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SAKARYA UNIVERSITY
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IMPACT OF TRANSPORTATION NETWORK TOPOLOGY ON THE CAPACITY AND TRAVEL TIME RELIABILITY

M.Sc. THESIS

Ahmed Farhan FARAH

Department	**:**	**CIVIL ENGINEERING**
Field of Science	**:**	**TRANSPORTATION**
Supervisor	**:**	**Asst. Prof. Dr. Hakan ASLAN**

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This thesis has been accepted on 21.12.2017 by agreement / majority vote by the following jury.

Asst. Prof. Dr. Hakan ASLAN Head of Jury	Prof. Dr. Halim CEYLAN Jury Member	Asst. Prof. Dr. Yusuf SUMER Jury Member

DECLARATION

I declare that all data in this thesis were obtained by myself in academic rules and all visual and written information as well as the results were presented in accordance with the academic and ethical rules, there is no distortion in the presented data, in case of utilizing other peoples' work they were refereed properly to scientific norms, the data presented in this thesis had not been used in any other thesis in this or in any other universities.

Ahmed Farhan FARAH

08.12.2017

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

D_0	: Zero flow control time
R_0	: Free flow link traversal time
T_0	: Free flow travel time
c_k	: Travel cost on path *k*
f_k	: Flow on path *k*
f_k^{rs}	: Flow on path *k* connecting O-D pairs of r and s
q_{rs}	: Trip rate between pairs r and s
t_a	: Traveltime on link a
x_a	: Equilibrium flow on link a
$\delta_{a,k}^{rs}$	: Definitional constraint
A & B	: End nodes of a link
AON	: All-or-nothing
BPR	: Bureau of Public Roads
CR	: Capacity restraint
d	: Diameter
DD	: Total actual distance between linked nodes
DI	: Detour index
Dir	: Direction of flow
DOTS	: Degradable Transportation Systems
DT	: Total straight distance between linked nodes
E	: Edges
G	: Graph
GIS	: Geographic Information System
HCM 2010	: Highway Capacity Manual 2010
INC	: Incremental
J	: Calibration parameter

L	: Length of link
L(G)	: Total length of the graph
ND	: Network density
O	: Order of node
O-D	: Origin – destination
P	: Sub-graph number
SO	: System optimum
SUE	: Stochastic user equilibrium
U	: Number of cycles
u	: Minimum cost
UE	: User equilibrium
V	: Vertices
VOC	: Volume to Capacity ratio
X	: Flow to capacity ratio
α	: Alpha index
β	: Beta index
γ	: Gamma index
η	: Eta index
θ	: Theta index
π	: Pi index
T	: Travel time in minutes
c	: Capacity (passenger car unit/hour)
v	: Traffic volume (passenger car unit/hour)

LIST OF FIGURES

LIST OF TABLES

ULAŞIM AĞI TOPOLOJİSİNİN KAPASİTE VE SEYAHAT SÜRESİ GÜVENİLİRLİĞİNE ETKİSİ

ÖZET

Anahtar kelimeler: Ulaşım şebeke topolojisi, Trafık atama modeli, TransCAD, Seyahat süresi ve Kapasite güvenilirliği

Genellikle şebeke topolojisinin etkinliğini kontrol eden çeşitli durumlar vardır. Örneğin, bir ulaşım şebekesindeki döngü sayısı ne kadar fazlaysa, doğal tehlikeler nedeniyle şebekenin bazı linklerinde hizmet düzeyi veya bağlantısal anlamda sorunlar ortaya çıksa bile, şebeke içindeki zonlar arası bağlantı göreceli olarak daha güçlü olacaktır. Bu çalışmada, ulaşım şebeke topolojisinin, ulaşım ağlarının kapasite ve seyahat süresi güvenilirliği üzerindeki etkisi ortaya koyulmaya çalışılmıştır. Kentsel alanlar için belirlenen üç temel şebeke yapısı , hem kullanıcı dengeli hem de kullanıcı dengesiz atama teknikleri kullanılarak seyahat süresi ve kapasite güvenilirliği açısından karşılaştırılmıştır.

Bu çalışmada elde edilen bulgulara göre, daha fazla sayıda link, dolayısı ile güzergah alternatifi olan ağ yapısının, diğer ağlara göre seyahat süresi ve kapasite bakımından daha güvenilir olduğu sonucuna varılmıştır. Ayrıca, kullanıcı dengeli, özellikle stokastik kullanıcı dengesi yöntemine göre elde edilen atama sonuçlarının daha iyi seyahat verileri ürettiği gözlemlenmiştir.

SUMMARY

Keywords: Network topology, Assignment methods, TransCAD, Travel time and Capacity reliability.

Generally there are several situations that control the effectiveness of network topology. For instance, the more the number of cycles of a network, the more the network is connected even in worse conditions if discontinuity comes to some links of the network due to natural hazards. This present study aims to reveal the effect of network topology on the capacity and travel time reliability of transportation networks. Three simple network structures for a small urban areas have been compared in terms of travel time and capacity reliability by using both non-equilibrium and equilibrium assignment techniques.

According to the findings obtained in this research, it was concluded that the network structure with more number of alternatives is more reliable in terms of travel times and capacity compare to other networks. Moreover, equilibrium assignment techniques particularly stochastic user equilibrium method revealed better assignment for trips.

CHAPTER 1. INTRODUCTION

1.1. Background

Transportation network reliability has become nowadays a favorite topic for analysis since the last three decades. The evolution of technology results in frequently increasing capacity performance of network and hence improves the travel time among different network locations. Natural phenomena such as earthquakes and landslides tend to lower the capacity of transportation networks [1]. Therefore, a rigorous research on network topology will mitigate undesirable conditions.

In literature, the term reliability in transportation networks has two aspects, reliability of connectivity which can guarantee an acceptable level of service for road traffic even if the function of some links of the network are degraded by disasters and reliability of travel time which is the probability of whether the travel between an origin and destination pair is possible within an acceptable threshold [2].

Generally, travel time reliability analysis focusses on congested urban networks with concern to the probability that a network will convey the required level of performance under unpredictable conditions [3]. In Highway Capacity Manual [4], several aspects of uncertainties are considered in the travel time reliability analysis. These can be listed as; frequent change in demand, special events that produce temporary, intense traffic demands and severe weather, incidents and work zones that reduce capacity.

Several studies issuing on reliability of transportation networks were conducted by several researchers. These researches were first started in the early 1980’s and began to gain even more attention in early 1990’s after devastating Kobe earthquake in Japan. Turnquist and Bowman [5] carried out a series of simulation tests to study the effect of the topology of urban network on travel time reliability.

Wakabayashi and Iida [6] proposed an approximation method to compute the connectivity between an O-D pair in a road network. The aim of the study was the calculation of connectivity measure for a non-degraded network.

Asakura and Kashiwadani [2] discussed road network reliability considering instability of traffic flow. They proposed a time reliability measure that is the probability of whether the travel between an origin and destination pair is possible within an acceptable travel time. Time reliability is an effective parameter for investigating network performance even normal conditions, when the network did not degraded due to natural hazards.

Du and Nicholson [7] presented a theoretical approach to scientifically address the main issues in the analysis and design of Degradable Transportation Systems (DoTS). They described network flows for a degraded network by employing User Equilibrium (UE) assignment methods.

Sanso and Milot [8] showed a reliability concept for urban transportation planning considering accidents by proposing three-T model to describe dynamic behavior of network users.

In transportation network theory, the demand is typified by the ambition to make a journey between two different locations. It is typically demonstrated by an origin-destination matrix which tries to capture and apprehend the propensity of travel between two locations (e.g., centroids or any normal nodes). On the other hand, supply is often characterised by the capacity of any particular connections of links in a network. Furthermore, supply is mostly regarded to be the substructure, which may incubate physical infrastructure such as bridges, roundabouts, number of lanes, roads, intersections etc., as well as the traffic light timings and general operational strategies [3].

The four-step planning model proposed by Mayer and Miller [9] attempts to model the interaction between the demand and supply. The output from this model includes various traffic cost parameters (e.g., travel time, delay, volume to capacity ratio, etc.) for the nodes, links, and the system as a whole.

The performance of a transportation network is measured by the output results of assignment techniques. Recently traffic measurements (e.g., travel time and speed) are attainable by integration of sub divided of an hour (i.e., 5 minute interval) or even a discrete, discontinuous level (e.g., personal vehicle) [3].

1.2. Problem Statement

In order to predict how the demand for mobility will be demonstrated in transportation networks, graph theory in mathematics is an essential tool. Graph theory reduces transport networks into two set of elements whereby vertices are the locations of interest; where trips start and end, and edges are the line segments among the locations of interest, commonly denoted as G (V, E) [10].

There are different types of network graphs. A '*null graph'* with zero edges, "*complete graphs*" with every vertex joined to every other vertex, "*cycles*" which only join the outside of the vertices, "*wheels*" which add a vertex at the center, "*directed graph*" in which the direction of flow is explicit and "*undirected graph*" where there is no direction implied and the link is assumed to yield in both direction [10 & 11].

Traffic assignment techniques are used to estimate the traffic flows on a network. These methods take as an input the matrix of flows that indicates the volume of traffic between origin and destination (O-D) pairs. Hence the traffic assignment methods predict the network flows associated with future planning scenarios, and generate the estimation of the link travel times and related attributes.

Historically there are a variety of traffic assignment techniques that have been developed and applied to different network topologies. These methods are mainly divided into equilibrium and non-equilibrium assignments. Equilibrium assignment techniques may include user equilibrium (UE), stochastic user equilibrium (SUE) and system optimum (SO) assignment while non-equilibrium assignment techniques are all-or-nothing (AON), incremental assignment (INC) and capacity restraint (CR) assignment [12].

For a network with thousands of links and zones, it is analytically almost impossible to analyse flows on links using assignment methods. One of the computer packages that enables a planner to efficiently model a network is TransCAD. TransCAD integrates Geographic Information System (GIS) with transportation modeling application. It is designed to aid transportation planners to map, analyse and design networks with different assignment techniques [13]. In this present study, the aid of TransCAD was fruitfully employed.

Most of network reliability studies concern service reliability which is travel time reliability of network. However, few studies if there is no concern for impact of capacity reliability on different network topologies.

1.3. Research Objectives

The objective of this study is to reveal the effect of network topology on the capacity and travel time reliability of different transportation network topologies. For this, three network topologies have been compared in terms of travel time and capacity reliability by using equilibrium and non-equilibrium assignment techniques.

The focus of this study will be on the following aspects:

- To compare different types of network topologies of a small area of urban networks and

- To test the efficiency of various traffic assignment methods for travel time and capacity reliability.

1.4. Structure of Thesis

This thesis consists of five chapters:

Chapter 1 introduces basic background information on reliability studies in transportation network, states the problems in need of consideration, proposes the objectives of the research and outlines thesis structure.

Chapter 2 reviews literature of several types of network topologies, overviews graph theory including basic definitions and measures of graph theory and summarizes major indices for selected network topologies.

Chapter 3 presents essential topics, including both equilibrium and non-equilibrium traffic assignment techniques, required input data for traffic assignment using TransCAD and a quick review of volume delay functions.

Chapter 4 evaluates the results of travel time and capacity reliability for selected network topologies. Three different network topologies have been compared in terms of travel time and capacity reliability by using equilibrium and non-equilibrium assignment techniques.

Chapter 5 concludes with a summary of findings and further future recommendations.

CHAPTER 2. LITURATURE REVIEW

This chapter reviews the litreture of transportation networks. A brief review about network topology followed by graph theory will be presented here. In graph theory, a thorough coverage of basic definitions of graph is followed by measures and indices. At the end of this chapter, a table will summarize the definitions and indices of graph theory for the selected network topologies.

2.1. Transportion Networks

The word network has been used as an interchangeable term for the structure and flow throughout the history of transportation systems. In the general sense, the term network denotes to the structure of routes within a system of locations of interest i.e. centroids and any other locations identified as nodes. In transportation networks known as edge is a single link connecting any two nodes [10 & 11].

Several types of transport topology exist to reflect the nature of transportation networks. Network topologies range between centripetal and centrifugal in terms of the accessibility they offer to destinations as in Figure 2.1.

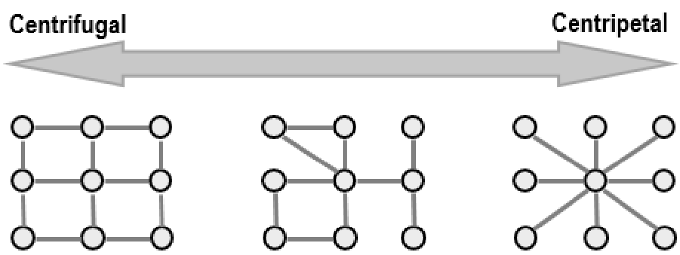


Figure 2.1. Network topology ranges [11]

A centripetal network favors a limited number of locations while a centrifugal network does not convey any specific locational advantages. Recent decades have seen the emergence of transport hubs, a strongly centripetal form, as a privileged network structure for many types of transportation services, notably for air transportation. Although hub networks often result in improved network efficiency, they have drawbacks related to their vulnerability of disruptions and delays at hubs, an outcome of the lack of direct connections [11].

2.2. Topology of Networks

Transportation networks, like many of the networks, are generally embodied as a set of locations of interest known as vertices and a set of links named edges or routes representing connections among those locations of interest. Topology is the arrangement of nodes (Vertices) and links (Edges) and their connectivity in a network. Thus, the purpose of a network data model is to provide an accurate representation of a network as a set of links and nodes [10 & 11].

Transportion networks can be classified in specific categories depending on a set of topological attributes that define them. For instance, if we consider the network pattern we have null, complete, cycles, wheels as an example. A '*null graph*' with zero edges, "*complete graph*" with every vertex joined to every other vertex, "*cycle*" which only joins the outside of the vertices, "*wheel*" which adds a vertex at the center. There are also other network pattern graphs such as, "*mesh*", "*linear*" and "*tree*" just to mention as in Figure 2.2. [10].

Farthermore if we consider the trend which the network follows we may have either directed or undirected graphs. A "*directed graph*" is a network in which the direction of flow is explicit and "*undirected graph*" where there is no direction implied and the link is assumed to have flows in both directions.

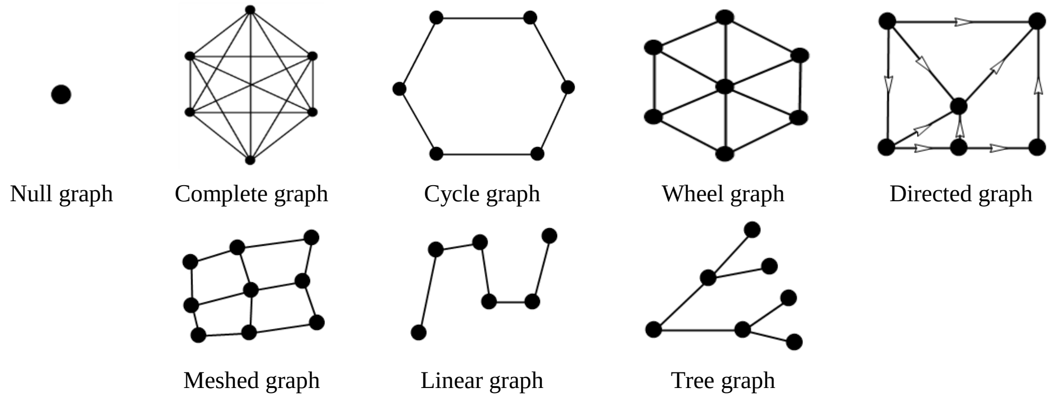


Figure 2.2. Different types of network topologies [10].

Networks deliver a level of transport service for network users which is related to its costs. An ideal network would be a network servicing all possible locations but would have high capital and operational costs.

Efficiency of a network can be measured through graph theory. These methods rest on the principle that the efficiency of a network depends partially on the lay-out of nodes (Vertices) and links (Edges). To be more precise, some network structures have a higher degree of accessibility than others, but careful consideration must be given to the basic relationship between the profits and costs of specific transportation networks. Inequalities among locations can often be measured by the quantity of links between points and the related costs generated by traffic flows.

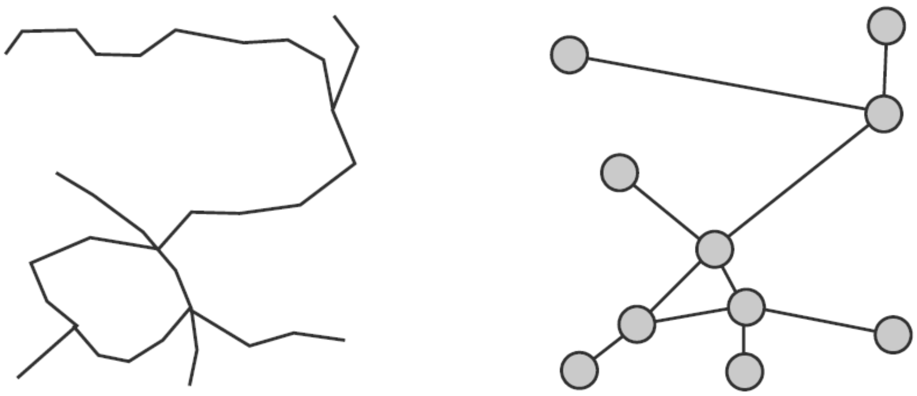
2.3. Graph Theory

In this section graph theory definition and necessary measurements for calculation of network properties will be discussed further.

2.3.1. Basic definitions

A graph is a representative of a network and of its situation (i.e. connectivity). The main objective of a graph is to exemplify the structure of the network rather than the appearance of a network. Graph theory is a branch of mathematics that deals with how networks can be encoded into a planner graph and their properties will be measured. See Figure 2.3.

The conversion of a real network into a graph is accomplished by following some basic rules. These rules may be summarized as; every destination and intersection point becomes a node and each connected node is linked by a straight segment. The actual network depending on its complexity, may be confusing in terms of revealing its connectivity [11].



a) b)

Figure 2.3. Representation of a network. a) Actual network, b) Graph network [11].

Some other graph representation rules may, although not very common, include adding special node types such as schools, places of worship, hospitals, etc. especially when it is required that the graph representation remains comparable to the actual network. Although it is not mandatory, the comparative location of each node can remain similar to its real world [11].

To understand the concept of graph theory, the following terms must be clearly explained:

- Graph; is a two set of elements whereby vertices or nodes (i.e. zones) are the locations of interest; where the trips originate, and edges (i.e. links) are the line segments among locations of interest. Thus G (V, E) [10 & 11].

- Vertex (Node); is the locations of interest such as districts, an administrative division, a road intersection or a transport terminal and denoted as V.

- Edge (Link); an edge which can be signified as E is a link between any two places of interest or nodes. The link (i, j) connects the nodes i and j. A link can be defined as the abstraction of a transportion infrastructure supporting movements among nodes.

- Planar graph; which can be defined as a graph where every intersection of two edges is a vertex. Since this graph is located within a plane, its topology is two-dimensional. See figure 2.4. a.

- Non-planar graph; is also a graph where there are no vertices at the intersection of at least two edges. In this situation, there is a possibility of having an interchange movement through over passing for the continuation of the movement. A non-planar graph has potentially many more links than a planar graph. Refer Figure 2.4. b.

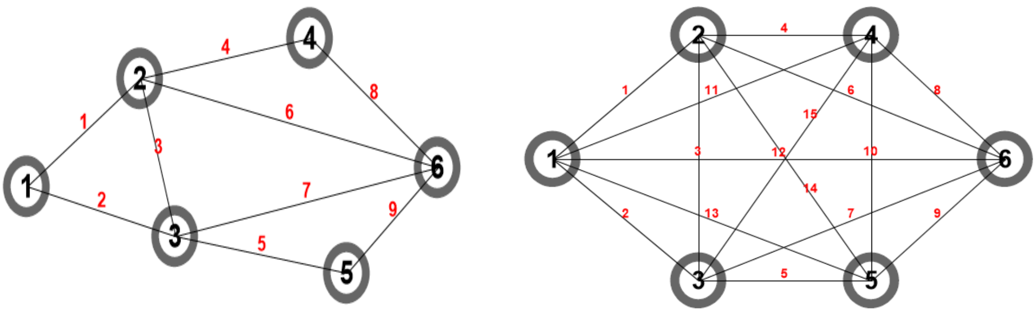


Figure 2.4. Graph representation for a basic transportation network topology [14]

Summarizing the above terminologies, the graph on Figure 2.4a has the following definition: G = (V, E); V = (1, 2, 3, 4, 5, 6); E = (1, 2), (1, 3), (2, 3), (2, 4), (3, 5), (2, 6), (3, 6), (4, 6) and (5,6). Add on, the graph is a planner where every intersection of two edges is a vertex.

Like any other network systems, transportation networks enable the movement of people and goods through their links. Thus, graph theory represents the flow through the links as linkages which can be considered as in the following terms:

- Path; A path is a series of links from an origin to a destination that are traveled in the same direction. Finding all the possible paths in a graph is a fundamental attribute in measuring accessibility. For instance, in Figure 2.4a to calculate the number or paths between nodes (1&6), we have P1 (1, 4, 8), P2 (1, 6), P3 (2, 7) and P4 (2, 5, 9). Some other paths are also available for different nodes.

- Cycle; a cycle is a chain like structure where the initial and terminal node is the same and which does not use the same link more than once. See Figure 2.5.

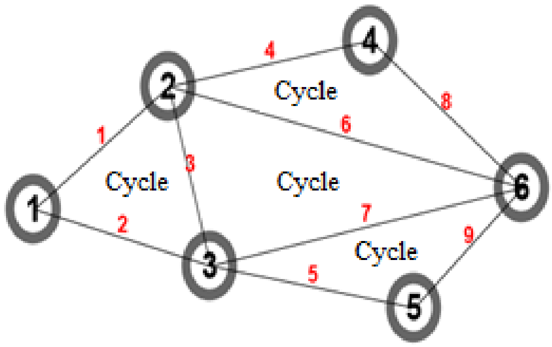


Figure 2.5. Cyclic graph network [14]

- Circuit; A path where the initial and terminal node correspond.

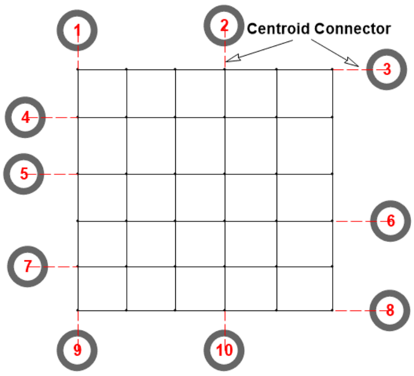
- Symmetry; a network or a graph network is symmetrical if each pair of nodes is linked in both directions. By convention, a line without an arrow represents a link where it is possible to move in both directions.

- Asymmetry; a network where the flow in links occurs just in one direction.

