ASSESSMENT OF A TOLL PLAZA BRIDGE USING TRAFFIC MICROSIMULATION

by

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ABSTRACT

Today, traffic congestion has been a problem leading into dramatic consequences, such as driver's stress caused by waiting in the traffic, economic losses due to wasted time and oil, reduced quality of air because of the wasted oil and disproportionate pollutant emission and resulting in reduced quality of life for the drivers and the country.

The objective of this study is to suggest solutions to minimize the total waiting time in the Fatih Sultan Mehmet Bridge toll plaza system which should result in reduced wasted oil consumption, pollutant emission, economic losses, and increased quality of life, using a microscopic traffic simulation software, AIMSUN. A model will be developed by coding the network of the Fatih Sultan Mehmet Bridge traffic system and traffic demand and control data observed from the field in the software. This will provide the users of the model and the decision makers an environment to experiment different toll plaza configurations and observe the outputs, which would be very expensive and very difficult to experiment in real life in the presence of the existing system.

In the first part of the study, necessary data for the model are collected, statistical input data analysis is applied, the traffic system network model is developed, and the model is validated. In the second part, alternative toll plaza configuration designs are experimented, and according output data are recorded to five performance measures; toll plaza throughput, total system throughput, total delay, fuel consumption, and pollutant emission. In the final part of the study, the results of the alternatives are evaluated and compared with each other using statistical analysis techniques. The alternative, removing the extra lane, showed evident improvements. Fuel consumption is decreased by 61 per cent, total system throughput is increased by two per cent, pollutant emission is decreased by 76 per cent, total delay is decreased by 95 per cent, and throughput is increased by 2 percent.

ÖZET

Günümüzde trafik sıkışıklığı; sürücü stresi, boşa harcanan benzin ve zaman nedeniyle ortaya çıkan ekonomik kayıplar, hava kirliliği gibi dramatic sonuçlar yaratan ve sürücülerin ve ülkenin yaşam kalitesini düşüren bir problem haline gelmiştir.

Bu çalışmanın amacı, mikroskopik bir trafik simulasyon yazılımı olan AIMSUN kullanılarak, Fatih Sultan Mehmet Köprüsü gişe sistemindeki toplam bekleme süresini azaltmak aracılığı ile, fazla benzin tüketimini, hava kirliliğini, ekonomik kayıpları düşürecek ve yaşam kalitesini yükseltecek çözüm önerilerinde bulunmaktır.

Çalışmanın ilk bölümünde, model için gerekli girdi verileri toplanmış, girdi verileri için istatistiki analiz yapılmış, trafik sistemi ağının modeli kurulmuş ve modelin geçerliliği gösterilmiştir. Çalışmanın ikinci kısmında, çözüm önerileri yaratabilecek farklı gişe yapısı tasarım seçenekleri oluşturulmuş ve benzetim yöntemi ile analiz edilmiştir. Performans ölçüm parametreleri olarak seçilen gişe araç geçiş sayıları, sistemden çıkan toplam araç sayısı, toplam gecikme süresi, benzin tüketimi ve hava kirliliği değerleri ile ilgili benzetim çıktı verileri elde edilmiş ve kaydedilmiştir. Çalışmanın son bölümünde, seçeneklerden elde edilen çıktı verileri değerlendirilmiş ve istatistiki analiz yöntemleri kullanılarak, performans ölçüm parametreleri temel alınarak seçenekler karşılaştırılmıştır. Ek şerit uygulamasının kaldırıldığı seçenek, mevcut duruma gore belirgin bir iyileştirme sağlamıştır. Benzin tüketimi yüzde 61 azalmış, sistemden çıkan araç sayısı yüzde iki artmış, hava kirliliğine neden olan gaz emisyonu yüzde 76 azalmış, toplam gecikme süresi yüzde 95 azalmış, gişelerden geçen araç sayısı yüzde iki artmıştır.

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LIST OF SYMBOLS/ABBREVIATIONS

OGS	Electronic toll collection (Otomatik geçiş sistemi in Turkish)
KGS	Credit card toll collection (Kartlı geçiş sistemi in Turkish)
CO	Carbon monoxide
GDH	General Directorate of Highways
FSM	Fatih Sultan Mehmet (Bridge name)
MOE	Measure of effectiveness
q	Flow
h_t	Time headway
h_d	Distance headway
k	Density
u_t	Time mean speed
u_s	Space mean speed
u_f	Free flow speed
k_c	Capacity density
k_j	Jam density
M	Markovian distribution
G	General distribution
N	Number of servers
FIFO	First come first served
ITS	Intelligent transportation systems
HCM	Highway Capacity Manual
CASH	Cash payment system
TEM	Transport European Motorway
F_i	Fuel consumption rate for idle vehicles
F_d	Fuel consumption rate for decelerating vehicles
v	Speed of vehicle for the fuel consumption model
a	Acceleration of the vehicle
c_1	First constant for fuel consumption model
c_2	Second constant for fuel consumption model
v_m	Speed at which fuel consumption is minimum
F_1	Fuel consumption rate at speed v_1

F_2	Fuel consumption rate at speed v_2
λ	Arrival rate
$\overline{X}$	Model estimate for the mean
S^2	Model estimate for the variance
ε	Percentage error
μ	True mean
ε'	Adjusted percentage error
α	Probability of making Type I error
δ	Half length of confidence interval
$t_{n-1,1-\alpha/2}$	t-value with n-1 degrees of freedom and at α level of significance
H_0	Null hypothesis
S	Model estimate for standard deviation
HC	Hydro carbon
NO_x	Nitrogen oxides

1 INTRODUCTION

One common characteristic all global cities share and will continue to encounter over the next several decades is increasing traffic congestion. In Turkey, there is a strong tendency of people of all types to own their own private means of mobility and the inventory of cars, trucks, and buses has been increasing very fast in the last ten years. On the other hand, networks of roads and transit systems are not increasing with the same speed as the number of vehicles rise, resulting with greatly increasing traffic congestion. Table 1.1 involves the last ten years data about the total number of recorded vehicles and total length of roads (including motorways, state highways, and provincial roads) in Turkey, obtained from the web sites of General Directorate of Highways and Turkish Statistical Institute. In ten years, the number of vehicles has increased about 80 per cent whereas the total length of roads has increased only about six per cent.

Table 1.1. Total vehicle number and total road length data in Turkey between 1996-2006

Year	Total Length of Roads (km)	Total Number of Vehicles
1996	59999	6305707
1997	60225	6863462
1998	60841	7371541
1999	60885	7758511
2000	60923	8320449
2001	91090	8521956
2002	61305	8655170
2003	61368	8903843
2004	61491	10236357
2005	61814	11145826
2006	63714	11274767

Since the number of vehicles using highways increases faster than the length of highways increases, highway congestion occurs because the traffic demand approaches or exceeds the available capacity of the highway system. In order to finance new roads and highways, many governments use tolls at highways and bridges, which is also the case at the Fatih Sultan Mehmet Bridge (FSM Bridge). It is one of the two bridges that connect the Asian and European sides of Istanbul, and is located on the Trans European Motorway. It is a toll bridge, and a toll plaza with toll booths is situated before the bridge on the

European side. Toll is paid for one way passing from the European side to the Asian side. Since 1999, some of the toll booths, located to the far left as motorists approach them, are unmanned and equipped only with automatic payment system (Turkish: OGS) in order to enable fast through passing. In addition to OGS, another toll pay system with special magnetic cards (Turkish: KGS) was put in service for use at specific toll booths in 2005.

Highway congestion can vary significantly from day to day because traffic demand and available highway capacity are constantly changing. Traffic demands vary significantly by time of day, day of the week, and season of the year, and are also subject to significant fluctuations due to recreational travel, special events, and emergencies (e.g. evacuations). Available highway capacity, which is often viewed as being fixed, may also vary due to incidents (e.g. crashes and disabled vehicles), work zones, adverse weather conditions, and other causes. In the case of FSM Bridge, around 120,000 vehicles are passing daily in the Europe-Asia direction, unevenly distributed over the different time periods of the day, as it can be seen in Table A.1 in Appendix A. Because of the large number of vehicles using the FSM Bridge, the bridge works over its capacity. Hence at the rush hours, 17:00-20:00, long queues occur before the toll plaza. Except the large number of vehicles, the various service times in the toll booths also have effects on the queue. In addition to the long queues before the toll plaza, the vehicles also have to wait after the toll plaza because more vehicles than the capacity of the bridge are passing the bridge.

The traffic congestion at the FSM Bridge is not just a typical problem of chronic "rush hour" delay in Istanbul. It is a problem leading into dramatic consequences, such as driver’s stress caused by waiting in the traffic, and reduced quality of air because of the wasted oil and disproportionate pollutant emission. Vehicles cause an important portion of the CO emissions in the world. The traffic congestion also causes economic losses with the wasted time that could be used for production and because of the wasted fuel. As a combined effect of these problems, the traffic congestion creates a reduced quality of life for the drivers and the country.

1.1. Problem Statement

Istanbul faces lots of urban problems due to its increasing population, one of which is the traffic congestion. One of the points that experience serious traffic congestion is the FSM Bridge during the peak hours, between 17:00-20:00.

In the focus group meeting with the director of the 17^{th} Region General Directorate of Highways (GDH), he mentioned that the main problem is the overloading of the bridge and at some days, about 240.000 vehicles pass the bridge in both directions. This high number of usage causes queues to occur before and after the toll plaza, especially during the peak hours.

The economical loss due to the delay experienced at the total toll plaza system is about 1.2 billion dollars per year, because of the excessive fuel consumption and wasted manpower due to lost time during waiting. Besides the economical impact, the congestion also creates environmental problems due to exhaust emissions and psychological problems on the drivers due to the stress of waiting.

There are two major views to eliminate the congestion problem of FSM Bridge. The first view is that the problem is related with the toll plaza configuration. This view involves only operational solution suggestions, such as to increase or decrease the number of the toll booths, change the toll plaza configuration, and completely remove the toll plaza. The second view involves radical and strategical solution strategies such as construction of a third bridge on the Bosphorus, and application of high occupancy vehicle system, where vehicles with two or more passengers have lane priorities or toll fee advantages, to decrease the number of vehicles using the bridge. This thesis only investigates the affects the operational solution strategies.

1.2. Objectives of the Study

The objective of this study was to minimize the total waiting time in the FSM Bridge by minimizing the waiting time before and after the toll plaza. For that purpose, a queuing model was developed and simulation approach was employed for its solution. Queuing model provided the conceptual framework and limited the number of variants examined while simulation was used to compare and evaluate the variants.

The simulation model was calibrated to ensure that it accurately represented real life flow conditions. Toll booth outputs and queues before the toll booths collected from the field were used as the primary parameter for calibration. After calibration, the model was used to test and quantify the impact of a number of scenarios aimed at increasing the efficiency of the toll plaza system. Scenarios included operational strategies, structural changes, and mixtures of them. Operational strategies included changing the number of the different payment types while keeping the total number the same, closure of the reverse lane. Geometric change is decreasing the total number of toll booths.

A 1/5000 scale satellite picture of the toll plaza area is shown in Figure 1.1. The picture was provided by the Istanbul Transportation Coordination Center. The numbers on the picture are the elevations of those locations.

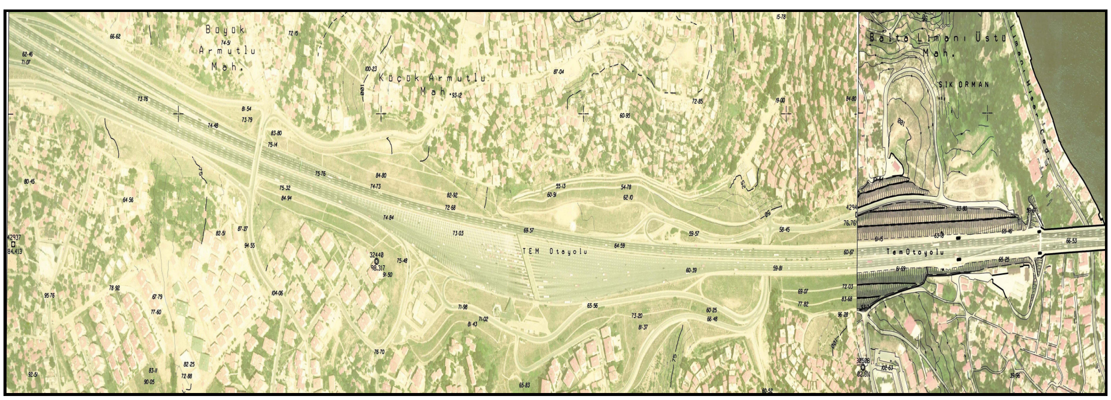


Figure 1.1. Picture of the European region of the study area

The study area started 1.1 km downstream of the toll plaza and ended at Kavacık intersection. The time period of the study was the evening peak period, between 17:00 and 20:00. The data collected and the video records taken showed that most severe condition was occurring on Fridays. Therefore, Friday was chosen to be the study day of the week.

The selected measures of effectiveness (MOEs) for this study were total system throughput, total toll plaza throughput, total delay, fuel consumption, and pollutant emission. The first three MOEs could be calculated as output variables by most of the simulation software. For the calculation of the last two MOEs, simulation software that runs simulation in micro level was necessary because the calculation of these MOEs required the emulation of the flow of individual vehicles of different types throughout the simulation time period as they traveled in a road network and considered their speeds and speed changes which was difficult or impossible to simulate using traditional mathematical models. For that purpose, application-oriented traffic microsimulation software or general purpose simulation software capable to simulate in micro level could be used for the FSM Bridge model.

At the end of the study, it was aimed to come out with a configuration of the toll plaza (the number and location of different types of toll booths) which should improve the delays, fuel consumption, and pollutant emission.

1.3. Literature Survey

Literature survey showed that there are some researches conducted on the traffic congestion problems within the toll plaza areas on freeways and/or bridges for solving the congestion problems through improving the toll plaza design. Methodology followed in these researches mostly contains simulation techniques.

Poon and Dia [1], developed a microscopic traffic simulation model capable of evaluating toll booth performance using AIMSUN, a microscopic simulation package. The research was based in Brisbane and the Gateway Bridge, a toll bridge with three electronic pass toll booths (E-toll), four manual toll booths, and two auto toll booths. The model was used to test and quantify the impact of a number of scenarios, including increasing the number of heavy vehicles, increasing the traffic demand to the expected 2011 flows (the expected completion date of another bridge in Brisbane), and operating all toll booths under E-toll conditions, aimed at increasing the efficiency of the toll area. Selected measures of effectiveness are delay times and system throughput. Analysis of scenarios found that an increase in the proportion of heavy vehicles had little bearing on the overall performance of the system. The existing toll configuration was unable to support the expected 2011 flows. Extreme congestion and extended delays were apparent. The analysis of the third scenario showed that four fully automated E-toll lanes were capable of handling the expected 2011 flows.

Al-Deek [2] conducted sensitivity analysis of the toll plaza delay at the Holland-East toll plaza, the busiest of all Orlando-Orange County Expressway Authority toll plazas, using a stochastic object-oriented discrete-event microscopic simulation model TPSIM. The toll plaza has been analyzed using 84 different scenarios each with different values of three variables (electronic toll collection (ETC) market penetration, plaza configuration, traffic volume) and three measures of effectiveness (plaza throughput, average queuing delay, and total plaza queuing delay). Regardless of the plaza configuration and traffic volumes, if only 10 per cent of the vehicles can switch from manual lanes to E-pass lanes, the total plaza delay can be reduced to half, the plaza hourly throughput can be increased by more than 20 per cent (where the manual lanes work over capacity), average queuing delay per vehicle can be reduced by more than 90 sec. Moving one ETC lane to the left of the toll plaza when there is only one E-pass lane does not create a significant change, whereas moving two dedicated ETC lanes from the middle to the left of the plaza causes 30 per cent increase in the plaza delay. The plaza configuration with moving three ETC lanes from the middle to the most left of the plaza created a five percent decrease in the plaza delay.

In the study by van Dijk et.al. [3], a combined queuing and simulation study has been executed for the design of a toll plaza. The goal of the project was to determine the number and different type of toll booths in terms of single or multiple payment functionalities in order that the toll plaza could handle the traffic flows with traffic of forecasts without any problems after the construction has been completed. With input data including payment system configuration, arrival pattern, and service times, the performance of various toll booth configurations has been measured by using measures of effectiveness such as waiting times, queue lengths and workload. Three scenarios with different toll plaza configurations, including to separate the lanes and to offer only one type of payment system at every toll booth, to offer all payment systems at all toll booths and have the vehicles queue in one line, and to use specialized lanes to keep the variability per lane to a minimum. If one or more ticket booths were underutilized they served for vehicles using other type of payments. Results of simulation showed that fewer toll booths were required than planned in the initial design. This reduction was achieved by separating the payment systems to reduce the variance in service times at every toll booth. One group of payment systems with similar service times could be grouped. This grouping of payment systems enabled incoming traffic to switch to a toll booth with short waiting times.

1.4. Organization of the Thesis

Chapter Two reflects theoretical foundation of traffic systems and reviews in detail the concept of traffic microsimulation. After basic definitions and concepts for traffic flow and toll plaza systems are introduced, queuing systems are explained in terms of its characteristics and models used in order to form a conceptual framework for the queuing at toll plazas. Advantages as well as limitations and disadvantages of traffic simulation are listed. Methodology of traffic simulation followed in similar investigations has been explained through the steps of problem definition, objective setting and methodology selection, data collection, development and statistical analysis of input data, base model development, verification of the model, and validation of the model.

In Chapter Three, the model development of FSM Bridge toll plaza is illustrated. The simulation methodology explained in Chapter Two is carried out for the FSM Bridge, up to the design and simulation of alternatives.

Simulation results and output data analysis of seven alternatives, including the existing system, are given in Chapter Four. The model outputs, fuel consumption, pollutant emissions, total delay, and toll plaza throughput are used to compare the alternatives. The results and the comparison of the alternatives are summarized in tables and figures given within the Chapter Four and related appendices.

Finally, conclusions drawn and recommendations for future work are discussed in Chapter Five.

2 OVERVIEW OF TRAFFIC SYSTEMS AND MICROSIMULATION

Traffic is the collection of all the movement of motorized vehicles, non-motorized vehicles (such as bikes) and pedestrians on the roads. The purpose of traffic researches is to provide the users of the road with safe and comfortable transportation at shortest time.

2.1. Traffic System Concepts

The variables that are used in the traffic flow theory and some traffic system definitions are listed below [4, 5];

- **Flow:** It is the number of vehicles that pass a section on the road in one unit time. Its unit is vehicle/hour. It's denoted by the letter, q.
- **Headway:** Headway is measured in two ways. The first is the time difference between the arrival of two following vehicles passing a point on the road, h_t, and its unit is second. The second is the distance between the front bumpers of two following vehicles, h_d, and its unit is meter.
- **Density***:* It is the number of vehicles that are present at a given length of road at an instance. It is denoted by the letter, k, and its unit is vehicle/kilometer.
- **Time Mean Speed (Spot Speed):** It is the average speed of vehicles on the road. Its unit is kilometer/hour and it is denoted by the letter, u_t.
- **Travel Time***:* It is the time required for a vehicle to travel from the origin point to the destination. The sum of the travel times of all vehicles on the road gives the total travel time.
- **Average Travel Time:** It is calculated by dividing the total travel time by the number of vehicles.
- **Space Mean Speed:** It is calculated by dividing the distance to travel by the average travel time and it is denoted by the letter, u_s. Its unit is kilometer/hour.
- **Bottleneck:** A bottleneck is a section of a road or highway with a carrying capacity substantially below that characterising other sections of the same road or highway. This is

often a narrow part of a road, perhaps also with a smaller number of lanes. It may be due to a narrow bridge or tunnel, a deep cutting or narrow embankment.

• **Reverse Lane:** A reverse lane, also referred as counterflow lane, is a lane in which traffic may travel in either direction, depending on certain conditions. Typically, it is meant to improve traffic flow during rush hours, by having overhead traffic lights, lighted street signs, or road separators notify drivers which lanes are open or closed to driving.

The relationship between the three variables q, u and k relies on the main equation of the traffic flow theory, q = u * k.

• **Speed – Density Relation**: Figure 2.1 shows the relation between speed and density. Speed of vehicles decreases with increasing flow. The maximum speed will be observed at the lowest density accepted at the beginning. Speed at zero density is called the free-flow speed, u_f. Until the capacity density, k_c, speed decreases slowly. After the capacity density, speed decreases faster, and at the jam density, k_j, vehicles stop and speed becomes zero.

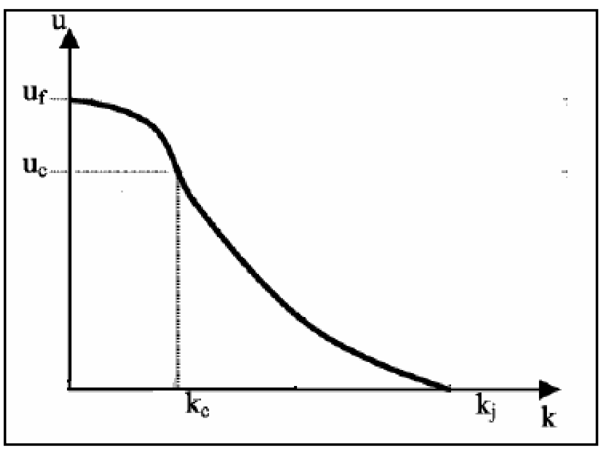


Figure 2.1. Speed – density relation curve

• **Speed – Flow Relation:** Figure 2.2 shows the relation between speed and flow. Flow is zero either at the free-flow speed, where the density is zero, or when speed is zero, where either there is a jam or there are no vehicles on the road. Speed of vehicles decreases from the free-flow speed with increasing flow on the road. The decrease of speed continues until the flow reaches its capacity. Speed of vehicles increases from zero with increasing flow on the road. The increase of speed continues until the flow reaches its capacity. Slightly below and above the capacity of the flow, the flow is uncertain. When the flow gets above its capacity value forced flow appears. The vehicles move and stop at this situation and queuing occurs.

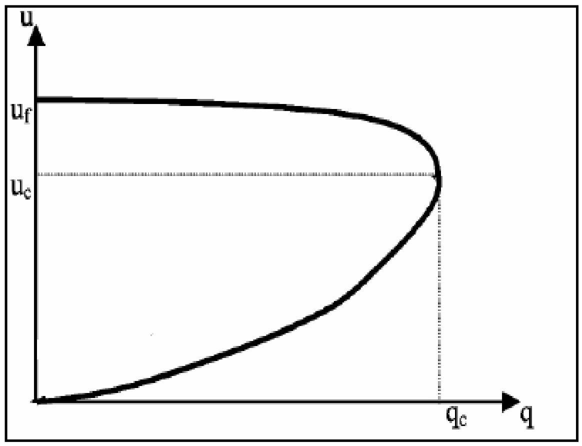


Figure 2.2. Speed – flow relation curve

• **Flow – Density Relation:** Figure 2.3 shows the relation between flow and density. At zero density, flow is also zero. As the density on the road increases, the flow increases until it reaches its capacity value. After that point, k_c, the flow decreases as the density increases and this decrease continues until the jam density, k_j, is reached.

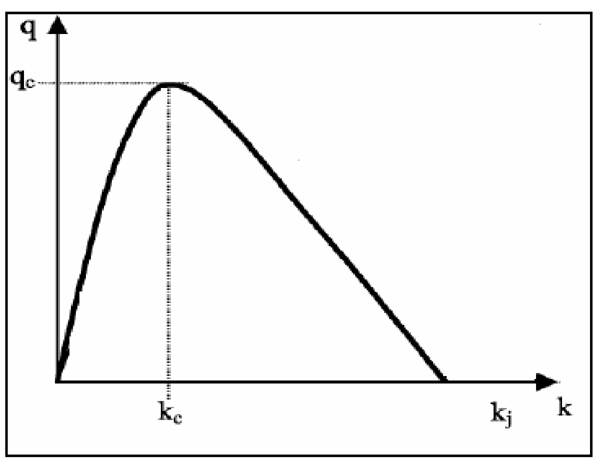


Figure 2.3. Flow - density relation curve

Traffic mainly varies according to three different time periods, which are hourly, daily and seasonal.

- **Hourly Differences:** Traffic varies during the different hours in a day. In metropolitan traffic, traffic demand starting at the early morning hours reaches its maximum between 07:00-10:00 in one direction and then decreases. The traffic demand again reaches its maximum value in the other direction between 17:00-20:00. These time periods of maximum traffic demand at the morning and evening hours are called the *peak* hours.
- **Daily Differences:** The metropolitan traffic demand differs according to the different days of the week. The demand is usually higher in the working days than the weekends due to school and work traffic, except in recreational routes. The working days can also be grouped as Monday-Friday and Tuesday-Wednesday-Thursday. The traffic demand is higher on Monday and Friday than the other working days.
- **Seasonal Differences:** The traffic demand varies in different seasons and months. Since summer is the holiday season and the schools are closed in summer, the metropolitan traffic demand decreases and the traffic demand in the touristic regions increases.

2.2. Toll Plaza Systems

A toll plaza is present on the toll roads where a fee is collected for the use of the road. According to the types of the toll booths the service times change. Even for the same types of toll booths, the service times may differ because of some factors, such as human factors, and weather conditions. A slight difference in service time at a toll booth can directly impact all the vehicles queued in that lane and the approaching vehicles. Any improvement in the service times of the toll booths and the waiting time of the vehicles in the queues would have economical, environmental, and psychological benefits.

2.2.1. Toll Plaza Concepts

A toll plaza is an area on a highway or before/after a bridge where a fee is collected for the use of the road or bridge. The toll plaza can be used on both directions of the road, which is the case of the toll plaza on the highways, or it can be present only on one direction, which is the case on some bridges, for instance, the two bridges on Bosphorus.

As shown in Figure 2.4, a toll plaza system has three parts; approaching area, toll plaza, merging area [6].

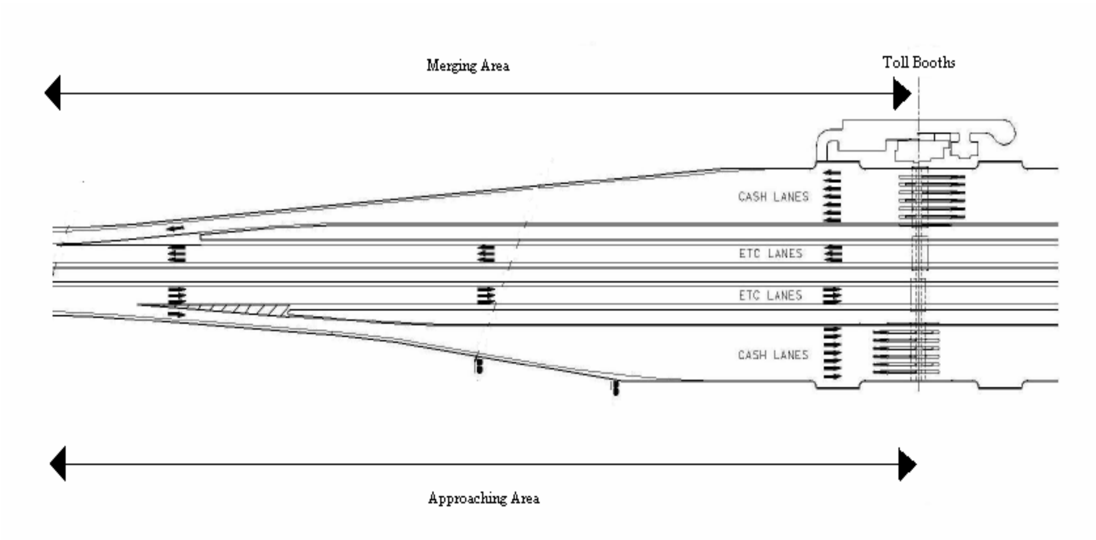


Figure 2.4. Toll plaza system [6]

The approaching area is the part of the system before the toll plaza. At this area, the number of the lanes increases from the number of lanes of the road to the number of the toll booths in the toll plaza [6].

In toll plazas there are different types of toll booths according to the payment types. The most common payment types used at the toll plazas are as follows [6]:

- **Manual Cash Payment:** The driver has to stop to make the payment. If the driver does not have the exact toll fee, he/she has to wait for the attendant to make change. The human factor is very effective at this type of the toll booth in the service time.
- **Credit Card Payment:** The service time of this type of toll booth is shorter than the manual cash payment toll booths, but the driver still has to stop at the toll booths. He/she lets an electronical device to read a type of credit card and moves away.
- **Electronic Toll Collection (ETC):** This type of toll payment system has the shortest service time and the driver has not to stop at the toll booth. With the help of an electronical device in the car and the electronical system at the toll booths the driver passes the toll booth without stopping.

The merging area is the part of the system after the toll plaza. At this area, the number of the lanes decreases from the number of toll booths back to the number of the lanes of the road or of the bridge and a bottleneck is created [6].

