122		
		8:45-9:00	143	117		
4	**401**	8:00-8:15	132	162	0.148	0.852
		8:15-8:30	229	169		
		8:30-8:45	196	167		
		8:45-9:00	98	167		
	402	8:00-8:15	32	30	0.198	0.802
		8:15-8:30	56	32		
		8:30-8:45	48	33		
		8:45-9:00	24	30		
	403	8:00-8:15	127	87	0.121	0.879
		8:15-8:30	111	86		
		8:30-8:45	143	94		
		8:45-9:00	98	83		
	404	8:00-8:15	266	182	0.154	0.846
		8:15-8:30	290	206		
		8:30-8:45	272	195		
		8:45-9:00	229	208		
	405	8:00-8:15	466	385	0.148	0.842
		8:15-8:30	323	186		
		8:30-8:45	234	198		
		8:45-9:00	261	174		
	406	8:00-8:15	64	48	0.201	0.799
		8:15-8:30	49	24		
		8:30-8:45	23	21		
		8:45-9:00	25	21		
5	**501**	8:00-8:15	120	152	0.233	0.767
		8:15-8:30	210	142		
		8:30-8:45	180	79		
		8:45-9:00	90	69		
	502	8:00-8:15	180	230	0.243	0.757
		8:15-8:30	315	196		
		8:30-8:45	270	121		
		8:45-9:00	135	112		
	503	8:00-8:15	159	128	0.107	0.893
		8:15-8:30	165	126		
		8:30-8:45	162	133		
		8:45-9:00	154	130		
	504	8:00-8:15	262	230	0.134	0.866
		8:15-8:30	277	236		
		8:30-8:45	355	241		
		8:45-9:00	309	236		
		8:00-8:15	255	240		
		8:15-8:30	261	206		

	505	8:30-8:45	134	98	0.107	0.893
		8:45-9:00	132	87		
	506	8:00-8:15	254	204	0.116	0.884
		8:15-8:30	239	188		
		8:30-8:45	109	83		
		8:45-9:00	141	111		
6	601	8:00-8:15	114	146	0.128	0.872
		8:15-8:30	198	142		
		8:30-8:45	170	139		
		8:45-9:00	85	96		
	602	8:00-8:15	140	170	0.124	0.876
		8:15-8:30	242	179		
		8:30-8:45	207	165		
		8:45-9:00	104	84		
	603	8:00-8:15	119	92	0.170	0.830
		8:15-8:30	141	95		
		8:30-8:45	98	75		
		8:45-9:00	113	75		
	604	8:00-8:15	389	287	0.171	0.829
		8:15-8:30	402	289		
		8:30-8:45	393	249		
		8:45-9:00	301	236		
	605	8:00-8:15	221	181	0.111	0.889
		8:15-8:30	219	170		
		8:30-8:45	169	158		
		8:45-9:00	131	90		
	606	8:00-8:15	91	60	0.199	0.801
		8:15-8:30	83	59		
		8:30-8:45	77	58		
		8:45-9:00	71	39		
7	701	8:00-8:15	88	108	0.159	0.841
		8:15-8:30	152	108		
		8:30-8:45	131	86		
		8:45-9:00	65	62		
	702	8:00-8:15	132	162	0.134	0.866
		8:15-8:30	229	161		
		8:30-8:45	196	154		
		8:45-9:00	98	105		
	703	8:00-8:15	386	207	0.244	0.756
		8:15-8:30	379	207		
		8:30-8:45	231	204		
		8:45-9:00	214	186		
	704	8:00-8:15	251	222	0.124	0.876
		8:15-8:30	311	219		
		8:30-8:45	182	155		
		8:45-9:00	173	141		
		8:00-8:15	101	78		
		8:15-8:30	98	72		

	705	8:30-8:45	90	70	0.131	0.869
		8:45-9:00	87	69		
	706	8:00-8:15	173	134	0.103	0.897
		8:15-8:30	164	127		
		8:30-8:45	143	125		
		8:45-9:00	128	117		
8	**801**	8:00-8:15	84	48	0.363	0.637
		8:15-8:30	144	55		
		8:30-8:45	123	55		
		8:45-9:00	61	57		
	802	8:00-8:15	112	87	0.293	0.707
		8:15-8:30	177	92		
		8:30-8:45	203	91		
		8:45-9:00	98	90		
	803	8:00-8:15	117	80	0.345	0.655
		8:15-8:30	201	80		
		8:30-8:45	173	77		
		8:45-9:00	86	79		
	804	8:00-8:15	48	26	0.387	0.613
		8:15-8:30	45	20		
		8:30-8:45	51	16		
		8:45-9:00	29	17		
	805	8:00-8:15	99	73	0.208	0.792
		8:15-8:30	102	67		
		8:30-8:45	113	65		
		8:45-9:00	93	65		
	806	8:00-8:15	112	55	0.296	0.704
		8:15-8:30	93	55		
		8:30-8:45	97	52		
		8:45-9:00	89	52		
	807	8:00-8:15	50	58	0.259	0.741
		8:15-8:30	85	39		
		8:30-8:45	74	43		
		8:45-9:00	38	32		
	808	8:00-8:15	69	71	0.371	0.629
		8:15-8:30	121	49		
		8:30-8:45	105	57		
		8:45-9:00	52	49		
	809	8:00-8:15	79	64	0.258	0.642
		8:15-8:30	137	50		
		8:30-8:45	120	51		
		8:45-9:00	60	48		
	810	8:00-8:15	73	29	0.387	0.613
		8:15-8:30	80	33		
		8:30-8:45	67	30		
		8:45-9:00	44	29		
	811	8:00-8:15	111	45	0.353	0.647
		8:15-8:30	94	40		
		8:30-8:45	82	45		
		8:45-9:00	66	47		