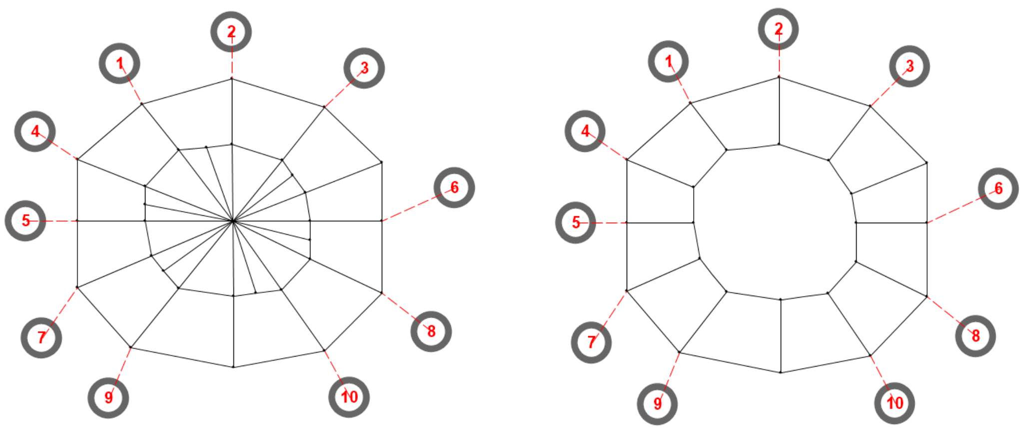
- Connectivity; is a property of the transportation network when all its distinct pairs of nodes are linked together. Direction is not a subject of matter to describe the connectivity of the network.

2.3.2. Measures and indexes of graph theory

In this study, three different types of transportation network topology of a small scale urban region have been exogenously chosen, see Figure 2.6. Several measures and indices initially developed by Kansky [15] can be used to analyze efficiency of these networks. Basically, three types of measures can be used to define the structural attributes of any graph. These measures can be summarized as follows;



Topology 1 (mesh network)



Topology 2 (wheel network) Topology 3 (cycle network)

Figure 2.6 Selected network topologies for analytical study

- Diameter (d); is a property of network graph where the length of the shortest path between the furthest nodes is achieved. Diameter measures the extent of a graph and the topological length between any two important nodes. The greater the diameter, the less linked a network will be.

- Number of cycles (U); is the maximum number of independent cycles in a graph. Number of cycle (U) is estimated as follows:

$$U = E - V + P \tag{2.1}$$

where;

(E) is the number of edges in the graph, (V) is the number of the vertices and (P) is a sub-graph number which is usually taken as 1 [16].

- Demand of a node (O); this property is also called order of the vertices. It is the number of attached links to a node. This property shows the importance of node in the graph. The higher its value, the more a node is important in a graph as many links converge to it.

Now let us look into Indexes of graph networks. Indexes involve the comparison of one measure over another mentioned just above. For such a reason, they are methods to represent the structural properties of a graph. Indexes for graph networks can be reviewed as follows:

- Network density (ND); is a measure of network land occupation property which satisfies the development of the network. Network density can be measured as:

$$ND = \frac{L}{S} \tag{2.2}$$

where;

(L) is the total length of links in km and (S) is the square surface of network in km^2.

- Detour index (DI); is a measure of the efficiency of a transport network in terms of how well it overcomes distance. The more the detour index gets to 1, the more the network is spatially efficient. Detour can be calculated as;

$$DI = \frac{DT}{DD} \tag{2.3}$$

where;

(DT) is the total straight distance among linked nodes and (DD) is the total actual distance among linked nodes.

- Alpha index (α); is the measure of connectivity of a network which is the ratio of number of cycles in a graph to the maximum number of cycles. The higher the alpha index, the more a network is connected.

$$\alpha = \frac{(E-(V-1))}{((0.5V(V-1))-(V-1))} \tag{2.4}$$

- Beta index (β); measures the level of connectivity in a graph and is expressed by the ratio between the numbers of edges (E) over the number of vertices (V).

$$\beta = \frac{E}{V} \tag{2.5}$$

- Gamma index (γ); is a measure of connectivity that considers the relationship between the number of observed vertices and the number of possible edges. The value of gamma is between 0 and 1, that is the value of 0 indicates that the network is not connected at all and 1 which indicates that the network is fully connected.

$$\gamma = \frac{E}{3(V-2)} \tag{2.6}$$

- Theta index (θ); is the measure of the functionality of a node for calculating the average amount of traffic per intersection. The higher theta is, the greater the load of the network.

$$\theta = \frac{Q(G)}{V} \tag{2.7}$$

where;

$Q(G)$ is the total amount of traffic available in the network and V is the total amount of vertices in the network.

- Eta index (η); is a property of the network which calculates the average length per link. Generally adding new vertices will cause the eta index to decrease as the average length per link declines.

$$\eta = \frac{L(G)}{E} \tag{2.8}$$

where;

L (G) is the total length of the network and E is the total number of links in the network

- Pi index (π); is the measure of the relationship between the total length of the graph L(G) and the distance along its diameter D (d); that is the shortest distance between the furthest vertices. The higher the value of this index, the more the network is developed, that means the network has more vertices and edges.

$$\pi = \frac{L(G)}{D} \tag{2.9}$$

Table 2.1. summarizes the measures and indexes of graph theory for the selected network topologies. Apart from the diameter which has been calculated using the aid of TransCAD, all other measures and indexes have been calculated regarding the above formulae.

Table 2.1. Summary of measures and indexes of selected network topologies

Measures and Indexes	Network Topology 1	Network Topology 2	Network Topology 3
Diameter (D)	4.34 km	2.28 km	3.64 km
Number of cycles (U)	61	61	37
Order of node (O)	1	1	1
Network density (ND)	*	*	*
Detour index (DI)	*	*	*
Alpha index (α)	1.64	1.64	0.97
Beta index (β)	7	7	4.6
Gamma index (γ)	2.92	2.92	1.92
Theta index (θ)	**	**	**
Eta index (η)	0.55	0.55	0.53
Pi index (π)	8.79	16.73	6.74

* Since selected network topologies are virtual examples, there is no real data available.
** No exact real data concerning the networks is available.

2.4. Transportation in Urban Planning

Transportation is an important element of modern society. It is capable of producing significant benefits but still giving rise to many negative externalities. In such a condition, appropriate policies need to be planned to maximize the profits and minimize the inconveniences. In this section, definition of transportation policy and urban planning will be briefed as far as the policy process, elements of transportation planning are concerned. Finaly transportation and the urban structure will also be briefly reviewed.

2.4.1. Definition of transportation policy and planning

Policy and planning are used very loosely and are frequently interchangeable in many transportation studies. Transportation policy is the development of a set of concepts and proposals that are established to achieve particular aims relating to socio-economic development, the functioning and performance of the transportation system.

Transportation planning covers all those activities involving the analysis and evaluation of past, present and prospective problems associated with the demand for the movement of people, goods and information at a local, national or international level and the identification of solutions in the context of current and future characteristics of economic, social, environmental, and technical developments in the light of the aspirations and concerns of the society which it serves [11].

2.4.2. The transportation policy process

Policies are developed in response to the existence of a perceived problem or an opportunity. Following are some main vital considerations for the policy process [11]:

- Who has identified the problem? Is it widely recognized by society as a whole or is it limited in scope, to a local pressure group.

- Do the public authorities have the interest to respond? There are usually many more problems than the policy makers are willing to address.

- Do the public authorities wish to exercise the instruments necessary to carry out a policy response? The problem may be recognized, but public authorities may have little ability to influence.

- What is the timescale? How pressing is the problem, and how long would a response take? Policy makers are disreputably prone to attempt only short-term interventions.

The response to above transportation policy process lies correctly on identification of the problem. No policy response is likely to be effective without a clear definition of the issue. The following elements need to be considered in addressing urban case transportation problems [11]:

- Who has identified the problem, and why should it be seen to be a problem?

- Is there agreement on the problem? If there is no agreement that a problem exists, it is unlikely that a strong policy response will be forthcoming.

- Is it an issue that can be addressed by public policy?

- Is it too soon to develop a policy?

2.4.3. Transportation planning

Transportation planning is usually focused on specific problems at a local level. Transportation planning process has a number of similarities with the policy process. These similarities may include, identifying a problem, seeking options and implementing the chosen strategy. The four major sequential steps in transportation demand forcasting are: trip generation, trip distribution, modal split , and trip assignment [11 & 12]. They involved the use of mathematical models, including regression analysis, entropy-maximizing models, and critical path analysis [11 & 12].

Traffic problems have increased considerably over the past 50 years, despite a great deal of urban transportation planning. There is a rising realisation that perhaps planning has failed. The following seven elements need to be considered in transportation planning process [11 & 12]:

- Situation definition. Defining situation is a more complicated stage in modern transportation planning. It involves all the activities needed to understand the situation that gives rise for transportation improvement.

- Problem definition. The aim of this step is to describe the problem in terms of objectives to be realised by the project.

- Search for solution. This part of planning process addresses a variety of ideas, designs, and system configurations that may provide answers to the addressed problem.

- Analysis of performance. This step estimates outcomes of the proposed alternatives, identifying benefits, and assessing costs under present and future conditions.

- Evaluation of alternatives.

- Choosing a project.

- Specification and construction.

2.4.4. Urban transportation planning and urban form

Urban transportation planning involves evaluation and selection of highway or any other transit facilities to serve present and future land use. It considers proposed developments and improvements that will occur within planning period. Urban transportation planning process follows same procedures outlined in transportation planning process [12]. Urban form refers to the spatial imprint of an urban transportation system as well as the adjacent physical infrastructures. Urban mobility problems nowadays have increased along with urbanisation, a trend reflected in the growing size of the cities and in the increasing proportion of the urbanised population. This is due to demographic growth and rural to urban migration, but more importantly to a fundamental change in the socioeconomic environment of human activities. Consequently, there is a wide variety of urban forms, spatial structures and associated urban transportation systems.

Urban form and its spatial structure are articulated by nodes (vertex) and linkages (edges). Urban transportation is organized in three broad categories of collective, individual and freight transportation [11].

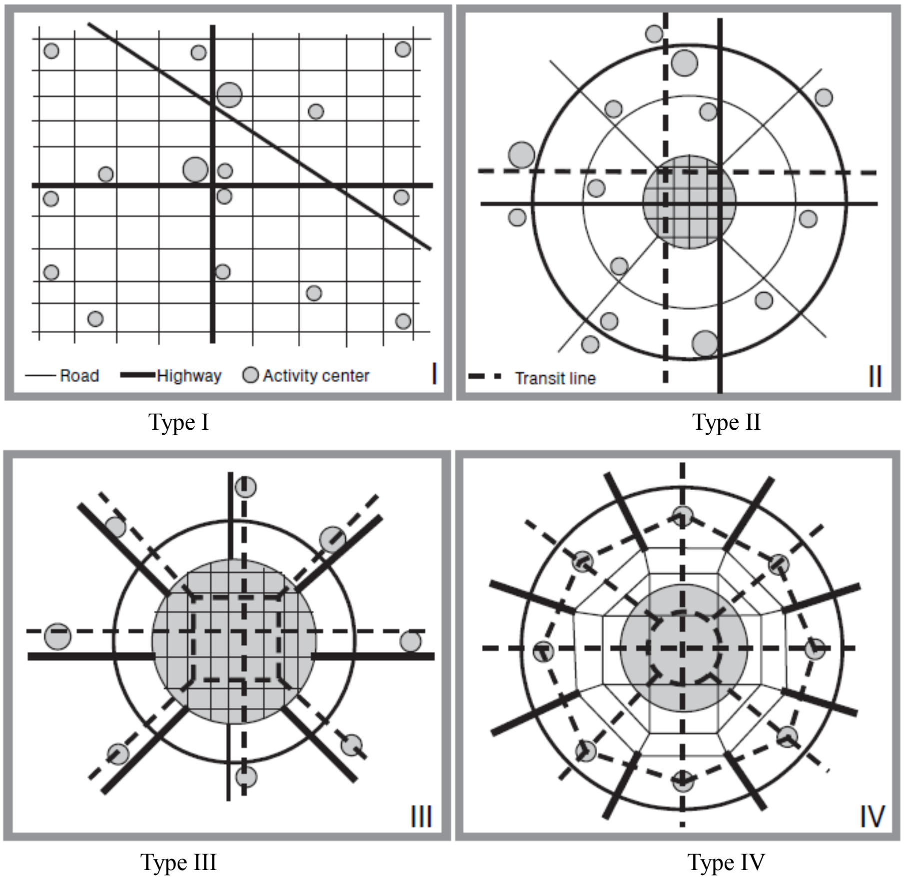
- Collective transportation (public transit). The purpose of collective transportation is to provide publicly accessible mobility over specific parts of a city.

- Individual transportation. This includes any mode where mobility is the outcome of a personal choice and means such as the automobile, walking, etc.

- Freight transportation. As cities are dominant centers of production and consumption, urban activities are accompanied by large movements of freight.

2.4.5. Transportation and the urban structure

In urban areas, increasing nature of the number of trips generally rooted from rapid and expanded urbanisation occurring around the world. Due to these facts, cities have traditionally reacted to growth in mobility by expanding the transportation supply. Several urban spatial structures have accordingly developed with the reliance on the automobile being the most important discriminatory factor. Following are four major types of urban spatial structure that can be identified at the metropolitan scale, as can be seen in Figure 2.7.



Type I Type II

Type III Type IV

Figure 2.7. Four main urban spatial structures [11]

Type I urban structure is termed as completely motorized network. This urban structure represents an automobile-dependent city with a limited centrality. Usually this type of urban structure characterized by low to average land use densities and assumes free movements among all locations.

Type II named as weak center represents the spatial structure where many activities are located in the periphery. These urban structures are characterized by average land use densities and a concentric pattern. Generally the central business district is relatively accessible by the automobile. The result is an under-used public transit system, which is unprofitable in most instances and thus requires subsidies.

Type III – strong center. This characterizes cities having a high land use density and high levels of accessibility to urban transit. There are thus limited needs for highways and parking space in the central area, where a set of high capacity public transit lines service most of the mobility needs. The productivity of this urban area is thus mainly related to the efficiency of the public transport system.

Type IV is termed traffic limitation. This urban structure represents those urban areas that have efficiently implemented traffic control and modal preference in their spatial structure. Usually the central area is dominated by public transit. They have a high land use density and were planned to limit the usage of the automobile in central zones for a variety of reasons, such as to preserve its historical character or to avoid congestion.

CHAPTER 3. MATERIALS AND METHODOLOGIES

This chapter reviews traffic assignment of both equilibrium and non-equilibrium assignment methods. These methods include user equilibrium, stochastic user equilibrium, system optimum, all-or-nothing, incremental assignment and capacity restraint assignment techniques. The necessary input data of traffic assignment using TransCAD will also be revealed. Finally we will conclude this chapter by summarizing the travel time functions.

3.1. Traffic Assignment Techniques

Traffic assignment is a key element in the urban travel demand forecasting process. Traffic assignment techniques are used to estimate the traffic flows on a network. These methods take a matrix of flows as an input indicating the volume of traffic between origin and destination (O-D) pairs. They also take the network topology as another input through the link characteristics and link performance functions. The flows for each O-D pair are loaded onto the network based on the travel time or impedance of the alternative paths that could carry this traffic [12].

The traffic assignment techniques predict the network flows associated with future planning scenarios, and generate estimation of the link travel times and related to attributes that are the basis for benefits and air quality impacts. The traffic assignment techniques are also used to generate the estimates of network performance used in the mode choice and trip distribution or destination choice stages related to transport topologies [12].

Historically, a wide variety of traffic assignment techniques have been developed and applied. These models can be classified as equilibrium traffic assignment techniques and non-equilibrium assignment techniques. Many of the older traffic assignment techniques, i.e. all-or-nothing method, that have been used have undesirable results, to be explained in detail later, will not be used in this present study.

For a network with thousands of links and zones, it is impossible or extremely laborious to analyse flows on links using assignment techniques analytically. One of the computer packages that enables a planner to efficiently model a network is TransCAD. TransCAD integrates Geographic Information System (GIS) with transportation modeling application. TransCAD provides the widest array of traffic assignment procedures that can be used for modeling urban traffic. These procedures include numerous alternatives to be used for modeling intercity passenger and freight traffic [12 & 13].

3.2. Non-equilibrium Traffic Assignment Techniques

3.2.1. All-or-nothing assignment method

In this method the trips from any origin to any destination point are loaded onto a single, minimum cost path between them. This model is unrealistic as only one path between every O-D pair is utilized even if there is another path with the same or nearly same travel cost.

Furthermore, traffic on links is assigned without consideration of whether or not there is adequate capacity or congestion; travel time is a fixed input and does not vary depending on the congestion on a link. However, this model may be reasonable in sparse and uncongested networks where there are few alternative routes and they have a large difference in travel cost. Also it can be sometimes used for assigning truck trips or assigning inter-city or inter-regional trips [12 & 18]. In this study, this method of assignment has been excluded.

3.2.2. Incremental assignment method

Incremental assignment is a process in which divisions of the total demand are assigned in steps. In each step, a fixed proportion of total demand is assigned, based on all-or-nothing assignment. After each step, link travel times are recalculated based on link volumes. When there are many increments used, the flows may resemble an equilibrium assignment; however, this method does not yield an equilibrium solution. Consequently, there will be inconsistencies between link volumes and travel times that can lead to errors in evaluation measures. Incremental assignment is influenced by the order in which volumes for O-D pairs are assigned, raising the possibility of additional bias in results [18].

The exact nature of the assignment methods is presented through the following algorithm [18];

Step 1:
Divide the entire trip-distribution matrix (or origin-destination matrix) into
n ($x_{4\sim5}$) smaller part matrices. Note that, the sum of all the part matrices should be equal to the original trip-distribution matrix.
Set counter m=1.
Set x_a^{m-1}=0 for all a.
(Also note that in the following, x_a^{m-1}refers to the number of trips from i to j as per the m^{th} part matrix.).

Step 2:
Set V_a = 0 for all links.
Assuming $\tau_a(x_a^{m-1})$ as the link travel times, assign the trips of the m^{th}part matrix using all-or-nothing assignment technique. Store the link volumes obtained from the all-or-nothing assignment technique as V_a.

Step 3:
Update the link volumes using x_a^m

$x_a^m = x_a^{m-1} + Va$

Step 4:

If m=n, then report x_a^m as x_a and Stop. Else, set $m = m + 1$and go to Step 2.

3.2.3. Capacity restraint model

Capacity Restraint attempts to approximate an equilibrium solution by iterating between all-or- nothing traffic loadings and recalculating link travel times based on a congestion function that reflects link capacity. Unfortunately, this method does not converge and can flip-flop back and forth in the loadings on some links [19]. Becouse this method does not converge to an equilibrium solution, the results are highly dependent on the specific number of iterations to be run. Performing one more or one less iteration usually changes the results substantially [18].

3.3. Equilibrium Traffic Assignment techniques

3.3.1. User equilibrium (UE) assignment

User equilibrium assignment technique is based on Wardrop's first principle in which no travelers can improve their travel times by shifting routes. This method uses an iterative technique to achieve convergent solution where in each iteration, network link flows are computed, which incorporate link capacity restraint effects and flow-dependent travel times [12 & 18].

User equilibrium method for a given O-D pair can be written as follows:

$$f_k(c_k - u) = 0 \tag{3.1}$$

$$c_k - u >= 0 \tag{3.2}$$

where;

f_k is the flow on path k,

c_k is the travel cost on path k, and

u is the minimum travel cost of O-D pair.

The above two equations can be interpreted as follows:

- If c_k- u = 0, from Eq (3.1) f_k >= 0. This means that all used paths will have same travel time.

- If c_k- u >= 0, then from equation 3.1 f_k = 0. This means that all unused paths will have travel time greater than the minimum cost path.

The solution to the above equilibrium conditions given by the solution of an equivalent nonlinear mathematical optimization program as follows:

$$Minimize \quad Z = \sum_a \int_0^{x_a} t_a\,(x_a)\,dx \tag{3.3}$$

$$Subject\ to \sum_k f_k^{rs} = q_{rs} \tag{3.4}$$

$$x_a = \sum_r \sum_s \sum_k \delta_{a,k}^{rs}\, f_k^{rs} \tag{3.5}$$

where;

k is the path,

x_a equilibrium flows on link a,

t_a travel time on link a,

f_k^{rs} is the flow on path k connecting O-D pair r-s,

q_{rs} total trips between r and s and

$\delta_{a,k}^{rs}$ is a definitional constraint and is given by

$$\delta_{a,k}^{rs} = \begin{cases} 1, & if\ link\ a\ belongs\ to\ path\ k \\ 0, & otherwise \end{cases} \tag{3.6}$$

3.3.2. Stochastic user equilibrium (SUE) assignment

Stochastic user equilibrium is generalization of user equilibrium that assumes travelers do not have perfect information concerning network attributes and/or they perceive travel costs in different ways. In some circumstances, SUE assignments might produce more realistic results than the deterministic UE model, because SUE permits use of less attractive as well as the most-attractive routes. Less-attractive routes will have lower utilization, but will not have zero flow as they do under user equilibrium method.

SUE assignment methods can be calculated using the following equation [19]:

$$Minimize \quad Z = \sum_{rs} q_{rs} S_{rs}[c^{rs}(x)] + \sum_{\mathrm{a}} \mathrm{x_a t_a(x_a)} - \sum_{a} \int_0^{x_a} t_a(\omega) d\omega \tag{3.7}$$

$$S_{rs}[c^{rs}(x)] = E[min_{kE\ Nrs,}\{c_k^{rs}\}|c^{rs}(x)] \tag{3.8}$$

The conditioning of the random variable c_k^{rs}on $c^{rs}(x)$in Eq (3.8) implies that the expectation is taken at a given flow level, x. In TransCAD, SUE is computed using the Method of Successive Averages (MSA), which is known to be a convergent method [19] although the rate of convergence may not be rapid. Due to the nature of this method, a large number of iterations should be used [12].

3.3.3. System optimum (SO) assignment

The system optimum assignment is based on Wardrop's second principle, which states that drivers cooperate with one another in order to minimize total system travel time. This assignment can be thought of as a model in which congestion is minimized when drivers are told which routes to be used. Obviously, this is not a behaviorally realistic model, but it can be useful to transportation planners and engineers, trying to manage the traffic to minimize travel costs and therefore achieve an optimum social equilibrium [18].

SO assignment methods can be calculated using the following equation:

$$\text{Minimize} \quad Z = \sum_a x_a t_a(x_a) \tag{3.9}$$

$$\text{Subject to } \sum_k f_k^{rs} = q_{rs} \tag{3.10}$$

$$x_a = \sum_r \sum_s \sum_k \delta_{a,k}^{rs} f_k^{rs} \tag{3.11}$$

where;

k is the path,

x_a equilibrium flows in link a,

t_a travel time on link a,

f_k^{rs} flow on path k connecting O-D pair r-s,

q_{rs} total trips between r and s and

$\delta_{a,k}^{rs}$ is a definitional constraint and is given by

$$\delta_{a,k}^{rs} = \begin{cases} 1, & if\ link\ a\ belongs\ to\ path\ k \\ 0, & otherwise \end{cases} \tag{3.12}$$

3.4. Required Input Data for Traffic Assignment

When preparing to run a traffic assignment using TransCAD, there are required and optional inputs that should be provided. The standard required inputs for traffic assignment are the network, the requisite network attributes based on the method to be used, and the origin-destination (O-D) matrix defining the demand. In addition, there are many other optional inputs such as intersection delays due to traffic signals[12]. In this section, each input data will be looked through and reviewed briefly.