2.2.2. Queuing at Toll Plazas

A queuing system can be described as customers arriving for service, waiting for service if it is not immediate in the system, and if having waited for service, leaving the system after being served. In any system, in which arrivals place demand upon a finite capacity resource, queues occur. Depending on the number of servers, number of service stops and the number of queues, there are 4 main queuing models: single server systems, multiple servers in parallel systems, multiple single servers systems, and multiple servers in series systems. The queuing system in toll plazas can be thought as a multiple single server system as shown in Figure 2.5 [7].

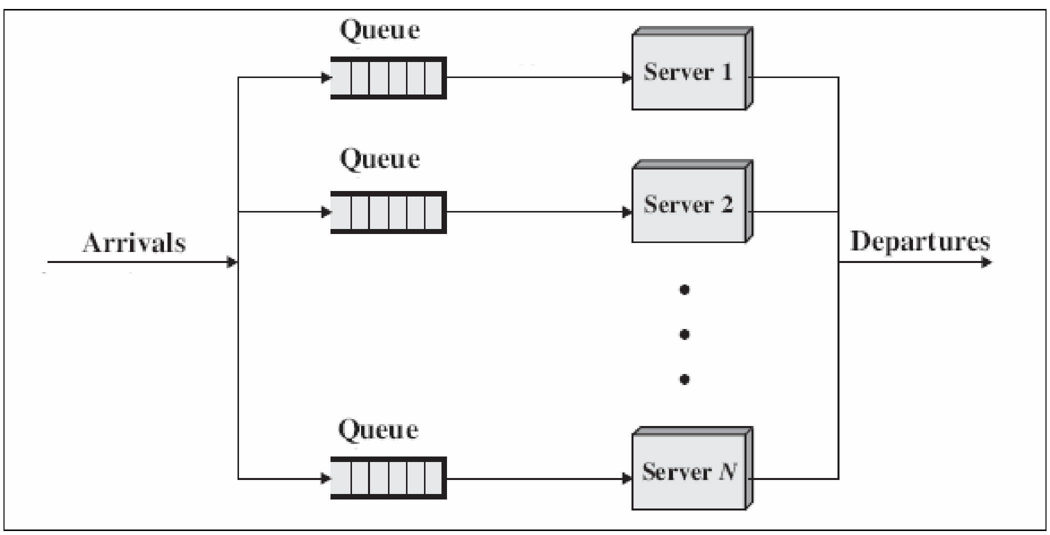


Figure 2.5. Multiple single servers system [7]

The queuing system at toll plazas can be classified by the Kendall's notation as M/G/N/∞/∞/FIFO. The arrivals of the vehicles to the system are Poisson processes. The service times of the servers, which are the toll booths in the toll plazas, may change according to the payment type. For manual cash payment and credit card payment types, the service times may differ for every driver. Also in the cash payment type toll booths, the service time is also affected by the service attendant. For ETC toll booths, the service times can be considered as constant, because there is no effect of driver or service attendant on the service time. If the lane after the ETC toll booth is blocked due to congestion, the driver may have to wait much longer at the toll booth than a driver who waits in a cash or credit card payment toll booth for service. Hence, the distribution of service time can be taken as general for toll plaza systems. N, the number of servers, may change according to traffic demand. Toll plazas with high traffic demand have usually more servers than toll plazas with lower traffic demand. It is difficult to assign a value for the capacity of the queues and for the system population in a toll plaza system. Hence, these values can be taken as infinity. The queuing discipline is FIFO (first come first serve).

The queuing system before the toll plaza is analogous with the bank system. Customers in a bank join the queue of the server according to the transaction they want to do. After they are served, they leave the bank. In a similar way, vehicles join the queue of the toll booth according to their payment type, but unlike the bank system, vehicles leaving the toll plaza may join another queue depending on the traffic demand. This is analogous to the queues in production systems. On an assembly line, units leaving a machine continue to the next machine on the assembly line. When more than one unit arrives at the machine or when a unit arrives at the machine when the machine is busy, they have to wait until the machine becomes idle and queuing occurs. In a similar way, at the merging area, when two or more vehicles arrive at the same time to the merging point or when the lane is occupied by a vehicle when new vehicles arrive at the merging point, they have to wait until they join the lane and queuing occurs.

Two factors that determine the total waiting time in a toll plaza are the queues before the toll plaza and the congestion due to merging after the toll booths. In a toll plaza a driver will choose the lane with the least queue length according to his/her payment type in order to minimize the total travel time. So the objective of a toll plaza design should be to minimize the average travel time of all drivers [3, 6].

In a toll booth, vehicles slow down or wait for the service of toll collection, while at the merging area, drivers may have to slow down or even stop if the capacity of the road is exceeded to complete their merging movement. [6].

• **Toll Booth Queuing System:** Delay at a toll booth results from the requirement to pay a toll for using the facility and is influenced by a number of factors including method of payment and characteristics of drivers and service attendants, if any. The drivers choose which toll booth to enter according to their payment system. So the toll booths in a toll plaza do not get equal arrivals. The arrival rate of a toll booth with cash payment may be larger than a toll booth with ETC since the number of cars with ETC equipment may not be much. Also the service times of different toll booth types are different. A vehicle with ETC equipment drives through an ETC toll booth usually slowing down but without stopping; whereas, a driver using the cash payment toll booth have to stop to give the cash to the attendant. Furthermore even for the same type of toll collection booths service times vary which is caused by the varying characteristics of drivers, weather and road conditions, etc. These characteristics make the nature of delay at a toll plaza a more random variable.

The toll plaza can be considered as a multiple N single server system in parallel with Poisson arrival rates and exponential or constant service rates, where N is the number of toll booths in the toll plaza. The queue discipline is First In First Out [6].

An assumption can be made for the calculation of the arrival rates of the single queues by dividing the total flow to the approach area by the number of the toll booths N. But this assumption would be wrong since the drivers choose the lane according to their payment type. Hence, the arrival rate of each toll booth must be obtained from the field separately.

• **Merging Point Queuing System:** In the merging area cars from two or more lanes merge into one. When a driver at one lane arrives at the merging point the waiting time depends on whether there is another car in the other lane(s). If the other lane(s) is/are empty, the driver can directly pass through, if not, the driver has to stop and wait [6].

• **Total Toll Plaza Queuing System:** The total time a vehicle spends in the toll plaza system is the duration between the times when the vehicle enters the toll booth (or the queue before the toll booth) and the time the vehicle enters the merging point. The delay the vehicle experiences depends on the queue before the toll booth and the congestion in the merging area.

2.3. Traffic Systems Microsimulation

According to Shannon [8], simulation, in general, is "the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system". It is a powerful tool for the analysis of new system designs, retrofits to existing systems and proposed changes to operating rules. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the system [9, 10, 11].

Traffic microsimulation is the dynamic and stochastic modeling of individual vehicle movements on a second or sub-second basis for the purpose of assessing the traffic performance of highway and street systems, transit, and pedestrians. Each vehicle is moved through the network of transportation facilities on a split second by split second basis according to the physical characteristics of the vehicle (length, maximum acceleration rate, etc.), the fundamental rules of motion (e.g. acceleration times time equals velocity, velocity times time equals distance) and rules of driver behavior (car following rules, lane changing rules, etc.).Microsimulation can provide the analyst with a wealth of valuable information on the performance of the existing transportation system and potential improvements to it. With the help of microsimulation, the analyst is able to model complex highway junctions and congested networks. In addition, microsimulation softwares provide a visual representation of the proposed effects on traffic operations [12, 13].

2.3.1. Applications of Traffic Microsimulation

There are many traffic microsimulation software developed for different facilities (such as freeways, urban streets, arterials, toll plazas). Some examples of these models are AUTOS, METROPOLIS, PARAMICS, VISSIM, DYNASMART, DYNAMIT, INTEGRATION, THOREAU, and AIMSUN. Some traffic microsimulation studies completed with these and other microsimulation software are listed below [14];

• Modeling traffic flows in networks involving advanced traffic control and route guidance systems by Yang and Koutsopolos using MITSIM.

• Evaluation of alternative scenarios for increasing capacity and improving traffic flow on a freeway connection by Korve Engineers using WATSim.

• Evaluation of the benefits of In-vehicle Information Systems (IVIS) by Al-Deek et. al. using FREQ8.

• Effects of ramp metering on a motorway and neighboring surface streets by Stewart using PARAMICS.

• Impacts of the High Occupancy Vehicle (HOV) lane implementation for a highway by Abdulhai et. al. using PARAMICS.

• Integration of PARAMICS and Geographic Information Systems by Trapp.

• Simulation of different incident scenarios and use of the simulation output to test the algorithms for incident detection by Cheu et. al. using PARAMICS.

• Simulation analysis of Route Diversion Strategies for freeway incident management by Cragg and Demetsky using CORSIM.

• Computer simulation approach to urban freeway control by Hamad using INTRAS.

2.3.2. Advantages and Disadvantages of Microsimulation

Traffic microsimulation models use computerized techniques to track the movements of individual vehicles through a street network. They use a system of rules that define driver behavior and vehicle performance. A traffic microsimulation model is operated by setting up a model street network, loading it with virtual vehicles, tracking the movements of the vehicles as they maneuver through the network, and summing the results of all vehicles to determine measures of effectiveness. Most traffic microsimulation models allow the analyst to create a real-time picture of the operating street network and observe vehicle interactions on the computer screen.

In contrast, with traditional methodologies, it is possible to input the overall characteristics of the facility and its traffic demand and determine overall measures of effectiveness such as level of service and delay. With traditional analysis, however, it is not possible to track individual vehicle movement

Advantages of microsimulation are as follows [10, 11, 14, 15]:

• Capability to examine certain complex traffic problems (e.g. intelligent transportation systems, complex junctions, shockwaves, effects of incidents).

• Ability to model an entire street network or facility and observe the effect of changes on one part of the network to the performance of the entire network.

• Micro-simulation can be used to develop new systems and optimize their effectiveness.

• Ability to model unusual geometric or traffic control features (such as roundabouts, transit signal priority treatment, and pedestrians) that are not handled in traditional methodologies.

• Ability to model the effects of queued vehicles on the performance of the facility. This includes simple queuing situations, such as short turn lanes, as well as more complex situations, such as ramp meters and toll plazas.

• Traffic simulation models that include a real-time animation of traffic allow non-technical audiences to visualize the potential results of alternative traffic scenarios.

• It provides the simulation of individual vehicle movements, rather than aggregate groups of movements.

• It treats traffic like vehicles.

• Microsimulation models may provide representation of actual driver behavior and network performance.

• It can produce outputs on a wide range of measures of effectiveness. Many of these impacts, such as the amount of pollution emissions are often difficult to measure in the field.

• Demand can be varied over time and space.

• Unusual arrival and service patterns, which do not follow traditional mathematical distributions, can be modeled.

Simulation also has some limitations and disadvantages;

• A great deal more time is required to analyze a problem with simulation models than with more traditional techniques.

• Simulation models typically require more data than traditional methodologies.

• Small errors in setting up the parameters for the simulation can lead to large errors in the overall results.

• It is difficult to determine the accuracy of traffic simulation models. While all of the major software models currently in use are believed to be valid, there has been relatively little accuracy testing done by the transportation profession. In addition to the question of whether the software is accurate, there is also a question of whether the analyst has correctly applied the software. Accuracy is also a question in the use of more traditional methods, but they are simpler, easier to check, and have generally been in use in the profession for a much longer period of time.

• Because most simulation models use random number generation, the results will vary slightly for each separate run of a traffic simulation model.

2.3.3. Key Steps of Traffic Microsimulation

The overall process of developing and applying a microsimulation model to a specific traffic problem involves the 9 major steps explained in the following sections. The success of the analysis highly depends on the care given to each of these steps.

2.3.3.1.Problem Definition. The first step in every problem-solving task is to define and formulate the problem. The problem and the formulations must be clear to everyone dealing with the system under study. At this step the objectives of the study, input data, performance measures, system configuration, required time and resources and any specific questions to be answered by the study must be well defined [16,17].

There are lots of problems with traffic systems: congestions on highways, on intersections, and at traffic signals, traffic accidents, delays, design mistakes in traffic systems, alcoholic drivers, safety design problems, air pollution due to exhaust emissions of vehicles, economic impacts of wasted oil consumption due to congestion, etc. Under the availability of time and resources, according to the problem under study, an appropriate microsimulation model must be selected, required input data related with the study must be collected, and necessary performance measures must be selected.

2.3.3.2.Objectives Setting and Methodology Selection. Microsimulation may become a very time consuming and resource intensive effort if not successfully managed. It is important for the analyst to obtain the most effective results with minimum costs and resources. To achieve an effective analysis the objectives, breadth, approach, tools, resources, and time schedule for the study must be well defined [12].

Before starting the analysis, study objectives must bet set exactly. This will ensure a cost and resource effective analysis. The objectives show the questions to be answered by the study. In the case of an existing system the question would be "How to improve?", whereas in a newly designed, not existing system the question would be "Will it work?" [9, 12, 16].

After the study objectives are set, the geographic and temporal boundaries (such as the range of alternative options, MOEs), the length of the congestion, congestion time period, specific vehicle types, tolerable error) of the study must be set [12,13].

Besides microsimulation, there are several number of analytical approach categories such as sketch-planning tools, travel demand models, analytical/deterministic tools, traffic signal optimization tools, macroscopic simulation models, and mesoscopic simulation models [18].

Sketch-planning methodologies and tools produce general order-of-magnitude estimates of travel demand and traffic operations in response to transportation improvements. They allow for the evaluation of specific projects or alternatives without conducting an in depth engineering analysis. Such techniques are primarily used to prepare preliminary budgets and proposals, and are not considered to be a substitute for the detailed engineering analysis often needed later in the project implementation process. Sketch-planning approaches are typically the simplest and least costly of the traffic analysis techniques. Sketch-planning tools perform some or all of the functions of other analytical tool types, using simplified analyses techniques and highly aggregated data. However, sketch-planning techniques are usually limited in scope, analytical robustness, and presentation capabilities [18].

Travel demand models have specific analytical capabilities, such as the prediction of travel demand and the consideration of destination choice, mode choice, time-of-day travel choice, and route choice, and the representation of traffic flow in the highway network. These are mathematical models that forecast future travel demand based on existing conditions, and future projections of household and employment characteristics. Travel demand models were originally developed to determine the benefits and impact of major highway improvements in metropolitan areas. However, they were not designed to evaluate travel management strategies, such as intelligent transportation systems (ITS)/operational strategies. Travel demand models only have limited capabilities to accurately estimate changes in operational characteristics (such as speed, delay, and queuing) resulting from implementation of ITS/operational strategies. These inadequacies generally occur because of the poor representation of the dynamic nature of traffic in travel demand models [18].

Most analytical/deterministic tools implement the procedures of the Highway Capacity Manual (HCM). These tools quickly predict capacity, density, speed, delay, and queuing on a variety of transportation facilities and are validated with field data, laboratory test beds, or small-scale experiments. Analytical/deterministic tools are good for analyzing the performance of isolated or small-scale transportation facilities; however, they are limited in their ability to analyze network or system effects [18].

Traffic signal optimization tools are primarily designed to develop optimal signal-phasing and timing plans for isolated signal intersections, arterial streets, or signal networks. This may include capacity calculations; cycle length; splits optimization, including left turns; and coordination/offset plans [18].

Macroscopic simulation models are based on the deterministic relationships of the flow, speed, and density of the traffic stream. The simulation in a macroscopic model takes place on a section-by-section basis rather than by tracking individual vehicles. Macroscopic models have considerably fewer demanding computer requirements than microscopic models. They do not, however, have the ability to analyze transportation improvements in as much detail as the microscopic models [18].

Mesoscopic simulation models combine the properties of both microscopic and macroscopic simulation models. As in microscopic models, the mesoscopic models' unit of traffic flow is the individual vehicle. Their movement, however, follows the approach of the macroscopic models and is governed by the average speed on the travel link. Mesoscopic model travel simulation takes place on an aggregate level and does not consider dynamic speed/volume relationships. As such, mesoscopic models provide less fidelity than the microsimulation tools, but are superior to the typical planning analysis techniques [18].

From these approaches, microsimulation is the best approach under the following conditions [18];

• There is a well-defined and complex traffic operational problem to be solved.

• There are significant issues of queuing of vehicles from a particular intersection to adjacent intersections or from one roadway facility to another.

• There is a need for decision makers and/or the public and to visualize the results of a proposed improvement through a real-time animation.

• There is a great deal of cost difference between roadway improvements alternatives under consideration. In this case, the money that could be saved by making the appropriate decision tends to justify the cost of conducting the traffic simulation.

• Conditions that violate the basic assumptions of other available analytical tools,

• Conditions not covered by other available analytical tools

• Testing of vehicle performance, guidance, and driver behavior modification options

• Sufficient data and resources are available.

• Less data-intensive approaches cannot yield satisfactory results.

The basic criteria for software selection are technical capabilities and input-output interfaces. The selected software should be able to accurately forecast the traffic performance of the alternatives considered in the analysis and to handle the size of the problem under study. Its ability to analyze the appropriate geographic scope for the analysis (isolated intersection, single roadway, corridor, or network), various travel modes (bus, train, truck, bicycle, and pedestrian traffic), vehicle movement logic (lane changing, car following), to directly produce and output performance measures (crashes, throughput, speed, delays, queue lengths, cost savings, emissions), and its capability of modeling various facility types (freeways, ramps, arterials, toll plazas) [12, 18].

Input, output, and the ability of the software to interface with other software that will be used in the study are other key point in the software selection. The software must be able to produce reports of the selected MOEs for the evaluation of the system [12, 18].

2.3.3.3.Data Collection. Data collection is necessary for the estimation of the input parameters to the model, for calibration of the model, and for obtaining probability distributions for the random variables used in the model. According to the project under study and the microsimulation software data needed may be various. In most of the traffic microsimulation studies following types of data are necessary [9, 10,12];

- **Road geometry:** Most models need geometric data such as number of lanes, length of the lanes and free flow speed. These data may be obtained from project drawings, field measurements, geographical information systems or satellite pictures (Google Earth).
- **Traffic controls:** Control data involve the location of traffic control devices and signal timings. These data can be obtained from the field or from the files of the agencies operating the traffic controls.
- **Demand:** Most of the microsimulation models need basic demand data such as arrival volumes and turn movements at the intersections at the study area. These data must be collected within the microsimulation model study area for the duration of the proposed simulation analysis period.
- **Calibration data:** Calibration data include performance measurements such as capacity, traffic volume measurements, trip durations, speed, delays and queuing parameters (arrival rate, queue length, waiting time). Except capacities, the rest of the data must be collected from the field to achieve a more useful calibration.

In addition to the basic data, traffic microsimulation models need data concerning the vehicle and driver characteristics (vehicle length, max. acceleration, driver behavior). It’s difficult to collect these data from the field; in general values for these data are used as they are set by default in the software.

2.3.3.4.Development and Statistical Analysis of Input Data. Input data development involves review and error checking of the data collected in the field. Upstream and downstream volumes must be consistent. Geometric data and control data must be reviewed for any violations of design standards or traffic engineering principles. If real speed values are necessary for the study, floating cars must be reviewed [12].

If there are volume differences between points that are very close, the analyst must find the possible reasons. The possible reasons may be counting mistakes, traffic sources or sinks between two points, or queuing between two points. In case of counting error, the counting process must be repeated. Differences due to source/sinks do not need to be balanced, but the source/sinks must be included in the model. To balance the differences due to queues the analyst may extend the counting duration in order to include all demand in both counts [12].

Input data, such as arrival rate and service rate, may be of probabilistic nature. Statistical analysis of these data is necessary. This procedure involves three steps [9, 10, 17];

1) **Identifying the Distribution with Data:** To assign a probability distribution function to the input data, drawing a histogram is helpful. According to the shape of the histogram, a family of probabilistic distributions is selected.

2) **Choosing Parameters to Determine a Specific Distribution:** The values of the parameters of the selected distributions must be specified from the collected data in order to apply hypothesis testing.

3) **Evaluation of the Chosen Distribution and the Associated Parameters for Goodness-of-fit:** The Chi-square is a standard goodness-of-fit test. With the help of the Chi-square test, the probabilistic distribution of the input data can be determined. If the result of the test indicates that the assumption of the probability distribution is wrong, the procedure is repeated with a new probability distribution [9, 10].

2.3.3.5.Base Model Development. Base model development is the translation of the project under study into a computer-recognizable format. The model development is a multi-step process. The analyst should first create the geography of the project as the basement of the model. Then the model is developed by coding the links and nodes, filling in the link geometries, adding traffic control data at appropriate nodes, entering travel demand data, coding driver behavior data, and selecting the model run control parameters, in sequence. The software used and the scope of the study determines which of these characteristics will be coded [9, 12].

Links are one-directional segments on streets and highways. They represent the length of the segments and involve data that give the geometric characteristics of the roads or highways between the nodes. Nodes are the points where two or more link intersects. They are used at intersections and points where link geometry changes. The locations of the nodes can be obtained from the satellite pictures, maps, or field measurements. The link-node diagram, Figure 2.6, is a map to develop the microsimulation model. It defines which streets and highways will be included in the model and how they will be defined. A map or satellite can be used in the microsimulation software over which the diagram can be overlaid [12].

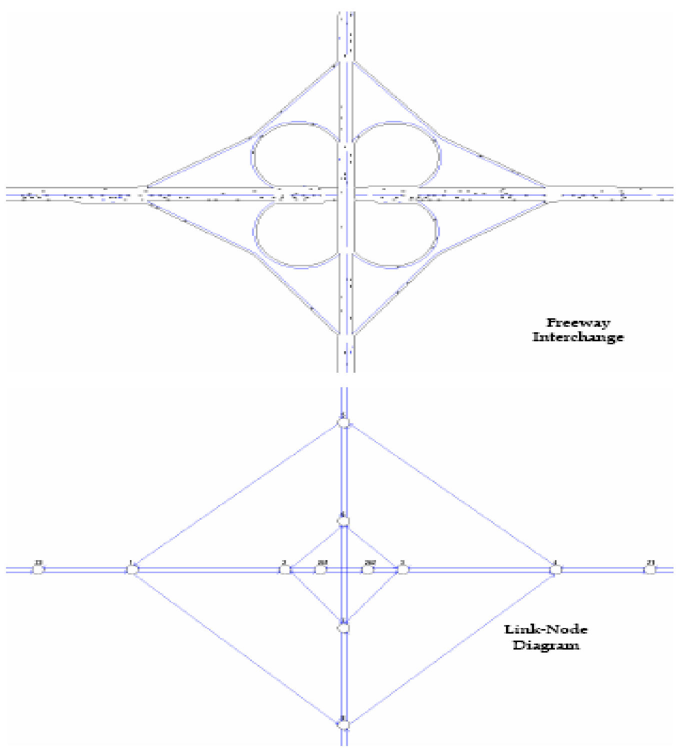


Figure 2.6. Link-node diagram example [12]

After finishing the link-node diagram, the available physical and operational characteristics should be coded into the model such as number of lanes, the lane width, link length, grade, curvature, pavement conditions (dry, wet), sight distance, bus stop locations, crosswalks and other pedestrian facilities, bicycle lanes [12].

Traffic controls help drivers navigate, assign the right-of-way at intersections, indicate laws such as speed limits and parking regulations, advise potential hazards, indicate passing and no passing zones, deliver information to assure that traffic is orderly and safe. Mostly used traffic controls are yield signs, stop sign, signals, and ramp metering. Traffic control data can best be obtained from the files of the agencies operating the traffic controls (for traffic signals and ramp meters), or from field inspection (for signs, although some agencies maintain excellent sign inventories) [12].

Traffic demand may be defined as the number of vehicles that want to pass the study area during simulation time period and the percentage of vehicle types. Also it may be necessary to reflect the change in the demand along the simulation time period. In most microsimulation models, traffic entering and leaving the links is calculated with the help of some parameters. Coding of the traffic demand should start with the external nodes, where traffic enters the model. After that, the analyst should code all the turning movements and route choices. Important traffic data are entry volumes according to vehicle type, turning percentages at all intersections and junctions, vehicle data, bus operations, and bicycle and pedestrian demands [12].

If there are observed field data, the driver behavior data are coded in. If not, the default behavior data of the microsimulation software are used (such as free flow speed, discharge headway, start-lost time). Some examples of driver behavior data are minimum headway in car-following, gap for lane changing, driver's ability of information, and drivers response to information (route switching) [12].

All simulation software packages include some parameters to realize customized modeling. These parameters change according to the software, including length of simulation time, selected measures of effectiveness or outputs, resolution of simulation results, and other system parameters to run the model [12].

2.3.3.6.Error Checking (Verification of the model). Verification of the model is used to assure that the microsimulation model reflects the conditions of the real life system under study. It is one of the principal steps of a successful model. This step involves checking for software, input, and other possible errors and correcting them, if any, so that the calibration process does not result in parameters that are distorted to compensate for overlooked coding errors [9,12].

To avoid software errors, the latest innovations about the software must be pursued via internet and forums. The selected software should be able to produce output parameters required for the analysis. If not, software capable to produce the selected MOEs must be chosen [12].

Input error checking involves checking the model in terms of network and demand. Basic connections of the network (links and nodes), link geometry (lengths, number of lanes, free flow speed, etc.), intersection controls (control type, control data), and forbidden turns, closed lanes, lane restrictions at intersections and links must be checked. Vehicle mix proportions and characteristic descriptions, identified sources and sinks for traffic, turning percentages must be checked and zone volumes must be verified against traffic counts.

Animation review may be used to watch the vehicle behavior and to decide on the reasonableness of the microsimulation model. Review of the animation output is a two-step process. First, simulation is run with very small demand that does not cause any congestion. Each vehicle must be observed separately along the network and unexpected slow-downs must be determined. These slow-downs are generally caused by minor coding errors. Then, the simulation will be repeated with a demand of 50% of the existing demand, which again should not cause any congestion. If congestion occurs, that is caused by a coding error that can affect the distribution of the vehicles and is difficult to notice. All the entry and exit flows must be checked to verify that all demand is loaded correctly and moved through the network [9,12].

In case of unexpected vehicle behavior, at points of congestion, detailed observation must be done. The vehicle behavior from the simulation must be compared to the real vehicle behavior on the field at the same time period. If the network is created using satellite photo or maps, the unexpected vehicle behavior can be revealed with field inspection. If the model is expected to produce realistic vehicle behavior, the network should be rebuilt at points of congestion. In commercial microsimulation models, which require detailed and extensive coding, another reason of unexpected vehicle behavior may be erroneous data entry that can not be easy to recognize [9, 12].

When the simulation does not work successfully, after all the error checks of the previous sections are finished, then the expected performance might be beyond the capabilities of the software, or there may be a software error. If the problem is caused by the limitations of the software, the analyst can work around the limitations of the software by tricking and forcing in order to produce the desired performance. If the software limits are too great, alternate software capable to produce the desired performance should be selected. In the case of a software error, testing can be done by coding simple test problems (such as a single link) where the result (such as mean speed) can be calculated manually and compared to the model [12].

The analyst can decide that the error checking process is finished when all input data are correct, all default parameters are reasonable, and the animation results are reasonable according to judgments and field inspections. After the error checking is finished, a model is developed, but still calibration of the model is essential before the analysis of different alternative designs [12].

2.3.3.7.Validation of the Microsimulation Model. Validation is concerned with determining whether the simulation model is an accurate representation of the system under study. The goal of model validation is to ensure that the developed microsimulation model can be used by the decision maker to make decisions that would be same if the decisions have been made after experimenting with the real system in case it is feasible and cost-effective [9].

Calibration is a detailed study used for the validation of the model. It is an iterative process to adjust the model parameters in order to increase the model's ability to create local driver behavior and traffic characteristics [9, 12].

No microsimulation software contains all the variables that affect real-world traffic conditions. Even the most detailed microsimulation model contains only a portion of parameters that affect real-world traffic conditions and are user adjustable. The objective of calibration is to find the set of parameter values for the model that best produces local traffic conditions and behavior [12].

One important assumption of calibration is that the travel behavior in the model is reliable. There is no need to confirm the produced delay, travel time and, density with correctly coded input data [12].

Microsimulation models contain lots of parameters. These impact the simulation results in a manner that is often correlated with that of the other. Examining all of these parameters can create a never-ending circular process where a new problem may occur when another is fixed. Therefore, dividing the calibration process into logical and sequential steps would be a good strategy [12].

The available parameters of the model can be divided into two categories which should be dealt separately; parameters which have been assured and do not need to be adjusted, and parameters which have been less assured and needs to be adjusted. Although it is advantageous to adjust many parameters in order to make a better calibration of the model to the local conditions, the set of adjustable parameters must be kept as minimum as possible in order to minimize the effort required to calibrate them [12].

The set of adjustable parameters can be further subdivided into calibration for capacity and calibration for route choice which can be further subdivided into two categories which are global calibration and fine tuning [12].