	812	8:00-8:15	87	30	0.316	0.684
		8:15-8:30	100	29		
		8:30-8:45	75	29		
		8:45-9:00	69	29		
9	**901**	8:00-8:15	104	51	0.354	0.646
		8:15-8:30	113	50		
		8:30-8:45	123	52		
		8:45-9:00	79	53		
	902	8:00-8:15	83	113	0.169	0.831
		8:15-8:30	146	110		
		8:30-8:45	127	122		
		8:45-9:00	63	124		
	903	8:00-8:15	103	38	0.384	0.616
		8:15-8:30	88	38		
		8:30-8:45	91	42		
		8:45-9:00	67	42		
	904	8:00-8:15	56	19	0.388	0.612
		8:15-8:30	39	19		
		8:30-8:45	29	17		
		8:45-9:00	23	17		
	905	8:00-8:15	109	64	0.219	0.781
		8:15-8:30	113	62		
		8:30-8:45	79	67		
		8:45-9:00	83	66		
	906	8:00-8:15	201	103	0.259	0.741
		8:15-8:30	193	108		
		8:30-8:45	79	100		
		8:45-9:00	88	101		
	907	8:00-8:15	89	37	0.396	0.604
		8:15-8:30	101	35		
		8:30-8:45	53	33		
		8:45-9:00	67	37		
	908	8:00-8:15	63	95	0.163	0.837
		8:15-8:30	110	104		
		8:30-8:45	95	105		
		8:45-9:00	51	111		
	909	8:00-8:15	100	42	0.388	0.612
		8:15-8:30	112	45		
		8:30-8:45	89	45		
		8:45-9:00	83	39		
	910	8:00-8:15	95	36	0.384	0.616
		8:15-8:30	78	32		
		8:30-8:45	51	32		
		8:45-9:00	39	28		
	911	8:00-8:15	94	49	0.301	0.699
		8:15-8:30	69	47		
		8:30-8:45	101	50		
		8:45-9:00	92	49		
		8:00-8:15	199	80		
		8:15-8:30	107	81		

	912	8:30-8:45	120	90	0.287	0.713
		8:45-9:00	111	84		
	1001	8:00-8:15	141	112	0.299	0.701
		8:15-8:30	251	112		
		8:30-8:45	216	107		
		8:45-9:00	139	109		
	1002	8:00-8:15	107	80	0.316	0.684
		8:15-8:30	187	81		
		8:30-8:45	161	76		
		8:45-9:00	82	77		
	1003	8:00-8:15	108	75	0.337	0.663
		8:15-8:30	190	79		
		8:30-8:45	164	73		
		8:45-9:00	93	75		
	1004	8:00-8:15	89	39	0.371	0.629
		8:15-8:30	102	44		
		8:30-8:45	76	41		
		8:45-9:00	77	35		
	1005	8:00-8:15	172	60	0.358	0.642
		8:15-8:30	98	59		
		8:30-8:45	100	59		
		8:45-9:00	77	59		
10	1006	8:00-8:15	90	43	0.370	0.630
		8:15-8:30	97	38		
		8:30-8:45	80	40		
		8:45-9:00	80	40		
	1007	8:00-8:15	75	90	0.144	0.856
		8:15-8:30	131	93		
		8:30-8:45	113	92		
		8:45-9:00	58	88		
	1008	8:00-8:15	101	77	0.138	0.862
		8:15-8:30	113	77		
		8:30-8:45	97	77		
		8:45-9:00	89	77		
	1009	8:00-8:15	76	82	0.150	0.85
		8:15-8:30	131	90		
		8:30-8:45	114	87		
		8:45-9:00	59	85		
	1010	8:00-8:15	78	41	0.356	0.644
		8:15-8:30	102	41		
		8:30-8:45	76	44		
		8:45-9:00	93	43		
	1011	8:00-8:15	100	42	0.365	0.635
		8:15-8:30	83	39		
		8:30-8:45	87	40		
		8:45-9:00	69	39		
	1012	8:00-8:15	67	49	0.312	0.688
		8:15-8:30	94	50		
		8:30-8:45	101	47		
		8:45-9:00	97	48		