3.4.1. Origin destinatoion (O-D) matrix

The O-D matrix contains the vehicle counts (volumes) to be assigned for each network topology as in Table 4.2 in chapter four. The IDs contained in the row and column headings of the matrix view must match the node IDs in the network. Cells in the matrix whose IDs are not in the network are not assigned to the network and the raw and the column IDs not found in the network are reported in the log file of the program so care should be followed during preparing O-D matrix.

3.4.2. Network

Transportation networks used for traffic assignment techniques in this study are compatible with the networks required by TransCAD. A network is a special TransCAD data structure that stores important connectivity, link, and node characteristics of transportation systems and facilities. TransCAD networks [12] are defined, derived, and used in conjunction with a line layer and its associated endpoint layer. The network is created and used for analysis in TransCAD because of its extremely efficient and compact format.

To create a network, the line layer must be determined, the nodes and links are to be decided, and the fields that contain link and node costs attributes must be chosen. The resulting line network will include all nodes, links, and attributes chosen from the information of the O-D flow matrix layer. The network set up for TransCAD must contain all the origin and destination nodes as well as all links that may be used by the O-D trips. All of the link attributes to be used must be included when network is formed [12]. The following Table 3.1. summarizes the requirements for each assignment method needed by TransCAD.

Table 3.1. Summary of the requirements for each traffic assignment technique [12]

	Assignment Method	Required Attributes	Required Settings
Equilibrium methods	User equilibrium (UE)	Time & Capacity	Iterations, alpha & beta
	Stochastic user equilibrium (SUE)	Time & Capacity	Iterations, alpha & beta, function & error
	System optimum (SO)	Time & Capacity	Iterations, alpha & beta
Non-equilibrium methods	All-or-nothing (AON)	Time	None
	Incremental	Time & Capacity	Increments, alpha & beta
	Capacity restraint	Time & Capacity	Iterations, alpha & beta

3.5. Travel Time Functions

In most traffic assignment techniques, travel time function is used to express travel times of a road link as a function of traffic volume. Usually these functions are expressed as the product of the free flow time multiplied by a normalized congestion function. Travel time function has characteristic that will represent a traveler's behavior which is essential to resemble the actual behavior of a road network modeled. Travel time function contributes to delay time on a link to stimulate the properties of the lanes on the link which attributes to the driving behavior of road users. Eq. (3.11) shows the normal form of travel time function [12].

$$T = T_0 * f\left(\frac{v}{c}\right) \tag{3.13}$$

Where; $T =$ travel time in minute, $T_0 =$ free flow travel time, $v =$ Traffic volume (passenger car unit/hour), $c =$ Capacity (passenger car unit/hour).

There are some developed travel time functions that have been observed in literature. These observed functions are pre-programmed in TransCAD and provided to easy calculate delay in travel time. Here some of the main common travel time functions are listed, but the reader may refer literature for more functions.

3.5.1. The bureau of public roads (BPR)

The Bureau of Public Roads formulation is one of the most-commonly and more popular used for link performance functions. The BPR function (Traffic Assignment Manual, BPR, 1964) is very well suited for use in conjunction with traffic assignment techniques. With a suitable choice of parameters, this function can represent a wide variety of flow-delay relationships (including those of many other travel time models) [12].

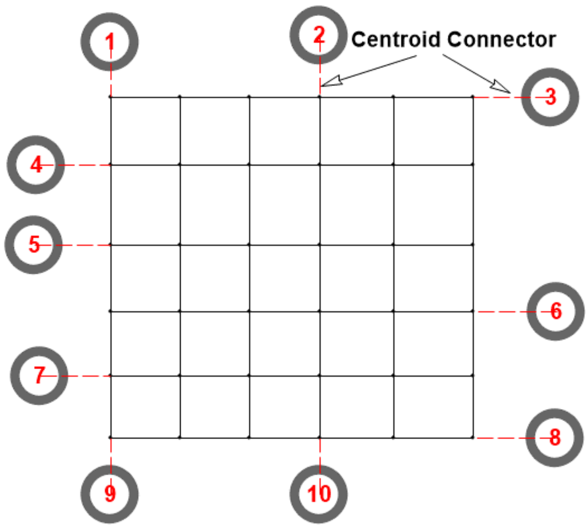
$$T_a = t_{ao} * \left[1 + \alpha_i \left(\frac{x_a}{c_a}\right)^{\beta}\right] \tag{3.14}$$

Where; T_a = travel time in minute, t_{ao} = free flow travel time, X_a= Traffic volume (passenger car unit/hour), c = Capacity (passenger car unit/hour), α_i& β are constants which are taken as 0.15 and 4.0 respectively. In this study BPR volume delay function have been used to calculate the delay in each link after traffic assignment.

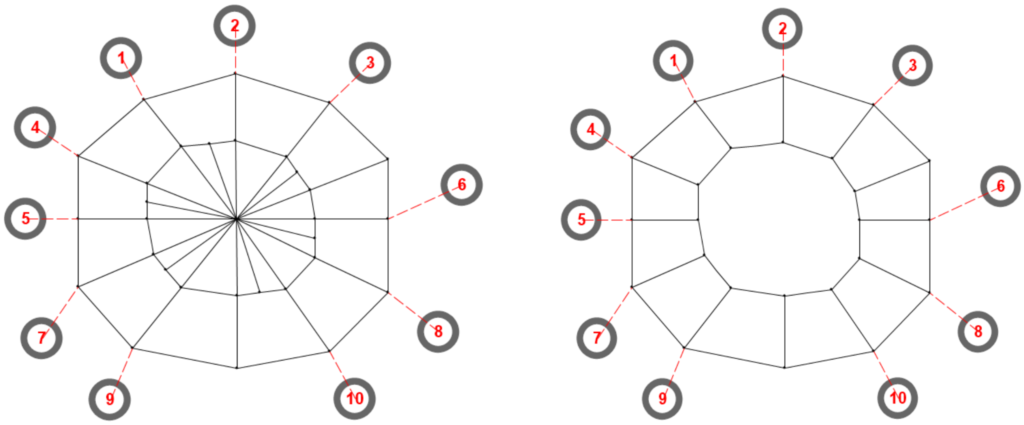
CHAPTER 4. PROPOSED STUDY

4.1. Review of The Analytical Study

In this present study, the effect of network structure on the capacity and travel time reliability has been investigated. For such a purpose, three different types of network topology of a small scale urban region have been chosen as depicted in Figure 4.1. The properties of links such as free flow travel time, distance of each link and capacities for the network topologies have been prepared using Matlab version 2017b [20] by generating random integers. Refer Tables 4.1., 4.4. and 4.6. for link properties of different topologies. Furthermore network topologies share same amount of zones (centroids) as in Table 4.2. It is worth to mention that the O-D matrix has been generated by the same version of Matlab. Throughout the study network topology and network structure will be used interchangeably.



Topology 1 (mesh network)



Topology 2 (wheel network)   Topology 3 (cycle network)

Figure 4.1. Different network topologies for analytical study

As illustrated in Figure 4.1. network topologies vary from mesh, wheel and cyclic topology. Though the real nature of network topologies reflects the existence of central zones, in this study the network topologies have been drawn to reflect the idealized graphs to show the theoretical concept of assignment techniques using software package (TransCAD). Moreover, the third topology; cyclic network, has been drawn with double cycles to see the effect of the inner cycle in the reliability concept of the network.

In this present study the free flow travel times of each link in each direction are calculated according to a fixed speed (50 km/h; speed limit for urban roads) and used as an input value to find the shortest paths.

Table 4.1. Properties of network topology 1

Link ID	Length (Km)	Dir	AB Free flow travel time (min)	BA Free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
1	0.70	0	0.84	0.84	1154	1057
2	0.21	0	0.26	0.26	1304	1462
3	0.48	0	0.57	0.57	1241	1394
4	0.21	0	0.26	0.26	1283	1331
5	0.56	0	0.67	0.67	1070	1043
6	0.92	0	1.10	1.10	1235	1410
7	0.73	0	0.88	0.88	1203	1498
8	0.58	0	0.69	0.69	1223	1081
9	0.66	0	0.79	0.79	1347	1457

Table 4.2. (Continue)

Link ID	Length (Km)	Dir	AB Free flow travel time (min)	BA Free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
10	0.21	0	0.25	0.25	1123	1304
11	0.22	0	0.27	0.27	1116	1111
12	0.47	0	0.57	0.57	1063	1346
13	0.74	0	0.89	0.89	1276	1352
14	0.74	0	0.89	0.89	1274	1475
15	0.65	0	0.78	0.78	1048	1021
16	0.78	0	0.94	0.94	1160	1057
17	0.63	0	0.75	0.75	1085	1321
18	0.45	0	0.54	0.54	1427	1389
19	1.00	0	1.19	1.19	1177	1024
20	0.65	0	0.78	0.78	1265	1342
21	0.94	0	1.12	1.12	1170	1213
22	0.89	0	1.07	1.07	1447	1384
23	0.18	0	0.21	0.21	1058	1181
24	0.35	0	0.42	0.42	1420	1099
25	0.15	0	0.18	0.18	1138	1453
26	0.24	0	0.28	0.28	1121	1053
27	0.78	0	0.93	0.93	1174	1287
28	0.46	0	0.55	0.55	1081	1121
29	0.73	0	0.88	0.88	1406	1361
30	0.18	0	0.21	0.21	1034	1312
31	0.70	0	0.84	0.84	1368	1227
32	0.45	0	0.54	0.54	1380	1392
33	0.49	0	0.59	0.59	1031	1169
34	0.82	0	0.98	0.98	1399	1076
35	0.37	0	0.44	0.44	1047	1312
36	0.45	0	0.54	0.54	1015	1138
37	0.89	0	1.07	1.07	1451	1008
38	0.91	0	1.10	1.10	1370	1487
39	0.81	0	0.97	0.97	1048	1057
40	0.38	0	0.45	0.45	1293	1114
41	0.11	0	0.14	0.14	1187	1055
42	0.25	0	0.30	0.30	1388	1487
43	0.33	0	0.40	0.40	1415	1077
44	0.53	0	0.63	0.63	1427	1348
45	0.44	0	0.53	0.53	1233	1061

Table 4.3. (Continue)

Link ID	Length (Km)	Dir	AB Free flow travel time (min)	BA Free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
46	0.13	0	0.16	0.16	1218	1359
47	1.00	0	1.20	1.20	1312	1454
48	0.20	0	0.24	0.24	1456	1370
49	0.85	0	1.02	1.02	1386	1116
50	0.95	0	1.14	1.14	1436	1108
51	0.85	0	1.02	1.02	1082	1358
52	0.25	0	0.30	0.30	1446	1394
53	0.27	0	0.32	0.32	1205	1203
54	0.42	0	0.51	0.51	1321	1405
55	0.71	0	0.85	0.85	1058	1030
56	0.94	0	1.12	1.12	1424	1091
57	0.24	0	0.29	0.29	1456	1137
58	0.94	0	1.13	1.13	1078	1477
59	0.83	0	1.00	1.00	1077	1079
60	0.25	0	0.30	0.30	1364	1179
61	0.62	0	0.74	0.74	1271	1166
62	0.16	0	0.19	0.19	1064	1411
63	0.98	0	1.17	1.17	1417	1077
64	0.31	0	0.37	0.37	1265	1265
65	0.90	0	1.08	1.08	1401	1191
66	0.69	0	0.82	0.82	1041	1471
67	0.46	0	0.55	0.55	1112	1476
68	0.47	0	0.57	0.57	1427	1498
69	0.24	0	0.28	0.28	1313	1188
70	0.12	0	0.15	0.15	1355	1190

A & B are the end nodes of a link and Dir is the direction of flow where 0 means flow is in both direction.

To make the network more realistic, the origin and destination (O-D) matrix has been designed to resample more like a real distribution matrix with a total amount of 19,142 trips. Additionally, the diagonal of the trip matrix was kept 0 indicating that there is no intrazonal trips. The folloing Table 4.2. shows the O-D matrix.

Tablo 4.2. Origin and Destination (O-D) trip matrix

		Destinations									
	Zones	1	2	3	4	5	6	7	8	9	10
Origins	1	0	164	239	345	102	187	179	162	210	276
	2	293	0	136	292	140	286	223	311	101	190
	3	123	149	0	322	142	125	211	103	213	291
	4	154	305	285	0	216	304	298	134	239	278
	5	121	114	126	306	0	197	237	312	161	250
	6	296	213	123	154	152	0	204	178	246	180
	7	248	162	232	303	134	314	0	238	256	240
	8	180	193	181	164	272	243	153	0	192	154
	9	257	139	220	287	266	187	302	104	0	139
	10	326	247	126	198	156	230	336	179	286	0

Table 4.3. represents the shortest travel times among zones for network topology 1. It was solved by employing TransCAD which uses some algorithms to predict the shortest path that connects any two zones.

Tablo 4.3. The shortest travel times (min) between zones for network topology 1

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.60	4.60	2.41	3.68	4.06	4.52	5.21	4.07	3.42
2	2.60	0.00	3.34	3.33	3.77	3.32	3.78	4.47	3.33	2.68
3	4.60	3.34	0.00	5.33	5.77	3.59	5.73	4.86	5.28	4.35
4	2.41	3.33	5.33	0.00	2.83	4.59	4.04	5.74	3.59	3.95
5	3.68	3.77	5.77	2.83	0.00	4.27	3.07	5.42	2.62	3.63
6	4.06	3.32	3.59	4.59	4.27	0.00	3.40	2.53	2.95	2.02
7	4.52	3.78	5.73	4.04	3.07	3.40	0.00	4.39	1.59	2.60
8	5.21	4.47	4.86	5.74	5.42	2.53	4.39	0.00	3.94	2.09
9	4.07	3.33	5.28	3.59	2.62	2.95	1.59	3.94	0.00	2.15
10	3.42	2.68	4.35	3.95	3.63	2.02	2.60	2.09	2.15	0.00

Similarly, Table 4.4. summarizes the input properties of network topology 2. Likewise in Table 4.1., this table also reveales the free flow travel time and the capacity in (vec/hr) of each link in each direction.

Tablo 4.4. Properties of network topology 2

Link ID	Length (Km)	Dir	AB Free flow travel time (min)	BA Free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
1	0.70	0	0.84	0.84	1154	1057
2	0.21	0	0.26	0.26	1304	1462
3	0.48	0	0.57	0.57	1241	1394
4	0.21	0	0.26	0.26	1283	1331
5	0.56	0	0.67	0.67	1070	1043
6	0.92	0	1.10	1.10	1235	1410
7	0.73	0	0.88	0.88	1203	1498
8	0.58	0	0.69	0.69	1223	1081
9	0.66	0	0.79	0.79	1347	1457
10	0.21	0	0.25	0.25	1123	1304
11	0.22	0	0.27	0.27	1116	1111
12	0.47	0	0.57	0.57	1063	1346
13	0.74	0	0.89	0.89	1276	1352
14	0.74	0	0.89	0.89	1274	1475
15	0.65	0	0.78	0.78	1048	1021
16	0.78	0	0.94	0.94	1160	1057
17	0.63	0	0.75	0.75	1085	1321
18	0.45	0	0.54	0.54	1427	1389
19	1.00	0	1.19	1.19	1177	1024
20	0.65	0	0.78	0.78	1265	1342
21	0.94	0	1.12	1.12	1170	1213
22	0.89	0	1.07	1.07	1447	1384
23	0.18	0	0.21	0.21	1058	1181
24	0.35	0	0.42	0.42	1420	1099
25	0.15	0	0.18	0.18	1138	1453
26	0.24	0	0.28	0.28	1121	1053
27	0.78	0	0.93	0.93	1174	1287
28	0.46	0	0.55	0.55	1081	1121
29	0.73	0	0.88	0.88	1406	1361
30	0.18	0	0.21	0.21	1034	1312
31	0.70	0	0.84	0.84	1368	1227
32	0.45	0	0.54	0.54	1380	1392
33	0.49	0	0.59	0.59	1031	1169
34	0.82	0	0.98	0.98	1399	1076
35	0.37	0	0.44	0.44	1047	1312
36	0.45	0	0.54	0.54	1015	1138

Tablo 4.4. (Continue)

Link ID	Length (Km)	Dir	AB Free flow travel time (min)	BA Free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
37	0.89	0	1.07	1.07	1451	1008
38	0.91	0	1.10	1.10	1370	1487
39	0.81	0	0.97	0.97	1048	1057
40	0.38	0	0.45	0.45	1293	1114
41	0.11	0	0.14	0.14	1187	1055
42	0.25	0	0.30	0.30	1388	1487
43	0.33	0	0.40	0.40	1415	1077
44	0.53	0	0.63	0.63	1427	1348
45	0.44	0	0.53	0.53	1233	1061
46	0.13	0	0.16	0.16	1218	1359
47	1.00	0	1.20	1.20	1312	1454
48	0.20	0	0.24	0.24	1456	1370
49	0.85	0	1.02	1.02	1386	1116
50	0.95	0	1.14	1.14	1436	1108
51	0.85	0	1.02	1.02	1082	1358
52	0.25	0	0.30	0.30	1446	1394
53	0.27	0	0.32	0.32	1205	1203
54	0.42	0	0.51	0.51	1321	1405
55	0.71	0	0.85	0.85	1058	1030
56	0.94	0	1.12	1.12	1424	1091
57	0.24	0	0.29	0.29	1456	1137
58	0.94	0	1.13	1.13	1078	1477
59	0.83	0	1.00	1.00	1077	1079
60	0.25	0	0.30	0.30	1364	1179
61	0.62	0	0.74	0.74	1271	1166
62	0.16	0	0.19	0.19	1064	1411
63	0.98	0	1.17	1.17	1417	1077
64	0.31	0	0.37	0.37	1265	1265
65	0.90	0	1.08	1.08	1401	1191
66	0.69	0	0.82	0.82	1041	1471
67	0.46	0	0.55	0.55	1112	1476
68	0.47	0	0.57	0.57	1427	1498
69	0.24	0	0.28	0.28	1313	1188
70	0.12	0	0.15	0.15	1355	1190

Table 4.5. shows the shortest travel times among zones for network topology 2. Again it was solved by employing TransCAD like table 4.3.

Table 4.5. The shortest travel times (min) between zones for network topology 2

Zones	1	2	3	4	5	6	7	8	9	10
1	0	1.67	2.03	2.62	3.3	3.97	3.25	2.74	4.11	3.33
2	1.67	0	1.5	2.61	3.05	3.5	3	2.33	3.7	2.92
3	2.03	1.5	0	2.97	3.41	3.34	3.36	2.69	4.06	3.28
4	2.62	2.61	2.97	0	2.61	4.65	2.96	3.42	4.39	4.01
5	3.3	3.05	3.41	2.61	0	4.15	2.23	2.92	3.66	3.51
6	3.97	3.5	3.34	4.65	4.15	0	4.1	1.73	4.72	2.32
7	3.25	3	3.36	2.96	2.23	4.1	0	2.87	2.51	3.46
8	2.74	2.33	2.69	3.42	2.92	1.73	2.87	0	3.49	1.09
9	4.11	3.7	4.06	4.39	3.66	4.72	2.51	3.49	0	3.54
10	3.33	2.92	3.28	4.01	3.51	2.32	3.46	1.09	3.54	0

Similarly, table 4.4. summarizes the input properties of network topology 2. Likewise in table 4.1., this table also reveales the free flow travel time and the capacity in (vec/hr) of each link in each direction.

Table 4.6. Properties of network topology 3

Link ID	Length (Km)	Dir	AB free flow travel time (min)	BA free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
1	0.70	0	0.84	0.84	1154	1057
2	0.21	0	0.26	0.26	1304	1462
3	0.48	0	0.57	0.57	1241	1394
4	0.21	0	0.26	0.26	1283	1331
5	0.56	0	0.67	0.67	1070	1043
6	0.92	0	1.10	1.10	1235	1410
7	0.73	0	0.88	0.88	1203	1498
8	0.58	0	0.69	0.69	1223	1081
9	0.66	0	0.79	0.79	1347	1457
10	0.21	0	0.25	0.25	1123	1304
11	0.22	0	0.27	0.27	1116	1111
12	0.47	0	0.57	0.57	1063	1346
13	0.74	0	0.89	0.89	1276	1352
14	0.74	0	0.89	0.89	1274	1475

Table 4.6. (Continue)

Link ID	Length (Km)	Dir	AB free flow travel time (min)	BA free flow travel time (min)	AB Capacity (Vec/hr)	BA Capacity (Vec/hr)
15	0.65	0	0.78	0.78	1048	1021
16	0.78	0	0.94	0.94	1160	1057
17	0.63	0	0.75	0.75	1085	1321
18	0.45	0	0.54	0.54	1427	1389
19	1.00	0	1.19	1.19	1177	1024
20	0.65	0	0.78	0.78	1265	1342
21	0.94	0	1.12	1.12	1170	1213
22	0.89	0	1.07	1.07	1447	1384
23	0.18	0	0.21	0.21	1058	1181
24	0.35	0	0.42	0.42	1420	1099
25	0.15	0	0.18	0.18	1138	1453
26	0.24	0	0.28	0.28	1121	1053
27	0.78	0	0.93	0.93	1174	1287
28	0.46	0	0.55	0.55	1081	1121
29	0.73	0	0.88	0.88	1406	1361
30	0.18	0	0.21	0.21	1034	1312
31	0.70	0	0.84	0.84	1368	1227
32	0.45	0	0.54	0.54	1380	1392
33	0.49	0	0.59	0.59	1031	1169
34	0.82	0	0.98	0.98	1399	1076
35	0.37	0	0.44	0.44	1047	1312
36	0.45	0	0.54	0.54	1015	1138
37	0.89	0	1.07	1.07	1451	1008
38	0.91	0	1.10	1.10	1370	1487
39	0.81	0	0.97	0.97	1048	1057
40	0.38	0	0.45	0.45	1293	1114
41	0.11	0	0.14	0.14	1187	1055
42	0.25	0	0.30	0.30	1388	1487
43	0.33	0	0.40	0.40	1415	1077
44	0.53	0	0.63	0.63	1427	1348
45	0.44	0	0.53	0.53	1233	1061
46	0.13	0	0.16	0.16	1218	1359

Table 4.7. summarizes the shortest travel times among zones for network topology 3. Again it was solved by employing TransCAD like table 4.3.

Table 4.7. The shortest travel times (min) between zones for network topology 3

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	1.67	2.03	2.62	3.02	4.03	2.97	4.38	4.14	4.66
2	1.67	0.00	1.50	2.61	3.01	3.50	2.96	3.85	4.13	4.44
3	2.03	1.50	0.00	2.97	3.37	3.34	3.32	3.69	4.49	4.28
4	2.62	2.61	2.97	0.00	2.61	4.97	2.96	5.14	4.39	5.34
5	3.02	3.01	3.37	2.61	0.00	5.37	2.23	4.50	3.66	4.70
6	4.03	3.50	3.34	4.97	5.37	0.00	4.88	1.73	4.72	2.32
7	2.97	2.96	3.32	2.96	2.23	4.88	0.00	3.65	2.51	3.85
8	4.38	3.85	3.69	5.14	4.50	1.73	3.65	0.00	3.49	1.09
9	4.14	4.13	4.49	4.39	3.66	4.72	2.51	3.49	0.00	3.54
10	4.66	4.44	4.28	5.34	4.70	2.32	3.85	1.09	3.54	0.00

4.2. Reults of Analytical Study

Here the results of the analytical study will be presented for all network topologies mentioned. At the begining, results of network topology 1 will be briefly presented using both equilibrium and non-equilibrium assignment techniques followed by network topology 2 and finaly for network topology 3. Output results after trip assignment will be concisely given here and further discussed in chapter 5.