Capacity calibration involves calibrating the parameters related with capacity in order to best replicate local field measurements of capacity. It is an important process since capacity has an important effect on predicted system performance, such as delay and queues. The aim of this process is to find the best values for capacity parameters so that the model produces results as close as possible to the field measurements. The output of the microsimulation models can not be called capacity; it's just the number of vehicles passing a given point. [12].

The parameters to be selected for calibration must be the ones which directly affect the capacity. Some parameters for calibration are mean following headway, driver reaction time, critical gap for lane changing, and minimum separation in stop and go conditions for freeway facilities [12].

After the decision of the calibration parameter(s), the model will be simulated for different values of the parameter for several runs. The different parameter values must be in a logical and acceptable user specified range. Setting a range is necessary to avoid solutions that violate laws of physics, vehicle performance limits, and driver behavior extremes. Student-t test can be used to find the parameter values with which simulation output fits best in a given confidence level with the real life data used for calibration [12].

After the global capacity calibration is finished, there may be still points in the model where the model performance deviates from the field measurements. To avoid this problem fine tuning might be needed where link-specific capacity adjustments which are not coded in the model (such as presence of on-street parking, narrow shoulders, etc.) should be done [12].

Route choice calibration is only necessary in systems where the model network has more than one route. The global calibration of route choice calibration involves adjustments of parameters such as actual cost and travel time of each route. Student-t test can be applied again to find the optimum parameter value. When the global calibration is finished, link-specific adjustments to cost or travel time are made during the fine-tuning step [12].

In this last step of calibration, performance measures, such as travel time, queue lengths, and waiting time, which can be collected from the field are compared with the simulation output of these performance measures. Some statistical tests, such as t-approach, can be used for this comparison [9, 10, 12].

2.3.3.8.Alternative Designs and Analysis of Output Data. Alternative analysis is the reason for developing and calibrating the simulation model. The alternative analysis may involve forecasting the future demand for base case and simulating different alternative designs with this future demand, if a demand forecast model is present. After the model is run several times, the output is reviewed, relevant statistics are extracted, and various analyses of the results are performed such as hypothesis testing [12].

The forecast for the future demand might be done by trend-line method. With the assumption that the recent percentage growth rate will continue in the future, future demand can be forecasted. During forecasting, care must be given to ensure that the future demand forecast is a reasonable estimate of the arriving traffic at the study area during analysis period [12].

MOEs are the system performance measures showing the degree to which a particular alternative design meets the desired objectives. They may be key indicators of system performance and localized breakdowns in the system. Possible MOEs may be total network flow, total delay, average speed, flow at a specific point, and more objective specific output data such as fuel consumption and pollutant emission [12].

Besides the overall system performance, localized system breakdowns must be evaluated, if any. A persistent short queue that lasts too long, a signal phase failure, or a blocked link, where a queue backs up into an upstream intersection, are examples of localized breakdowns [12].

The driver behavior of the microsimulation models is uncertain. In every run of the alternative, the model assigns a different random number seed giving a different mix of driver behavior. Hence, each run of the alternative ends with different results. The average and standard deviation of these results must be computed and the confidence intervals must be determined [12].

After the simulation of the base model, alternatives to improve the existing conditions, which may involve some operational strategies and/or some geometric changes, must be designed. Then these alternative designs are simulated with the parameters assigned in the calibration process for several runs, to provide output data for the MOEs on the system design of interest. These data will be analyzed in order to find the best alternative [10, 12].

Before starting the simulations two parameters must be decided; number of repetitions for each alternative and warm-up period [12].

Microsimulation models randomly generate vehicles, select their destination, select their route, and determine their behavior during their move through the network for each run. A single run is not sufficient to reflect any field condition. The results of individual runs can vary by 25 percent and higher standard deviations can be expected for systems operating at or near capacity. Hence each alternative must be run for several times. The standard deviation, the desired confidence level, and desired confidence interval are required to estimate the number of runs [12].

The length of the confidence interval is decided by the analyst. If very similar alternatives are tested, a small confidence interval will be desired, but if testing alternatives differ much, than a larger confidence interval can be tolerated [12].

Traffic microsimulation models start with zero vehicles in the system, which does not consider the initial conditions and causes biases in the results. In order avoid this problem; an initial period (called warm-up period) is necessary for the simulation. The warm-up period is the time period which is necessary to create the initial conditions of the system and which is not included in the reported statistics for system performance. Many simulation software packages create the warm-up period automatically [9, 10, 12, 19].

Output analysis refers to the analysis of data generated by a simulation. In this step, the different alternatives are evaluated using the result outputs of the simulation runs. The system performance results are interpreted and various analyses are applied for assessing the robustness of the results by using several statistical tests. For example, hypothesis testing can be used to evaluate multiple alternatives. [12, 19].

2.3.3.9.Reporting and Documentation. The final report presents the assumptions, analytical steps, and results of the analysis in sufficient detail for decision-makers to understand the basis for and implications of choosing among the project alternatives. The final report should include the following [12, 18];

- Study objectives and scope;
- Overview of study approach (tools used, methodology, rationale);
- Data collection (sources and methods);
- Calibration tests and results (which parameters modified and why);
- Forecast
- Description of alternatives
- Results

2.4. Microsimulation of Toll Plazas

Toll plaza systems are specific examples of traffic systems. As mentioned before, toll plaza systems are multiple single parallel server queuing systems. The analysis of queuing processes can be completed in two ways: by traditional queuing analysis or by simulation. Queuing theory with its fine-tuned analysis provides a base for a somewhat simplified and easier to use set of tools known as Model Building and Simulation. Simulation from adequate models is the technique that bridges the gap between the theoretical plane of queuing theory and the practical tool of a decision support system. Queuing theory and simulation work hand-in-glove to uncover and smooth out some of the rough spots in a productive process - whether this involves delivering a service or a fabricated item to the immediate consumer. Simulation models only work because of the analytic power of queuing theory which underlies and enables them [20].

The advantage of queuing analysis is that it provides the conceptual framework and insights of how queuing systems behave. It directs the way of thinking in complex queuing situations. However, it is impractical and is also highly limited in system complexity since it is based on exponential assumptions for arrival patterns and service times [3].

Simulation, on the other hand, is a powerful and easily accessible modeling tool in highly complex queuing situations while allowing arbitrary input distributions. But, it lacks a conceptual framework and insights for design or optimization questions, such as selecting which variants or configurations to analyze. Also it must be kept in mind that a simulation analysis delivers only a statistical estimate of the real system [3].

The advantage of a hybrid approach, using queuing theory and simulation, lies on that it combines the best of both methods: conceptual framework and insights from queuing with the modeling and evaluation potential for real life situations by simulation. Queuing insights can limit the number of variants to be examined, while simulation compares and evaluates the different variants.

3 MODEL DEVELOPMENT

The traffic system under study in this thesis was the FSM Bridge. The system has three sources and three sinks, shown as SO and SI in Figures 3.1 and 3.2. Vehicles may enter the system from TEM, Etiler, and Kavacık sources and they can leave the system at Etiler, Kavacık, and TEM sinks. A 20-lane toll plaza is present on the Europe-Asia direction on the European side. Of the 20 toll booths, seven are electronic pass system (OGS), eight are cash payment system (CASH), and five are card pass system (KGS). The configuration of the toll plaza is shown in Figure 3.1. Except the two most right toll booths, labeled 1 and 2 in Figure 3.1., the vehicles arrive at the toll booths from the Transport European Motorway (TEM). The payment system of the toll booths 2, 3, 6, 7, 8, 9, 10, and 11 are CASH, whereas the toll booths 1, 4, 16, 17, 18, 19, and 20 are OGS toll booths and the toll booths 5, 12, 13, 14, and 15 are KGS toll booths. The toll booth serving for vehicles arriving from TEM are grouped according to the payment type, except the three toll booths at the right most side of the toll plaza. These are one KGS, one OGS, and one CASH toll booths to serve for the trucks, long vehicles, and buses which drive on the right lanes of TEM, to avoid any accidents that may occur if these vehicles try to pass to any of the toll booths left of the toll plaza. The number of lanes increases from six to 20 in the approach area and it decreases to four after the toll plaza in the merging area. The reverse lane entrance, shown in Figure 3.2., is the point on TEM at Kavacık intersection, where vehicles, which entered the reverse lane in the opposite direction after the toll plaza, return back to TEM in Europe-Asia direction.

The software infrastructure for modeling and analysis is shown in Figure 3.3. Statistical analysis of quantitative input data, such as arrival times and service times, was conducted with the input analyzer module of ARENA. The traffic system under study was coded into the AIMSUN traffic microsimulation software. AIMSUN uses several sub-models, such as fuel consumption and pollutant emission sub-models, to calculate output variables fuel consumption and exhaust emissions. The output data obtained from AIMSUN was analyzed using MS Access and Excell. Output data of the simulations were stored in Access database and Excell was used to apply statistical tests of the output data.

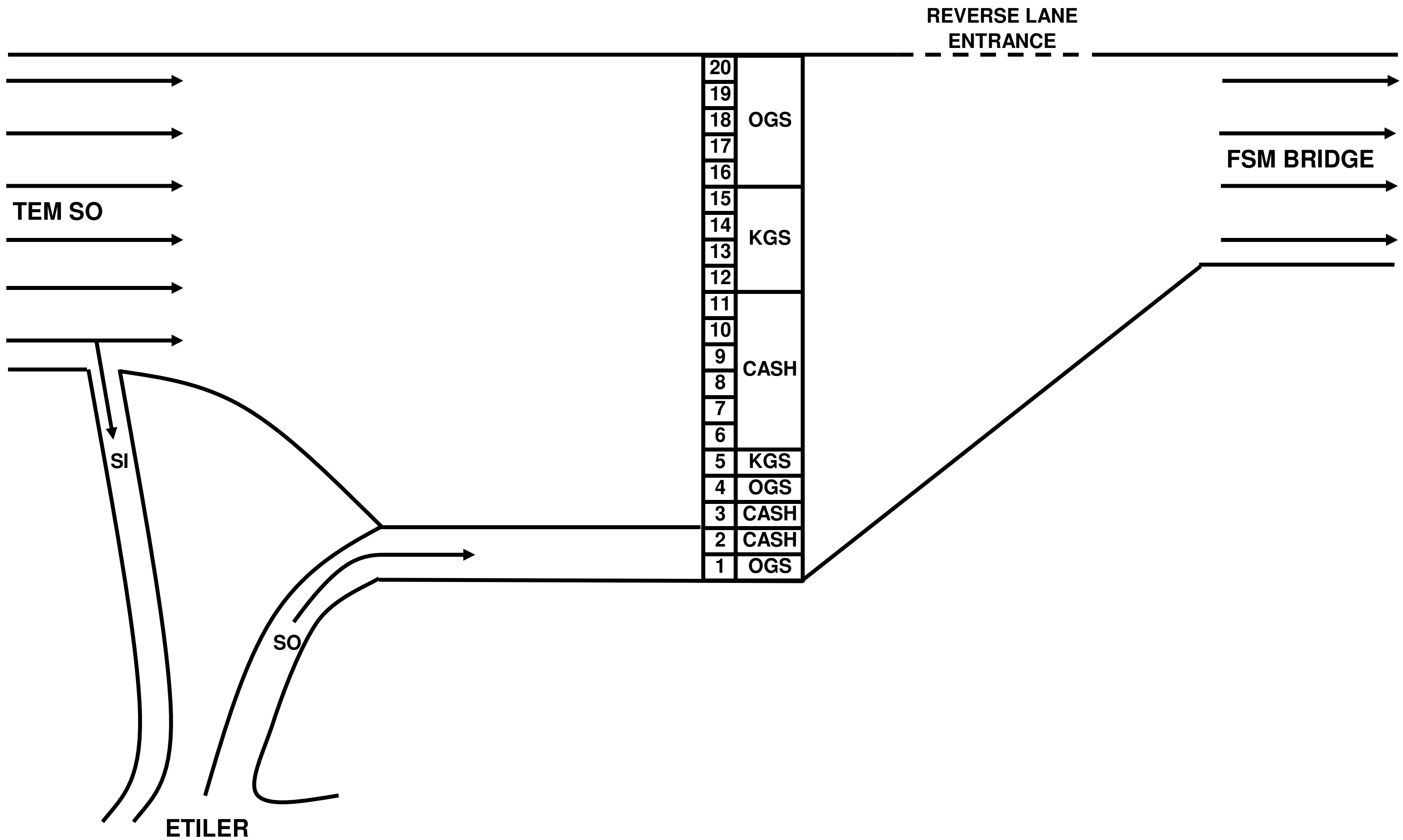


Figure 3.1. Drawing of FSM Bridge toll plaza area

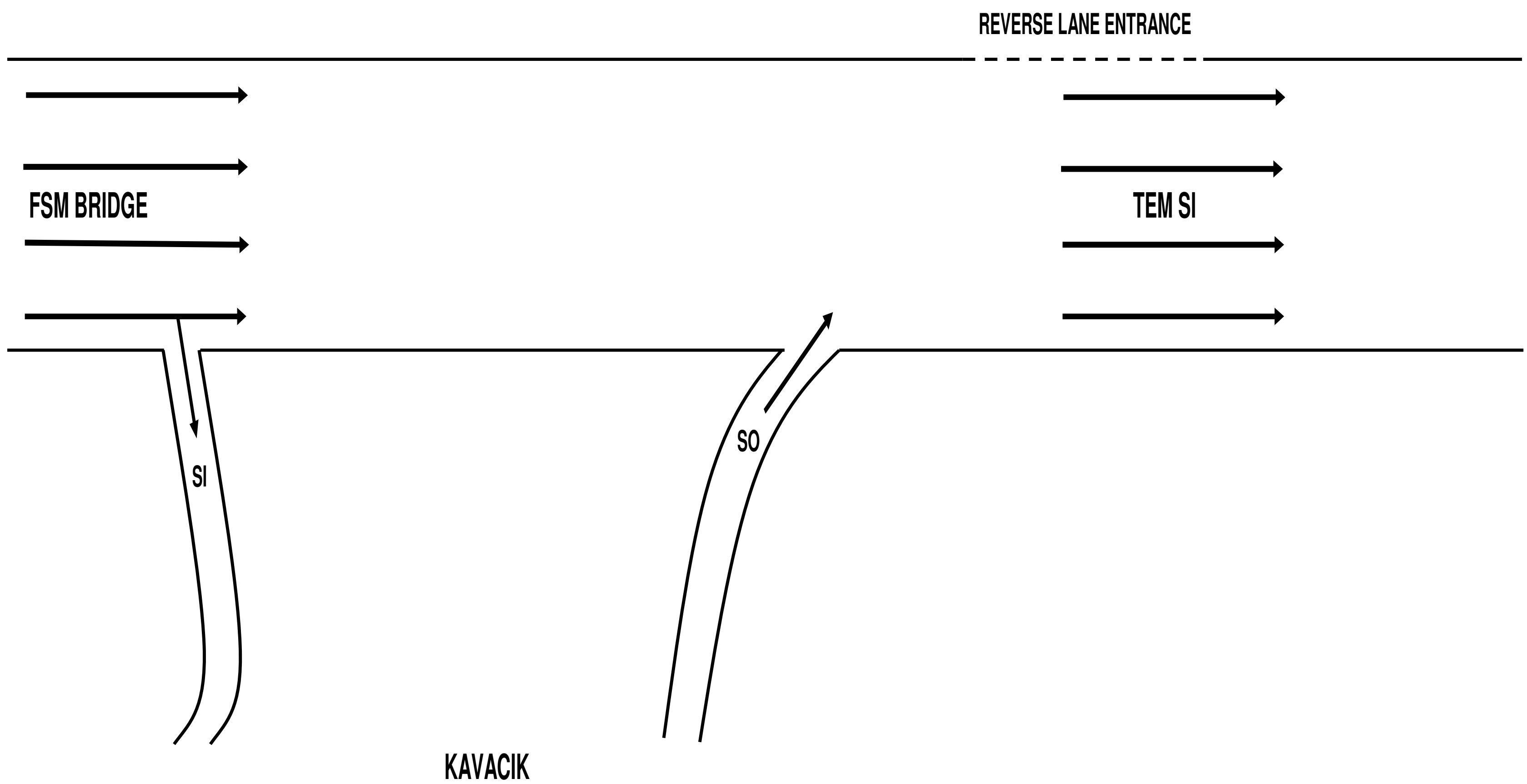


Figure 3.2. Drawing of Kavacık intersection

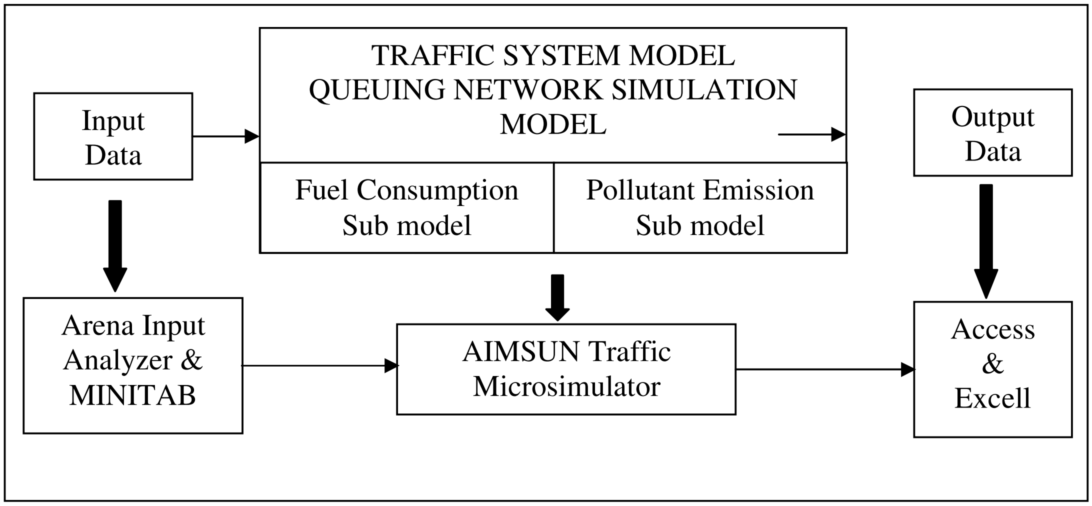


Figure 3.3. Software infrastructure for modeling & analysis

3.1. Methodology Selection

As mentioned in the introduction chapter, for the assessment of FSM Bridge, simulation software that runs simulation in micro level was necessary because the calculation of some MOEs required the emulation of the flow of individual vehicles of different types throughout the simulation time period as they traveled in a road network and considered their speeds and speed changes which was difficult or impossible to simulate using traditional mathematical models. For that purpose, application-oriented traffic microsimulation software or general purpose simulation software capable to simulate in micro level could be used for the FSM Bridge model.

General purpose simulation software packages, which may also be called simulation languages, are general in nature and provide a great deal of modeling flexibility in many application areas. They can be used for any application, but might have special features for certain ones. They require programming language knowledge and model development is done by coding, which may require development and coding of many sub models. They are difficult to use, and require much effort and time

Application-oriented traffic microsimulation software packages, which may be called traffic simulators, are designed to be used for traffic system applications and the model is developed by using graphics, dialog boxes, and pull down menus. They involve many sub models (such as traffic control sub models, environmental sub models, traffic behavior sub models) for specific objects and are easy to learn, but are not flexible. They can be used only for traffic systems, but require less time and effort for modeling than the simulation languages. Traffic simulators have higher animation capabilities for traffic systems which is very helpful for verification and validation of the model.

In this study, AIMSUN (Advanced Interactive Microsimulation for Urban and Non-Urban Networks), an application-oriented simulation software developed by TSS (Transportation Simulation Systems in Barcelona.), was selected for the analysis.

AIMSUN is a full function microscopic simulation tool with a broad range of simulation capabilities, and is able to simulate surface street networks, freeways, interchanges, traffic controls such as ramp metering. It has no specific feature to model toll booths. Instead, ramp metering was used to represent the toll booths, where entering a mean and standard deviation value of the delay for ramp metering, caused the vehicles to stop and wait in the toll booths.

In an AIMSUN network, vehicles enter the network at entry points and their movements through the network are determined by car following, lane changing, and gap acceptance algorithms. Each vehicle is assigned a set of vehicle and driver attributes which are used by these algorithms to model vehicle movement. Vehicle attributes such as length, width, maximum speed, and normal and maximum acceleration are assigned when a vehicle enters the network. Users can select from a wide variety of vehicle types, and within each type there will be some variation in these parameters based on statistical distributions. The same is true for driver characteristics such as desired minimum headways and speed acceptance (obedience to the speed limit). AIMSUN simply establishes mean driver performance values and varies driver behavior for each vehicle about the mean (within specified minimum and maximum values). Turning speeds also vary by the driver type.

In the gap acceptance algorithms, after some period of waiting for an acceptable gap, most drivers will begin to accept shorter and shorter gaps as their wait time increases.

AIMSUN attempts to replicate this behavior with initial gap values that decrease after a specified wait time.

AIMSUN can function as either a stochastic model, where vehicles travel through the network based on turn probabilities; route choice is based on actual traffic conditions and may vary at different points in the simulation.

AIMSUN produces output parameters such as traffic flows, density, mean and standard deviation of speed and travel time, total travel time, total distance traveled, delay, number of stops, fuel consumption, and pollutant emission, where the last two outputs are very important for the scope of this thesis.

AIMSUN uses two environmental models to calculate the fuel consumption and pollutant emissions. These two sub-models of AIMSUN are explained briefly in this section [21].

The fuel consumption model assumes that each vehicle is either idling, cruising at a constant speed, accelerating or decelerating. At each time step the state of each vehicle is determined and the model then uses an appropriate formula, which is shown in Table 3.1, to calculate the fuel consumption for this state. For idling and decelerating vehicles the rate, F_i and F_d respectively, (in ml/s) can be assumed to be constant. For an accelerating vehicle it is given by the formula (c_1+c_2 a v), where c_1 and c_2 are constants, a and v are the vehicle acceleration and speed respectively [21].

The following fuel consumption equation (in ml/s), for a cruising vehicle moving at speed v (km/h), has been determined by Akçelik (1982). It contains three constants; k_1, k_2 and v_m, which need to be determined empirically for each vehicle type. v_m is the speed at which the fuel consumed per km traveled is a minimum. Typically this is around 50 km/h. The rate of use of fuel over time is given by [21]:

$$dF/dt = k_1[1+(v^3/2v^3_m)]+k_2v \tag{3.1}$$

Amongst the figures given are the fuel consumption in liters per 100km, for vehicles traveling at speeds of 90km/h and 120km/h. These figures can be used to determine the constants k_1 and k_2 above. If F_1 and F_2 are the fuel consumption rates in liters per 100km for a vehicle traveling at a constant speed of either v_1 or v_2 respectively, then [21]:

$$k_1 = (F_1 - F_2)\, v_1\, v_2\, v^3_m / 180(2\, v_2\, v^3_m - 2\, v_1\, v^3_m + v_2 v^3_1 - v_1 v^3_2) \tag{3.2}$$

$$k_2 = (2\, F_2 v_2 v^3_m - 2\, F_1 v_1 v^3_m + F_2 v_2 v^3_1 - F_1 v_1 v^3_2)/360(2\, v_2 v^3_m - 2 v_1 v^3_m + v_2 v^3_1 - v_1 v^3_2) \tag{3.3}$$

Table 3.1. Fuel Consumption Formula [21]

Vehicle State	**Fuel Consumed during Δt (ml)**
Idling	$F_i \Delta t$
Acceleration with acceleration a (m/s^2) and speed v (m/s)	$(c_1 + c_2\, a\, v)\, \Delta t$
Cruising at speed v (m/s)	$(k_1[1+(v^3/2v^3_m)]+k_2 v)\Delta t$
Decelerating	$F_d \Delta t$

In the pollutant emission model, as in the fuel consumption model, the vehicle state and the vehicle speed/acceleration is used to evaluate the emission from each vehicle by referencing look-up tables for each pollutant, which give emissions (in g/s) for every relevant combination of vehicle behavior, speed/acceleration. Three pollutants, Carbon Monoxide, Nitrogen Oxides, and unburned Hydrocarbons, are considered, corresponding to three most widely used pollutants. Input parameters required for the model are emission rate for accelerating vehicles, emission rate for decelerating vehicles, emission rate for idling vehicles, and a look-up table for vehicles cruising at a constant speed consisting of a set of pairs speed break point, emission rate [21].

The version used in this study was a student license version of AIMSUN Microsimulation Software with the following limitations;

- No scripting was allowed.

• Networks containing more than 20 km total lanes length and 10 nodes were not allowed to simulate. (Total lanes length is calculated by summing up the multiplication of the link length with its lane number over the total number of links.)

• Simulation of public lanes (public transportation of buses, coding their lines, timetables, stops and stop times, reserved lanes for buses) was not allowed.

3.2. Data Collection

The necessary data for the AIMSUN microsimulation model were the geometric layout, traffic demand data, and traffic control data.

The description of geometric layout including section lengths, number and width of lanes was obtained from field observations and from the satellite picture as portrayed in Figure 1.1.

Traffic demand data contained the arrival and departure volumes of the toll booths, sinks and sources of the study area. The hourly numbers of vehicles leaving the toll booths were provided by the GDH FSM Bridge Maintanence-Operation Center for every single toll booth. The summary of the reports obtained from GDH are given in Appendix A. For one week, the toll plaza area and Kavacık intersection areas were recorded by video cameras between 17:00-20:00 on everyday (Figure 3.4. and Figure 3.5.). Vehicles arriving each toll booth, leaving the network at sinks and entering the network at sources were counted from those video records hourly. For toll plaza region, the lengths of the queues were observed for each toll booth at the beginning and end of the one hour periods.

Since Friday was the study day of the week, detailed vehicle counting has been done for Friday according to different vehicle type groups for calibration purposes.

Table 3.2 contains hourly traffic flow data of different vehicle classes one to three between 17:00-20:00 on Friday, 26.05.2006. Vehicle flow data for other days of the week between 20-26.05.2006 are given in Appendix A.

Vehicle class one includes passenger cars and jeeps. AIMSUN does not have a vehicle type for motorcycles. In addition, the number of motorcycles passing the toll plaza was ignorable compared to other types of vehicles. Hence, the motorcycles were included in the first vehicle class. Car vehicle type was used for vehicle class one in AIMSUN. Vehicle class two includes minibuses, pick-ups, and small trucks with two axes. Van vehicle type was used for vehicle class two in AIMSUN. All buses, trucks with more than three axes, and trailers were included vehicle class three. Bus vehicle type was used for vehicle class three in AIMSUN.

Figure 3.4. Toll plaza area (26/05/2006 – 18:01)

Figure 3.5. Kavacık intersection (Kavacık source on the left, Kavacık sink on the right, 26/05/2006 – 18:07)

Toll booth number is the number of the toll booth used in this thesis. The row “Etiler Sink” contains the number of vehicles that leave the system before entering the toll booths. Vehicles arrive to the Etiler Sink and to the toll booths from three to 20 from TEM. For the toll booths 1 and 2, the vehicles arrive from the Etiler source. The row “Kavacık Sink” contains the number of vehicles that leave the system at Kavacık interection, the row “Kavacık Through” contains the number of vehicles that continue driving on TEM and the row “Kavacık Source” contains the number of vehicles that enter TEM at Kavacık intersection.

The AIMSUN simulation software needs the number of vehicles entering the network at each source and the splitting percentages between all sections for each type of. This required data were determined by using the data given in Table 3.2.

Traffic control data involve the speed limitations and the service times of KGS and CASH toll booths. Speed limitations were taken as 30 km/h for OGS type of toll booths, which is the speed limitation applied on the toll plaza area. The service times for the study period Friday, 17:00-20:00, were collected from the field on the study area on the next Friday (03.06.2006). For every CASH toll booth service times of 42 samples and for every

KGS toll booth service times of 15 samples were collected, and they were tabled in Appendix A.

3.2.1. Input Data Analysis

The Input Analyzer module of ARENA [16] was used for input data analysis. The Input Analyzer is provided as a standard component of the Arena environment. This versatile tool can be used to determine the quality of fit of probability distribution functions to input data. It may also be used to fit specific distribution functions to a data file to allow comparing distribution functions or to display the effects of changes in parameters for the same distribution. Arena's fits are based essentially on mean squared error between the data histogram and the candidate theoretical distribution. Arena has essentially eleven theoretical distributions it considers for fitting the data. These include unbounded distributions such as gamma and Weibull, as well as bounded distributions such as beta and uniform. Arena chooses the best from these, according to its least mean square error. Parameters are generally estimated from the data by maximum likelihood.

Statistical analysis was applied for 3 data types: arrivals of the vehicles, service times of KGS toll booths, and service times of CASH toll booths.