4.2.1. Network topology 1

Network topology 1 with different assignment techniques was at first exemplified. It is well known that assignment techniques use the link capacity as a function of link flow and for that reason legend is generated by TransCAD to show the ratio of volume of links to the capacity of the link itself. The main outputs that have been taken into consideration were the link flows in both directions that is (AB & BA flow), travel times of each link after assignment method, ratio of volume to the capacity of link and the speed of each link in each direction.

Figure 4.2. shows network topology 1 assigned with trips using incremental assignment technique. As stated earlier it is obvious from the figure that most of the centroid – connector link types have been colored with dark which means the ratio of

link volume to the capacity exceeds the maximum allowable default value which was kept as 1.8 by TransCAD.

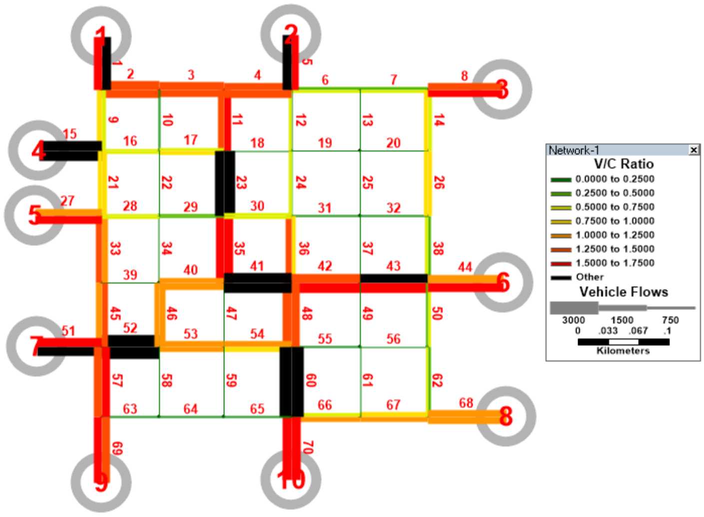


Figure 4.2. Traffic assignment of topology 1 with incremental method

The table below illustrates the output results of network topology 1. For instance, link 5 is a centroid connector which connects centroid 2 to the network system as depicted in Figure 4.2. The total amount of flow assigned to the link is 3658 trips/hr in both directions and the maximum volume to capacity ratio (VOC) is 1.84. The speed of the link has reduced from free flow speed of 50 km/h to 18.37 km/h for the link direction connected to the network; that is from zone 2 to the network and 24.77 km/h for the reverse link direction (i.e. AB & BA).

Table 4.8. Network topology 1 after assignment using incremental method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1890	2124	4014	0.43	0.43	0.43	1.45	1.45	1.45	29.15	29.05
3	1703	1945	3648	0.87	0.89	0.89	1.37	1.40	1.40	32.99	32.22
4	1791	1726	3517	0.41	0.37	0.41	1.40	1.30	1.40	30.88	34.02
5	1972	1686	3658	1.83	1.36	1.83	1.84	1.62	1.84	18.37	24.77
6	710	651	1361	1.12	1.11	1.12	0.58	0.46	0.58	49.37	49.84
7	710	651	1361	0.90	0.88	0.90	0.59	0.43	0.59	48.88	49.51
8	1679	1668	3347	1.06	1.28	1.28	1.37	1.54	1.54	32.90	27.26

Table 4.8. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
9	1116	1017	2133	0.85	0.82	0.85	0.83	0.70	0.83	46.81	48.41
10	249	241	490	0.25	0.25	0.25	0.22	0.18	0.22	50.00	50.00
11	1406	1713	3119	0.37	0.50	0.50	1.26	1.54	1.54	35.48	26.46
12	611	320	932	0.58	0.57	0.58	0.58	0.24	0.58	48.67	49.45
13	0	0	0	0.89	0.89	0.89	0.00	0.00	0.00	50.00	50.00
14	1028	958	1986	0.95	0.91	0.95	0.81	0.65	0.81	46.90	48.59
15	2213	2371	4584	3.11	4.18	4.18	2.11	2.32	2.32	12.56	9.32
16	716	577	1293	0.96	0.95	0.96	0.62	0.55	0.62	48.73	49.13
17	904	757	1660	0.80	0.76	0.80	0.83	0.57	0.83	47.01	49.60
18	134	0	134	0.54	0.54	0.54	0.09	0.00	0.09	50.00	50.00
19	0	0	0	1.19	1.19	1.19	0.00	0.00	0.00	50.00	50.00
20	0	0	0	0.78	0.78	0.78	0.00	0.00	0.00	50.00	50.00
21	972	1169	2140	1.20	1.26	1.26	0.83	0.96	0.96	47.00	44.60
22	0	0	0	1.07	1.07	1.07	0.00	0.00	0.00	50.00	50.00
23	2176	2470	4645	0.77	0.81	0.81	2.06	2.09	2.09	13.97	13.30
24	746	320	1066	0.42	0.42	0.42	0.53	0.29	0.53	49.44	49.95
25	0	0	0	0.18	0.18	0.18	0.00	0.00	0.00	50.00	50.00
26	1028	958	1986	0.31	0.31	0.31	0.92	0.91	0.92	46.49	46.64
27	1824	1580	3404	1.74	1.25	1.74	1.55	1.23	1.55	26.85	37.53
28	606	562	1168	0.56	0.56	0.56	0.56	0.50	0.56	49.45	49.71
29	547	562	1109	0.88	0.88	0.88	0.39	0.41	0.41	49.60	49.56
30	606	697	1302	0.21	0.21	0.21	0.59	0.53	0.59	50.00	50.00
31	249	300	549	0.84	0.84	0.84	0.18	0.24	0.24	49.99	49.97
32	249	300	549	0.54	0.54	0.54	0.18	0.22	0.22	49.99	49.98
33	1445	1441	2886	0.93	0.79	0.93	1.40	1.23	1.40	31.56	37.01
34	59	0	59	0.98	0.98	0.98	0.04	0.00	0.04	50.00	50.00
35	1831	2050	3882	1.06	0.83	1.06	1.75	1.56	1.75	20.99	26.63
36	1414	1029	2443	0.84	0.59	0.84	1.39	0.90	1.39	31.95	45.44
37	0	0	0	1.07	1.07	1.07	0.00	0.00	0.00	50.00	50.00
38	729	709	1437	1.11	1.11	1.11	0.53	0.48	0.53	49.05	49.26
39	0	0	0	0.97	0.97	0.97	0.00	0.00	0.00	50.00	50.00
40	1541	1231	2772	0.59	0.55	0.59	1.19	1.10	1.19	38.89	41.41
41	2309	2218	4527	0.44	0.55	0.55	1.95	2.10	2.10	14.97	12.00
42	2293	2107	4401	0.64	0.48	0.64	1.65	1.42	1.65	23.61	31.15
43	2293	2107	4401	0.81	1.28	1.28	1.62	1.96	1.96	24.32	15.48

Table 4.8. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
44	1746	2073	3819	0.84	1.16	1.16	1.22	1.54	1.54	37.78	27.45
45	1445	1441	2886	0.68	0.80	0.80	1.17	1.36	1.36	38.82	32.98
46	1231	1482	2713	0.19	0.19	0.19	1.01	1.09	1.09	42.16	40.22
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	2046	1756	3802	0.38	0.34	0.38	1.41	1.28	1.41	31.54	35.59
49	0	0	0	1.02	1.02	1.02	0.00	0.00	0.00	50.00	50.00
50	465	586	1051	1.14	1.15	1.15	0.32	0.53	0.53	49.92	49.42
51	2127	2143	4270	3.30	1.97	3.30	1.97	1.58	1.97	15.43	25.90
52	2698	2689	5387	0.85	0.92	0.92	1.87	1.93	1.93	17.75	16.25
53	1216	1458	2674	0.37	0.42	0.42	1.01	1.21	1.21	43.82	38.24
54	1216	1458	2674	0.56	0.60	0.60	0.92	1.04	1.04	44.61	42.08
55	116	165	281	0.85	0.85	0.85	0.11	0.16	0.16	50.12	50.11
56	116	0	116	1.12	1.12	1.12	0.08	0.00	0.08	50.00	50.00
57	1856	1877	3733	0.40	0.61	0.61	1.27	1.65	1.65	35.56	23.50
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	50.00	50.00
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	50.00	50.00
60	2781	2684	5465	1.08	1.51	1.51	2.04	2.28	2.28	13.92	9.94
61	0	165	165	0.74	0.74	0.74	0.00	0.14	0.14	50.00	50.00
62	581	586	1166	0.19	0.19	0.19	0.55	0.42	0.55	49.86	50.30
63	24	48	72	1.17	1.17	1.17	0.02	0.04	0.04	50.00	50.00
64	24	48	72	0.37	0.37	0.37	0.02	0.04	0.04	50.00	50.00
65	24	48	72	1.08	1.08	1.08	0.02	0.04	0.04	50.00	50.00
66	1141	981	2122	1.00	0.84	1.00	1.10	0.67	1.10	41.52	49.03
67	1141	1146	2287	0.64	0.58	0.64	1.03	0.78	1.03	43.04	47.59
68	1732	1721	3453	0.76	0.72	0.76	1.21	1.15	1.21	37.32	39.22
69	1901	1904	3805	0.46	0.56	0.56	1.45	1.60	1.60	31.00	25.85
70	2084	1998	4082	0.28	0.33	0.33	1.54	1.68	1.68	26.10	21.90

On the other hand, the shortest travel times among the zones after incremental trip assignment are presented in Table 4.9. Incremental assignment technique which uses iterative method to split total trips between origin and destination zones into small quantities easier to be assigned to the network uses all-or-nothing technique to assign trips following shortest path. For that reason, it is not preferable to use this technique for large urban areas where trips are so huge.

Table 4.9. The shortest travel time (min) between zones after traffic assignment of network topology 1

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	4.77	6.70	6.73	4.99	7.60	7.32	8.26	6.32	6.78
2	5.98	0.00	5.12	8.47	5.73	6.29	7.73	6.94	6.72	5.47
3	7.20	4.41	0.00	9.69	6.59	4.59	8.58	5.48	7.58	6.19
4	6.37	6.95	8.89	0.00	5.55	9.29	7.89	9.85	6.88	8.37
5	6.27	5.74	7.28	7.19	0.00	6.85	5.32	7.28	4.32	5.81
6	8.05	5.54	4.45	10.05	6.10	0.00	6.78	2.90	5.77	3.93
7	9.43	8.31	9.84	10.35	6.15	7.98	0.00	7.97	4.27	6.49
8	8.70	6.19	5.71	10.71	6.75	3.26	6.83	0.00	5.36	2.51
9	7.20	6.08	7.62	8.12	3.92	5.75	3.05	5.44	0.00	3.41
10	7.57	5.06	6.60	9.57	5.61	4.42	5.48	2.63	3.45	0.00

In the same manner, network topology 1 was again assigned with trips using user equilibrium assignment technique. This time more reliable output has been achieved compared to the first assignment method. See Table 4.10.

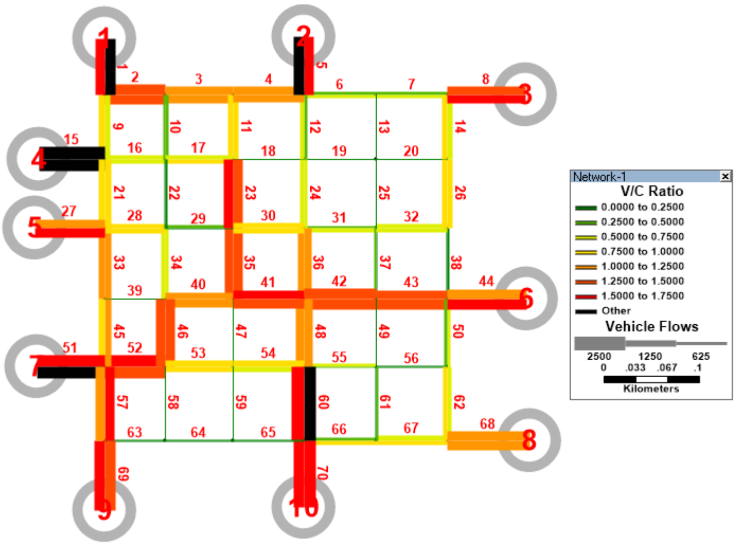


Figure 4.3. Traffic assignment of topology 1 using user equilibrium (UE) technique

For instance, in the first assignment technique, almost 14 links have not been assigned with trips while in UE technique trips have been assigned to 4 pairs of them. This is because user equilibrium (UE) assignment technique uses Wordrop's first principle stated earlier in chapter three, so no travelers can improve or reduce their travel times by shifting routes which satisfies equilibrium has reached.

Table 4.10. Network topology 1 after user equilibrium assignment method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1718	1914	3632	0.38	0.37	0.38	1.32	1.31	1.32	33.37	33.64
3	1493	1602	3095	0.75	0.72	0.75	1.20	1.15	1.20	38.44	40.05
4	1408	1494	2902	0.32	0.32	0.32	1.10	1.12	1.12	39.80	39.14
5	1972	1686	3658	1.83	1.36	1.83	1.84	1.62	1.84	18.37	24.77
6	660	594	1254	1.11	1.11	1.11	0.53	0.42	0.53	49.58	49.95
7	660	594	1254	0.89	0.88	0.89	0.55	0.40	0.55	49.11	49.59
8	1679	1668	3347	1.06	1.28	1.28	1.37	1.54	1.54	32.90	27.26
9	1120	1059	2179	0.85	0.82	0.85	0.83	0.73	0.83	46.77	48.11
10	454	541	995	0.25	0.25	0.25	0.40	0.42	0.42	50.00	50.00
11	964	987	1951	0.29	0.30	0.30	0.86	0.89	0.89	45.12	44.71
12	787	653	1440	0.60	0.57	0.60	0.74	0.49	0.74	47.34	49.07
13	0	0	0	0.89	0.89	0.89	0.00	0.00	0.00	49.89	49.89
14	1085	1008	2093	0.96	0.92	0.96	0.85	0.68	0.85	46.24	48.31
15	2213	2371	4584	3.11	4.18	4.18	2.11	2.32	2.32	12.56	9.32
16	716	745	1461	0.96	0.97	0.97	0.62	0.71	0.71	48.73	48.01
17	841	746	1587	0.79	0.76	0.79	0.77	0.56	0.77	47.81	49.64
18	0	0	0	0.54	0.54	0.54	0.00	0.00	0.00	50.00	50.00
19	0	0	0	1.19	1.19	1.19	0.00	0.00	0.00	50.42	50.42
20	0	0	0	0.78	0.78	0.78	0.00	0.00	0.00	50.00	50.00
21	1144	1211	2354	1.27	1.29	1.29	0.98	1.00	1.00	44.29	43.83
22	100	311	412	1.07	1.07	1.07	0.07	0.22	0.22	49.91	49.89
23	1805	1733	3538	0.48	0.36	0.48	1.71	1.47	1.71	22.65	30.33
24	787	653	1440	0.43	0.43	0.43	0.55	0.59	0.59	49.30	49.08
25	0	0	0	0.18	0.18	0.18	0.00	0.00	0.00	50.00	50.00
26	1085	1008	2093	0.32	0.32	0.32	0.97	0.96	0.97	45.45	45.68
27	1824	1580	3404	1.74	1.25	1.74	1.55	1.23	1.55	26.85	37.53
28	991	862	1853	0.61	0.58	0.61	0.92	0.77	0.92	45.38	47.68
29	252	564	816	0.88	0.88	0.88	0.18	0.41	0.41	49.77	49.55
30	1028	1009	2036	0.24	0.22	0.24	0.99	0.77	0.99	44.86	48.87
31	700	425	1125	0.85	0.84	0.85	0.51	0.35	0.51	49.49	49.89
32	704	857	1561	0.55	0.55	0.55	0.51	0.62	0.62	49.50	48.95
33	1232	1184	2415	0.77	0.68	0.77	1.19	1.01	1.19	38.17	43.04
34	840	609	1449	1.00	1.00	1.00	0.60	0.57	0.60	49.25	49.44
35	1510	1769	3279	0.73	0.66	0.73	1.44	1.35	1.44	30.60	33.73

Table 4.10. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
36	1237	1359	2596	0.72	0.70	0.72	1.22	1.19	1.22	37.58	38.31
37	432	4	436	1.07	1.07	1.07	0.30	0.00	0.30	49.85	49.91
38	228	304	532	1.10	1.10	1.10	0.17	0.20	0.20	49.63	49.62
39	0	0	0	0.97	0.97	0.97	0.00	0.00	0.00	50.00	50.00
40	1575	1231	2806	0.60	0.55	0.60	1.22	1.11	1.22	38.08	41.40
41	1725	1640	3366	0.23	0.26	0.26	1.45	1.55	1.55	28.24	25.12
42	1992	2037	4029	0.49	0.46	0.49	1.44	1.37	1.44	30.55	32.72
43	1989	1605	3594	0.63	0.70	0.70	1.41	1.49	1.49	31.22	28.46
44	1746	2073	3819	0.84	1.16	1.16	1.22	1.54	1.54	37.78	27.45
45	1232	1184	2415	0.61	0.65	0.65	1.00	1.12	1.12	43.34	40.42
46	1716	1830	3546	0.25	0.24	0.25	1.41	1.35	1.41	30.64	32.65
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	1674	1667	3342	0.30	0.32	0.32	1.15	1.22	1.22	39.61	37.62
49	0	0	0	1.02	1.02	1.02	0.00	0.00	0.00	50.00	50.00
50	565	584	1149	1.14	1.15	1.15	0.39	0.53	0.53	49.82	49.43
51	2127	2143	4270	3.30	1.97	3.30	1.97	1.58	1.97	15.43	25.90
52	2131	2139	4270	0.51	0.55	0.55	1.47	1.53	1.53	29.28	27.30
53	984	1105	2089	0.34	0.35	0.35	0.82	0.92	0.92	47.46	45.74
54	984	1105	2089	0.53	0.54	0.54	0.74	0.79	0.79	47.23	46.73
55	293	634	927	0.85	0.87	0.87	0.28	0.62	0.62	50.00	49.06
56	270	148	418	1.12	1.12	1.12	0.19	0.14	0.19	50.00	50.00
57	1777	1738	3515	0.39	0.53	0.53	1.22	1.53	1.53	37.25	27.30
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	49.91	49.91
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	49.80	49.80
60	2365	2138	4504	0.71	0.79	0.79	1.73	1.81	1.81	21.22	19.06
61	23	486	509	0.74	0.74	0.74	0.02	0.42	0.42	50.27	50.04
62	835	732	1567	0.20	0.19	0.20	0.78	0.52	0.78	47.81	49.98
63	163	127	290	1.17	1.17	1.17	0.12	0.12	0.12	50.00	50.00
64	163	127	290	0.37	0.37	0.37	0.13	0.10	0.13	50.00	50.00
65	163	127	290	1.08	1.08	1.08	0.12	0.11	0.12	50.00	50.00
66	864	514	1377	0.88	0.82	0.88	0.83	0.35	0.83	47.14	50.38
67	886	1000	1886	0.58	0.57	0.58	0.80	0.68	0.80	47.32	48.64
68	1732	1721	3453	0.76	0.72	0.76	1.21	1.15	1.21	37.32	39.22
69	1901	1904	3805	0.46	0.56	0.56	1.45	1.60	1.60	31.00	25.85
70	2084	1998	4082	0.28	0.33	0.33	1.54	1.68	1.68	26.10	21.90

Likewise, the shortest travel time paths among network centroids after assignment using user equilibrium (UE) method is presented in Table 4.11. It is obvious from the results that (UE) technique is more convenient in network assignment rather than incremental assignment technique with respect of travel time after trip assignment. For instance, the travel time between centroid 1 and 8 (furthest zones) after incremental assignment technique is (8.26 min) while after using UE technique it reduced to (7.74 min).

Table 4.11. Shortest travel time (min) between zones after traffic assignment of network topology 1

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	4.50	6.42	6.73	5.06	6.84	7.17	7.74	6.14	5.89
2	5.69	0.00	5.11	8.27	5.63	5.85	6.97	6.76	5.94	4.91
3	6.91	4.40	0.00	9.49	6.66	4.59	8.00	5.50	6.97	5.75
4	6.38	6.73	8.65	0.00	5.63	8.58	7.73	9.48	6.70	7.63
5	6.30	5.56	7.38	7.21	0.00	6.47	5.09	7.37	4.07	5.52
6	7.11	5.06	4.45	9.19	5.63	0.00	5.58	2.91	4.56	3.33
7	9.20	7.64	9.46	10.11	5.89	7.17	0.00	7.58	4.25	5.73
8	8.36	6.31	5.71	10.45	6.88	3.26	6.34	0.00	5.32	2.47
9	6.88	5.32	7.15	7.80	3.58	4.86	2.96	5.27	0.00	3.41
10	6.49	4.45	5.99	8.58	5.01	3.67	4.47	2.46	3.45	0.00

In the final attempt to assign traffic to network topology 1 stochastic user equilibrium (SUE) technique has been utilized, see Figure 4.4. Generally this method assumes that travelers have less information about the network and they observe travel costs in different ways. Stochastic user equilibrium (SUE) technique might produce more realistic result than normal user equilibrium technique in some circumstances. Comparing the two techniques, in UE the traveler has a past knowledge of the network and has a choice to select the shortest path though he/she can not reduce his/her travel time by changing path, while in SUE the traveler has less information about the network and assignment of trips are done by Method of Successive Averages (MSA), which is known to be a convergent method.

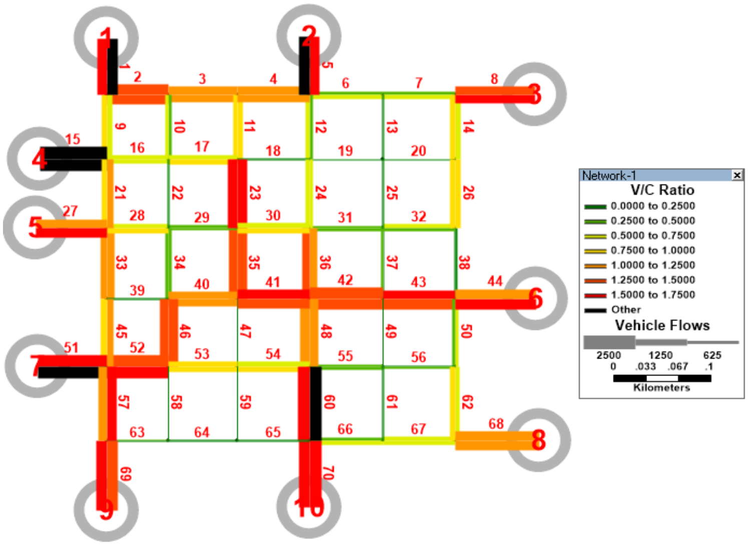


Figure 4.4. Traffic assignment of topology 1 using stochastic user equilibrium (SUE) technique

Table 4.12. shows more realistic result than normal user equilibrium (UE) model that is because SUE permits use of less attractive as well as the most-attractive route. That means less attractive routes will have lower utilization but won't have zero flow as was the case with user equilibrium (UE) method and incremental method.