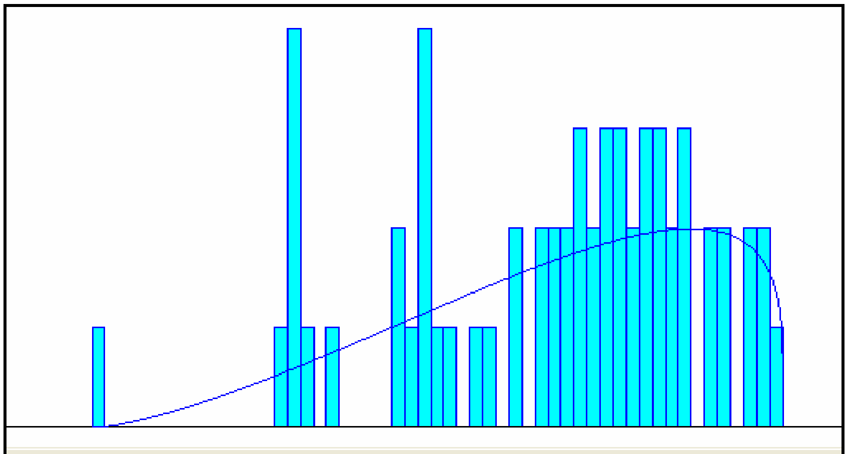
The arrival process data used for the input data analysis are the data collected between 17:00-18:00 on 26.05.2006 Friday and are given in Appendix A. These data were obtained by counting the vehicles arriving from TEM to the toll plaza. Figure 3.6 shows the result of the best fit function of ARENA. The results showed that at the 0.434 significance level we would have rejected that the arrival data are Beta with shape factors 2.46 and 1.23, a scale factor of 53 and right shifted by 116. But, arrival processes are usually assumed to have a Poisson distribution with rate λ. Hence the arrival data were tested for Poisson distribution. Figure 3.7 shows the results of the Poisson distribution curve that has been fit by ARENA. The results showed that at the 0.0279 significance level we would have rejected the hypothesis that the arrival data are Poisson with a rate of 151 veh/min.

The service time data used for the input data analysis are the data collected between 17:00-20:00 on 03.06.2006 Friday and is given in Appendix A. The exponential, Weibull, gamma, lognormal, and truncated normal distributions have all been used as models of service times in different situations.

The mean and standard deviation of service times for KGS toll booths are 3.77 sec and 2.18 sec, respectively. Figure 3.8 shows the result of the best fit function of ARENA. At a significance level of less than 0.005, we would reject that the KGS service time data are Erlang with a rate of 1.39, a shape factor of 2, and right shifted by 0.999. Table 3.3 shows the corresponding p-values and square error values for all distributions fitted by ARENA. We would reject the hypothesis that the KGS service data are any of these distributions at a significance level lower than 0.005.

Table 3.2. Hourly traffic flow data for 26.05.2006 Friday between 17:00-20:00

26.05.2006 Friday Traffic Flow Data										
		Vehicle Class 1			**Vehicle Class 2**			**Vehicle Class 3**		
		17:00-18:00	**18:00-19:00**	**19:00-20:00**	**17:00-18:00**	**18:00-19:00**	**19:00-20:00**	**17:00-18:00**	**18:00-19:00**	**19:00-20:00**
TEM		7061	7107	6754	1810	1822	1634	181	175	160
Etiler Sink		643	746	500	255	293	90	0	0	0
Etiler Source		918	804	730	106	206	92	0	0	0
Kavacık Sink		2183	1882	1735	345	432	503	95	112	111
Kavacık Through		4258	3205	4420	1177	822	1128	101	48	56
Kavacık Source		723	1157	663	93	143	15	115	110	108
Toll Booth Type	**Toll Booth Number**	**Arrival Volume**								
		Vehicle Class 1			**Vehicle Class 2**			**Vehicle Class 3**		
OGS	20	733	639	579	77	75	94	0	0	1
	19	1009	880	798	211	205	257	0	0	1
	18	586	511	463	109	106	133	2	2	3
	17	791	690	625	132	128	160	13	12	20
	16	1068	932	844	236	229	286	26	25	38
	4	224	295	503	190	230	182	100	96	31
	1	644	635	580	74	162	73	0	0	0
KGS	15	143	187	145	28	28	25	2	2	13
	14	141	184	143	38	38	34	1	1	6
	13	145	190	147	26	26	24	1	1	6
	12	157	206	159	42	42	38	2	2	13
	5	48	48	57	23	17	11	8	8	3
CASH	11	167	211	223	56	74	55	4	3	5
	10	183	232	245	55	73	54	5	5	8
	9	198	251	265	60	79	58	1	1	1
	8	218	275	291	43	57	42	0	0	0
	7	198	251	265	44	58	43	2	2	3
	6	188	237	251	31	41	30	4	3	5
	3	221	140	250	152	21	19	12	11	4
	2	274	169	150	32	44	19	0	0	0

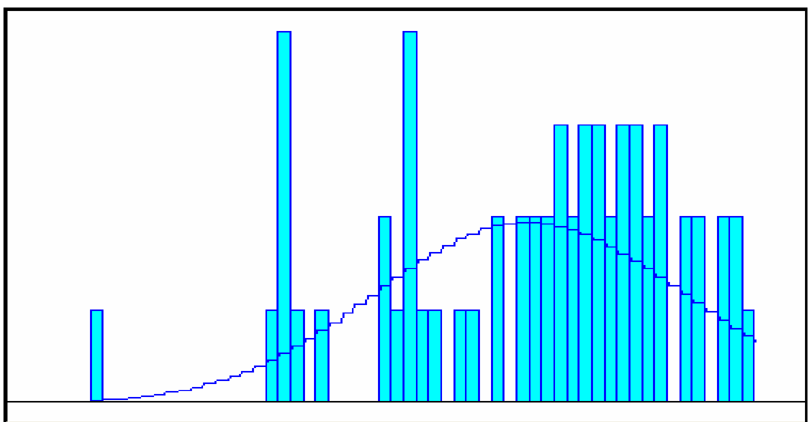


```
        Distribution Summary

Distribution:   Beta
Expression:     116 + 53 * BETA(2.46, 1.23)
Square Error:   0.013668

Chi Square Test
  Number of intervals   = 8
  Degrees of freedom    = 5
  Test Statistic        = 4.95
  Corresponding p-value = 0.434
```

Figure 3.6. ARENA screenshot for best fit test of the arrival data



```
        Distribution Summary

Distribution:   Poisson
Expression:     POIS(151)
Square Error:   0.015559

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 5
  Test Statistic        = 12.6
  Corresponding p-value = 0.0279
```

Figure 3.7. ARENA screenshot for Poisson fit test of the arrival data

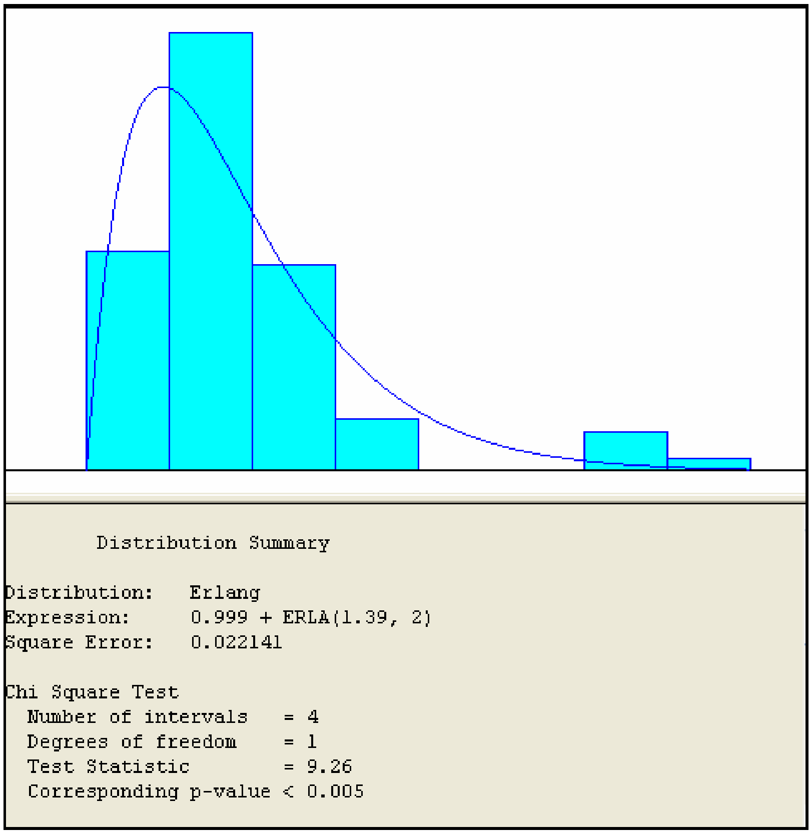


Figure 3.8. ARENA screenshots for fit test of the KGS service time data

Table 3.3. P-values and square error values of different distributions for KGS service time data

Distribution Funciton	p-value	Sq. Error
Erlang	< 0.005	0.0221
Gamma	< 0.005	0.0358
Weibull	< 0.005	0.0370
Normal	< 0.005	0.0524
Beta	< 0.005	0.0601
Lognormal	< 0.005	0.0885
Exponential	< 0.005	0.0903
Triangular	< 0.005	0.1105
Uniform	< 0.005	0.1820

The mean and standard deviation of service times for CASH toll booths are 5.41 sec and 3.54 sec, respectively. Figure 3.9 shows the result of the best fit function of ARENA. The results showed that at the 0.0435 significance level we would have rejected that the CASH service time data are Beta with shape factors 1.01 and 2.77, a scale factor of 17 and right shifted by 1. Table 3.4 shows the corresponding p-values and square error values for all distributions fitted by ARENA.

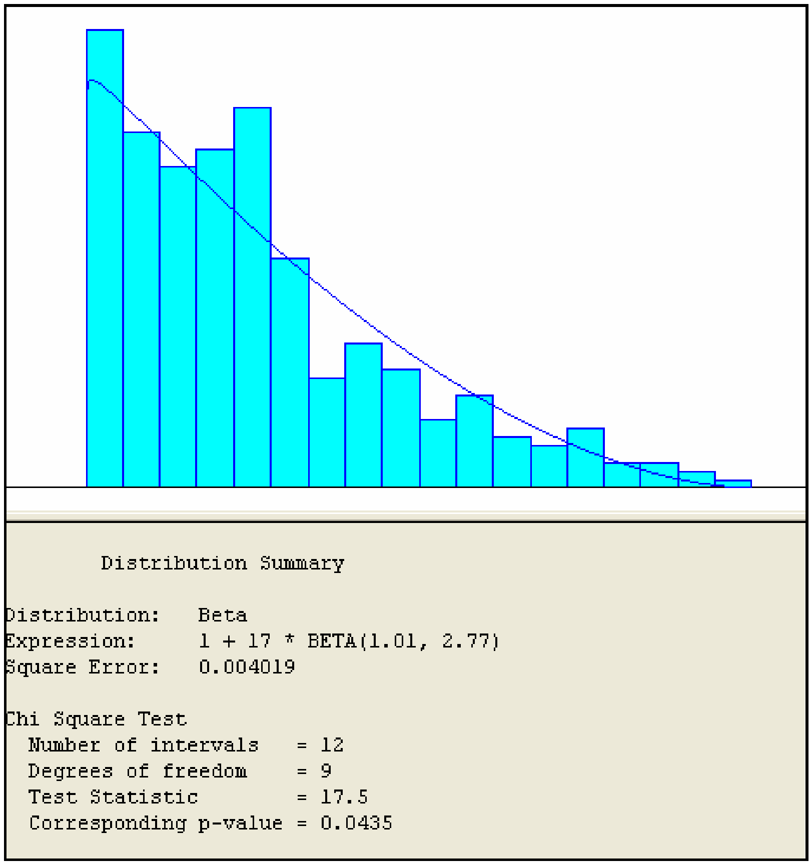


Figure 3.9. ARENA screenshot for best fit test of the CASH service time data

Table 3.4. P-values and square error values of different distributions for CASH service time data

Distribution Funciton	p-value	Sq. Error
Beta	0.0435	0.00402
Weibull	0.041	0.00418
Gamma	0.0616	0.00481
Erlang	0.0132	0.00587
Exponential	0.0216	0.00587
Lognormal	< 0.005	0.01190
Triangular	< 0.005	0.01400
Normal	< 0.005	0.02070
Uniform	< 0.005	0.04590

3.3. Base Model Development

Before coding the model in AIMSUN, the Link-Node diagram of the network model was drawn as shown in Figure 3.11. The boxes are the entries and exits of the system. The arrows are the links of the networks of different lengths and lane numbers. The circles are the nodes where the links are connected to each other.

Figure 3.12 shows the AIMSUN microsimulation software screen. The 1/5000 scaled satellite picture of the toll plaza area was placed as the background. The links and nodes were coded based on that satellite picture.

3.3.1. Coding of the Links

A link is a group of contiguous lanes where vehicles move in the same direction. The partition of the traffic network into links is governed by the physical boundaries of the area and the existing splitting movements. Entrance, exit, and right and left sides are defined according to the vehicles' movements as shown in Figure 3.10.

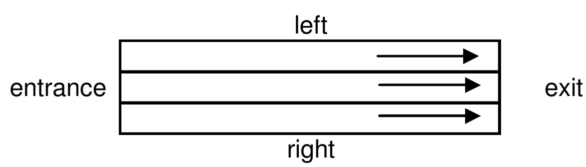


Figure 3.10. Drawing of a three-lane link

This process involves coding of the network described in the Link-Node diagram into AIMSUN. In Figure 3.13 it is portrayed how the links before the toll plaza were coded by referencing the satellite picture. The links were created systematically in the direction of the flow. The links were coded with a logical lane increase in order that the total number of lanes is equal to the number of the toll booths. The sinks and sources were placed. The lane widths and lane numbers were observed from the field and the satellite picture.

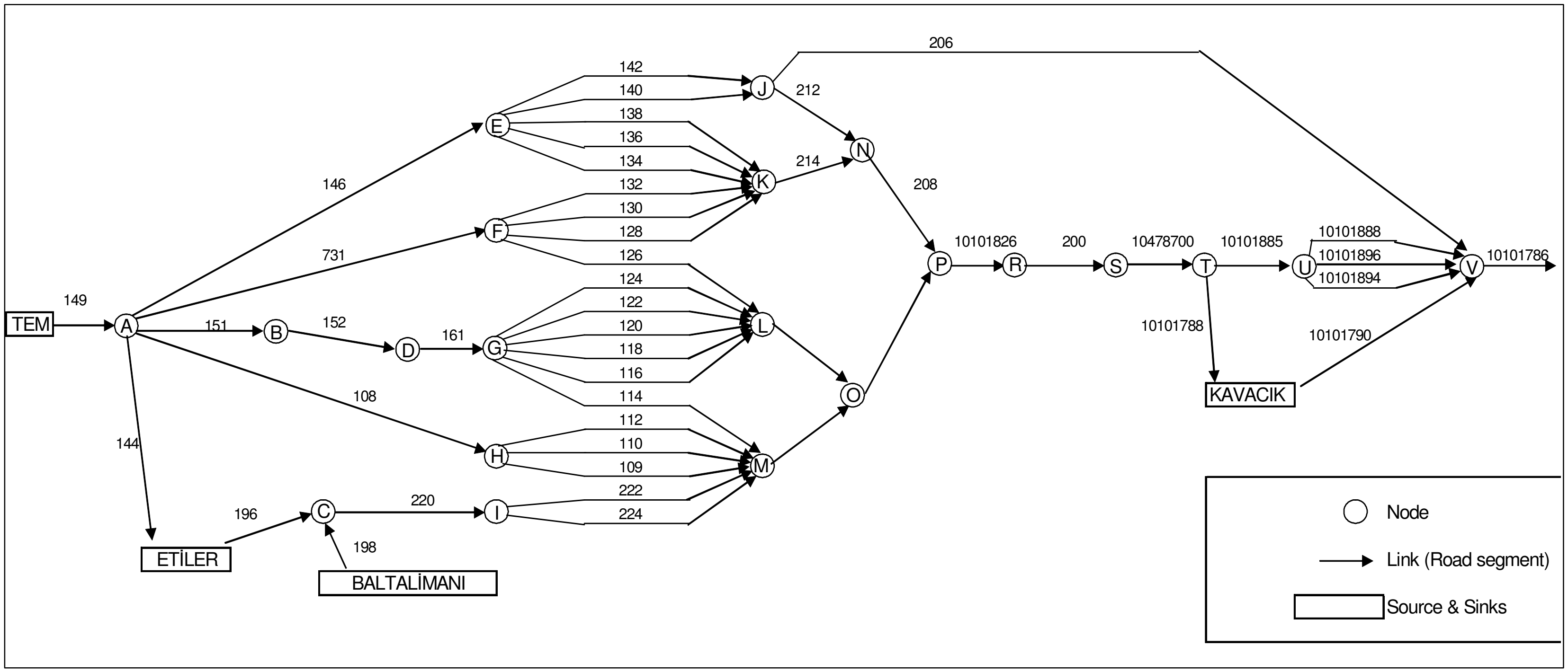


Figure 3.11. Link-Node Diagram

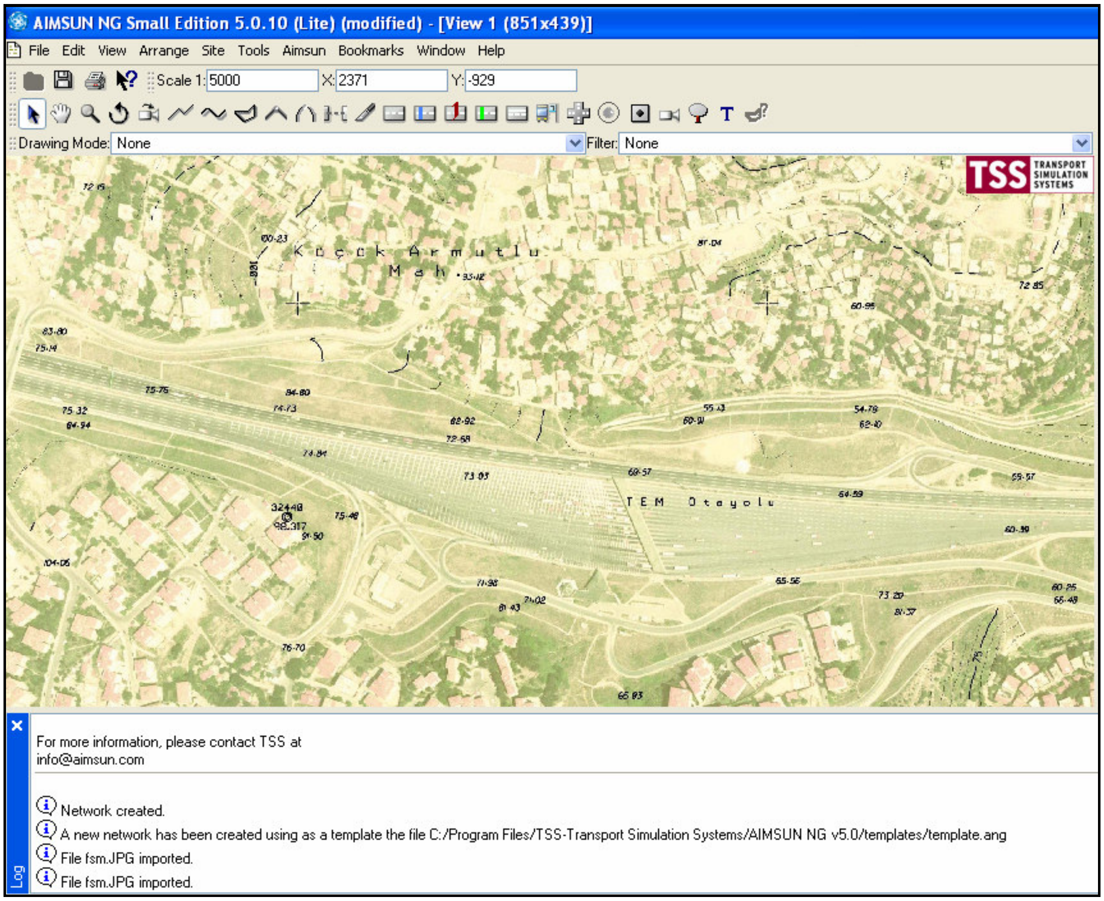


Figure 3.12. Placement of the picture of the area to the AIMSUN screen

The link 149 make up the total six lanes arriving from TEM. The link 144 is the Etiler sink from TEM. The link 194 is the Etiler source, from which vehicles enter the toll booths 1 and 2. The links 196 and 198 are the two links from which vehicles arrive to the Etiler source from Etiler and Baltalimanı, respectively. The links 146, 151, 152, 731, 161, 108, 220 are the links that were coded for the purpose to fit the network to the field conditions and to obtain logical vehicle moving where the number of lanes increase from six to eighteen.

Figure 3.14 shows coding of the toll booths. The links 142, 140, 138, 136, and 134 are the five OGS toll booths, named 20 to 16 in the thesis respectively. The links 132, 130, 128, and 126 are the four KGS toll booths, named 15 to 12 in the thesis respectively. The links 124, 122, 120, 118, 116, and 114 are the six CASH toll booths, named 11 to 6 in the thesis respectively. The links 102, 110, and 109 are respectively KGS, OGS, and CASH toll booths, named 5 to3 respectively. The last two toll booths, 222 and 224, are of CASH and OGS type, respectively, which serve to the vehicles arriving to the toll plaza from the Etiler source. They are named 2 and 1 in the thesis respectively. The speed limits entered for these links are those used in the study area, 30 km/h. In the CASH and KGS toll booths the vehicles have to stop to make the payment, whereas in the OGS toll booths the vehicles continue moving without stop. Hence, a ramp metering, the small boxes on the toll booth links, was placed on the CASH and KGS toll booths to create a delay. The coding of the delay for these ramp meterings will be explained in the "Control Plan" section.

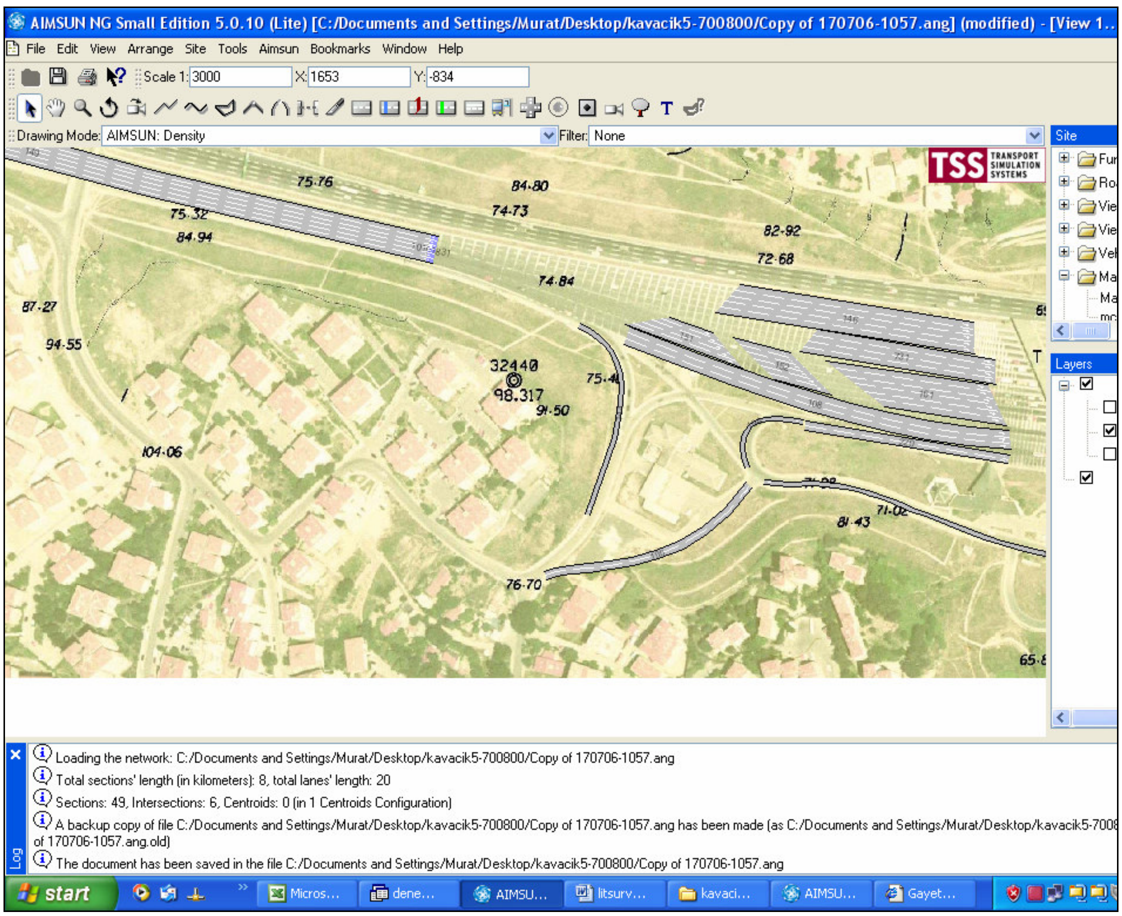


Figure 3.13. Links downstream of the toll plaza

In Figure 3.15 it is shown how the links upstream of the toll plaza were coded. The link 200 is the four lane road to the FSM Bridge. The link 206 is the reverse lane, which is on the opposite direction and is open between 16:00 and 20:00, for work days. The links 208, 212, 214, 216, 10478680, 10101848, and 10101826 are the links that were coded for the purpose to fit the network to the field conditions and to obtain logical vehicle moving where the number of lanes decreases from twenty to four.

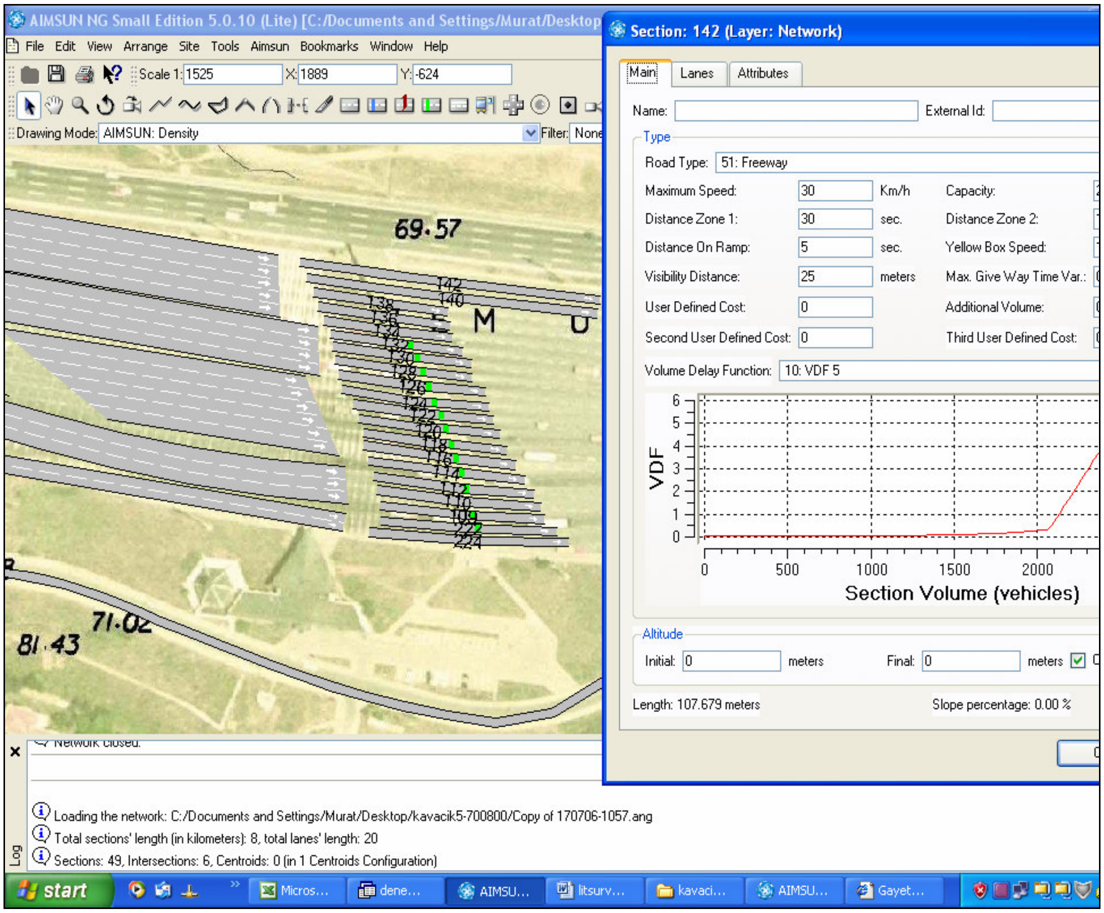


Figure 3.14. Links of the toll plaza

In the last step of coding of the links, the links of the Kavacık intersection are created as shown in Figure 3.16. The link 10101788 is the Kavacık exit where vehicles leave TEM and drive to Anadolu Hisarı and Kavacık. At the Kavacık intersection, the vehicles using the reverse lane, link 206, return back to TEM. Because of safety considerations, the first lane of TEM is closed for approximately 50 meters, allowing the vehicles coming from the reverse lane enter TEM. Among that length, the number of lanes of TEM for the vehicles coming from the bridge decreases to 3. The link 10101885 is the part of TEM between the Kavacık exit and the point where the lane number decreases to 3. The part of TEM, where the lane number is 3, was modeled by 3 single lane links (10101888, 10101894, 10101896) in order to create turnings due to lane closure, which is one of the causes of congestion after the bridge. The link 10101790 is the Kavacık source. The link 10101786 is the part of TEM after the Kavacık intersection, where the number of lanes increases back to 4.