Table 4.12. Network topology 1 after stochastic user equilibrium assignment method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1721	1909	3630	0.38	0.37	0.38	1.32	1.31	1.32	33.30	33.75
3	1391	1562	2953	0.71	0.70	0.71	1.12	1.12	1.12	40.85	40.87
4	1465	1498	2963	0.33	0.32	0.33	1.14	1.13	1.14	38.62	39.06
5	1972	1686	3658	1.83	1.36	1.83	1.84	1.62	1.84	18.37	24.77
6	715	597	1312	1.12	1.11	1.12	0.58	0.42	0.58	49.35	49.94
7	725	624	1349	0.90	0.88	0.90	0.60	0.42	0.60	48.81	49.55
8	1679	1668	3347	1.06	1.28	1.28	1.37	1.54	1.54	32.90	27.26
9	1071	1018	2089	0.84	0.82	0.84	0.80	0.70	0.80	47.29	48.40
10	603	620	1223	0.25	0.25	0.25	0.54	0.48	0.54	49.78	50.02
11	870	1007	1878	0.28	0.30	0.30	0.78	0.91	0.91	46.32	44.39
12	786	651	1437	0.60	0.57	0.60	0.74	0.48	0.74	47.35	49.07
13	27	10	37	0.89	0.89	0.89	0.02	0.01	0.02	49.89	49.89
14	1055	943	1998	0.95	0.91	0.95	0.83	0.64	0.83	46.60	48.67

Table 4.12. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
15	2213	2371	4584	3.11	4.18	4.18	2.11	2.32	2.32	12.56	9.32
16	794	713	1507	0.97	0.97	0.97	0.68	0.67	0.68	48.20	48.29
17	943	787	1730	0.81	0.76	0.81	0.87	0.60	0.87	46.42	49.47
18	2	2	4	0.54	0.54	0.54	0.00	0.00	0.00	50.00	50.00
19	1	0	1	1.19	1.19	1.19	0.00	0.00	0.00	50.00	50.00
20	19	0	19	0.78	0.78	0.78	0.02	0.00	0.02	50.00	50.00
21	1062	1248	2310	1.23	1.31	1.31	0.91	1.03	1.03	45.70	43.11
22	181	274	455	1.07	1.07	1.07	0.13	0.20	0.20	49.90	49.90
23	1809	1790	3599	0.48	0.38	0.48	1.71	1.52	1.71	22.54	28.71
24	787	652	1439	0.43	0.43	0.43	0.55	0.59	0.59	49.30	49.09
25	27	28	55	0.18	0.18	0.18	0.02	0.02	0.02	50.00	50.00
26	1055	924	1979	0.31	0.30	0.31	0.94	0.88	0.94	46.02	47.23
27	1824	1580	3404	1.74	1.25	1.74	1.55	1.23	1.55	26.85	37.53
28	935	759	1695	0.60	0.57	0.60	0.87	0.68	0.87	46.29	48.64
29	417	514	931	0.88	0.88	0.88	0.30	0.38	0.38	49.72	49.62
30	1030	949	1979	0.24	0.22	0.24	1.00	0.72	1.00	44.81	49.40
31	618	380	998	0.85	0.84	0.85	0.45	0.31	0.45	49.69	49.93
32	620	802	1422	0.54	0.55	0.55	0.45	0.58	0.58	49.70	49.19
33	1215	1333	2549	0.76	0.74	0.76	1.18	1.14	1.18	38.64	39.74
34	691	509	1200	0.99	0.99	0.99	0.49	0.47	0.49	49.76	49.83
35	1541	1700	3241	0.75	0.63	0.75	1.47	1.30	1.47	29.61	35.46
36	1328	1351	2679	0.78	0.70	0.78	1.31	1.19	1.31	34.72	38.52
37	449	30	480	1.07	1.07	1.07	0.31	0.03	0.31	49.84	49.91
38	253	305	559	1.10	1.10	1.10	0.18	0.21	0.21	49.63	49.62
39	0	90	91	0.97	0.97	0.97	0.00	0.09	0.09	50.10	50.10
40	1465	1304	2769	0.56	0.58	0.58	1.13	1.17	1.17	40.63	39.54
41	1723	1721	3444	0.23	0.29	0.29	1.45	1.63	1.63	28.31	22.86
42	1977	2130	4107	0.49	0.49	0.49	1.42	1.43	1.43	30.90	30.66
43	1947	1680	3627	0.62	0.76	0.76	1.38	1.56	1.56	32.19	26.21
44	1746	2073	3819	0.84	1.16	1.16	1.22	1.54	1.54	37.78	27.45
45	1215	1243	2458	0.61	0.68	0.68	0.99	1.17	1.17	43.63	38.84
46	1665	1735	3400	0.24	0.22	0.24	1.37	1.28	1.37	31.99	34.86
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	1784	1652	3436	0.32	0.32	0.32	1.22	1.21	1.22	37.38	37.96
49	0	0	0	1.02	1.02	1.02	0.00	0.00	0.00	50.00	50.00

Table 4.12. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
50	524	636	1160	1.14	1.16	1.16	0.36	0.57	0.57	49.87	49.20
51	2127	2143	4270	3.30	1.97	3.30	1.97	1.58	1.97	15.43	25.90
52	2213	2077	4290	0.55	0.52	0.55	1.53	1.49	1.53	27.42	28.75
53	994	928	1922	0.34	0.34	0.34	0.82	0.77	0.82	47.34	48.08
54	994	928	1922	0.53	0.52	0.53	0.75	0.66	0.75	47.14	48.04
55	504	415	920	0.86	0.85	0.86	0.48	0.40	0.48	49.73	49.92
56	444	220	664	1.12	1.12	1.12	0.31	0.20	0.31	50.00	50.00
57	1622	1802	3424	0.36	0.56	0.56	1.11	1.58	1.58	40.34	25.51
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	49.91	49.91
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	49.80	49.80
60	2259	2150	4409	0.64	0.80	0.80	1.66	1.82	1.82	23.49	18.80
61	60	195	255	0.74	0.74	0.74	0.05	0.17	0.17	50.00	50.00
62	968	856	1823	0.21	0.19	0.21	0.91	0.61	0.91	45.83	49.52
63	99	282	381	1.17	1.17	1.17	0.07	0.26	0.26	50.00	50.00
64	99	282	381	0.37	0.37	0.37	0.08	0.22	0.22	50.00	50.00
65	99	282	381	1.08	1.08	1.08	0.07	0.24	0.24	50.00	49.98
66	694	682	1376	0.84	0.83	0.84	0.67	0.46	0.67	49.03	50.14
67	754	877	1631	0.57	0.56	0.57	0.68	0.59	0.68	48.64	49.26
68	1732	1721	3453	0.76	0.72	0.76	1.21	1.15	1.21	37.32	39.22
69	1901	1904	3805	0.46	0.56	0.56	1.45	1.60	1.60	31.00	25.85
70	2084	1998	4082	0.28	0.33	0.33	1.54	1.68	1.68	26.10	21.90

Similarly, the shortest travel time paths among network centroids after employing stochastic user equilibrium traffic assignment SUE method are presented in table 4.13. It is obvious from the results that (SUE) technique is more reliable in network assignment rather than other assignment techniques. For instance, the travel time between centroid 1 and 8 (furthest zones) after user assignment technique is (7.74 min) while after using SUE technique it reduced to (7.62min).

Table 4.13. Shortest travel time (min) between zones after traffic assignment of network topology 1

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	4.46	6.40	6.72	5.02	6.79	7.10	7.62	6.05	5.82
2	5.68	0.00	5.12	8.25	5.61	5.89	6.98	6.72	5.92	4.92

Table 4.13. (Continue)

Zones	1	2	3	4	5	6	7	8	9	10
3	6.90	4.40	0.00	9.47	6.63	4.58	7.99	5.49	6.94	5.72
4	6.37	6.69	8.63	0.00	5.59	8.61	7.68	9.44	6.62	7.64
5	6.32	5.58	7.34	7.23	0.00	6.38	5.08	7.21	4.02	5.41
6	7.20	5.15	4.44	9.29	5.70	0.00	5.69	2.91	4.63	3.37
7	9.21	7.62	9.39	10.22	5.97	7.13	0.00	7.50	4.22	5.70
8	8.34	6.29	5.70	10.43	6.80	3.27	6.26	0.00	5.21	2.47
9	6.93	5.34	7.11	7.94	3.70	4.85	3.00	5.22	0.00	3.41
10	6.50	4.45	5.97	8.60	4.96	3.65	4.43	2.41	3.37	0.00

4.2.2. Network topology 2

In this section, results of the analytical study of network topology 2 with different assignment techniques are optimized. This second network topology is termed as wheel network. The main parameters that have been taken into consideration were also the same as the previous networks. Figure 4.5. shows network topology 2 assigned with trips using incremental assignment technique.

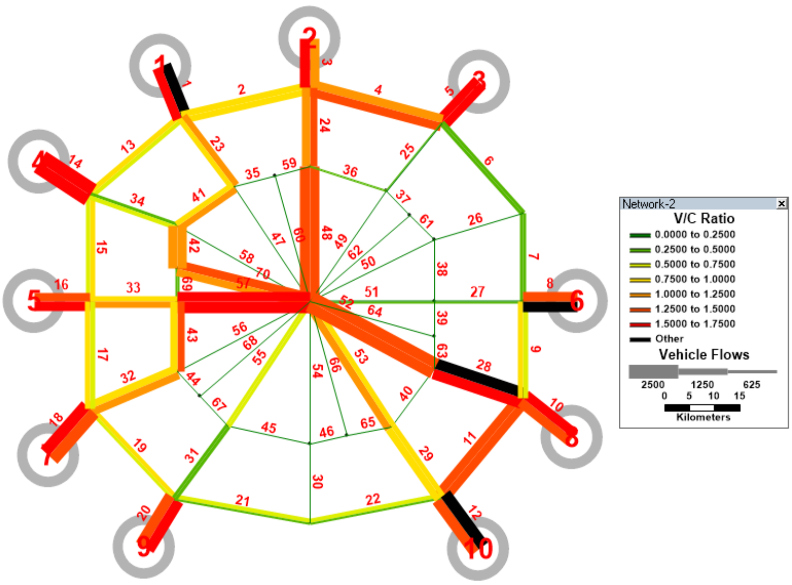


Figure 4.5. Traffic assignment of topology 3 using incremental model

Table 4.14. Network topology 2 after assignment using incremental method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1105	1208	2313	0.28	0.28	0.28	0.85	0.83	0.85	44.98	45.30
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	1678	1657	3334	0.37	0.35	0.37	1.31	1.24	1.31	33.69	35.63
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	523	514	1037	1.11	1.10	1.11	0.42	0.36	0.42	49.94	50.05
7	523	514	1037	0.88	0.88	0.88	0.43	0.34	0.43	49.51	49.67
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	1079	1061	2140	0.84	0.82	0.84	0.80	0.73	0.80	47.21	48.10
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64
11	1611	1634	3244	0.45	0.46	0.46	1.44	1.47	1.47	29.62	28.74
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	959	744	1703	0.93	0.90	0.93	0.75	0.55	0.75	47.61	49.21
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	753	896	1649	0.81	0.85	0.85	0.72	0.88	0.88	48.08	45.92
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	935	990	1925	0.81	0.79	0.81	0.86	0.75	0.86	46.55	48.12
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	656	855	1511	1.21	1.28	1.28	0.56	0.83	0.83	49.70	46.99
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10
21	430	724	1154	1.12	1.14	1.14	0.37	0.60	0.60	50.22	49.42
22	430	724	1154	1.07	1.08	1.08	0.30	0.52	0.52	49.85	49.35
23	1004	1250	2254	0.24	0.25	0.25	0.95	1.06	1.06	45.86	43.27
24	1637	1475	3112	0.53	0.62	0.62	1.15	1.34	1.34	39.53	33.65
25	288	266	554	0.18	0.18	0.18	0.25	0.18	0.25	49.97	49.99
26	0	0	0	0.28	0.28	0.28	0.00	0.00	0.00	50.00	50.00
27	153	489	642	0.93	0.93	0.93	0.13	0.38	0.38	50.32	50.17
28	1945	1893	3838	1.42	1.22	1.42	1.80	1.69	1.80	19.50	22.61
29	1062	1293	2355	0.92	0.99	0.99	0.76	0.95	0.95	47.46	44.35
30	0	0	0	0.21	0.21	0.21	0.00	0.00	0.00	50.00	50.00
31	616	524	1140	0.85	0.84	0.85	0.45	0.43	0.45	49.69	49.75
32	1434	1306	2740	0.63	0.60	0.63	1.04	0.94	1.04	42.56	44.79
33	1120	964	2084	0.71	0.63	0.71	1.09	0.82	1.09	41.22	46.60
34	716	516	1232	0.99	0.99	0.99	0.51	0.48	0.51	49.69	49.81
35	0	0	0	0.44	0.44	0.44	0.00	0.00	0.00	50.00	50.00

Table 4.14. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
36	266	288	554	0.54	0.54	0.54	0.26	0.25	0.26	49.96	49.97
37	0	0	0	1.07	1.07	1.07	0.00	0.00	0.00	50.00	50.00
38	0	0	0	1.10	1.10	1.10	0.00	0.00	0.00	50.00	50.00
39	0	0	0	0.97	0.97	0.97	0.00	0.00	0.00	50.00	50.00
40	0	0	0	0.45	0.45	0.45	0.00	0.00	0.00	50.00	50.00
41	1004	1250	2254	0.15	0.18	0.18	0.85	1.19	1.19	43.78	36.38
42	1720	1766	3486	0.41	0.39	0.41	1.24	1.19	1.24	36.94	38.50
43	1306	1434	2740	0.44	0.59	0.59	0.92	1.33	1.33	44.64	33.64
44	0	0	0	0.63	0.63	0.63	0.00	0.00	0.00	50.00	50.00
45	0	0	0	0.53	0.53	0.53	0.00	0.00	0.00	50.00	50.00
46	0	0	0	0.16	0.16	0.16	0.00	0.00	0.00	50.00	50.00
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	1925	1740	3665	0.35	0.33	0.35	1.32	1.27	1.32	34.29	35.96
49	0	0	0	1.02	1.02	1.02	0.00	0.00	0.00	50.00	50.00
50	0	0	0	1.14	1.14	1.14	0.00	0.00	0.00	50.00	50.00
51	153	489	642	1.02	1.02	1.02	0.14	0.36	0.36	50.00	49.87
52	1945	1893	3838	0.45	0.45	0.45	1.35	1.36	1.36	33.53	33.12
53	1062	1293	2355	0.35	0.38	0.38	0.88	1.07	1.07	46.42	42.18
54	0	0	0	0.51	0.51	0.51	0.00	0.00	0.00	50.00	50.00
55	616	524	1140	0.86	0.86	0.86	0.58	0.51	0.58	49.27	49.62
56	0	0	0	1.12	1.12	1.12	0.00	0.00	0.00	50.00	50.00
57	2185	1790	3975	0.51	0.56	0.56	1.50	1.57	1.57	28.20	25.84
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	50.00	50.00
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	50.00	50.00
60	0	0	0	0.30	0.30	0.30	0.00	0.00	0.00	50.00	50.00
61	0	0	0	0.74	0.74	0.74	0.00	0.00	0.00	50.00	50.00
62	0	0	0	0.19	0.19	0.19	0.00	0.00	0.00	50.00	50.00
63	0	0	0	1.17	1.17	1.17	0.00	0.00	0.00	50.00	50.00
64	0	0	0	0.37	0.37	0.37	0.00	0.00	0.00	50.00	50.00
65	0	0	0	1.08	1.08	1.08	0.00	0.00	0.00	50.00	50.00
66	0	0	0	0.82	0.82	0.82	0.00	0.00	0.00	50.00	50.00
67	0	0	0	0.55	0.55	0.55	0.00	0.00	0.00	50.00	50.00
68	0	0	0	0.57	0.57	0.57	0.00	0.00	0.00	50.00	50.00
69	480	369	849	0.28	0.28	0.28	0.37	0.31	0.37	49.30	49.00
70	1439	1596	3035	0.18	0.22	0.22	1.06	1.34	1.34	40.31	32.31

Comparing to previous stated network, network topology 2 showed a lesser performance in terms of travel time, flow and speed of each link. For instance Table 4.15. shows travel times for shortest path after trip assignment from zone 1 to zone 8 to be about 4.71 min while in network topology 1 was 8.26 min.

Table 4.15. The shortest travel times between zones after traffic assignment of network topology 3

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.73	3.68	4.41	5.05	6.43	4.82	4.71	5.63	5.03
2	3.84	0.00	2.82	4.11	4.74	5.57	4.51	4.03	4.95	4.35
3	4.36	2.39	0.00	4.62	5.13	5.36	4.90	4.39	5.31	4.71
4	5.46	4.04	4.99	0.00	4.56	7.73	4.73	5.72	6.19	6.04
5	6.00	4.59	5.36	4.43	0.00	7.02	3.61	5.01	5.08	5.33
6	6.19	4.21	4.43	6.45	5.85	0.00	5.62	2.32	5.88	3.39
7	5.71	4.30	5.00	4.36	3.37	6.67	0.00	4.66	3.40	4.98
8	5.62	3.89	4.56	5.56	4.96	3.38	4.73	0.00	4.39	1.89
9	6.52	4.80	5.47	6.07	5.08	6.94	3.65	4.39	0.00	4.56
10	6.54	4.82	5.49	6.49	5.88	5.21	5.65	2.66	5.31	0.00

Network topology 2 was also assigned with trips using user equilibrium assignment technique. This time better relive in more links comparing to the first assignment method can be seen. See Figure 4.6. and Table 4.16.

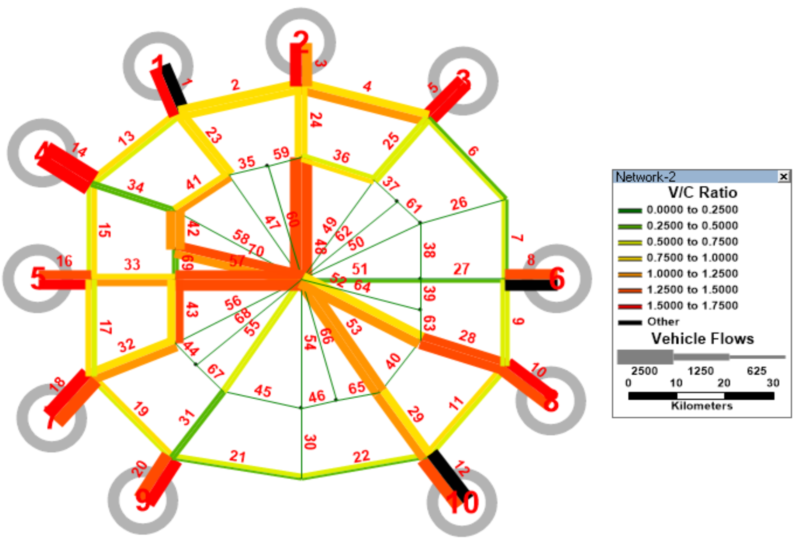


Figure 4.6. Traffic assignment of topology 2 using user equilibrium method

Table 4.16. Network topology 2 after assignment using user equilibrium method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1270	1336	2606	0.30	0.29	0.30	0.97	0.91	0.97	42.70	43.88
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	1313	1317	2630	0.30	0.30	0.30	1.02	0.99	1.02	41.62	42.36
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	688	642	1330	1.12	1.11	1.12	0.56	0.46	0.56	49.47	49.86
7	688	642	1330	0.89	0.88	0.89	0.57	0.43	0.57	48.99	49.52
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	862	785	1647	0.81	0.80	0.81	0.64	0.54	0.64	48.90	49.50
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64
11	878	719	1597	0.29	0.28	0.29	0.79	0.65	0.79	46.23	47.63
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	969	834	1803	0.93	0.91	0.93	0.76	0.62	0.76	47.52	48.83
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	753	896	1649	0.81	0.85	0.85	0.72	0.88	0.88	48.08	45.92
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	935	990	1925	0.81	0.79	0.81	0.86	0.75	0.86	46.55	48.12
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	656	855	1511	1.21	1.28	1.28	0.56	0.83	0.83	49.70	46.99
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10
21	430	724	1154	1.12	1.14	1.14	0.37	0.60	0.60	50.22	49.42
22	430	724	1154	1.07	1.08	1.08	0.30	0.52	0.52	49.85	49.35
23	929	1132	2061	0.23	0.24	0.24	0.88	0.96	0.96	47.22	45.65
24	1170	945	2115	0.45	0.45	0.45	0.82	0.86	0.86	46.77	46.22
25	755	795	1550	0.19	0.18	0.19	0.66	0.55	0.66	48.59	49.34
26	0	0	0	0.28	0.28	0.28	0.00	0.00	0.00	51.43	51.43
27	242	600	843	0.93	0.94	0.94	0.21	0.47	0.47	50.31	49.97
28	1421	1490	2911	0.80	0.81	0.81	1.31	1.33	1.33	34.67	34.17
29	1370	1419	2789	1.00	1.04	1.04	0.97	1.04	1.04	43.85	42.28
30	0	0	0	0.21	0.21	0.21	0.00	0.00	0.00	51.43	51.43
31	616	524	1140	0.85	0.84	0.85	0.45	0.43	0.45	49.69	49.75
32	1434	1306	2740	0.63	0.60	0.63	1.04	0.94	1.04	42.56	44.79
33	1120	964	2084	0.71	0.63	0.71	1.09	0.82	1.09	41.22	46.60
34	626	506	1132	0.99	0.99	0.99	0.45	0.47	0.47	49.90	49.84
35	0	48	48	0.44	0.44	0.44	0.00	0.04	0.04	50.45	50.45

Table 4.16. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
36	795	755	1550	0.57	0.56	0.57	0.78	0.66	0.78	47.32	48.59
37	0	0	0	1.07	1.07	1.07	0.00	0.00	0.00	50.00	50.00
38	0	0	0	1.10	1.10	1.10	0.00	0.00	0.00	50.00	50.00
39	0	0	0	0.97	0.97	0.97	0.00	0.00	0.00	50.00	50.00
40	0	0	0	0.45	0.45	0.45	0.00	0.00	0.00	50.00	50.00
41	929	1084	2013	0.15	0.16	0.16	0.78	1.03	1.03	44.63	40.38
42	1555	1591	3146	0.37	0.36	0.37	1.12	1.07	1.12	40.44	41.79
43	1306	1434	2740	0.44	0.59	0.59	0.92	1.33	1.33	44.64	33.64
44	0	0	0	0.63	0.63	0.63	0.00	0.00	0.00	50.00	50.00
45	0	0	0	0.53	0.53	0.53	0.00	0.00	0.00	50.00	50.00
46	0	0	0	0.16	0.16	0.16	0.00	0.00	0.00	50.00	50.00
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	1925	1740	3665	0.35	0.33	0.35	1.32	1.27	1.32	34.29	35.96
49	0	0	0	1.02	1.02	1.02	0.00	0.00	0.00	50.00	50.00
50	0	0	0	1.14	1.14	1.14	0.00	0.00	0.00	50.00	50.00
51	242	600	843	1.02	1.03	1.03	0.22	0.44	0.44	49.98	49.72
52	1421	1490	2911	0.34	0.36	0.36	0.98	1.07	1.07	43.87	41.81
53	1370	1419	2789	0.40	0.41	0.41	1.14	1.18	1.18	40.49	39.23
54	0	0	0	0.51	0.51	0.51	0.00	0.00	0.00	50.00	50.00
55	616	524	1140	0.86	0.86	0.86	0.58	0.51	0.58	49.27	49.62
56	0	0	0	1.12	1.12	1.12	0.00	0.00	0.00	50.00	50.00
57	2037	1673	3710	0.46	0.49	0.49	1.40	1.47	1.47	31.54	29.16
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	50.00	50.00
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	50.00	50.00
60	0	48	48	0.30	0.30	0.30	0.00	0.04	0.04	50.00	50.00
61	0	0	0	0.74	0.74	0.74	0.00	0.00	0.00	50.00	50.00
62	0	0	0	0.19	0.19	0.19	0.00	0.00	0.00	50.00	50.00
63	0	0	0	1.17	1.17	1.17	0.00	0.00	0.00	50.00	50.00
64	0	0	0	0.37	0.37	0.37	0.00	0.00	0.00	50.00	50.00
65	0	0	0	1.08	1.08	1.08	0.00	0.00	0.00	50.00	50.00
66	0	0	0	0.82	0.82	0.82	0.00	0.00	0.00	50.00	50.00
67	0	0	0	0.55	0.55	0.55	0.00	0.00	0.00	50.00	50.00
68	0	0	0	0.57	0.57	0.57	0.00	0.00	0.00	50.00	50.00
69	597	517	1114	0.28	0.28	0.28	0.45	0.44	0.45	49.27	49.62
70	1422	1538	2960	0.18	0.21	0.21	1.05	1.29	1.29	40.61	33.84

Likewise comparing user equilibrium method to previous assignment method, network topology 2 showed a better performance in terms of travel time, flow and speed of each link. It is obvious from the results that (UE) technique is more convenient in network assignment rather than incremental assignment technique as already depicted in previous network. For instance Table 4.17. shows travel times for shortest path after trip assignment from zone 1 to zone 8 to be about 4.15 min while in previous assignment technique was 4.71 min.

Table 4.17. Shortest travel times between zones after traffic assignment of network topology 2

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.75	3.62	4.41	5.00	6.40	4.77	4.15	5.58	5.06
2	3.85	0.00	2.75	4.12	4.68	5.52	4.45	3.44	4.87	4.35
3	4.31	2.33	0.00	4.58	5.14	5.38	4.91	3.90	5.33	4.80
4	5.46	4.06	4.94	0.00	4.56	7.69	4.73	5.17	6.19	6.07
5	6.00	4.51	5.39	4.43	0.00	7.02	3.61	4.50	5.08	5.41
6	6.14	4.16	4.44	6.41	5.84	0.00	5.61	2.29	5.69	3.20
7	5.65	4.16	5.03	4.36	3.37	6.67	0.00	4.15	3.40	5.05
8	5.02	3.14	4.01	4.94	4.37	3.35	4.14	0.00	4.23	1.73
9	6.51	4.63	5.50	6.07	5.08	6.74	3.65	4.21	0.00	4.56
10	6.65	4.77	5.65	6.57	6.00	5.00	5.77	2.47	5.31	0.00

In the final attempt to assign traffic to network topology 2 stochastic user equilibrium (SUE) technique has been employed, see Figure 4.17. In the broadest sense, this method assumes that travelers have less information about the network and they individually perceive travel costs in different ways.

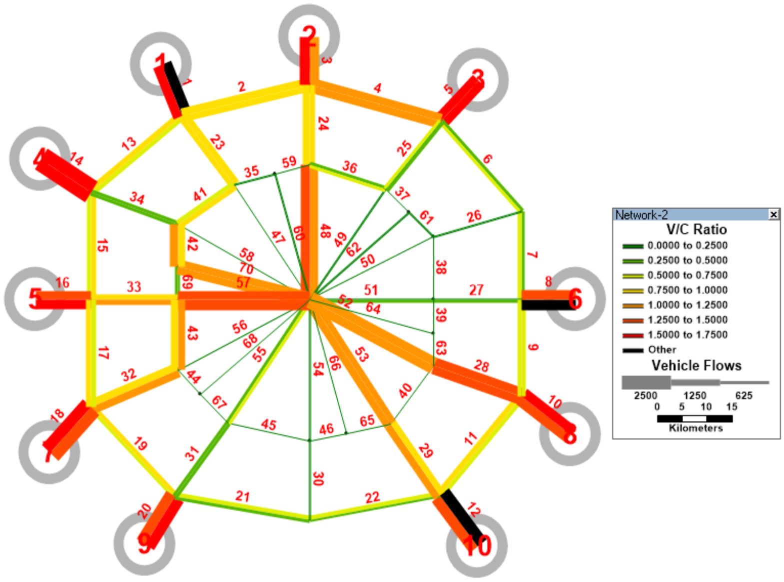


Figure 4.7. Traffic assignment of topology 2 using stochastic user equilibrium method

Table 4.18. Network topology 2 after assignment using stochastic user equilibrium method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	1273	1347	2619	0.30	0.29	0.30	0.98	0.92	0.98	42.66	43.74
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	1388	1463	2852	0.31	0.32	0.32	1.08	1.10	1.10	40.19	39.75
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	673	643	1316	1.11	1.11	1.11	0.54	0.46	0.54	49.53	49.86
7	717	647	1364	0.90	0.88	0.90	0.60	0.43	0.60	48.85	49.51
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	828	766	1594	0.81	0.80	0.81	0.61	0.53	0.61	49.07	49.56
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64
11	930	832	1762	0.29	0.28	0.29	0.83	0.75	0.83	45.59	46.69
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	973	857	1831	0.94	0.91	0.94	0.76	0.63	0.76	47.48	48.71
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	753	929	1681	0.81	0.86	0.86	0.72	0.91	0.91	48.08	45.34
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	934	988	1921	0.81	0.79	0.81	0.86	0.75	0.86	46.57	48.14
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	655	853	1507	1.21	1.28	1.28	0.56	0.83	0.83	49.71	47.03
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10

Table 4.18. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
21	517	740	1257	1.13	1.14	1.14	0.44	0.61	0.61	49.94	49.33
22	428	721	1149	1.07	1.08	1.08	0.30	0.52	0.52	49.85	49.36
23	940	1117	2057	0.23	0.24	0.24	0.89	0.95	0.95	47.02	45.93
24	1305	1019	2324	0.46	0.47	0.47	0.92	0.93	0.93	45.16	45.01
25	610	705	1315	0.18	0.18	0.18	0.54	0.48	0.54	49.39	49.59
26	5	44	48	0.28	0.28	0.28	0.00	0.04	0.04	50.00	50.00
27	270	591	861	0.93	0.94	0.94	0.23	0.46	0.46	50.00	49.99
28	1504	1529	3033	0.86	0.84	0.86	1.39	1.36	1.39	32.13	33.04
29	1255	1364	2619	0.96	1.01	1.01	0.89	1.00	1.00	45.44	43.23
30	90	19	108	0.21	0.21	0.21	0.09	0.01	0.09	50.00	50.00
31	531	510	1041	0.84	0.84	0.84	0.39	0.42	0.42	49.83	49.78
32	1434	1306	2740	0.63	0.60	0.63	1.04	0.94	1.04	42.56	44.79
33	1085	963	2048	0.70	0.63	0.70	1.05	0.82	1.05	42.09	46.61
34	639	505	1144	0.99	0.99	0.99	0.46	0.47	0.47	49.88	49.84
35	50	187	237	0.44	0.44	0.44	0.05	0.14	0.14	50.00	50.00
36	650	565	1215	0.55	0.54	0.55	0.64	0.50	0.64	48.77	49.55
37	0	0	0	1.07	1.07	1.07	0.00	0.00	0.00	50.00	50.00
38	0	0	0	1.10	1.10	1.10	0.00	0.00	0.00	50.00	50.00
39	0	0	0	0.97	0.97	0.97	0.00	0.00	0.00	50.00	50.00
40	0	0	0	0.45	0.45	0.45	0.00	0.00	0.00	50.00	50.00
41	890	930	1820	0.15	0.15	0.15	0.75	0.88	0.88	45.01	43.23
42	1529	1435	2964	0.37	0.34	0.37	1.10	0.96	1.10	40.95	44.25
43	1306	1342	2648	0.44	0.54	0.54	0.92	1.25	1.25	44.64	36.35
44	0	0	0	0.63	0.63	0.63	0.00	0.00	0.00	50.00	50.00
45	0	0	0	0.53	0.53	0.53	0.00	0.00	0.00	50.00	50.00
46	0	0	0	0.16	0.16	0.16	0.00	0.00	0.00	50.00	50.00
47	0	0	0	1.20	1.20	1.20	0.00	0.00	0.00	50.00	50.00
48	1870	1669	3539	0.34	0.32	0.34	1.28	1.22	1.28	35.50	37.59
49	46	55	100	1.02	1.02	1.02	0.03	0.05	0.05	50.00	50.00
50	0	0	0	1.14	1.14	1.14	0.00	0.00	0.00	50.00	50.00
51	270	591	861	1.02	1.03	1.03	0.25	0.43	0.43	49.97	49.73
52	1504	1529	3033	0.35	0.37	0.37	1.04	1.10	1.10	42.53	41.08
53	1255	1364	2619	0.38	0.40	0.40	1.04	1.13	1.13	43.02	40.57
54	90	19	108	0.51	0.51	0.51	0.07	0.01	0.07	49.41	49.41
55	531	510	1041	0.86	0.86	0.86	0.50	0.49	0.50	49.64	49.67

Table 4.18. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
56	92	0	92	1.12	1.12	1.12	0.06	0.00	0.06	50.36	50.36
57	1956	1628	3583	0.43	0.47	0.47	1.34	1.43	1.43	33.36	30.47
58	0	0	0	1.13	1.13	1.13	0.00	0.00	0.00	50.00	50.00
59	0	0	0	1.00	1.00	1.00	0.00	0.00	0.00	50.00	50.00
60	50	187	237	0.30	0.30	0.30	0.04	0.16	0.16	50.00	50.00
61	44	4	48	0.74	0.74	0.74	0.03	0.00	0.03	50.27	50.27
62	4	44	48	0.19	0.19	0.19	0.00	0.03	0.03	50.53	50.53
63	0	0	0	1.17	1.17	1.17	0.00	0.00	0.00	50.00	50.00
64	0	0	0	0.37	0.37	0.37	0.00	0.00	0.00	50.00	50.00
65	0	0	0	1.08	1.08	1.08	0.00	0.00	0.00	50.00	50.00
66	0	0	0	0.82	0.82	0.82	0.00	0.00	0.00	50.00	50.00
67	0	0	0	0.55	0.55	0.55	0.00	0.00	0.00	50.00	50.00
68	0	0	0	0.57	0.57	0.57	0.00	0.00	0.00	50.00	50.00
69	642	471	1113	0.28	0.28	0.28	0.49	0.40	0.49	49.47	49.47
70	1360	1436	2796	0.17	0.20	0.20	1.00	1.21	1.21	41.66	36.42

Equally, the shortest travel time path between network centroids after traffic assignment using stochastic user equilibrium (SUE) method is presented in Table 4.19. It is obvious from the results that (SUE) technique is more consistent in network assignment rather than other assignment techniques.

Table 4.19. Shortest travel times among zones after SUE traffic assignment of network topology 2

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.75	3.63	4.41	5.00	6.41	4.77	4.18	5.57	5.01
2	3.85	0.00	2.76	4.12	4.67	5.53	4.44	3.48	4.87	4.32
3	4.33	2.35	0.00	4.60	5.09	5.38	4.86	3.91	5.30	4.74
4	5.47	4.07	4.95	0.00	4.56	7.68	4.73	5.20	6.19	6.03
5	5.96	4.47	5.31	4.44	0.00	6.98	3.61	4.50	5.07	5.33
6	6.17	4.18	4.44	6.38	5.82	0.00	5.59	2.29	5.70	3.20
7	5.58	4.09	4.93	4.37	3.37	6.60	0.00	4.12	3.40	4.95
8	5.05	3.21	4.06	4.98	4.42	3.35	4.19	0.00	4.23	1.74
9	6.45	4.62	5.46	6.08	5.08	6.75	3.65	4.22	0.00	4.56
10	6.55	4.71	5.56	6.48	5.92	5.00	5.69	2.48	5.31	0.00

4.2.3. Network topology 3

This section deals with the illustration of the analytical study of final network topology with different assignment techniques is illustrated. This network topology is termed as cycle network and in some cases named as ring network. Same parameters that have been taken into consideration for all other networks were also adopted for this network. Figure 4.8. shows network topology 4 assigned with trips using incremental assignment technique.

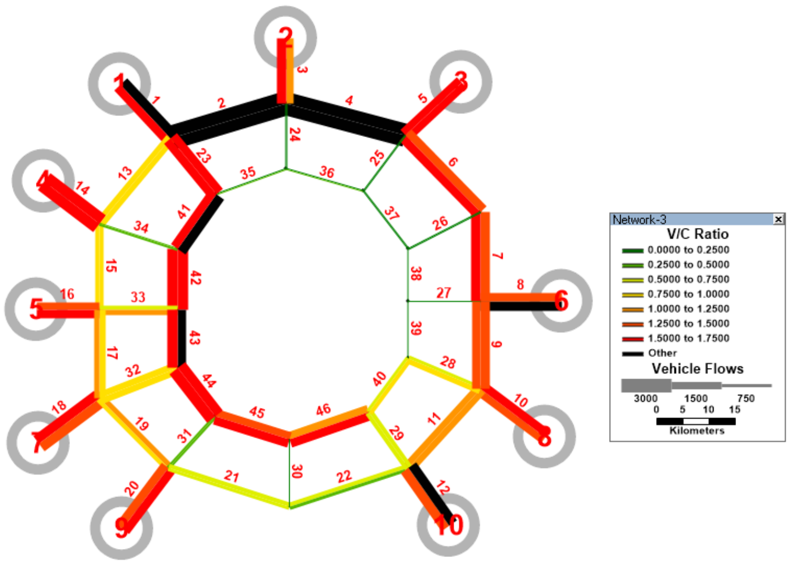


Figure 4.8. Traffic assignment of topology 3 using incremental model

Table 4.20. Network topology 3 after incremental assignment methods

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	2464	2759	5223	0.76	0.75	0.76	1.89	1.89	1.89	16.64	16.70
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	2545	2558	5103	0.86	0.79	0.86	1.98	1.92	1.98	14.59	15.90
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	1869	1885	3753	1.96	1.63	1.96	1.51	1.34	1.51	28.10	33.93
7	1998	1996	3994	1.88	1.30	1.88	1.66	1.33	1.66	23.24	33.80
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	1727	2051	3778	1.11	1.26	1.26	1.28	1.41	1.41	35.67	31.54
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64

Table 4.20. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
11	1332	1290	2623	0.35	0.34	0.35	1.19	1.16	1.19	37.47	38.41
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	1180	1080	2260	0.99	0.94	0.99	0.92	0.80	0.92	44.96	47.01
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	843	995	1838	0.83	0.89	0.89	0.80	0.97	0.97	47.04	44.05
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	1091	1280	2371	0.87	0.85	0.87	1.01	0.97	1.01	43.70	44.51
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	905	1065	1970	1.25	1.40	1.40	0.77	1.04	1.04	47.91	42.89
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10
21	626	872	1499	1.13	1.16	1.16	0.54	0.72	0.72	49.74	48.41
22	626	872	1499	1.08	1.10	1.10	0.43	0.63	0.63	49.65	48.75
23	1849	1788	3637	0.50	0.38	0.50	1.75	1.51	1.75	21.44	28.77
24	46	42	88	0.42	0.42	0.42	0.03	0.04	0.04	50.00	50.00
25	187	173	361	0.18	0.18	0.18	0.16	0.12	0.16	49.99	50.00
26	111	130	240	0.28	0.28	0.28	0.10	0.12	0.12	50.00	50.00
27	0	0	0	0.93	0.93	0.93	0.00	0.00	0.00	50.00	50.00
28	681	1036	1717	0.56	0.61	0.61	0.63	0.92	0.92	49.02	45.23
29	849	967	1816	0.90	0.91	0.91	0.60	0.71	0.71	48.80	47.94
30	0	0	0	0.21	0.21	0.21	0.00	0.00	0.00	50.00	50.00
31	554	472	1026	0.84	0.84	0.84	0.41	0.38	0.41	49.80	49.84
32	1291	1336	2626	0.60	0.61	0.61	0.94	0.96	0.96	44.85	44.36
33	1107	825	1933	0.71	0.61	0.71	1.07	0.71	1.07	41.54	48.04
34	401	308	710	0.98	0.98	0.98	0.29	0.29	0.29	49.98	49.38
35	320	214	533	0.44	0.44	0.44	0.31	0.16	0.31	50.00	50.00
36	278	167	446	0.54	0.54	0.54	0.27	0.15	0.27	49.96	50.00
37	235	111	346	1.07	1.07	1.07	0.16	0.11	0.16	49.90	49.91
38	106	0	106	1.10	1.10	1.10	0.08	0.00	0.08	49.64	49.64
39	106	0	106	0.97	0.97	0.97	0.10	0.00	0.10	50.00	50.00
40	681	931	1612	0.46	0.48	0.48	0.53	0.84	0.84	50.00	50.00
41	1948	1992	3940	0.29	0.41	0.41	1.64	1.89	1.89	22.58	16.21
42	2303	2255	4558	0.64	0.54	0.64	1.66	1.52	1.66	23.40	27.88
43	2283	1953	4236	0.81	1.05	1.05	1.61	1.81	1.81	24.55	18.88
44	2369	2085	4454	1.35	1.17	1.35	1.66	1.55	1.66	23.59	27.17
45	1898	1530	3428	0.98	0.87	0.98	1.54	1.44	1.54	27.04	30.21

Table 4.20. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
46	1898	1530	3428	0.30	0.20	0.30	1.56	1.13	1.56	25.87	39.28

Comparing to network topology 2 assigned with incremental model, network topology 3 showed a lesser performance in terms of travel time, flow and speed of each link. For instance Table 4.21. shows travel time for shortest path after trip assignment from zone 1 to zone 8 to be about 7.30 min while in network topology 2 was 4.71 min.

Table 4.21. Shortest travel times among zones after traffic assignment of network topology 3

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	3.21	4.65	4.47	5.16	8.37	5.38	7.30	6.89	8.27
2	4.32	0.00	3.31	4.64	5.16	7.27	5.32	6.19	6.83	7.16
3	5.26	2.82	0.00	5.49	5.63	6.65	5.79	5.57	7.29	6.55
4	5.50	4.56	5.98	0.00	4.58	9.66	4.80	7.97	6.31	8.25
5	6.08	5.07	5.94	4.47	0.00	9.63	3.67	6.84	5.17	7.11
6	7.57	5.48	5.27	7.80	7.94	0.00	7.10	2.59	6.08	3.57
7	6.07	5.06	5.93	4.46	3.43	8.09	0.00	5.11	3.45	5.39
8	7.97	5.88	5.67	7.85	6.83	3.81	5.33	0.00	4.31	1.80
9	7.90	6.89	7.77	6.29	5.27	7.28	3.77	4.29	0.00	4.57
10	9.68	7.59	7.39	9.01	7.99	5.52	6.49	2.54	5.35	0.00

In the same manner, network topology 3 was assigned with trips using user equilibrium assignment technique. This time better assignment in more links comparing to the first assignment method can be seen. See Figure 4.9. and Table 4.22.

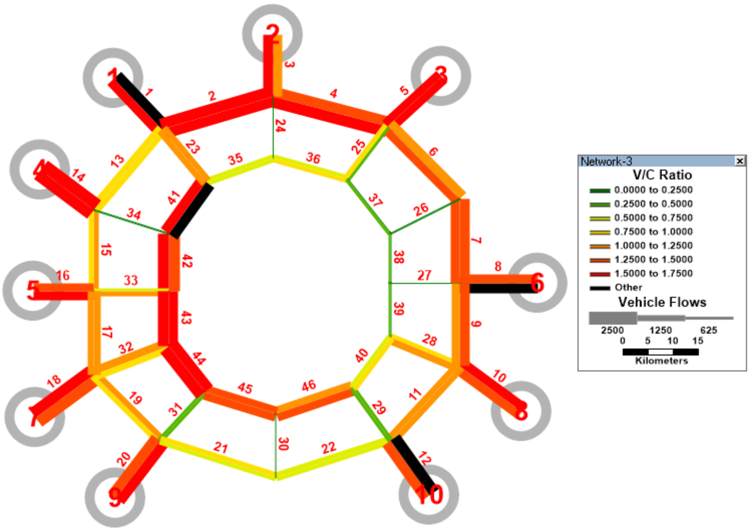


Figure 4.9. Traffic assignment of topology 3 using user equilibrium method

Table 4.22. Network topology 3 after user equilibrium assignment methods

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	2061	2242	4303	0.50	0.48	0.50	1.58	1.53	1.58	25.03	26.50
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	2100	1995	4095	0.54	0.46	0.54	1.64	1.50	1.64	23.34	27.59
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	1578	1762	3339	1.54	1.50	1.54	1.28	1.25	1.28	35.86	36.75
7	1796	1914	3709	1.54	1.23	1.54	1.49	1.28	1.49	28.53	35.56
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	1505	1950	3454	0.97	1.17	1.17	1.12	1.34	1.34	40.64	33.85
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64
11	1253	1230	2483	0.33	0.33	0.33	1.12	1.11	1.12	39.48	39.91
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	1113	1108	2221	0.97	0.95	0.97	0.87	0.82	0.87	45.90	46.73
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	942	1052	1994	0.86	0.91	0.91	0.90	1.03	1.03	45.55	42.77
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	1118	1385	2502	0.88	0.89	0.89	1.03	1.05	1.05	43.12	42.67
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	1078	1095	2174	1.32	1.42	1.42	0.92	1.07	1.07	45.60	42.14
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10
21	850	933	1783	1.17	1.18	1.18	0.73	0.77	0.77	48.34	47.85

Table 4.22. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
22	850	933	1783	1.09	1.10	1.10	0.59	0.67	0.67	49.03	48.41
23	1231	1190	2421	0.27	0.24	0.27	1.16	1.01	1.16	40.34	44.55
24	0	0	0	0.42	0.42	0.42	0.00	0.00	0.00	50.00	50.00
25	947	647	1594	0.19	0.18	0.19	0.83	0.45	0.83	46.64	49.71
26	152	218	370	0.28	0.28	0.28	0.14	0.21	0.21	51.43	51.41
27	0	0	0	0.93	0.93	0.93	0.00	0.00	0.00	50.00	50.00
28	862	1319	2182	0.58	0.71	0.71	0.80	1.18	1.18	47.31	38.96
29	689	663	1352	0.89	0.89	0.89	0.49	0.49	0.49	49.34	49.36
30	0	0	0	0.21	0.21	0.21	0.00	0.00	0.00	50.00	50.00
31	584	522	1106	0.84	0.84	0.84	0.43	0.43	0.43	49.75	49.76
32	1228	1494	2722	0.59	0.65	0.65	0.89	1.07	1.07	45.70	41.71
33	1066	666	1732	0.69	0.60	0.69	1.03	0.57	1.03	42.53	49.06
34	223	266	489	0.98	0.98	0.98	0.16	0.25	0.25	50.20	50.18
35	775	718	1493	0.46	0.45	0.46	0.74	0.55	0.74	48.28	49.78
36	775	718	1493	0.57	0.55	0.57	0.76	0.63	0.76	47.57	48.84
37	578	221	799	1.07	1.07	1.07	0.40	0.22	0.40	49.72	49.89
38	360	69	429	1.10	1.10	1.10	0.26	0.05	0.26	49.60	49.64
39	360	69	429	0.97	0.97	0.97	0.34	0.07	0.34	50.00	50.10
40	793	959	1752	0.46	0.49	0.49	0.61	0.86	0.86	49.61	46.81
41	1949	1965	3914	0.29	0.39	0.39	1.64	1.86	1.86	22.55	16.82
42	2172	2230	4403	0.57	0.53	0.57	1.57	1.50	1.57	26.31	28.42
43	2204	1862	4066	0.75	0.94	0.94	1.56	1.73	1.73	26.28	21.16
44	2144	2067	4211	1.11	1.15	1.15	1.50	1.53	1.53	28.61	27.60
45	1622	1482	3104	0.77	0.83	0.83	1.32	1.40	1.40	34.37	31.69
46	1622	1483	3105	0.24	0.19	0.24	1.33	1.09	1.33	33.12	40.21

Likewise making comparison between user equilibrium method to previous assignment methods, network topology 3 showed a better performance in terms of travel time, flow and speed of each link. It is obvious from the results that (UE) technique is more convenient in network assignment rather than incremental assignment technique.