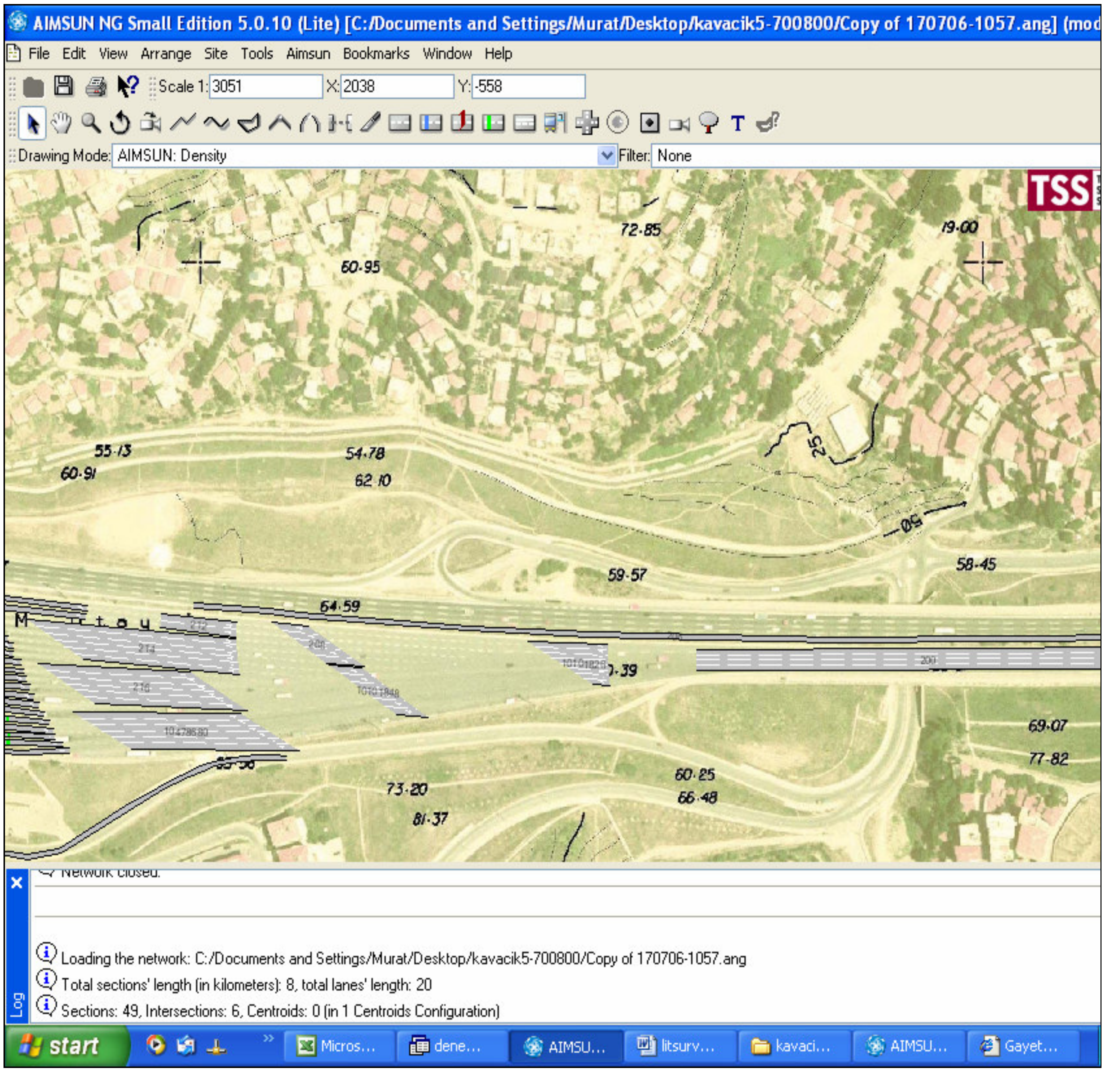


Figure 3.15. Links upstream of the toll plaza

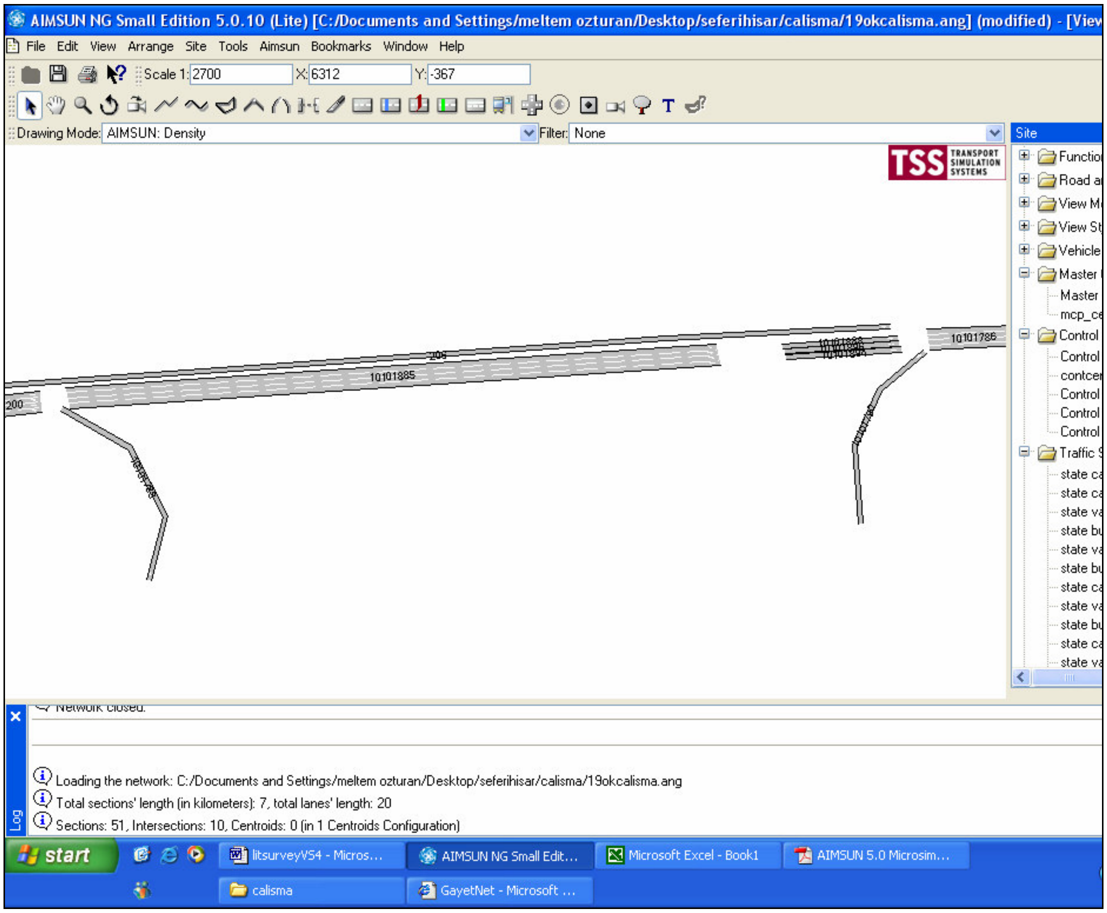


Figure 3.16. Links of the Kavacık intersection

3.3.2. Coding of the Nodes

A node is a point or an area in the network where vehicles change their direction and/or disperse. Hence, a node has one or more origin links and one or more destination links. The type of nodes used in the network of FSM Bridge was join node as shown in Figure 3.17 and Figure 3.18. In a splitting join node, vehicles move from the same origin link to two or more different destination links. In a merging join node, vehicles from two or more origin links merge to the same destination link.

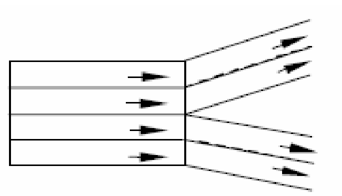


Figure 3.17. Splitting join node

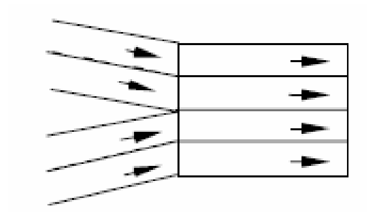


Figure 3.18. Merging join node

Possible movements of the vehicles from origin link(s) to the destination link(s) were coded with the nodes. Only for the Node 10101816, the snapshots of splitting movements between sections are shown in Figures 3.19 to Figure 3.23. The splitting movements in other nodes are only explained verbally.

• **Node 10101816:** This node is node A in the Link-Node diagram. Node 10101816 is the point where the lane numbers start to increase in the approach area. As shown in Figure 3.19, vehicles may move from the origin link 149 to 5 destination links: 108, 144, 146, 151, and 731. The 5-lane link 146 gets all the vehicles from the first 2 lanes of the 6-lane link 149 (The left most lane of a link is the first lane, and the right most lane of the link is the last one). Vehicles arrive to the 4-lane link 731 via the second lane of the link 149, as portrayed in Figure 3.20. Vehicles are allowed to move from the lanes 3, 4, and 5 of the link 149 to all lanes of the link 151, as shown in Figure 3.21. Vehicles are allowed to move from the last two lanes of the link 149 to all lanes of the link 108 as illustrated in Figure 3.22. Vehicles leaving TEM at the Etiler sink arrive to the link 144 from the last lane of the link 149, as shown in Figure 3.23.

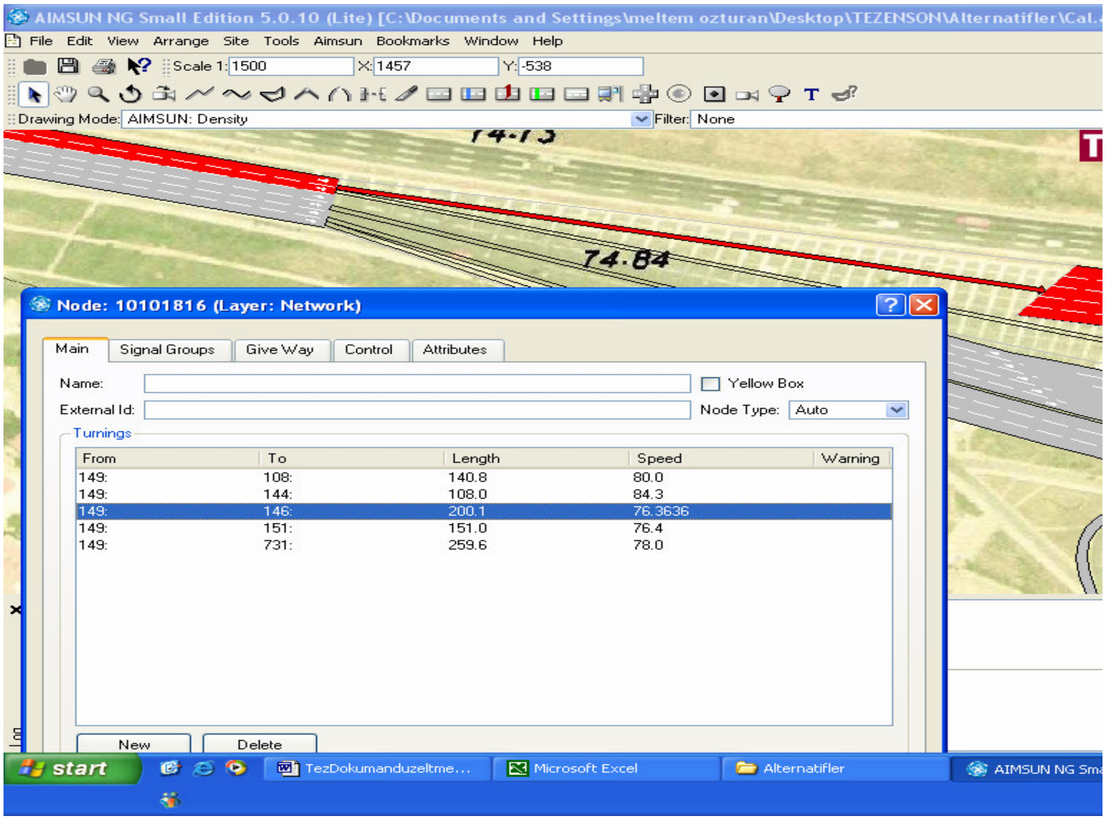


Figure 3.19. Coding of node 10101816 from link 149 to link 146

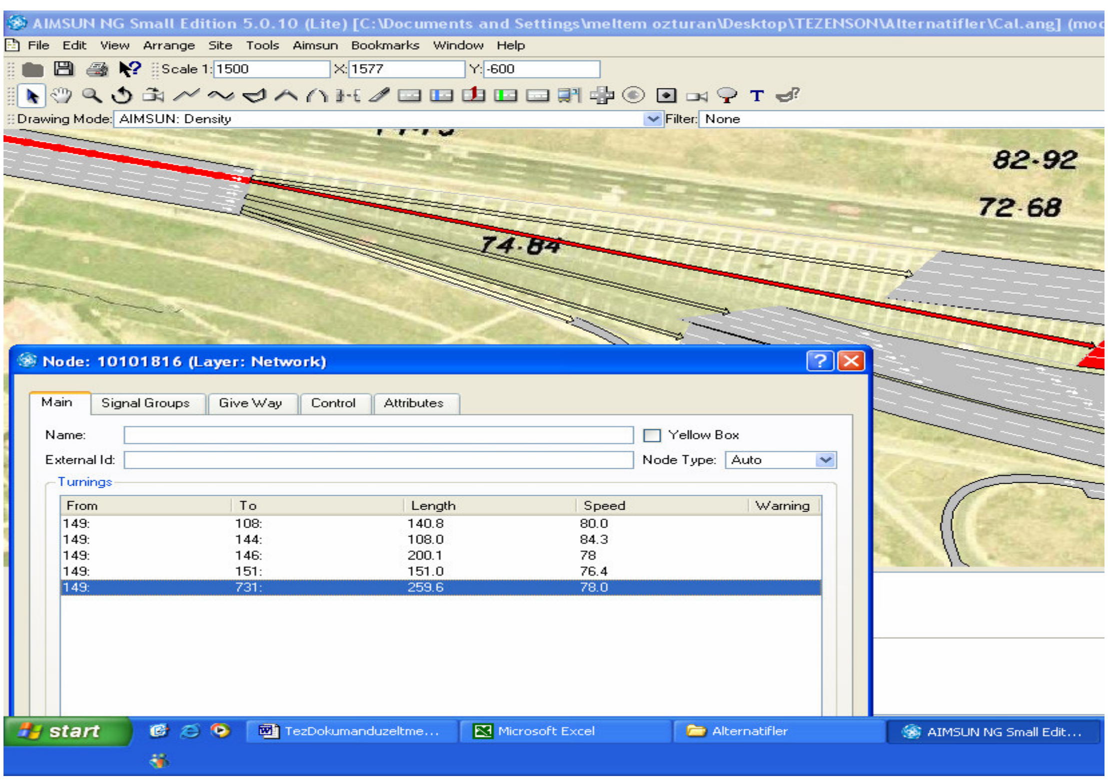


Figure 3.20. Coding of node 10101816 link 149 to link 731

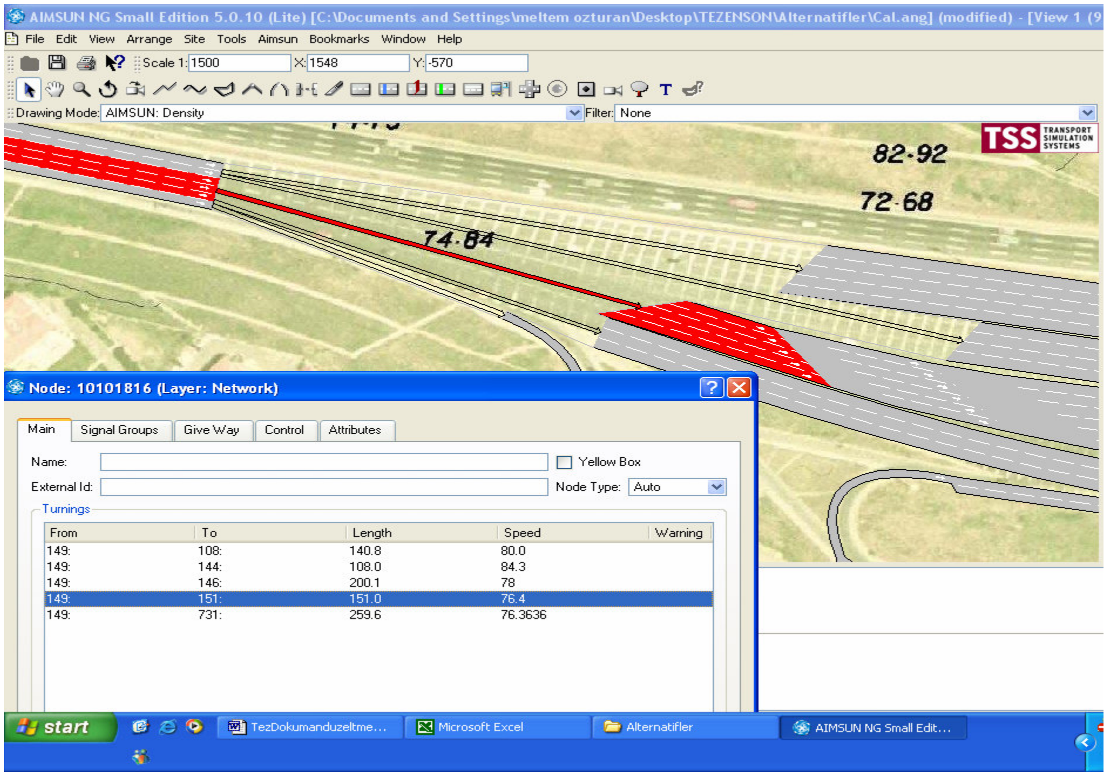


Figure 3.21. Coding of node 10101816 link 149 to link 151

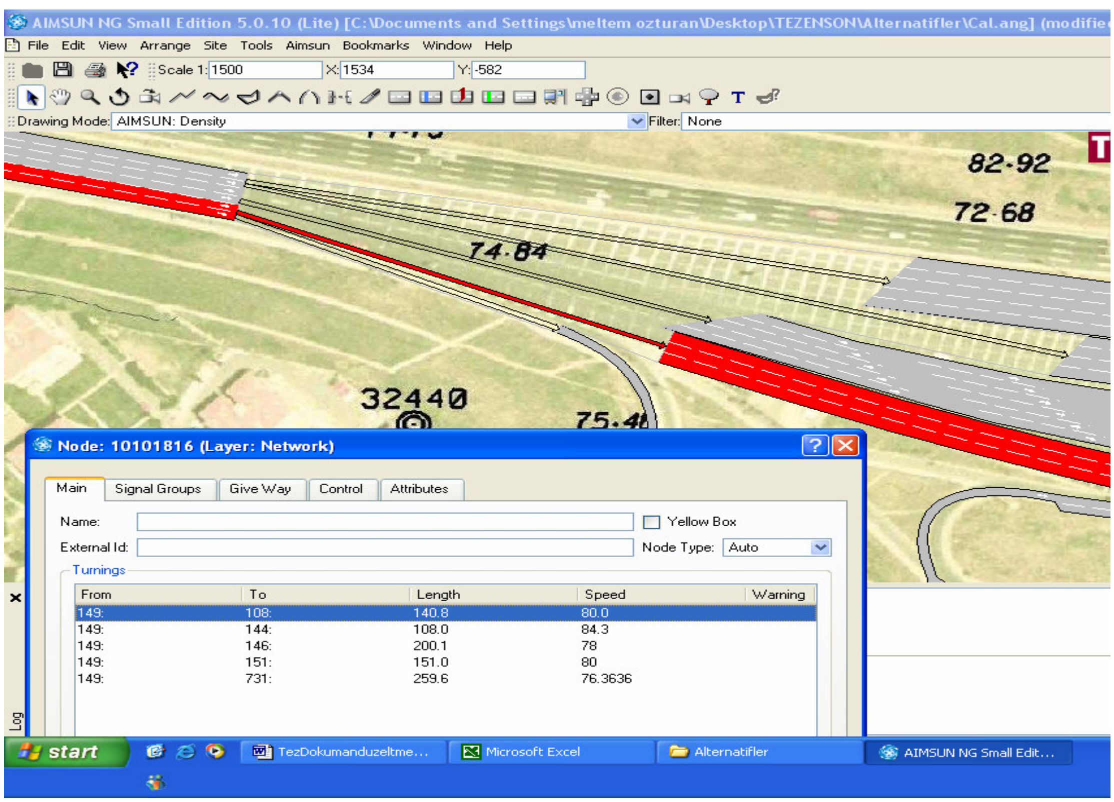


Figure 3.22. Coding of node 10101816 link 149 to link 108

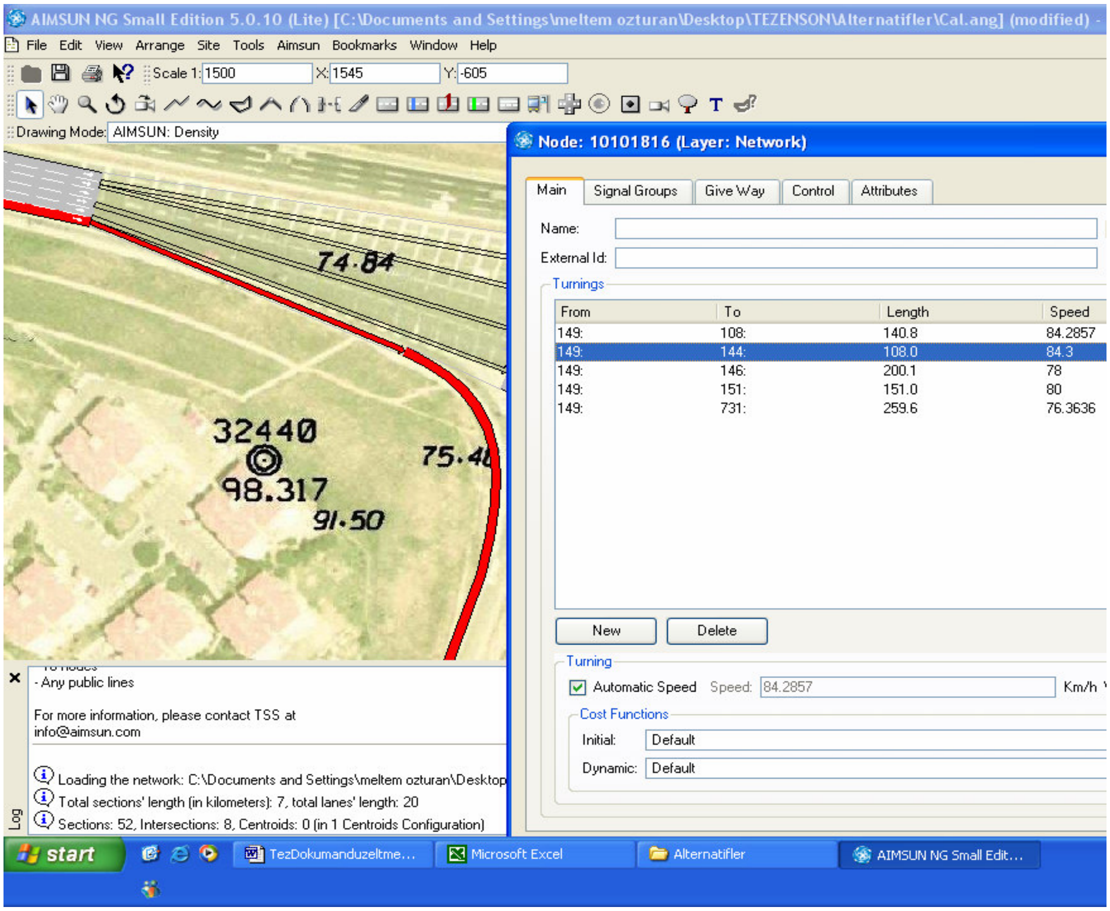


Figure 3.23. Coding of node 10101816 link 149 to link 144

• **Node 157:** Node 157 is the collection of nodes B, C, D, E, F, G, H, and I. It was created to connect the toll booths to the downstream links approaching from TEM and Etiler source. Only one lane is connected to one toll booth link. All of the vehicles entered the link 151 move to the link 161 via the link 152. The five lanes of the link 146 are connected to the five OGS toll booth links 142, 140, 138, 136, and 134. The four lanes of the link 731 are connected to the four KGS toll booth links 132, 130, 128, and 126. The six lanes of the link 161 are connected to the six CASH toll booth links 124, 122, 120, 118, 116, and 114. The three lanes of the link 108 are connected to the three toll booth links 112, 110, and 109. The two lanes of the link 220 are connected to the links 222 and 224.

The links 196 and 198 are connected to the link 194. Then the 1-lane link 194 is connected to two 2-lane link 220.

• **Node 232:** Node 232 is the collection of nodes J, K, L, and M. In node 232, the toll booth links are connected to the multilane links upstream of the toll plaza. Vehicles coming from the links 142 and 140 can move to the reverse lane, link 206, or to the 2-lane link 212. The links 138, 136, 134, 132, 130, and 128 are connected to the 6-lane link 214. Vehicles may flow from the links 138 and 136 to the first and second lanes of the link 214, respectively. Vehicles coming from the link 134 may flow to the third lane of the link 214, whereas vehicles arriving from the link 132 flow to the fourth lane of the link 214. In the last two connections to the link 214, vehicles arriving from the links 130 and 128 move to the fifth and sixth lanes of the link 214, respectively The 6-lane link 216 collects the vehicles arriving from the links 126, 124, 122, 120, 118, and 116. The links 126 and 124 are connected to the first and second lanes of the link 216, respectively. Vehicles coming from the links 122 and 120 may move to the third and fourth lanes of the link 216, respectively. Vehicles passing from the links 118 and 116 may move to the fifth and sixth lanes of the link 216, respectively. The vehicles passing the last six toll booth lanes are connected to the link 10478680. The links 114 and 112 are connected to the first and second lanes of the link 10478680, respectively. The link 110 is connected to the fourth and fifth lanes of the link 10478680. Link 109 is connected to the third and fourth lanes of the link 10478680. The link 222 is connected to the second and third lanes of the link 10478680. Finally, the link 224 is connected to the last two lanes of the link 10478680.

• **Node 256:** Node 256 is the collection of nodes N, O, P, and R. Node 256 is the location in the network where the links 212 and 214, and 216 and 10478680 merge. The link 212 is connected to the first two lanes of the link 208. Vehicles arriving from the link 214 may move to all of the lanes of the link 208. Vehicles may move from the link 216 to the first three lanes of the link 10101848, whereas the vehicles passing the link 10478680 may move to the last three lanes of the link 10101848.

• **Node 10478718:** The node 10478718 was coded to avoid the 20 km total lane length limitation of the limited student version of AIMSUN. If the section between the start of the Fatih Sultan Mehmet Bridge and Kavacık sink had been coded using a link with 4 lanes, the total lane length was going to acced the limitation, 20 km. Hence this link was coded using a node of the same length and width. The node is connected to link 10478700 before Kavacık sink.

• **Node 10478702:** In this node, vehicles coming from the FSM Bridge exit TEM using the Kavacık sink or continue driving on TEM. Vehicles may enter the Kavacık exit from the first lane of TEM.

• **Node 10101794:** In node 10101794, the number of lanes of TEM decrease from 4 to 3 because of the connection of the reverse lane to TEM. Vehicles from the last to lanes of the link 10101885 may enter the link 10101888. Vehicles may enter the link 10101896 from the third and fourth lanes of the link 10101885. Vehicles from the first to lanes of the link 10101885 may enter the link 10101894.

Vehicles coming from the reverse lane, link 10478695, may enter the last lane of the link 10101786, the four lane part of TEM after Kavacık intersection. Vehicles coming from the link 10101888 enter the last lane of the link 10101786. Vehicles coming from the link 10101896 enter the second and third lane of the link 10101786. Finally, the vehicles coming from the link 10101894 and the Kavacık source, link 10101786, enter the first lane of link 10101786.

3.3.3. Coding of the Service Times

In the model, the toll booths were represented by ramp metering. For each toll booth, except the OGS types, ramp metering was coded. Each toll booth was given a name, which is the number of the toll booth used in the thesis. For example, the first toll booth, which is a CASH toll booth, was named as 2 as shown in Figure 3.24. The type of ramp metering was chosen as delay, which caused the vehicle to stop and wait for a while (service time) at the toll booth. Then the mean and standard deviation were entered for the ramp metering as presented in Figure 3.24. The mean of the CASH toll booth service time is 5,41 seconds and the standard deviation is 3,54 seconds whereas the mean of the KGS toll booth service time is 3,77 seconds and the standard deviation is 2,18 seconds. No ramp metering was placed on the OGS toll booth links. Instead, speed limitations observed from the field were applied to those links, 30 km/h.

As default, AIMSUN assigns normal distribution for the service time distribution of the toll booths. To assign a different distribution for the service times, the function of the distribution had to be coded using C++ language into AIMSUN network. The AIMSUN limited student version used in the thesis did not allow coding and scripting. Hence, normal distribution was used for the service time distribution for both CASH and KGS toll booths. With the entered mean and standard deviation for the delay, AIMSUN assigned service times to the toll booths with truncated normal distribution and the range of the truncated normal distribution was [μ-δ, μ+δ]

As mentioned in the *Input Data Analysis* section, the result of the ARENA input analyzer for the distribution of the KGS service time data was Erlang distribution with a rate of 1.39, a shape factor of 2, and right shifted by 0.999. Instead the Erlang distribution, truncated normal distribution with the range [1.59, 5.95] was used. To see the differences, two data samples of 2473 data for each were created using ARENA for both Erlang and normal distributions with the parameters explained above. Obtained differences were as follows;

- The truncated normal distribution did not produce values less than 1.59 sec, which is μ-δ and greater than 5.95 sec, which is μ+δ.
- On average, 0.04 sec more service time delay was experienced per vehicle.

For the service times of the CASH toll booths, the result of the best fit function of ARENA input analyzer for the distribution of the CASH toll booth service time data was Beta distribution with shape factors 1.01 and 2.77, a scale factor of 17 and right shifted by 1. Instead the Beta distribution, truncated normal distribution with the range [1.87, 8.95] was used. To see the differences, two data samples of 8213 data for each were created using ARENA for both Beta and normal distributions with the parameters explained above. Obtained differences were as follows;

- The truncated normal distribution did not produce values less than 1.87 sec, which is μ-δ and greater than 8.95 sec, which is μ+δ.
- On average, 0.21 sec less service time delay was experienced per vehicle.

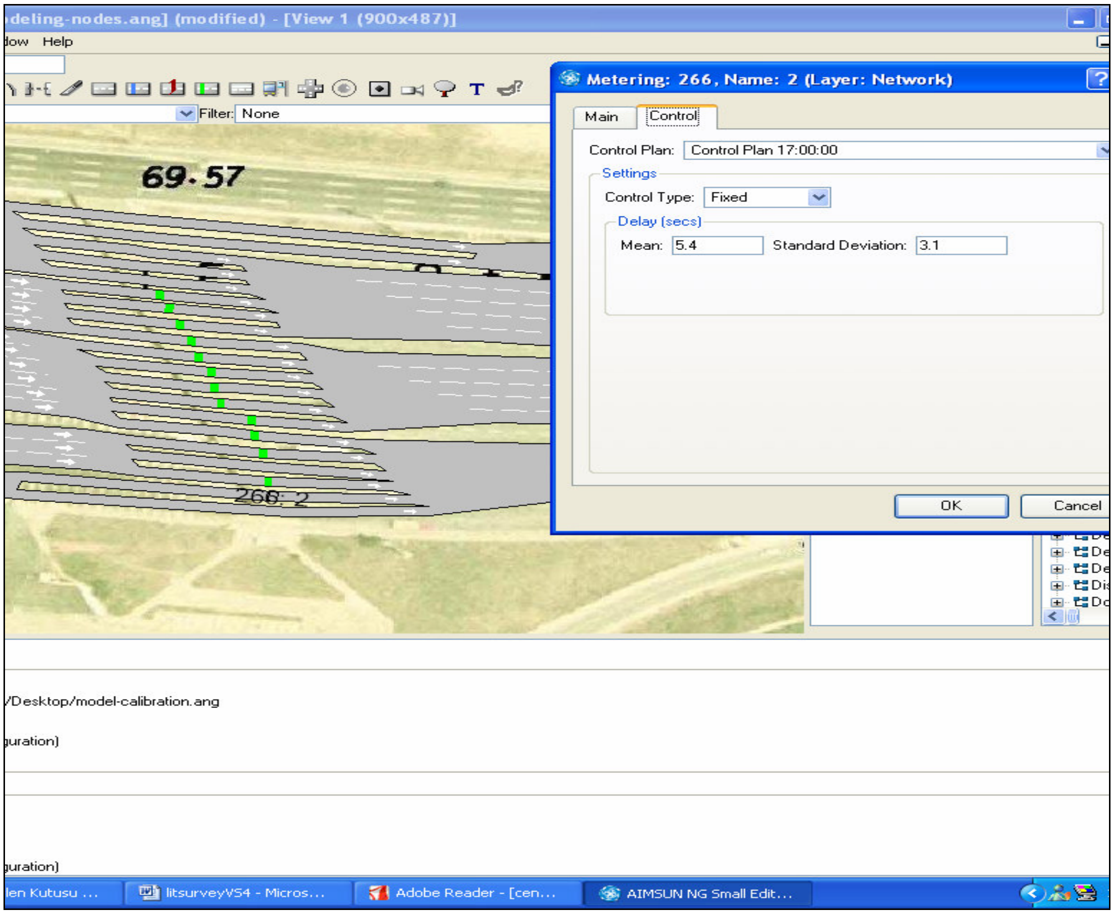


Figure 3.24. Coding of the service times

3.3.4. Coding of the Detectors

Detectors were used to collect vehicle count data from several points of the links. To the exit of each toll booth, a detector with the toll booth number was placed. Figure 3.25 shows the detector placed on the OGS toll booth number 20. All the data collected from the detectors was used in the calibration and alternative analysis steps.

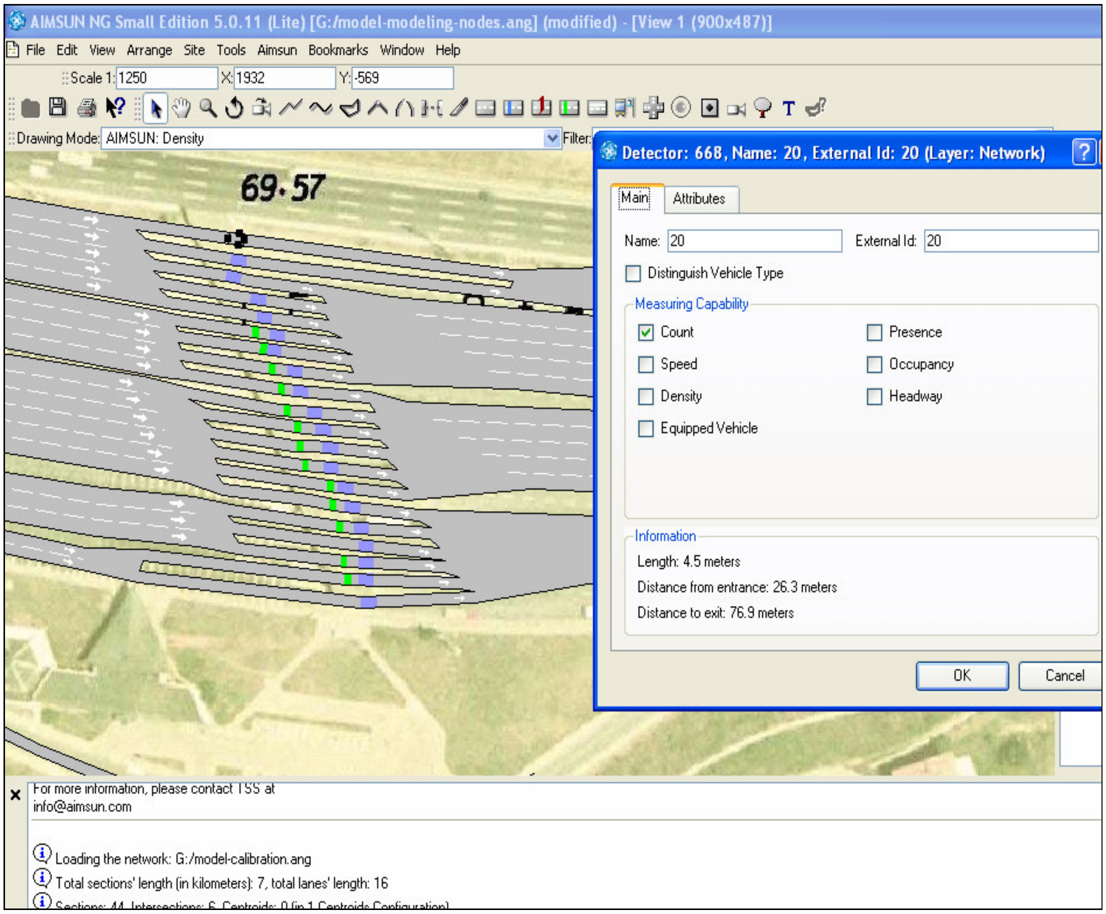


Figure 3.25. Coding of the detectors

3.3.5. Coding of the Traffic Demand Data

First step of coding of the demand data involves creating hourly traffic states according to vehicle types which make up together the traffic flow, as shown in Figure 3.26 and Figure 3.27. The coding of the traffic state for the vehicle type "car" between 17:00-18:00 is explained in this chapter.

First the vehicle type was selected, than the initial time and duration of the traffic state were entered in the "Input Flow" screen. Then the number of vehicles entering from each source was entered to the corresponding row at the flow column. Table 3.2 shows the number of vehicles arriving from TEM, Etiler source (Etiler and Baltalimanı), and Kavacık, which are 7061, 459, 459, and 723 , respectively. The vehicles entering from the Etiler source were assumed to arrive equally from Etiler and Baltalimanı.

After entering the input flows from the sources, the distribution of the arrival data was selected. Instead of assigning a distribution function for the arrival pattern of vehicles, AIMSUN assigns distribution functions for the interarrival times of the vehicles. The interarrival times of a Poisson process are exponential random variables. Hence, exponential distribution for the interarrival times was selected and a Poisson process for the arrival pattern of the vehicles was obtained. The flows entered in the "Input Flow" screen are taken as λ by AIMSUN and then the interarrival times are distributed exponentially with mean 1/λ.

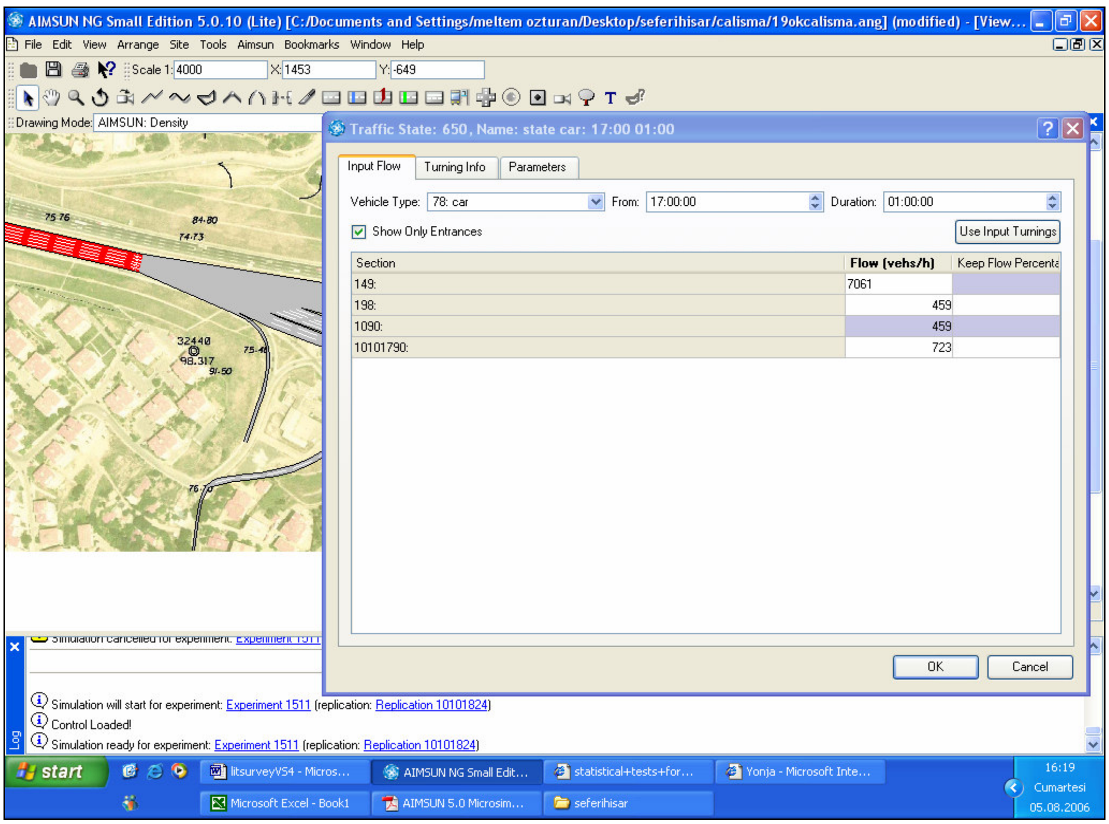


Figure 3.26. Coding of the traffic demand

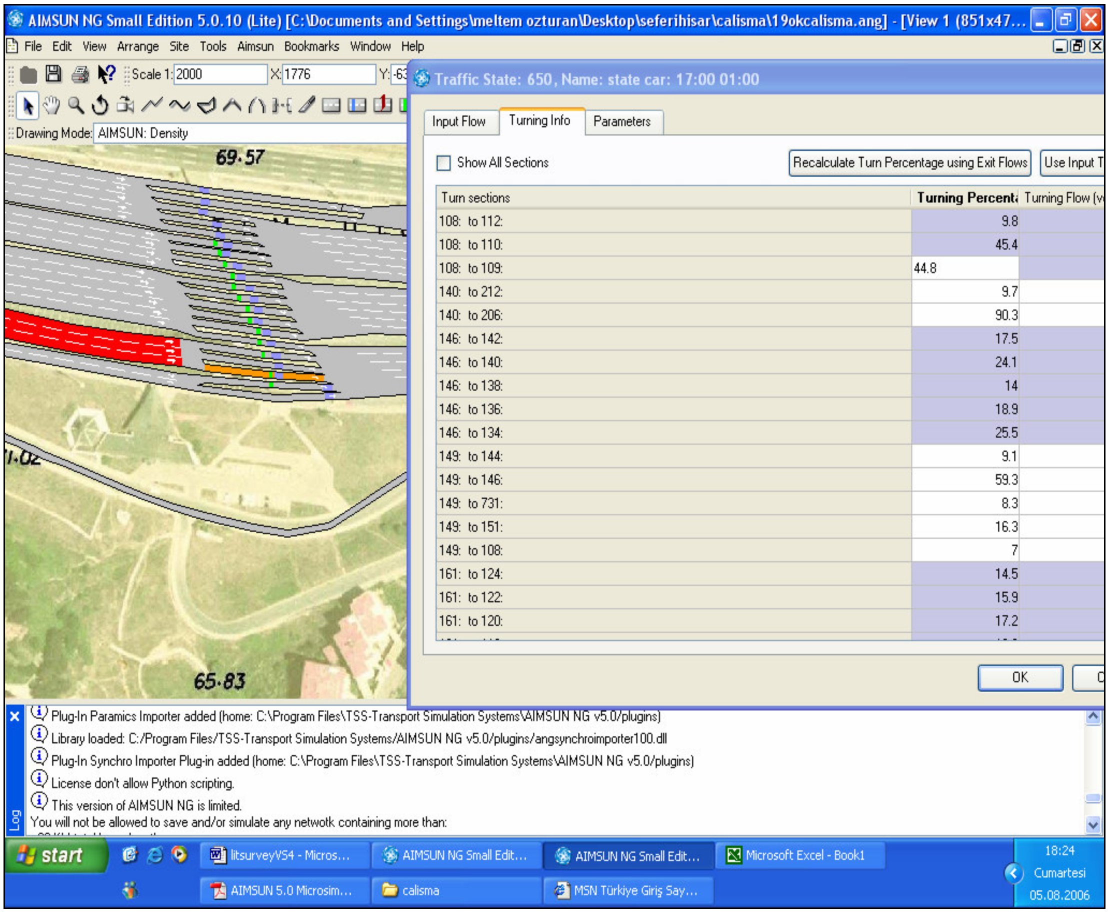


Figure 3.27. Coding of the splitting percentages

Figure 3.28 shows the vehicle arrival flows at the system entries, vehicle departure flows at the system exits, and splitting flows. Figure 3.29 shows the splitting percentages between sections. Table 3.5 summarizes the flows and percentages for vehicle class 1 between 17:00-18:00. The same data for other vehicle types and study hours are given in Appendix A.

The calculation of the splitting percentage is explained for the link 108 as an example. The splitting movements from the link 108 are the arrivals to the toll booths 3 to 5, which are links 109, 110, and 112, respectively. Total arrival number to the link 108 (494 veh/h) is the sum of the arrivals to the links 109, 110, and 112 (221 veh/h, 224 veh/h, 48 veh/h, respectively). The splitting percentages are calculated by dividing the arrival number to the links 109, 110, and 112 by the arrival number to the link 108. All of the remaining splitting percentages are calculated with the same logic.

Table 3.5. Car splitting percentages & flows between 17:00 – 18:00

17:00-18:00 Vehicle Class 1		
Turn Sections	**Percentage (%)**	**Flow (veh)**
108 to 112	9.8	48
108 to 110	45.4	224
108 to 109	44.8	221
140 to 212	10.0	X
140 to 206	90.0	
146 to 142	17.5	733
146 to 140	24.1	1009
146 to 138	14.0	586
146 to 136	18.9	791
146 to 134	25.5	1068
149 to 144	9.1	643
149 to 146	59.3	4187
149 to 731	8.3	586
149 to 151	16.3	1151
149 to 108	7.0	494
161 to 124	14.5	167
161 to 122	15.9	183
161 to 120	17.2	198
161 to 118	18.9	218
161 to 116	17.2	198
161 to 114	16.3	188
220 to 222	29.8	274
220 to 224	70.2	644
731 to 132	24.4	143
731 to 130	24.0	141
731 to 128	24.8	145
731 to 126	26.8	157
10101885 to 10101894	25.0	X
10101885 to 10101896	45.0	
10101885 to 10101888	30.0	
10478700 to 10101788	33.9	2183
10478700 to 10101885	66.1	4258
10478707 to 206	100.0	X
10478707 to 212	0.0	
X : Not counted for the full hour period! Percentages are estimated based on a sample of 100 vehicles.		

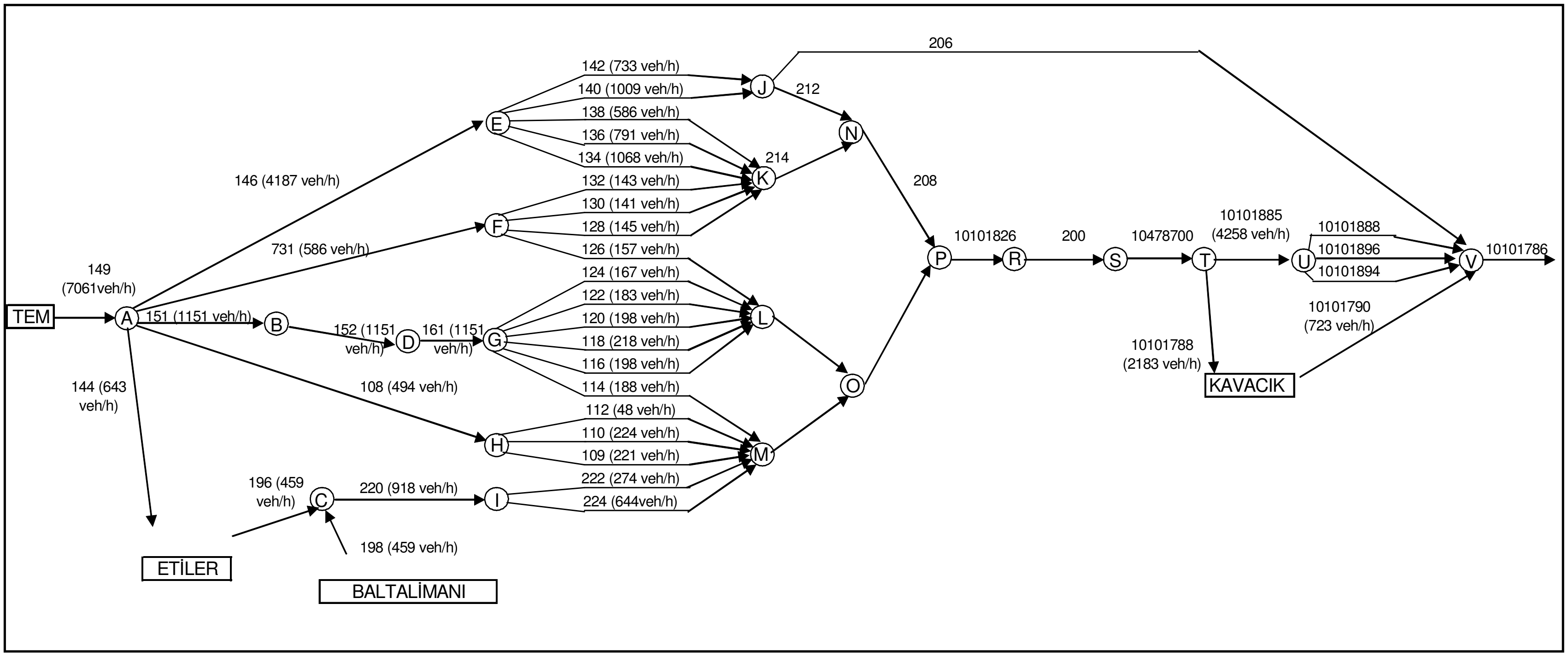


Figure 3.28. Splitting flows

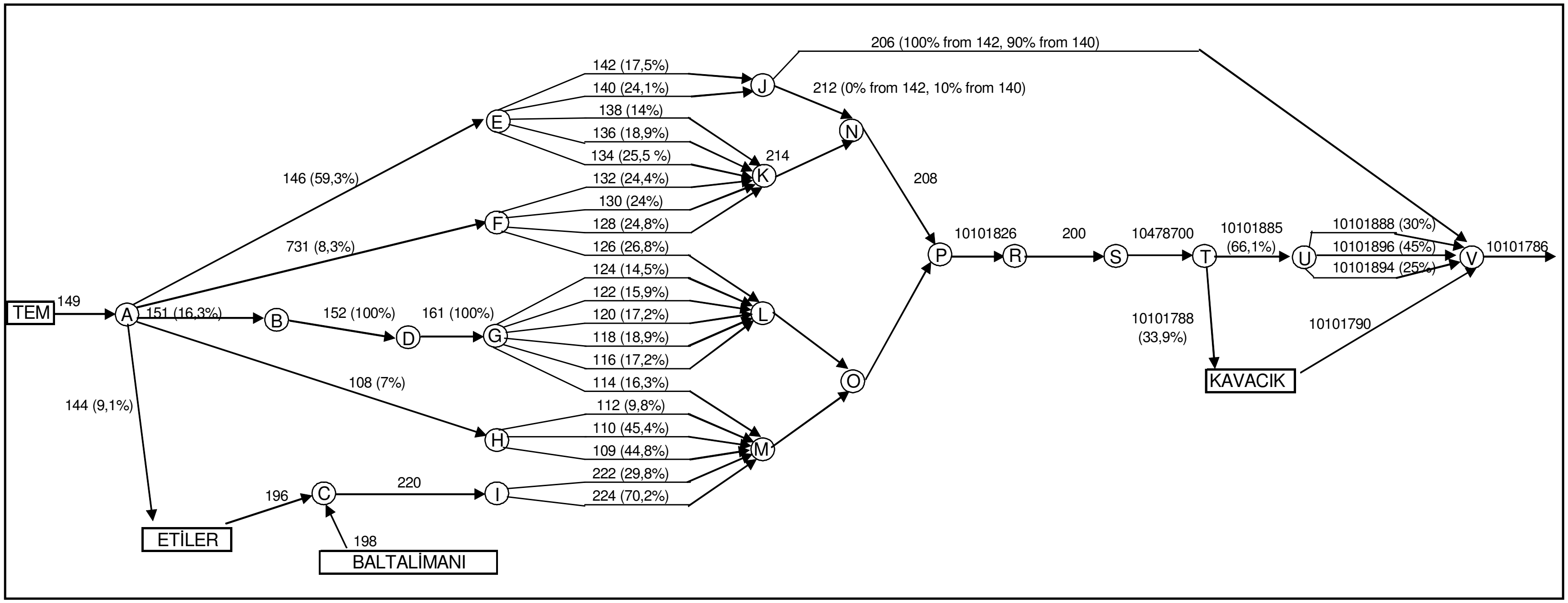


Figure 3.29. Splitting percentages

3.4. Error Checking

After the network has been created, the "Check and Fix Network" option of AIMSUN was run. This function checks whether there are any logical errors in the network. Possible errors might be that a section has no Road Type, that there is more than one metering per section, or that not all the lanes at the beginning or at the end of the section are connected. No error was found by AIMSUN.

The network was checked for expected queuing and vehicle movements. Although expected queuing occurred behind the CASH toll booths, no congestion occurred at OGS toll booths because congestion after the toll plaza could not be created. To make the model behave as real life system, the section in Kavacık, where the number of lanes of TEM is decreased to 3 because of the entry of the reverse lane, was modeled as three single lane sections instead of one three-lane section. The splitting percentages from TEM to these lanes were changed until the expected queuing has occurred. The splitting percentages are given in the Turning Percentages tables in Appendix A.

3.5. Validation of the Model

The validation of a model ensures the model created accurately represents reality. In this study, total plaza throughput and total number of vehicles passing one payment type between 17:00-20:00 were used to calibrate the base model. For the purpose of obtaining the initial conditions, which were the queues before the toll plaza and congestion after the toll plaza, one hour warm-up period was used and model was run between 16:00-17:00 with fictitious data. These data were created based on the toll plaza throughput between 16:00-17:00. Fictitious turning percentages were created to obtain the initial conditions.

For the calibration, the real life data obtained from GDH were used. During the calibration process the toll booth throughputs were observed under the effect of changed simulation parameters. Main parameter groups considered were vehicle attributes, section parameters and global network parameters.

Vehicle attributes are length, width, maximum desired speed, maximum acceleration, normal and maximum deceleration, speed acceptance, minimum distance between vehicles, and maximum give-way time for each vehicle type. It is possible to define not only mean values for the attributes of each vehicle type, but also the deviation, minimum and maximum values. The default values for the vehicle parameters of AIMSUN were used for the calibration process.

Section parameters are section speed limitations, turning speeds, visibility, yellow box speeds, distance zones, and capacity. They are applied locally to the vehicles when they are driving along a section, but may change when a vehicle enters a new section. For the calibration process, speed limitation restrictions were entered for the sections ranging from 30 km/h to 120 km/h depending on the section location and characteristics whereas other parameters of the sections were left unchanged.

Global parameters which are valid throughout the whole network are used for all vehicles driving anywhere in the network during the entire simulation experiment. These include:

Simulation Step: It is the system updating time interval. At every simulation step, the states of all the elements of the system are updated. It may range between 0.1 and 1.0 seconds. In the calibration process, simulation steps of 0.1 sec and 0.2 sec were used. Small simulation step times were used since the smaller the simulation step the higher the capacity values of the links are, because the drivers with smaller reaction times are more skilful. They can drive closer to the preceding vehicles, find gaps more easily, and accelerate earlier.

- Driver's Reaction Time: This is the time it takes a driver to react to speed changes in the preceding vehicle. It is used in the car-following model and for implementation reasons it is also taken same as the simulation time step.
- Reaction Time at Stop: This is the time it takes for a stopped vehicle to react to acceleration of the vehicle in front, or to a traffic light changing to green, or the light changing at the CASH and KGS toll booths from red to green. In this thesis, for the reaction time at stop values between 0.5, 0.6, 0.7, 0.8, 0.9, and 1.0 sec were used for calibration process [5].

The aim of the calibration process was to find the parameter values for which the model is considered to be valid. For that purpose, the simulation output values for the total toll plaza throughput value and for the total toll booth throughput values for each toll booth type were noted and they were expected to be consistent with the real life values obtained from GDH reports, which are 16538 vehicles for OGS toll booths, 2488 vehicles for KGS toll booths, 7459 vehicles for CASH toll booths, and 26485 vehicles for the total toll plaza.

In order to determine the required number of replications for each experiment, a t-test based incremental approach explained below, was used [19].

1.Initially, the model is simulated for $m \geq 2$ runs and initial estimates $\overline{X}(m)$ and $S^2(m)$ are calculated.