Table 4.23. Shortest travel times (min) among zones after traffic assignment of network topology 3

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.95	4.07	4.45	5.07	7.91	5.23	7.15	6.79	7.57
2	4.04	0.00	2.98	4.34	4.96	6.82	5.12	6.07	6.68	7.02
3	4.66	2.49	0.00	4.96	5.58	6.44	5.73	5.69	7.30	6.65
4	5.50	4.31	5.43	0.00	4.61	9.26	4.84	8.08	6.41	8.39
5	6.10	4.91	5.95	4.50	0.00	9.42	3.68	6.92	5.25	7.23
6	7.23	5.06	5.18	7.53	7.81	0.00	6.96	2.46	5.96	3.41
7	6.08	4.89	5.92	4.52	3.47	8.10	0.00	5.20	3.51	5.50
8	7.75	5.58	5.69	7.91	6.86	3.72	5.33	0.00	4.33	1.78
9	7.92	6.73	7.76	6.38	5.33	7.22	3.80	4.33	0.00	4.62
10	9.45	7.28	7.39	9.12	8.07	5.42	6.54	2.53	5.37	0.00

In the final attempt to assign traffic to network topology 3 stochastic user equilibrium (SUE) technique has been used, see Figure 4.10. Shortest paths regarding travel times among zones after traffic assignment of network topology 3 can also be referred in Table 4.24.

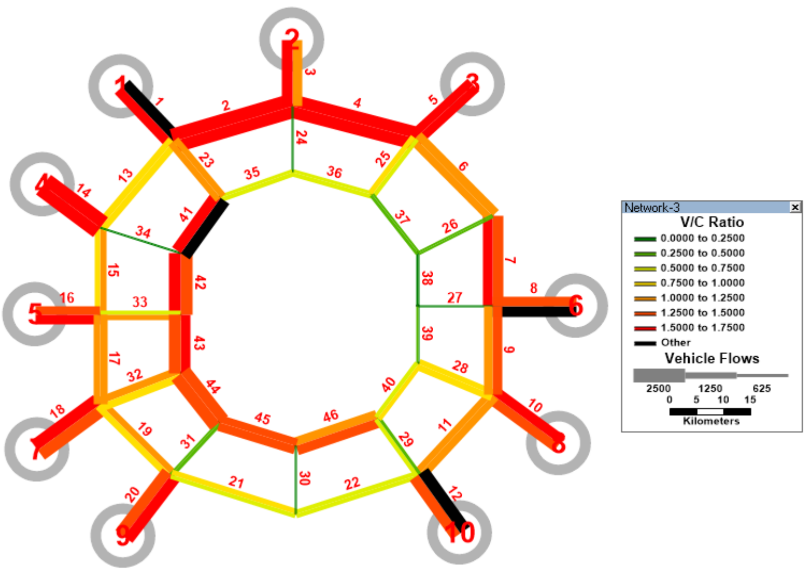


Figure 4.10. Traffic assignment of topology 3 using stochastic user equilibrium method

Table 4.24. Network topology 3 after assignment of trips using SUE assignment method

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
1	1864	1998	3862	1.70	2.45	2.45	1.62	1.89	1.89	24.74	17.15
2	2078	2289	4367	0.51	0.49	0.51	1.59	1.57	1.59	24.64	25.49
3	1972	1686	3658	1.12	0.75	1.12	1.59	1.21	1.59	25.83	38.25
4	2117	2080	4197	0.55	0.49	0.55	1.65	1.56	1.65	22.95	25.58
5	1679	1668	3347	1.28	1.33	1.33	1.57	1.60	1.60	26.26	25.31
6	1469	1587	3056	1.43	1.36	1.43	1.19	1.13	1.19	38.59	40.45
7	1813	1888	3701	1.56	1.21	1.56	1.51	1.26	1.51	28.06	36.10
8	1746	2073	3819	1.12	2.09	2.09	1.43	1.92	1.92	31.07	16.65
9	1535	1858	3392	0.99	1.10	1.10	1.14	1.27	1.27	40.02	35.90
10	1732	1721	3453	0.46	0.36	0.46	1.54	1.32	1.54	27.26	34.64
11	1195	1366	2561	0.32	0.36	0.36	1.07	1.23	1.23	40.83	36.42
12	2084	1998	4082	1.83	0.99	1.83	1.96	1.48	1.96	15.38	28.63
13	1131	1100	2231	0.97	0.95	0.97	0.89	0.81	0.89	45.66	46.81
14	2213	2371	4584	2.11	1.78	2.11	1.74	1.61	1.74	21.09	24.93
15	933	1120	2053	0.85	0.95	0.95	0.89	1.10	1.10	45.69	41.08
16	1824	1580	3404	1.80	1.64	1.80	1.57	1.49	1.57	25.97	28.47
17	1217	1378	2595	0.93	0.88	0.93	1.12	1.04	1.12	40.74	42.79
18	2127	2143	4270	0.94	1.00	1.00	1.49	1.54	1.54	28.73	27.03
19	1098	1173	2272	1.33	1.50	1.50	0.93	1.15	1.15	45.27	40.06
20	1901	1904	3805	1.38	1.25	1.38	1.50	1.42	1.50	28.33	31.10
21	809	961	1770	1.16	1.19	1.19	0.69	0.79	0.79	48.69	47.55
22	799	866	1665	1.08	1.09	1.09	0.55	0.63	0.63	49.22	48.79
23	1282	1236	2518	0.28	0.25	0.28	1.21	1.05	1.21	38.87	43.59
24	38	0	38	0.42	0.42	0.42	0.03	0.00	0.03	50.00	50.00
25	964	798	1762	0.19	0.18	0.19	0.85	0.55	0.85	46.42	49.33
26	301	344	645	0.28	0.28	0.28	0.27	0.33	0.33	49.96	49.93
27	0	80	80	0.93	0.93	0.93	0.00	0.06	0.06	50.00	50.00
28	955	1097	2051	0.60	0.63	0.63	0.88	0.98	0.98	45.98	44.12
29	689	840	1529	0.89	0.90	0.90	0.49	0.62	0.62	49.35	48.71
30	11	96	108	0.21	0.21	0.21	0.01	0.07	0.07	50.00	50.00
31	535	461	996	0.84	0.84	0.84	0.39	0.38	0.39	49.83	49.85
32	1318	1421	2739	0.61	0.63	0.63	0.96	1.02	1.02	44.45	42.99
33	1061	841	1902	0.69	0.61	0.69	1.03	0.72	1.03	42.66	47.90
34	237	178	415	0.98	0.98	0.98	0.17	0.17	0.17	50.00	50.00
35	749	692	1441	0.46	0.45	0.46	0.72	0.53	0.72	48.55	49.88

Table 4.24. (Continue)

Link ID	AB Flow trip/h	BA Flow trip/h	Total Flow trip/h	AB Time (min)	BA Time (min)	Max Time (min)	AB VOC	BA VOC	Max VOC	AB Speed (Km/h)	BA Speed (Km/h)
36	749	654	1402	0.56	0.55	0.56	0.74	0.57	0.74	47.87	49.20
37	678	417	1095	1.08	1.07	1.08	0.47	0.41	0.47	49.55	49.69
38	334	116	449	1.10	1.10	1.10	0.24	0.08	0.24	49.61	49.64
39	325	186	511	0.97	0.97	0.97	0.31	0.18	0.31	50.00	50.00
40	840	842	1682	0.46	0.47	0.47	0.65	0.76	0.76	49.35	48.30
41	1952	1963	3915	0.29	0.39	0.39	1.64	1.86	1.86	22.47	16.85
42	2186	2138	4324	0.58	0.49	0.58	1.58	1.44	1.58	25.99	30.47
43	2115	1847	3961	0.70	0.92	0.92	1.49	1.71	1.71	28.32	21.55
44	2133	1968	4101	1.10	1.06	1.10	1.49	1.46	1.49	28.86	30.02
45	1672	1433	3106	0.80	0.79	0.80	1.36	1.35	1.36	33.04	33.21
46	1683	1529	3211	0.25	0.20	0.25	1.38	1.12	1.38	31.52	39.31

The shortest travel time paths for between network centroids after traffic assignment using stochastic user equilibrium (UE) method is presented in Table 4.22. Though this time results after assignment of trips using (SUE) technique increase little more, yet since SUE method uses the principle of the traveler has less information about the network and assignment of trips are done by Method of Successive Averages (MSA), this assignment is better than other assignment techniques.

Table 4.25.The shortest travel times between zones after traffic assignment of network topology 3

Zones	1	2	3	4	5	6	7	8	9	10
1	0.00	2.96	4.09	4.45	5.10	7.84	5.17	7.09	6.74	7.58
2	4.06	0.00	2.99	4.36	5.02	6.75	5.08	6.00	6.66	6.94
3	4.71	2.52	0.00	5.02	5.60	6.36	5.66	5.61	7.24	6.56
4	5.50	4.32	5.44	0.00	4.60	9.20	4.89	7.96	6.47	8.38
5	6.07	4.89	5.91	4.53	0.00	9.40	3.73	6.80	5.31	7.22
6	7.13	4.94	5.03	7.44	7.81	0.00	6.85	2.47	5.97	3.42
7	6.05	4.86	5.88	4.55	3.47	7.99	0.00	5.16	3.52	5.49
8	7.58	5.39	5.47	7.75	6.73	3.65	5.20	0.00	4.32	1.77
9	7.78	6.59	7.61	6.49	5.40	7.18	3.87	4.35	0.00	4.61
10	9.27	7.12	7.20	8.95	7.93	5.39	6.40	2.56	5.37	0.00

CHAPTER 5. DISCUSSIONS AND CONCLUSIONS

5.1. Discussions

In this section, the findings and results of the proposed study will be further explained and discussed. Table 5.1. shows the comparison among the selected network topologies after trip assignment using incremental assignment methods. The records in Table 5.1. represent the total travel time before and after trip assignment from each single zone to all other every zone. For instance, the first record of the total free flow travel time column represents the related travel times for trips of zone 1 to all other zones. Moreover, if a comparison is done for total free flow travel time column, total travel time after trip asssgnment and total excess travel time of each network topology, it is noticeable that network topology 2 (wheel network) has the lowest among other network topologies. This is because network topology 2 has least diameter among other network topologies which was 2.28 km as mentioned earlier in chapter two. Diameter measures the extent of a graph and the topological length between any two important nodes. The greater the diameter, the less linked a network will be. Furthermore, topology 2 poses the highest pi index.

Table 5.1. Comparison of total travel time results of network topologies after incremental assignment

Incremental assignment									
	Network topology 1 (mesh network)			Network topology 2 (wheel network)			Network topology 3 (cyclic network)		
Zone ID	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)
1	34.57	59.47	24.90	27.02	42.47	15.45	29.52	53.68	24.16
2	30.62	58.45	27.83	24.28	38.93	14.65	27.67	50.20	22.53

Table 5.1. (Continue)

Incremental assignment									
	Network topology 1 (mesh network)			Network topology 2 (wheel network)			Network topology 3 (cyclic network)		
Zone ID	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)
3	42.85	60.30	17.45	26.64	41.16	14.52	28.99	51.06	22.07
4	35.81	70.04	34.23	30.24	49.44	19.20	33.61	57.60	23.99
5	35.06	56.07	21.01	28.84	46.43	17.59	32.47	53.98	21.51
6	30.73	53.57	22.84	32.48	44.34	11.86	34.86	53.39	18.53
7	33.12	70.78	37.66	27.74	42.44	14.70	29.33	46.97	17.64
8	38.65	56.01	17.36	23.28	38.97	15.69	31.52	49.44	17.92
9	29.52	50.60	21.08	34.18	47.49	13.31	35.07	54.03	18.96
10	26.89	50.40	23.51	27.46	48.04	20.58	34.22	61.56	27.34
Total	337.82	585.69	247.87	282.16	439.71	157.55	317.26	531.92	214.66

The total free flow travel time for network topology 2 which is 282.16 min (4.70 hrs) of the whole system before assignment of trips increased to 439.71 min (7.33 hrs) after trip assignment, with the increase of 157.55 min (2.63 hrs) in terms of whole network travel time.

Similarly, comparison among total travel time of the network topologies before and after traffic assignment have been depicted in Figures 5.1. through 5.3.

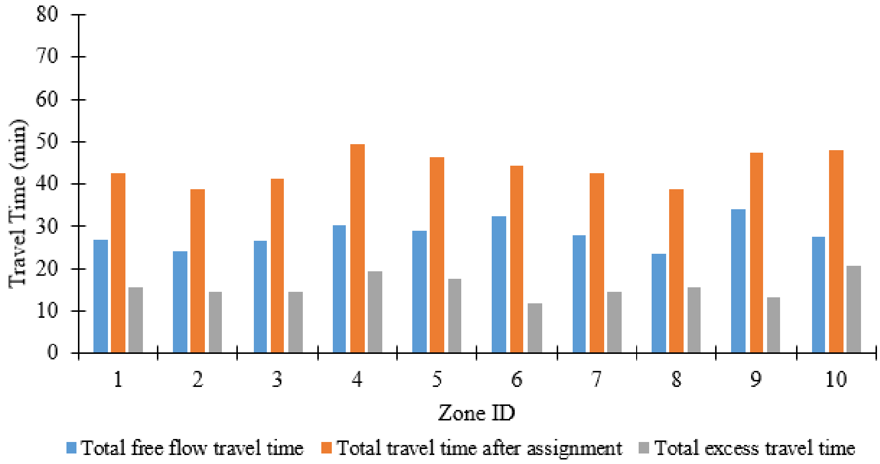


Figure 5.1. Total travel times from each zone to all other zones available for network topology 1 after trip assignment using incremental assignment methods.

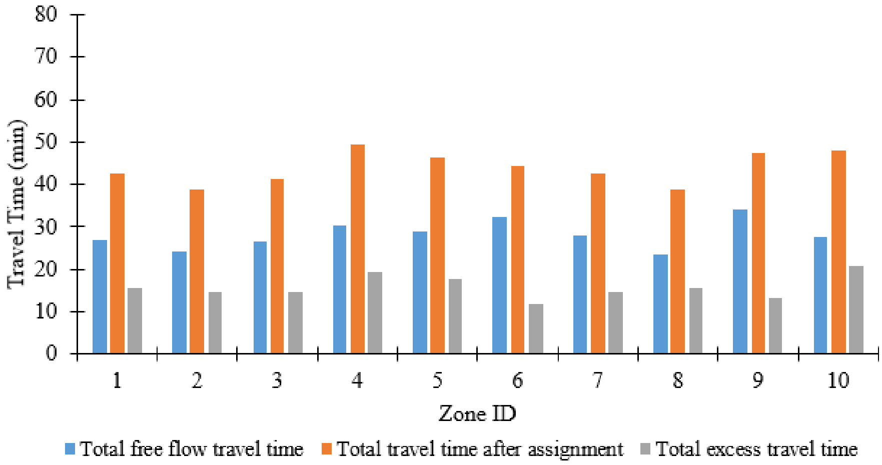


Figure 5.2. Total travel times from each zone to all other zones available for network topology 2 after trip assignment using incremental assignment methods.

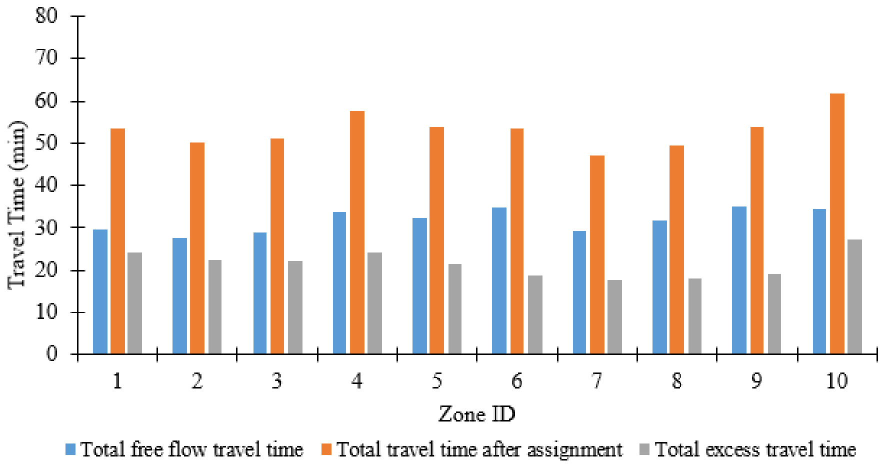


Figure 5.3. Total travel times from each zone to all other zones available for network topology 3 after trip assignment using incremental assignment methods.

At this stage the results of selected network topologies are compared through the findings obtained from user equilibrium assignment method. Once again it is recognizable from Table 5.2. that network topology 2 is better compare to other network topologies in terms of total free flow travel time, total travel time after trip asssgnment and total excess travel time after assignment of trips with regad to whole system. The total excess of travel time of the whole system after assignment of trips for topology 2 is 148.84 min (2.48 hrs) less than previous assignment technique, incremental method, with 157.55 min (2.63 hrs). As a result, it is noticable that UE model produces more efficient results in traffic assignment compare to incremental model.

Table 5.2. Comparison of total travel time results of network topologies after UE assignment

User equilibrium (UE) assignment									
	Network topology 1			Network topology 2			Network topology 3		
Zone ID	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)
1	34.57	56.49	21.92	27.02	41.74	14.72	29.52	51.19	21.67
2	30.62	55.15	24.53	24.28	38.03	13.75	27.67	48.04	20.37
3	42.85	58.28	15.43	26.64	40.68	14.04	28.99	49.50	20.51
4	35.81	67.51	31.70	30.24	48.88	18.64	33.61	56.83	23.22
5	35.06	54.95	19.89	28.84	45.96	17.12	32.47	53.96	21.49
6	30.73	47.82	17.09	32.48	43.78	11.30	34.86	51.62	16.76
7	33.12	67.02	33.90	27.74	41.85	14.11	29.33	47.19	17.86
8	38.65	55.11	16.46	23.28	34.93	11.65	31.52	48.95	17.43
9	29.52	47.22	17.70	34.18	46.95	12.77	35.07	54.09	19.02
10	26.89	44.57	17.68	27.46	48.20	20.74	34.22	61.16	26.94
Total	337.82	554.12	216.30	282.16	431.00	148.84	317.26	522.53	205.27

In the same manner, Figures 5.4. through 5.6. summarise the resulted records of Table 5.2. for comparison among total travel times of the network topologies before and after traffic assignment.

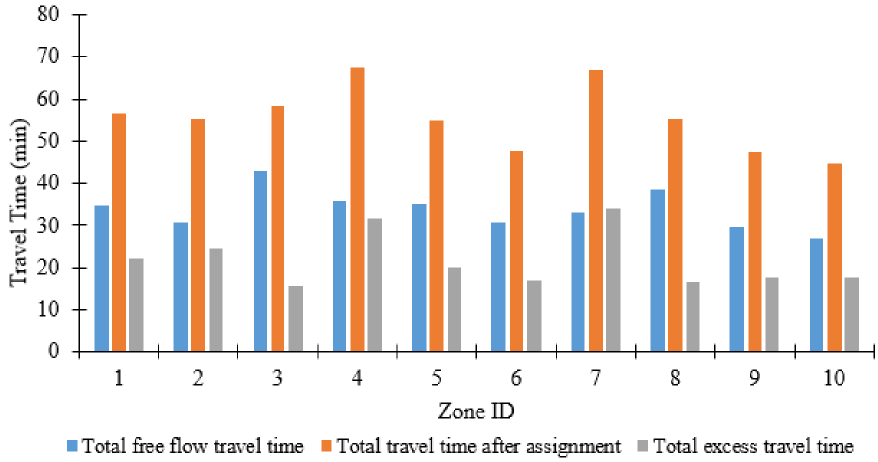


Figure 5.4. Total travel times from each zone to all other zones available for network topology 1 after trip assignment using user equilibrium assignment methods.

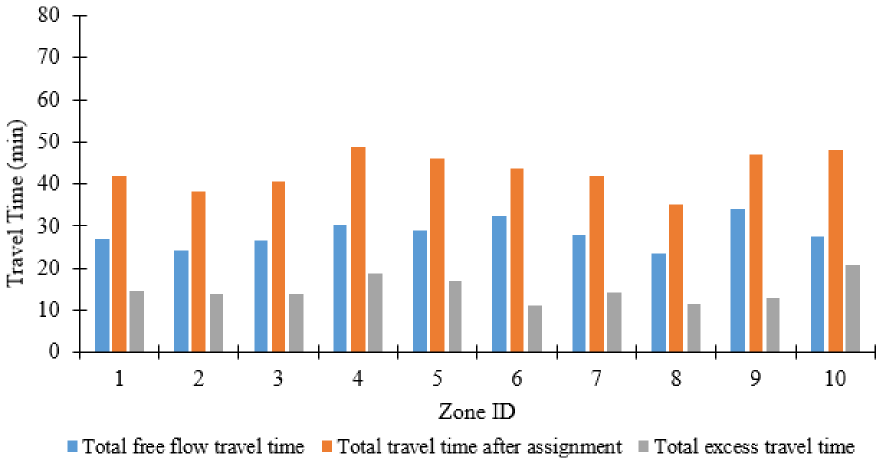


Figure 5.5. Total travel times from each zone to all other zones available for network topology 2 after trip assignment using user equilibrium assignment methods.