2.The percentage error is calculated between $\overline{X}(m)$ and the real throughput value,

$$\varepsilon = \left| \overline{X}(m) - \mu \right| / \left| \mu \right| \tag{3.4}$$

3.The adjusted percentage error is calculated,

$$\varepsilon' = \varepsilon / (1+ \varepsilon) \tag{3.5}$$

4.The model is run for one more replication and new $\overline{X}(n)$ and $S^2(n)$, where $n = m+1$, is calculated.

5.The desired level of significance α is decided.

6.The half-length of the confidence interval is calculated,

$$\delta(n,\alpha) = t_{n-1,1-\alpha/2} \, (S^2(n)/n)^{1/2} \tag{3.6}$$

7.if $\delta(n,\alpha) / \left| \overline{X}(n) \right| \leq \varepsilon'$, then $\overline{X}(n)$ can be used as an unbiased point estimate for μ, else one more replication must be run and the procedure must be repeated from the 5th step.

The results of this approach, as given in Table 3.6, have shown that 5 replications were satisfactory for 5% error and 0.05 significance level for total toll plaza throughput as targeted. Therefore, 5 replications were made for each experiment.

Table 3.6.Determination of replication numbers for calibration process

Experiment	m	Mean (m)	ε'	n	Mean (n)	Var (n)	t	δ(n,α)	δ(n,α) /Abs(Mean(n))	δ(n,α) /Abs(Mean(n))<ε'
1	4	26702.50	0.00815	5	26676.6	27955.3	2.13	159.27	0.00601	Yes
2	4	26832.75	0.01296	5	26882.2	33240.7	2.13	173.67	0.00656	Yes
3	4	26999.50	0.01906	5	26956.4	16840.3	2.13	123.61	0.00467	Yes
4	4	26869.25	0.01430	5	26760.8	62105.2	2.13	237.39	0.00896	Yes
5	4	26755.25	0.01010	5	26767.2	8444.2	2.13	87.53	0.00331	Yes
6	4	26802.25	0.01184	5	26828.2	18978.2	2.13	131.23	0.00495	Yes
7	4	27377.00	0.03258	5	27381.8	10974.7	2.13	99.79	0.00377	Yes
8	4	27343.75	0.03141	5	27347.2	14670.2	2.13	115.38	0.00436	Yes
9	4	27127.00	0.02367	5	27118.2	22165.7	2.13	141.82	0.00535	Yes
10	4	27038.75	0.02048	5	26876.4	187652.0	2.13	412.64	0.01558	Yes
11	4	25974.25	0.01892	5	25919.0	68699.0	2.13	249.67	0.00943	Yes
12	4	25530.50	0.03479	5	25471.0	134241.0	2.13	349.01	0.01318	Yes

With chosen significance level (0.05) and number of replications (5), the real life system throughputs and the model simulation throughput results were compared. A statistical test of the null hypothesis

$$H_0: \overline{X} = \mu$$

versus (3.7)

$$H_1: \overline{X} \neq \mu$$

where $\overline{X}$ is the average of the 5 simulation outputs and μ is the real life observation for the throughputs. Student-t test was used for the hypothesis testing. The test statistic was computed by the following formula;

$$t = (\overline{X} - \mu) \,/\, (S \,/\, (n)^{1/2}) \tag{3.8}$$

At 0.05 significance level and 4 degrees of freedom, the critical t-value is 2.78. For experiments with a t-value greater than $t_{critical}$, H_0 was rejected at 0.05 significance level.

The calibration process started with experiments having the smallest simulation step, 0.1 sec, 0.1 sec reaction time, and reaction stop times ranging from 0.5 to 1.0 sec. Changes of the parameters were done one at a time; i.e. the reaction time at stop has been increased by 0.1 sec increments while keeping the simulation step and reaction time constant. The mean values and standard deviations of toll booth throughputs were calculated for each toll booth type and for total toll plaza at each experiment. The summary results are given in Table 3.7. The detailed results are given in Appendix B. The absolute values of the t-values for the total toll plaza throughput, throughput from the OGS, CASH, and KGS toll booths of each experiment were calculated according to Equation 3.4. and are given in Table 3.8.

Table 3.7. $\overline{X}$ and S of vehicle throughputs for experiments with 0.1 sec simulation step

Exp No	Simulation Step (seconds)	Reaction Time at Stop (seconds)	OGS Throughput		KGS Throughput		CASH Throughput		TOTAL Throughput	
			$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
1	0.1	0.5	16896.6	113.78	2520.0	36.08	7260.0	70.18	26676.6	167.20
2	0.1	0.6	17012.2	129.74	2497.2	51.79	7372.8	97.04	26882.2	182.32
3	0.1	0.7	17062.4	84.82	2510.2	31.89	7383.8	97.47	26956.4	129.77
4	0.1	0.8	16921.2	95.01	2482.6	85.91	7357.0	92.54	26760.8	249.21
5	0.1	0.9	17001.6	96.37	2498.0	40.45	7267.6	62.60	26767.2	91.89
6	0.1	1.0	17012.6	106.65	2486.6	64.29	7329.0	130.08	26828.2	137.76

Table 3.8. t-values for vehicle throughputs of experiments with 0.1 sec simulation step

Experiment No	OGS	KGS	CASH	TOTAL
1	7.05	1.98	6.34	2.56
2	8.17	0.40	1.99	4.87
3	13.82	1.56	1.73	8.12
4	9.02	0.14	2.46	2.47
5	10.76	0.55	6.84	6.87
6	9.95	0.05	2.23	5.57

Since the desired confidence levels have not been reached with 0.1 sec simulation step, the simulation step has been increased by 0.1 sec and the same procedure has been repeated for simulation step 0.2 sec and reaction time 0.2 sec. The summary results are given in Table 3.9. The detailed results are given in Appendix B. The desired confidence levels have been reached at this stage, as shown in Table 3.10, and so the calibration process for throughput values was stopped.

Table 3.9. $\overline{X}$ and S of vehicle throughputs for experiments with 0.2 sec simulation step

Exp No	Simulation Step (seconds)	Reaction Time at Stop (seconds)	OGS Throughput		KGS Throughput		CASH Throughput		TOTAL Throughput	
			$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S	$\bar{x}$	S
7	0.2	0.5	17260	62.01	2548.6	33.31	7572.8	96.63	27382	104.76
8	0.2	0.6	17130	82.28	2553.8	29.44	7663.6	97.86	27347	121.12
9	0.2	0.7	16945	231.12	2591	122.76	7582.6	109.17	27118	148.88
10	0.2	0.8	16575	481.88	2609	236.12	7692.2	228.97	26876	433.19
11	0.2	0.9	15383	214.32	2929.2	82.96	7607.2	95.74	25919	262.10
12	0.2	1.0	14937	380.14	2863.4	119.87	7670.2	117.87	25471	366.39

Table 3.10. t-values for vehicle throughputs of experiments with 0.1 sec simulation step

Experiment No	OGS	KGS	CASH	TOTAL
7	26.05	4.07	2.63	19.14
8	16.08	5.00	4.68	15.92
9	3.93	1.88	2.53	9.51
10	**0.46**	**1.17**	**1.19**	**0.49**
11	16.17	15.95	4.64	6.48
12	9.42	7.00	4.01	6.19

According to the results of the student-t test, at 0.05 significance level we could not reject the null hypothesis that the model of Experiment 10 (0.2 sec simulation step and 0.8 sec reaction time at stop) represents the real life system.

The comparison of the throughputs of the simulation model of Experiment 10 with the throughput data obtained from GDH in Table 3.11 also showed that the model can produce throughput values very close to true values.

Table 3.11. Toll plaza vehicle throughputs comparison of experiment 10 with real data

Toll Booth Types	Experiment 10	Real Life (GDH)	Difference	Difference (%)
OGS	16384.4	16538.0	-153.6	-0.9%
KGS	2612.4	2488.0	124.4	5.0%
CASH	7612.4	7459.0	153.4	2.1%
TOTAL	**26649.2**	**26485**	**164.2**	**0.6%**

The discrepancies between the simulation output and real life system observation data were less than or equal to 5%, the maximum allowable error. Hence, the model was deemed to be calibrated. Having primarily used throughput, which is a quantitative measure to calibrate the model, a final qualitative check was undertaken for queue lengths. A visual assessment of the model for the queue has been performed by comparing the simulation results with the real conditions obtained through video records. Related video record and simulation snap-shots are given in Appendix C.

To see the effect of changing the simulation step on the simulation outputs, Experiment 10 was also run for the simulation step of 0.1 sec. Table 3.12 shows the averages and standard deviations for 5 runs of the two models where the reaction time and reaction time at stop are the same, 0.2 sec and 0.8 sec respectively, but the simulation steps are different, 0.1 sec and 0.2 sec.

Table 3.12. $\overline{X}$ and S of simulation outputs for 0.1 sec and 0.2 sec simulation steps

Simulation Step	**0.1 sec**		**0.2 sec**	
Calculated Parameters	$\bar{x}$	**S**	$\bar{x}$	**S**
OGS Throughput (vehicles)	17019.2	74.56	16384.4	746.61
KGS Throughput (vehicles)	2564.4	19.69	2612.4	238.07
CASH Throughput (vehicles)	7419.0	125.75	7612.4	287.25
Toll Plaza Throughput (vehicles)	27002.6	197.15	26609.2	819.24
Fuel Consumption (l)	47678.2	3376.10	51916.4	2737.49
Pollution (kg)	4585.4	438.52	5236.9	443.81
Total Delay (sec)	66865098	10523180.6	75668385.4	8800323.95
Total System Throughput (vehicle)	26903.0	246.47	26383.2	465.03

Detailed data of outputs for all replications with 0.1 sec and 0.2 sec simulation step are given in Appendix B. To see whether there was a statistically significant difference between the two models with 0.1 sec and 0.2 sec simulation steps, hypothesis testing has been applied. Table 3.13 gives the absolute t-values for the test.

Table 3.13. t-values for the hypothesis testing between two models with 0.1 sec and 0.2 sec simulation steps

Outputs	**t-value**
OGS Throughput (vehicles)	1.89
KGS Throughput (vehicles)	0.45
CASH Throughput (vehicles)	1.38
Toll Plaza Throughput (vehicles)	1.04
Fuel Consumption (l)	2.18
Pollution (kg)	2.33
Total Delay (sec)	2.03
Total System Throughput (vehicle)	2.21

The critical t-value for 0.05 significance level and 7 degrees of freedom is 2.36. All the t-values in Table 3.11 are less than $t_{critical}$. Hence, at 0.05 significance level it could not be rejected that the two models with 0.1 sec and 0.2 sec simulation steps have the same mean values.

As a result of the calibration process, the alternative designs were run with the parameters of Experiment 10, 0.2 sec simulation step, 0.2 sec reaction time, and 0.8 sec reaction time at stop.

4 DESIGN OF ALTERNATIVE SYSTEMS AND OUTPUT DATA ANALYSIS

As mentioned before, the model was going to be used to test and quantify the impact of a number of scenarios aimed at increasing the efficiency of the toll area. The scenarios included operational strategies, some structural changes, and mixtures of them. Operational strategies included changing the number of the different payment types while keeping the total number same. Structural change involved decreasing the total toll booth number.

The MOEs of the existing system and the alternative designs were compared in the output data analysis. Among the alternatives, the ones, if any, which gave improved MOEs outputs, were compared with each other, to find the design that give the best output for the MOEs.

4.1. Measures of Effectiveness

There were five MOEs selected for the evaluation of the alternatives; total system throughput, total toll plaza throughput, total delay, fuel consumption, and CO-emission. AIMSUN is able to measure all of these MOEs.

Total system throughput is the number of vehicles that passes the toll plaza and leaves the system after the toll plaza. It is the sum of vehicles passing the link 10101786, which is the part of TEM after the point where the reverse lane meets TEM again, and the link 10101788, which is the Kavacık sink. Although the vehicles entering at the Kavacık source have effect on the system performance, they do not use the toll plaza and are not affected from the congestion until Kavacık intersection. Hence the number of vehicles entering at Kavacık source is subtracted from the sum to calculate the total throughput of the system.

Throughput from the toll booths were reported by the detectors placed after the toll booths, as explained before in the “Coding of the Detectors” part. The number of vehicles passing each toll booth was stored in an Access database. By grouping and summing the throughputs, the total throughput values and the throughput values of different toll booth types used in the calibration process and comparison of alternatives were achieved.

In sections and turnings delay is defined as the difference between the expected travel time (time it takes to traverse the section or turning under ideal conditions) and the travel time. AIMSUN calculates mean delay time as the average of all vehicles passing a section or turning and stores it in an Access database. The total delay of the system was calculated by summing up the total delays of all sections and turnings. The total delay of a section or turning was calculated by multiplying its mean delay time and volume.

Fuel consumption is the total liters of fuel consumed in a section or turning by all the vehicles that have crossed it. Pollution emission is, for each pollutant (CO, HC, NO_x), the total kilogram of pollution emitted inside a section or turning by all the vehicles that have crossed it.

4.2. Alternative Designs

With the aim of improving the traffic flow of toll plaza of FSM Bridge, 6 different alternatives were designed in this study. Changes in operational strategies and geometric design were the basis of these alternatives. In the following sections, these alternatives, which are numbered from 2 to 7, are explained in detail. The total number of toll booths, and number of different toll booth types are summarized in Table 4.1. The existing system, when the thesis study had started, is considered to be Alternative 1 during the comparison of alternatives. Its configuration is shown in Figure 4.1 and Table 4.2.

Table 4.1. Number of different payment type toll booths of alternatives

	Number of Toll Booths			Reverse Lane	Remark
Alternative	**OGS**	**KGS**	**CASH**		
1	7	5	8	Yes	Design of the toll plaza at the beginning of the thesis.
2	6	3	11	Yes	
3	7	6	8	Yes	New design applied by GDH during the thesis.
4	6	3	6	Yes	The area obtained from the removal of 5 toll booths can be used as parking area for trucks.
5	20	0	0	No	
6	7	5	8	No	
7	6	5	7	Yes	Etiler source and related toll booths are removed. Vehicles using Etiler source are oriented to the TEM entry at Levent.

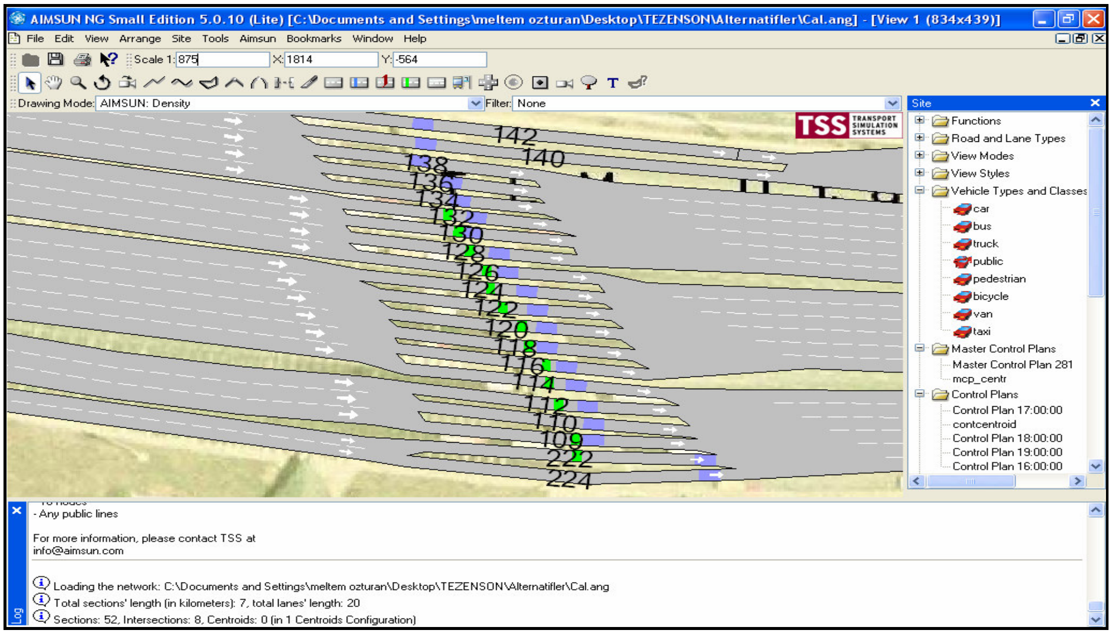


Figure 4.1. Toll plaza configuration AIMSUN snapshot of Alternative 1

Table 4.2. Toll booth numbers and types of Alternative 1

	ETILER		**TEM**																	
			TRUCKS			**PASSANGER CARS**														
Section	224	222	109	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142
Toll Booth Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Payment Type	OGS	CASH		OGS	KGS	CASH						KGS				OGS				

4.2.1. Alternative 2

This alternative involves changing the configuration of the toll booths keeping the total number of toll booths same as Alternative 1. The configuration of this alternative is shown in Figure 4.2 and Table 4.3. In this alternative, the number of total OGS toll booths has been decreased from 7 to 6. The number of KGS toll booths has been decreased by 5 to 3. The number of CASH toll booths has been increased from 8 to 11. The traffic demands for the toll booths of the new toll plaza configuration are as follows:

- The traffic demand and its distribution percentages to the toll booths 1 to 5 remained unchanged.

• The traffic demand of the 6 CASH toll booths for passenger cars, 6 to 11, of Alternative 1 was equally distributed to 9 CASH toll booths for passenger cars, 6 to 14, of Alternative 2.

• The traffic demand of the 4 KGS toll booths for passenger cars, 12 to 15, of the Alternative 1 was equally distributed to 2 KGS toll booths for passenger cars, 15 and 16, of Alternative 2.

• The traffic demand of the OGS toll booth 16 for passenger cars of Alternative 1 was equally distributed to OGS toll booths 17 and 18. The traffic demand of the OGS toll booths 19 and 20 remained unchanged.

The traffic data for Alternative 2 is given in Appendix D.

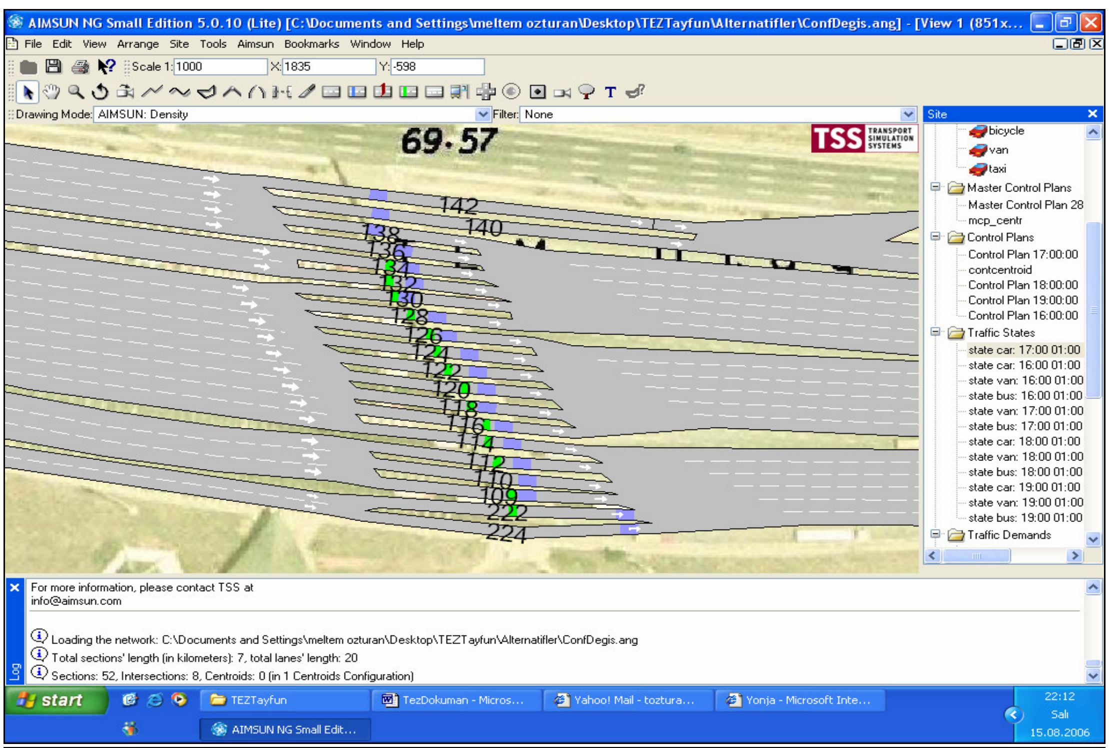


Figure 4.2. Toll plaza configuration AIMSUN snapshot of Alternative 2

Table 4.3. Toll booth numbers and types of Alternative 2

	ETILER		TEM																	
			TRUCKS			PASSANGER CARS														
Section	224	222	109	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142
Toll Booth Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Payment Type	OGS	CASH		OGS	KGS	CASH									KGS		OGS			

4.2.2. Alternative 3

This alternative is a new design already applied by GDH, started in June during the thesis is studied. To see the effect of this application, the new design was considered as an alternative in this thesis. The configuration of this alternative is shown in Figure 4.3 and Table 4.4.

In this alternative, the OGS toll booth on section 224, the toll booth 1 in Alternative 1, has been removed 50 meters ahead and a KGS toll booth was added next to it. As it can be seen in Figure 5.12 and Table 5.12, the toll booth on section 10520415 is an OGS toll booth and the toll booth on section 10520417 is a KGS toll booth.

The traffic demands for the toll booths of the new toll plaza configuration are as follows:

- The traffic demand and splitting percentages of the toll booths 3 to 20 of Alternative 1 remain unchanged in Alternative 3.
- It was assumed that as the result of the installation of the KGS toll booth in the Etiler source, some portion of the CASH toll booth users is going to change their payment type to KGS payment. This portion was calculated by taking the ratio of the overall KGS payment users to the overall CASH payment users of the whole toll plaza system into consideration.
- The number of OGS users in the Etiler source remained unchanged as in Alternative 1.

The traffic data for Alternative 3 is given in Appendix D.

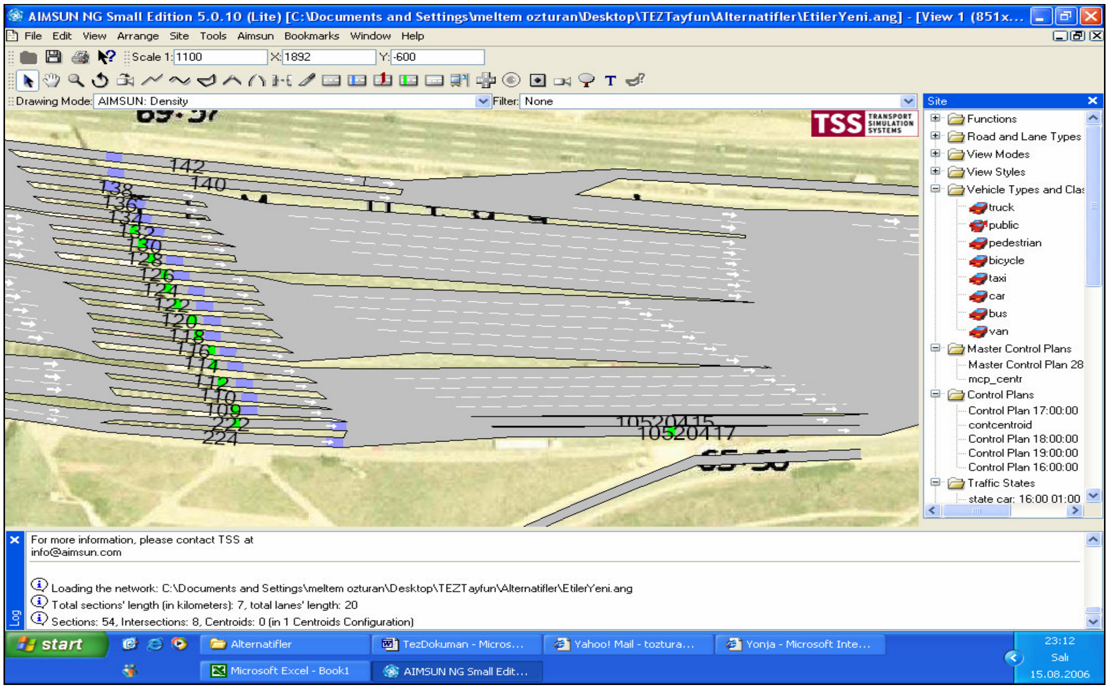


Figure 4.3. Toll plaza configuration AIMSUN snapshot of Alternative 3

Table 4.4. Toll booth numbers and types of Alternative 3

	ETILER			TEM																	
				TRUCKS			PASSANGER CARS														
Section	1052041	10520417	222	109	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142
Toll Booth Number	1	21	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Payment Type	OGS	KGS	CASH		OGS	KGS	CASH						KGS				OGS				

4.2.3. Alternative 4

This alternative involves a structural change of the toll plaza. In this alternative, there are also changes in the approach and merging areas. The configuration of this alternative is shown in Figure 4.4 and Table 4.5. The toll booths 4 to 8 in Alternative 1 have been deactivated. The number of toll booths serving to the vehicles arriving from TEM was decreased from 18 to 12. The toll booth 3 has been assigned for the service of vehicles arriving from Etiler, so the number of toll booth serving the vehicles arriving from Etiler was increased from 2 to 3. Vehicles were allowed to enter the reverse lane only from one toll booth, toll booth 15.

The traffic demands for the toll booths of the new toll plaza configuration are as follows:

- The traffic demand for the CASH toll booth in Etiler source, toll booth 3, remained same as Alternative 1.
- The traffic demand of the OGS toll booth in Etiler source, toll booth 1, in Alternative 1 was equally distributed between the two OGS toll booths, 2 and 3, in Alternative 4.
- The traffic demand of the toll booths 4,5, and 6 were taken same as the traffic demand of the toll booths 3,4, and 5 of Alternative 1, respectively.
- The traffic demand of the 6 CASH toll booths for the passenger cars, 6 to 11, of Alternative 1 was equally distributed between the 4 CASH toll booths for the passenger cars, 7 to 10, of Alternative 4.
- The traffic demand of the 4 KGS toll booths for the passenger cars, 12 to 15, of Alternative 1 was equally distributed between 2 KGS toll booths for the passenger cars, 11 and 12, of Alternative 4.
- The traffic demand for the 2 OGS toll booths for the passenger cars, 19 and 20, of Alternative 1, from which vehicles enter the reverse lane, was assigned to the OGS toll booth for the passenger cars, 15, from which vehicles enter the reverse lane in Alternative 4.
- The traffic demand of the 3 OGS toll booths for the passenger cars, 16 to 18, of Alternative 1, was equally distributed between 2 OGS toll booths for the passenger cars, 13 and 14, of Alternative 4.

The traffic data for Alternative 4 is given in Appendix D.

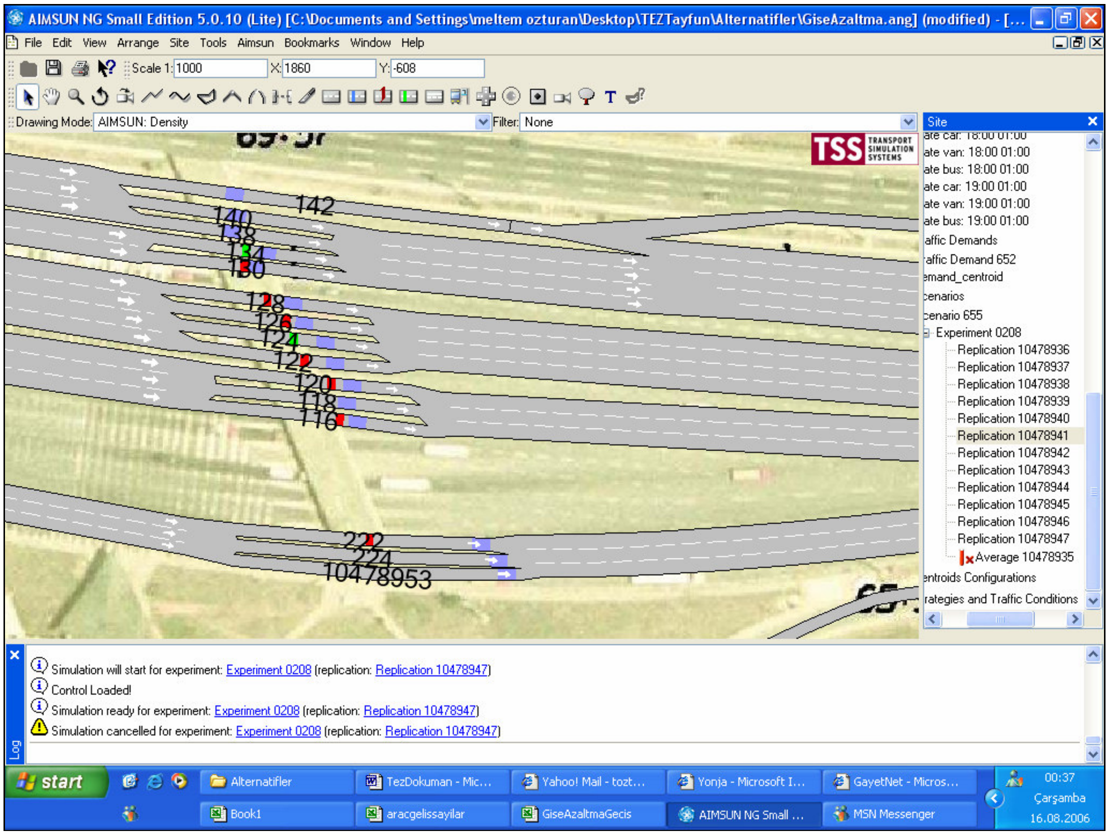


Figure 4.4. Toll plaza configuration AIMSUN snapshot of Alternative 4

Table 4.5. Toll booth numbers and types of Alternative 4

	ETILER			TEM											
				TRUCKS			PASSANGER CARS								
Section	10478953	224	222	116	118	120	122	124	126	128	130	134	138	140	142
Toll Booth Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Payment Type	OGS		CASH		OGS	KGS	CASH				KGS		OGS		

4.2.4. Alternative 5

This alternative is the case which always has been thought as a solution for the congestion problem in the FSM Bridge, converting all toll booths to OGS type toll booths. Since the entire toll booths are of the same type, no separation was required before the toll plaza (separations are used to separate different toll booth types). In addition to converting the entire toll booths to OGS type, reverse lane was removed. Since the reverse lane was removed, lane closure in Kavacık intersection, where the reverse lane enters TEM, was also removed. The configuration of this alternative is shown in Figure 4.5. The traffic demand arriving to the toll plaza from TEM was equally distributed between 18 toll booths. The traffic demand arriving to the toll plaza from Etiler was equally distributed between 2 toll booths.