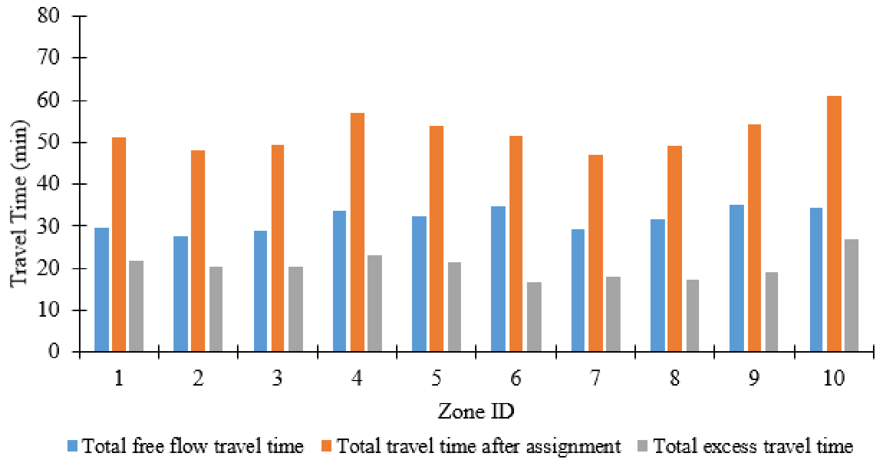


Figure 5.6. Total travel times from each zone to all other zones available for network topology 3 after trip assignment using user equilibrium assignment methods.

In the final attempt, a comparison among network topologies using stochastic user equilibrium assignment method is illustrated. Here, it can be seen from Table 5.3. that network topology 2 has yet the best travel times after assignment of trips compare to other network topologies. The total excess of travel time of the whole system after assignment of trips using SUE is 147.66 min (2.46 hrs) which is less than 148.84 min (2.48 hrs) previously resulted by UE assignment technique . As a result, it is obvious that SUE model produced the best results in traffic assignment compared to all other assignment techniques.

Table 5.3. Comparison of total travel time results of network topologies after SUE assignment

Stochastic User equilibrium (SUE) assignment									
	Network topology 1			Network topology 2			Network topology 3		
Zone ID	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)	Total free flow travel time (min)	Total travel time after trip assign (min)	Total excess travel time (min)
1	34.57	55.97	21.40	27.02	41.72	14.70	29.52	51.03	21.51
2	30.62	55.09	24.47	24.28	38.03	13.75	27.67	47.85	20.18
3	42.85	58.13	15.28	26.64	40.57	13.93	28.99	49.28	20.29
4	35.81	67.27	31.46	30.24	48.87	18.63	33.61	56.75	23.14
5	35.06	54.58	19.52	28.84	45.68	16.84	32.47	53.86	21.39
6	30.73	48.38	17.65	32.48	43.76	11.28	34.86	51.06	16.20
7	33.12	66.94	33.82	27.74	41.40	13.66	29.33	46.97	17.64
8	38.65	54.76	16.11	23.28	35.23	11.95	31.52	47.87	16.35
9	29.52	47.50	17.98	34.18	46.86	12.68	35.07	53.87	18.80
10	26.89	44.34	17.45	27.46	47.70	20.24	34.22	60.19	25.97
Total	337.82	552.95	215.13	282.16	429.82	147.66	317.26	518.73	201.47

The following Figures 5.7., 5.8. and 5.9. summarise the resulted records of Table 5.3. for the final comparison among total travel times of the network topologies before and after traffic assignment.

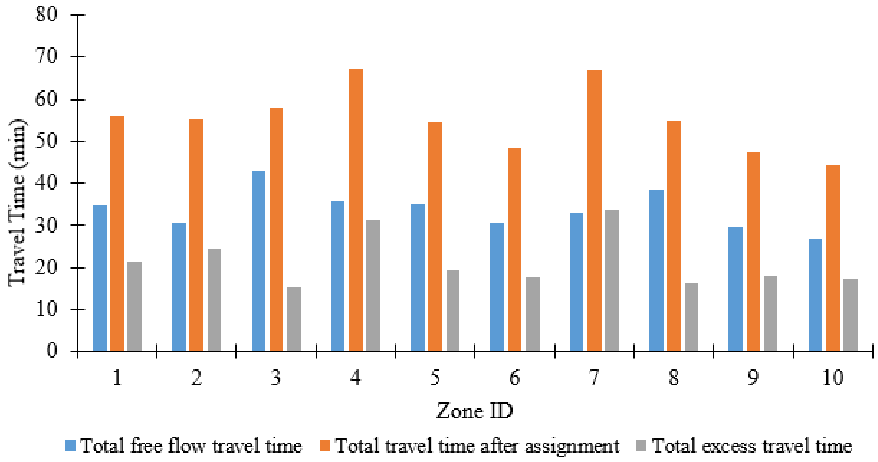


Figure 5.7. Total travel times from each zone to all other zones available for network topology 1 after trip assignment using stochastic user equilibrium assignment methods.

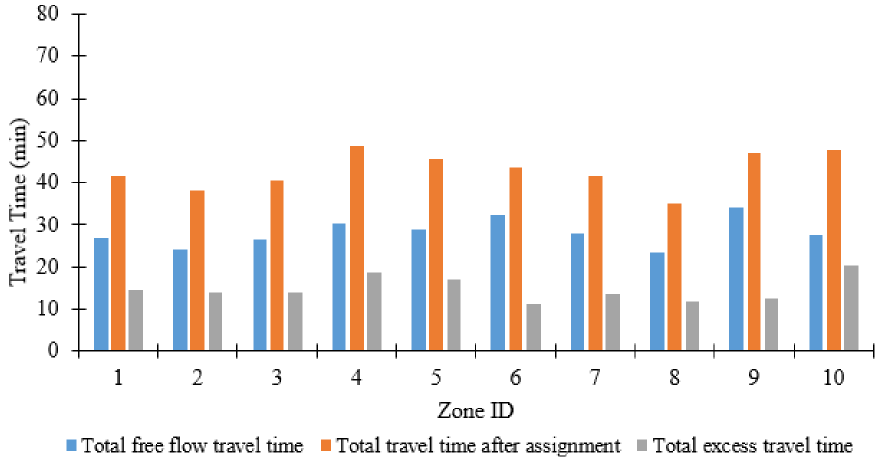


Figure 5.8. Total travel times from each zone to all other zones available for network topology 2 after trip assignment using stochastic user equilibrium assignment methods.

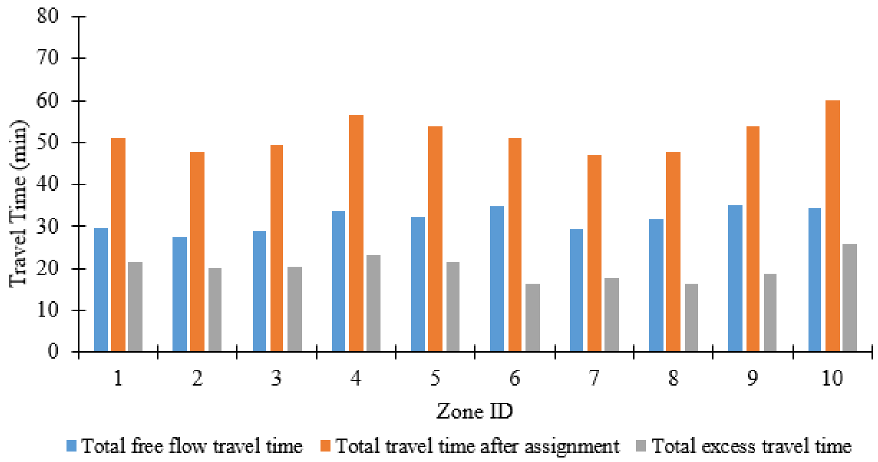


Figure 5.9. Total travel times from each zone to all other zones available for network topology 3 after trip assignment using stochastic user equilibrium assignment methods.

At this point, discussion about comparison among network topologies in terms of volume to capacity (VOC) ratio will be demonstrated. In the first attempt, network topology 1 with incremental, user equilibrium and stochastic user equilibrium assignment techniques is presented in Figures 5.10. to 5.12. In the first assignment technique (Figure 5.10.), volume to capacity (VOC) ratio of network topology 1 is between 0 and 3 with majority of links (38 links) less than 1 VOC ratio.

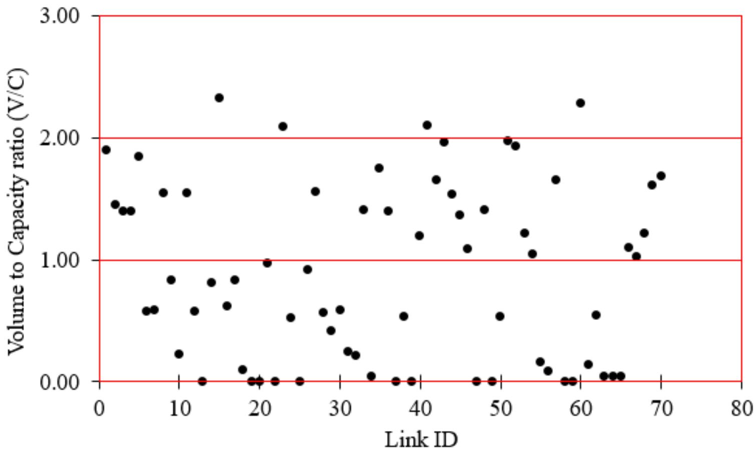


Figure 5.10. Volume to capacity ratio of network topology 1 after trip assignment using incremental assignment method.

In the second attempt, again network topology 1 with user equilibrium assignment technique is presented. This time the number of the links in topology 1 with volume to capacity (VOC) ratio between 0 and 1 has slightly increased to 43 links compare to previous assignment technique.

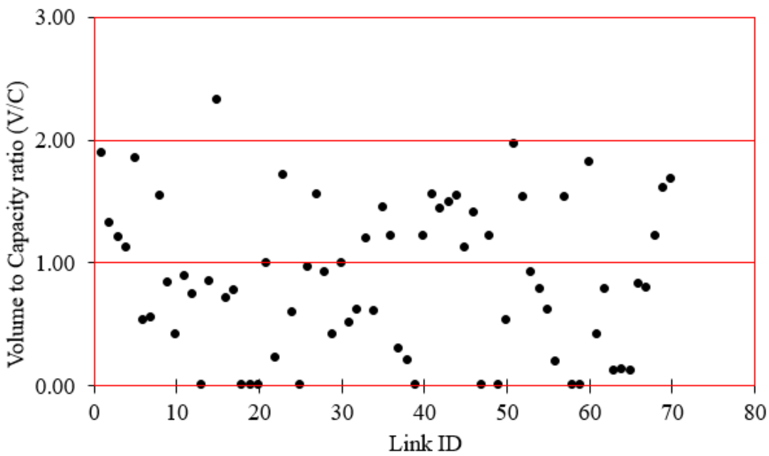


Figure 5.11. Volume to capacity ratio of network topology 1 after trip assignment using user equilibrium assignment method.

In the last attempt, network topology 1 with stochastic user equilibrium assignment technique is presented. This time, the number of the links of network topology 1 having the volume to capacity (VOC) ratio between 0 and 1 are 42 links. However, the total number of the links with almost 0 ratio have been minimized which clearly implies that stochastic user equilibrium assignment technique assigns trips more efficiently than any other assignment method.

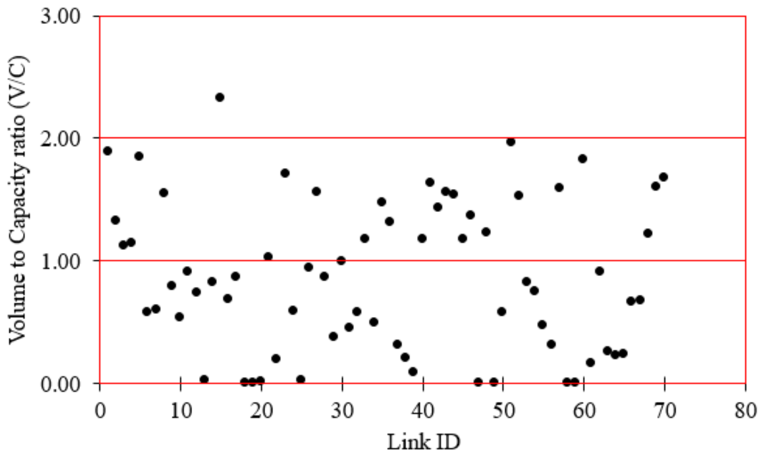


Figure 5.12. Volume to capacity ratio of network topology 1 after trip assignment stochastic using user equilibrium assignment method.

Similarly, the results of the network topology 2 with incremental, user equilibrium and stochastic user equilibrium assignment techniques are presented in Figures 5.13. through 5.15. In the first assignment technique, the number of the links of network topology 2 with volume to capacity (VOC) ratio less than 1 is 45 links.

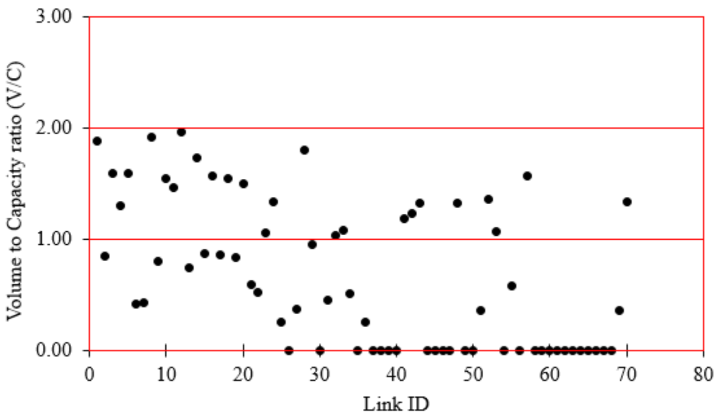


Figure 5.13. Volume to capacity ratio of network topology 2 after trip assignment using incremental equilibrium assignment method.

In the second attempt network topology 2 with user equilibrium assignment technique is presented. This time the number of links having volume to capacity (VOC) ratio between 0 and 1 slightly increased to 47 links which clearly specifies that user equilibrium method produces better results than incremental method as an assignment technique.

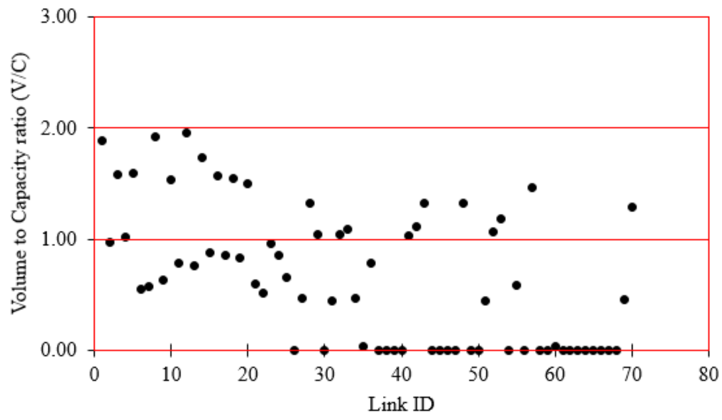


Figure 5.14. Volume to capacity ratio of network topology 2 after trip assignment using user equilibrium assignment method.

In the last attempt, network topology 2 with stochastic user equilibrium assignment technique is presented. This time the number of links having volume to capacity (VOC) ratio between 0 and 1 is 49.

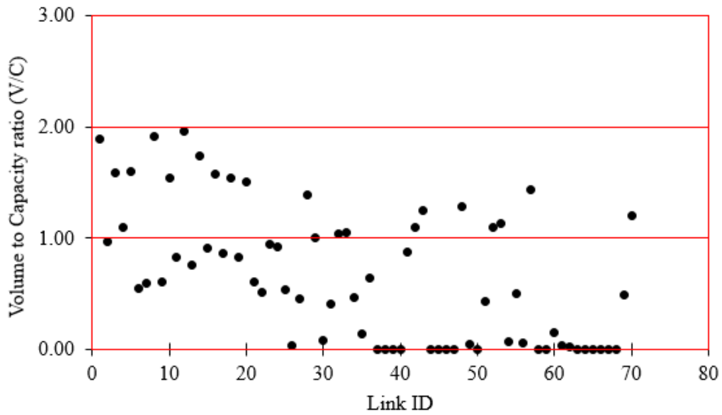


Figure 5.15. Volume to capacity ratio of network topology 2 after trip assignment using stochastic user equilibrium assignment method.

For the final discussion, network topology 3 with incremental, user equilibrium and stochastic user equilibrium assignment technique in terms of volume to capacity (VOC) ratio are presented in Figures 5.16. through 5.18. This network typology consists of 46 links. In the first assignment technique, volume to capacity (VOC) ratio of 21 links for this topology is between 0 and 1 and the remaining 25 links are in the region between 1 and 2.

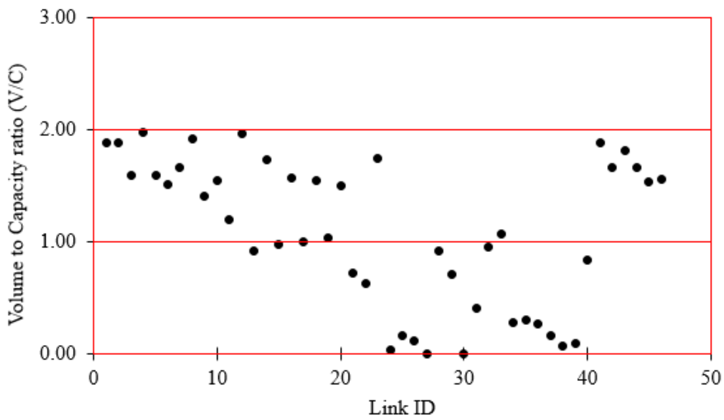


Figure 5.16. Volume to capacity ratio of network topology 3 after trip assignment using incremental assignment method.

At this stage, network topology 3 with user equilibrium assignment technique is presented. This time majority of links (29 link) lies in a volume to capacity (VOC) ratio between 1 and 2.

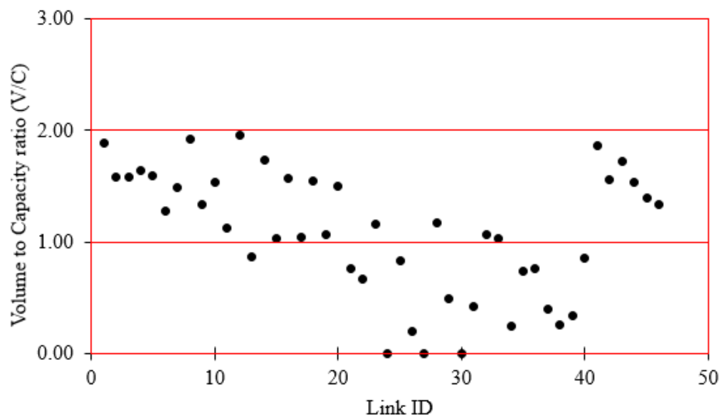


Figure 5.17. Volume to capacity ratio of network topology 3 after trip assignment using user equilibrium assignment method.

And finally, network topology 3 with stochastic user equilibrium assignment technique is presented. Topology 3 this time produced 28 links in between 1 and 2 as the volume to capacity ratio.

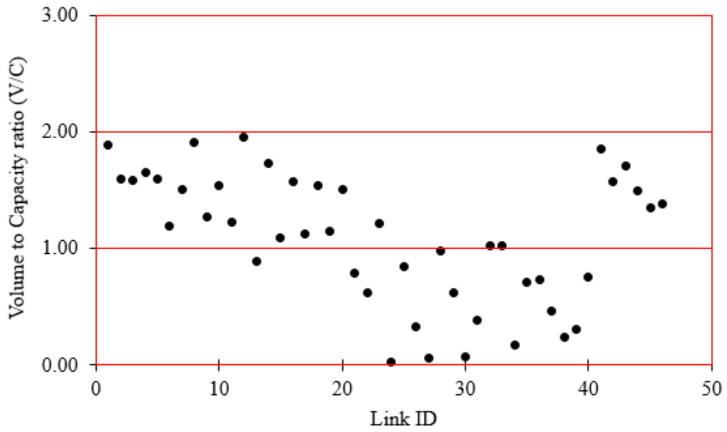


Figure 5.18. Volume to capacity ratio of network topology 3 after trip assignment using stochastic user equilibrium assignment method.

To make more clear judgement among the comparision of network topologies in terms of volume to capacity ratio (VOC), Table 5.4 summarizes the VOC ratios results for all network topologies.

Table 5.4. Summary of VOC ratios among selected network topologies

Assignment technique	Network topology 1			Network topology 2			Network topology 3		
	VOC ratios between			VOC ratios between			VOC ratios between		
	0 and 1	1 and 2	2 and 3	0 and 1	1 and 2	2 and 3	0 and 1	1 and 2	2 and 3
INC	38 (54.3%)	28 (40%)	4 (5.7%)	45 (64.3%)	25 (35.7%)	0 (0.0%)	21 (45.7%)	25 (54.3%)	0 (0.0%)
UE	43 (61.4%)	26 (37.1%)	1 (1.4%)	47 (67.1%)	23 (32.9%)	0 (0.0%)	17 (37%)	29 (63%)	0 (0.0%)
SUE	42 (60%)	27 (38.6%)	1 (1.4%)	49 (70.0%)	21 (30.0%)	0 (0.0%)	18 (39%)	28 (61%)	0 (0.0%)

The above table demonstrates the comparision among network topologies in terms of volume to capacity ratio (VOC) with different assignment techniques. This time unlike travel time reliability, comparison in capacity reliability among network topologies showed a different trend. For instance, topology 2 comes first for links that lie in the region between 0 and 1 followed by topology 1 and then topology 3 for all assignment techniques. The reason behind this is network topologies 1 and 2 have more alternatives to convey demand comparing to network topology 3.

5.2. Conclusion

In this present study, a comparison among three different network topologies with regard to travel time and capacity reliability is conducted using both equilibrium and non-equilibrium assignment techniques.

In order to reduce the computational cost for estimating reliability measures of the three selected topologies, a highly sophisticated computer package for transportation planning, TransCAD, is used. TransCAD is one of the computer packages that enables a planner to efficiently model a network. Analytical results show that the network graph with better topology has lower VOC ratio and only a slight increase in free flow travel time.

Comparision results among network topologies in terms of travel time reliability showed that the best network topology is topology 2 followed by topology 3 and in the third line comes the topology 1. The results compared among network topologies in terms of capacity reliability showed different trend. In the first line comes again network topology 2 , followed by network topology 1 and at the end comes network topology 3.

The results obtained in this thesis might be of great help for urban planners as far as the designing stages of the transportation networks are concerned, especially if there is a risk of highly fluctuating travels for the network systems.

Further studies for different input conditions are now on going. In particular, the probability of whether some links are closed to traffic due to natural hazards for a large scale urban networks. The results will be presented in the near future.

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RESUME

Ahmed Farhan Farah, was born in 10.10.1988 in United Arab Emirates. He finished his primary school in The UAE. He has graduated From Ubaya bin Ka'ab Secondary School in 2008 and get enrolled in Eelo University where he successfully graduated from department of civil engineering in 2012. In 2013, he got Turkish scholarship where he started his master's degree in civil engineering in 2014 and in 2015 he started his second master's degree at the same university. In 2017 he has finished his master's degrees and still continuing his doctorate in Sakarya University.