The traffic data for Alternative 5 is given in Appendix D.

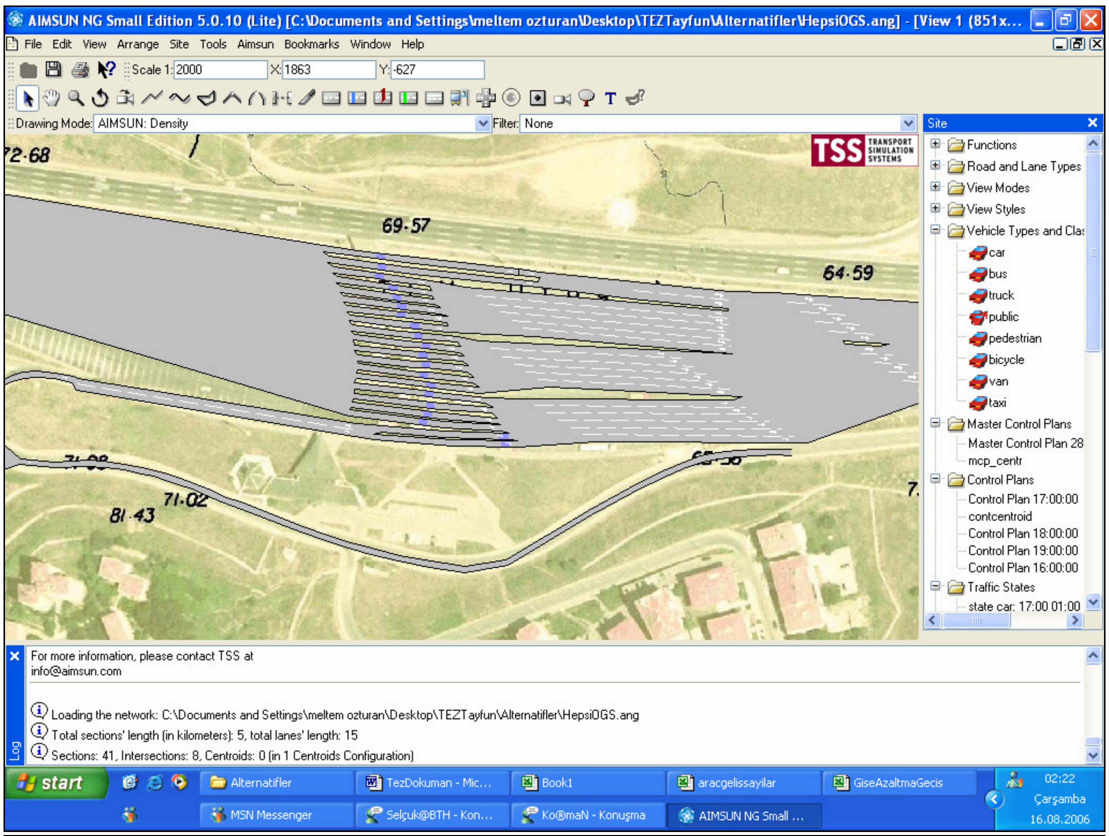


Figure 4.5. Toll plaza configuration AIMSUN snapshot of Alternative 5

4.2.5. Alternative 6

This alternative involves removal of the reverse lane only. Since the reverse lane was removed, lane closure in Kavacık intersection, where the reverse lane enters TEM, was also removed. The configuration of this alternative is shown in Figure 4.6. The traffic demand remained same as Alternative 1.

The traffic data for Alternative 6 is given in Appendix D.

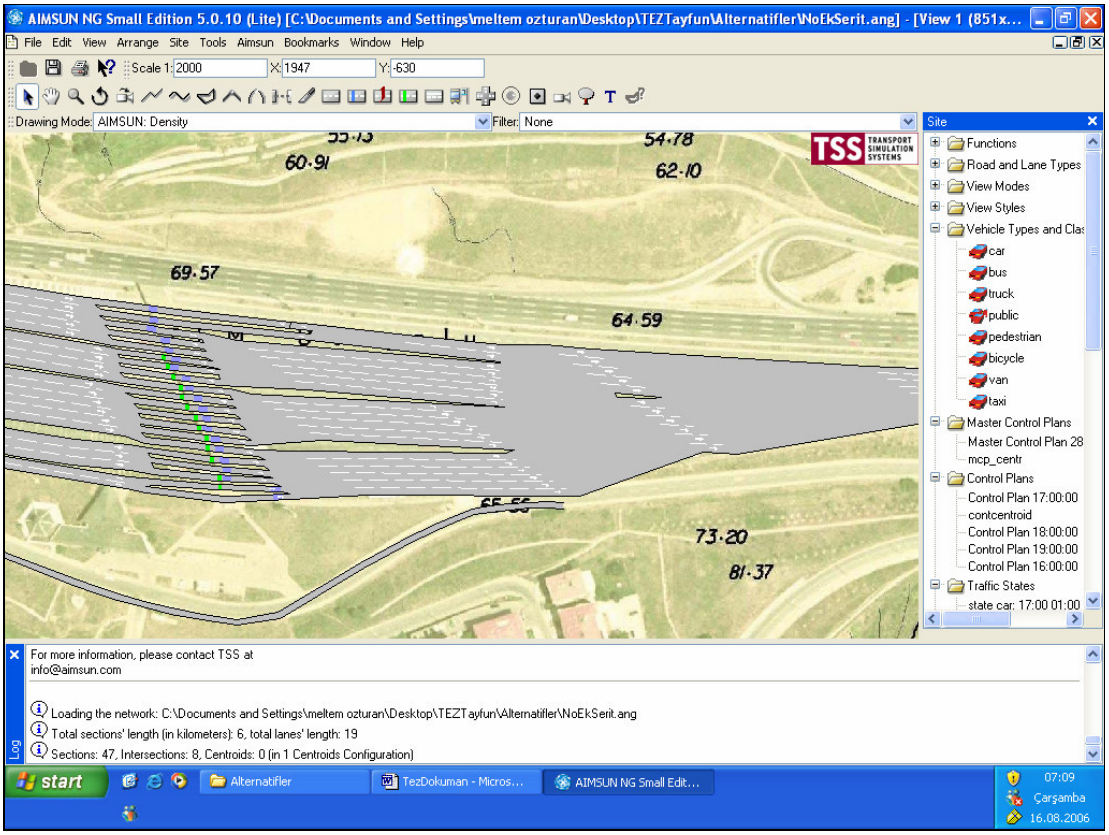


Figure 4.6. Toll plaza configuration AIMSUN snapshot of Alternative 6

4.2.6. Alternative 7

In this alternative, the Etiler source and the 2 toll booths serving the vehicles arriving from Etiler, 1 and 2, in Alternative 1 have been removed. The configuration of this alternative is shown in Figure 4.7 and Table 4.6. The traffic demand arriving from Etiler source in Alternative 1 was added to the traffic demand arriving from TEM for Alternative 7, while the splitting percentages to 18 toll booths serving the vehicles arriving from TEM remained unchanged.

The traffic data for Alternative 7 is given in Appendix D.

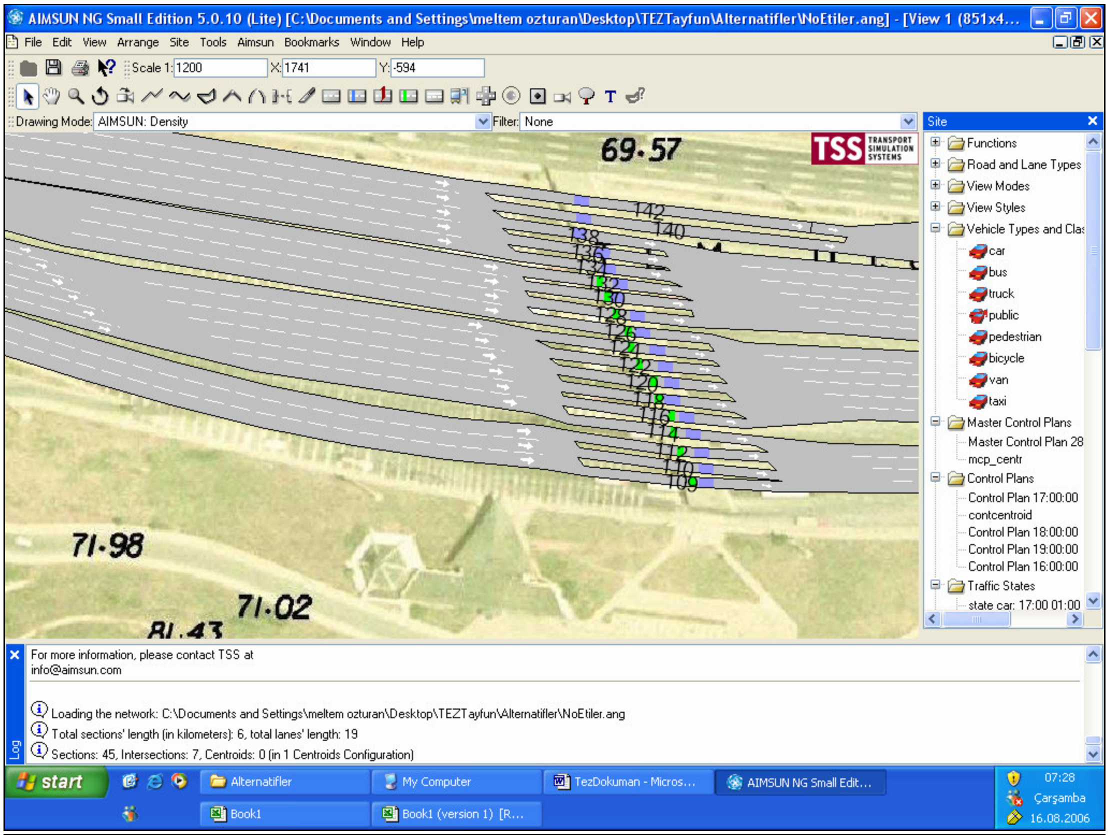


Figure 4.7. Toll plaza configuration AIMSUN snapshot of Alternative 7

Table 4.6. Toll booth numbers and types of Alternative 7

	TEM																	
	TRUCKS			PASSANGER CARS														
Section	109	110	112	114	116	118	120	122	124	126	128	130	132	134	136	138	140	142
Toll Booth Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Payment Type	CASH	OGS	KGS	CASH						KGS				OGS				

4.3. Simulation of Alternative Designs

In this step, the alternative design models were run for 10 replications. The decision of the number of runs was important in order to achieve the confidence level. For 95% confidence level, a minimum of 8 runs were necessary. This number of runs provided a confidence interval twice of the standard deviation of the model results for the true mean.

As the result of the calibration process, the alternative designs were run with 0.2 sec simulation step, 0.2 sec reaction time, and 0.8 sec reaction time at stop parameters.

The parameters that are used in the fuel consumption model are given in Table 4.7. The values for the fuel consumption parameters, F_i, F_d, c_1 and c_2, were taken from the AIMSUN 5.0 Microsimulator Users Manual, which were taken from the reports of UK Department of Transport [21]. The values of F_1 and F_2 were taken same for cars and vans. The F_1 and F_2 values used for cars and vans in this thesis were the fuel consumption values of a 1600 cc middle class car, Ford Escort [21]. The F_1 and F_2 values used for buses have been found in the internet. An average conventional bus consumes 42.7 l/100 km with 85 km/h speed, which can approximately be taken as the fuel consumption value for 90 km/h [22]. Increasing the speed from 90km/h to 120km/h can raise fuel consumption as much as 20%. Hence, the fuel consumption parameter at 120 km/h for buses was taken as 51.2 l/100km [23]. V_m was typically taken as 50 km/h [21].

Table 4.7. Parameters for fuel consumption model

	Vehicle Class 1	**Vehicle Class 2**	**Vehicle Class 3**
F_i (ml/s)	0.333	0.333	0.333
F_d (ml/s)	0.537	0.537	0.537
c_1 (ml/s)	0.42	0.42	0.42
c_2 (ml/s)	0.26	0.26	0.26
F_1 (l/100km)	5.4	5.4	42.7
F_2 (l/100km)	7.1	7.1	51.2
v_m (km/h)	50	50	50

The parameters that were used in the environmental model are given in Table 4.8. The parameters for cars and buses were given in the AIMSUN 5.0 Microsimulator Users Manual [21]. The same parameter values were used for cars and vans as suggested in the Manual.

Table 4.8. Parameters for pollution model

Vehicle Class 1				Vehicle Class 2				Vehicle Class 3			
	IER (g/s)	AER (g/s)	DER (g/s)		IER (g/s)	AER (g/s)	DER (g/s)		IER (g/s)	AER (g/s)	DER (g/s)
CO	0.06	0.377	0.072	**CO**	0.06	0.377	0.072	**CO**	0.05	0.377	0.072
Nox	0.0008	0.01	0.0005	**Nox**	0.0008	0.01	0.0005	**Nox**	0.005	0.01	0.0005
HC	0.0067	0.02	0.0067	**HC**	0.0067	0.02	0.0067	**HC**	0.0383	0.02	0.0067
Speed (km/h)		**Emission Rate (g/s)**		**Speed (km/h)**		**Emission Rate (g/s)**		**Speed (km/h)**		**Emission Rate (g/s)**	
10		0.06		10		0.06		10		0.097	
20		0.091		20		0.091		20		0.056	
30		0.13		30		0.13		30		0.05	
40		0.129		40		0.129		40		0.069	
50		0.09		50		0.09		50		0.056	
60		0.11		60		0.11		60		0.042	
70		0.177		70		0.177		70		0	

4.3.1. Simulation Results of Alternative Designs

The simulation results of the alternative designs involved total system throughput, total toll plaza throughput, total delay, and fuel consumption and pollution data. Their mean values and standard deviations were calculated for comparisons of the alternatives. Table 4.9 shows the simulation mean values and standard deviations of the MOEs for all alternatives. Detailed data of MOEs for all replications of all alternatives are given in Appendix E.

Table 4.9. $\overline{X}$ and S for MOEs of alternatives

Alternative		Fuel Consumption (l)	Total System Throughput (veh)	Toll Plaza Throuhput (veh)	Total Delay (sec)	Total Delay (hr)	Pollution (kg)		
							CO	HC	NOx
1	$\bar{x}$	51897.59	26702.50	26814.80	73751637.40	20486.57	5169.28	418.68	109.91
	S	2057.81	554.93	569.54	6844681.01	1901.30	336.59	30.79	6.79
2	$\bar{x}$	52811.33	26712.00	26631.80	74515435.30	20698.73	5216.47	423.80	110.68
	S	1415.50	474.92	406.45	6204327.90	1723.42	251.73	26.70	4.89
3	$\bar{x}$	53011.83	26381.10	26273.80	76728834.00	21313.57	5330.80	432.58	112.88
	S	1631.34	467.17	474.34	5794490.60	1609.58	282.20	25.70	5.73
4	$\bar{x}$	31637.53	24847.20	24654.10	27936799.90	7760.22	2724.94	205.29	59.30
	S	961.89	266.45	125.30	1159396.30	322.05	85.69	6.38	1.94
5	$\bar{x}$	20021.17	27326.20	27241.40	3567658.20	991.02	1233.61	88.99	26.61
	S	248.47	167.66	151.73	85756.04	23.82	12.00	0.85	0.36
6	$\bar{x}$	19455.41	27312.50	27261.30	5068176.90	1407.83	1289.84	95.60	27.42
	S	338.99	134.24	138.93	546669.75	151.85	33.54	2.79	0.74
7	$\bar{x}$	50105.98	26403.80	26457.20	63708309.40	17696.75	4819.51	377.87	103.33
	S	2657.07	564.31	461.25	7142391.78	1984.00	369.39	32.74	7.68

4.3.2. Hypothesis Testing

In Table 4.9, the means and standard deviations of all alternatives are shown together for comparison. It can be seen that there are differences in means of MOEs of different alternatives. Table 4.10 shows the effects different alternatives on the MOEs according to simulation results. A "+" sign indicates that the alternative caused an improvement for the corresponding MOE, and a "-"sign indicates that the alternative caused a worsening for the corresponding MOE. Since all three pollutants show similar variation trends for different alternatives, only CO was studied as a pollution parameter in this study.

Table 4.10. Comparison of alternatives with existing system

	Alternative						
MOE	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Fuel Consumption		-	-	+	+	+	-
Pollution-CO		-	-	+	+	+	+
Total Delay		-	-	+	+	+	+
Toll Plaza Throughput		-	-	-	+	+	-
Total System Throughput		+	-	-	+	+	-

In order to determine whether the observed differences in the simulation results were due to the differences in the alternatives or just the result of using different random number seeds, statistical hypothesis testing was applied.

First ANOVA test was applied to see whether there were alternatives which are significantly different from other alternatives. The null hypothesis, Ho, indicates that the means of all alternatives are equal. The summary of the results of the ANOVA test is given in Table 4.11. With 95% confidence level and 10 replications for each alternative, the F-values of all MOEs were greater than the critical F-value, 2.25. Hence Ho was rejected, indicating that there was at least one alternative which was significantly different than other alternatives.

Table 4.11. ANOVA test results

MOE	v-Numerator	v-Denominator	MSB	MSW	F-value	F>Fcrt	Ho
Total Delay	6	63	1.11E+16	2.45E+13	4.52E+02	Yes	Rejected
Fuel Consumption	6	63	2446876550	2437344.05	1003.911	Yes	Rejected
CO-Pollution	6	63	35353362.1	57337.9323	616.57895	Yes	Rejected
Toll Plaza Throughput	6	63	7836915.66	140764.378	55.673998	Yes	Rejected
Total System Throughput	6	63	6964912.124	169617.8841	41.062369	Yes	Rejected

Secondly, hypothesis testing was applied between pairs of alternatives to find the best alternative. The null hypothesis Ho indicates equal means of two alternatives. It is rejected if the t-value calculated is greater than the critical t-value, 2.1, with 95% confidence level and 18 degrees of freedom. In the first step of testing, Alternative 1, the existing system, and all other alternatives were compared. Then the alternatives, which have shown improvements in MOEs and were significantly different than the Alternative 1, were compared with each other.

The results of hypothesis testing between Alternative 1 and other alternatives are shown in Table 4.12, Table 4.13, Table 4.14, Table 4.15, and Table 4.16 for all MOEs. Detailed tables of these t-tests are given in Appendix F.

Table 4.12. Fuel consumption hypothesis testing

Fuel Consumption			
Alternative	**t-value**	**t-value>t-critical**	**Ho**
2	1.16	No	Not rejected
3	1.34	No	Not rejected
4	28.20	Yes	Rejected
5	48.63	Yes	Rejected
6	49.19	Yes	Rejected
7	1.69	No	Not rejected

Table 4.13. Total system throughput hypothesis testing

Total System Throughput			
Alternative	**t-value**	**t-value>t-critical**	**Ho**
2	0.04	No	Not rejected
3	1.40	No	Not rejected
4	9.53	Yes	Rejected
5	3.40	Yes	Rejected
6	3.38	Yes	Rejected
7	1.19	No	Not rejected

Table 4.14. Pollution-CO hypothesis testing

Pollution-CO			
Alternative	**t-value**	**t-value>t-critical**	**Ho**
2	0.36	No	Not rejected
3	1.16	No	Not rejected
4	22.25	Yes	Rejected
5	36.95	Yes	Rejected
6	36.27	Yes	Rejected
7	2.21	Yes	Rejected

Table 4.15. Total delay hypothesis testing

Total Delay			
Alternative	**t-value**	**t-value>t-critical**	**Ho**
2	0.26	No	Not rejected
3	1.05	No	Not rejected
4	20.87	Yes	Rejected
5	32.42	Yes	Rejected
6	31.63	Yes	Rejected
7	3.21	Yes	Rejected

Table 4.16. Toll plaza throughput hypothesis testing

Toll Plaza Throughput			
Alternative	**t-value**	**t-value>t-critical**	**Ho**
2	0.83	No	Not rejected
3	2.31	Yes	Rejected
4	11.72	Yes	Rejected
5	2.29	Yes	Rejected
6	2.41	Yes	Rejected
7	1.54	No	Not rejected

The reason for the difference of the simulation results for alternatives 4, 5, and 6 from Alternative 1 is due to the design differences for all MOEs. The difference between Alternative 1 and 3 is due to the random seed numbers of different replications for fuel consumption, CO-pollution, total delay, and total system throughput whereas the difference in toll plaza throughput is due to do difference in alternative designs. The difference between Alternative 1 and 7 is due to the random seed numbers of different replications for fuel consumption, toll plaza throughput, and total system throughput whereas the differences in CO-pollution and total delay are due to do difference in alternative designs. The tables show that the difference between Alternative 1 and 2 is due to the random seed numbers of different replications for all MOEs.

Table 4.17 and Table 4.18 show the amount and percentage differences between existing system and alternatives that are significantly different from the existing system, respectively. A "-" sign indicates an improvement caused by the alternative except for the toll plaza throughput and total system throughput values. The "-" sign in toll plaza throughput and total system throughput value indicates a worsening according to existing system.

Table 4.17. Differences in MOEs between existing system and Alternatives 4,5,6,7

Alternative	Fuel Consumption (l)	Total System Throughput (veh)	Pollution-CO (kg)	Delay (sec)	Delay (hr)	Toll Plaza Throughput (veh)
4	-20260.07	-1855.30	-2444.34	-45814837.50	-12726.34	-2160.70
5	-31876.42	623.70	-3935.67	-70183979.20	-19495.55	426.60
6	-32442.19	610.00	-3879.44	-68683460.50	-19078.74	446.50
7	-	-	-349.77	-10043328.00	-2789.81	-

Table 4.18. Percentage differences in MOEs between existing system and Alternatives 4,5,6,7

Alternative	Fuel Consumption	Total System Throughput	Pollution-CO	Delay	Toll Plaza Throughput (veh)
4	-39.0%	-6.9%	-47.3%	-62.1%	-8.1%
5	-61.4%	2.3%	-76.1%	-95.2%	1.6%
6	-62.5%	2.2%	-75.0%	-93.1%	1.7%
7	-	-	-6.8%	-13.6%	-

The alternatives that have significant improvement compared to Alternative 1 in any of the MOEs were also compared with each other. The results of hypothesis testing between these alternatives are shown in Table 4.19, Table 4.20, Table 4.21, Table 4.22, and Table 4.23 for all MOEs. Detailed tables of these t-tests are given in Appendix F.

Table 4.19. Hypothesis testing within Alternatives 4,5,6,7 for fuel consumption

Fuel Consumption			
Alternative Pairs	**t-value**	**t-value>t-critical**	**Ho**
4-5	36.98	Yes	Rejected
4-6	37.77	Yes	Rejected
4-7	20.67	Yes	Rejected
5-6	4.26	Yes	Rejected
5-7	35.65	Yes	Rejected
6-7	36.19	Yes	Rejected

Table 4.20. Hypothesis testing within Alternatives 4,5,6,7 for total system throughput

Total System Throughput			
Alternative Pairs	**t-value**	**t-value>t-critical**	**Ho**
4-5	24.90	Yes	Rejected
4-6	26.13	Yes	Rejected
4-7	7.89	Yes	Rejected
5-6	0.20	No	Not rejected
5-7	4.95	Yes	Rejected
6-7	4.95	Yes	Rejected

Table 4.21. Hypothesis testing within Alternatives 4,5,6,7 for Pollution-CO

Pollution-CO			
Alternative Pairs	**t-value**	**t-value>t-critical**	**Ho**
4-5	54.50	Yes	Rejected
4-6	49.32	Yes	Rejected
4-7	17.47	Yes	Rejected
5-6	4.99	Yes	Rejected
5-7	30.68	Yes	Rejected
6-7	30.09	Yes	Rejected

Table 4.22. Hypothesis testing within Alternatives 4,5,6,7 for total delay

Total Delay			
Alternative Pairs	**t-value**	**t-value>t-critical**	**Ho**
4-5	66,29	Yes	Rejected
4-6	56,42	Yes	Rejected
4-7	15,63	Yes	Rejected
5-6	8,58	Yes	Rejected
5-7	26,63	Yes	Rejected
6-7	25,89	Yes	Rejected

Table 4.23. Hypothesis testing within Alternatives 4,5,6,7 for toll plaza throughput

Toll Plaza Throughput			
Alternative Pairs	**t-value**	**t-value>t-critical**	**Ho**
4-5	41.58	Yes	Rejected
4-6	44.07	Yes	Rejected
4-7	11.93	Yes	Rejected
5-6	0.31	No	Not rejected
5-7	5.11	Yes	Rejected
6-7	5.28	Yes	Rejected

The results show that, except for the toll plaza throughput and total system throughput values of the alternatives pair 5-6, all the alternatives are significantly different from each other for all MOEs. Table 4.24 shows which alternative of the alternative pairs produces better results for the corresponding MOE.

Table 4.24. Comparison of Alternatives 4,5,6,7

Alternative Pairs	Fuel Consumption	Total System Throughput	Pollution-CO	Delay	Toll Plaza Throughput
4-5	5	5	5	5	5
4-6	6	6	6	6	6
4-7	4	7	4	4	7
5-6	6	-	5	5	-
5-7	5	5	5	5	5
6-7	6	6	6	6	6

5 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

In this study, microsimulation approach is used to evaluate the existing traffic condition of the Fatih Sultan Mehmet Bridge toll plaza system and to investigate alternative toll plaza designs which can cause improvements in the system efficiency.

After data collection, much care is given to calibrate the model, in order to obtain output data from the simulation model, which is going to represent the existing system and also is going to make the results of the alternative design simulations acceptable, as they are physically applied on the field and real life results are obtained. Following the calibration process, sufficient number of replications of 6 different alternative designs is made in order to evaluate the alternatives according to selected MOE. The results are compared with the existing system. Finally pair wise comparisons are applied to alternative designs, which are significantly different than the existing system and caused improvements, and the alternative design with best improvement is found.

Using AIMSUN, a flexible simulation software special for traffic systems, instead of a general purpose simulation software has enabled time and cost efficient study environment and a visual comparison of the designed model with real life system due to its traffic animation capability.

One of the major difficulties of this study has been obtaining traffic data. Taking video records of the study areas and counting the vehicles from those records have taken a lot of time. In addition to the difficulties in data collection, the limitations of the student licensed software have also brought some obstacles during simulation process. The fitted distributions for the CASH and KGS toll booth service times during the input data analysis step of the study could not be used for the simulations, because AIMSUN limited student version only included normal distribution for service time data. To assign other distribution functions, scripting was necessary, but scripting was not allowed at AIMSUN limited student version.

The results of this study have shown that some of the alternatives create economical, environmental, and psychological benefits by means of reduced fuel consumption, pollutant emission, and total delay, and also toll plaza efficiency due to increase in throughputs.

5.1. Conclusions

Followings are the main findings of the comparisons between the existing system and the alternative designs of the study:

1.Alternative 2, which is changing the configuration of the toll booths keeping the total number of toll booths same, has no affect on the MOEs compared to existing system.

2.Alternative 3 is the new design that has been applied by KGM since June. This alternative has no effect on the MOEs except toll plaza throughput, but it has caused a worsening in toll plaza throughput on the system as it can be also observed in real life.

3.In Alternative 4, which includes decrease in the total number of toll booths of the toll plaza, change in the geometry of the approach and merging area, there are significant improvements in fuel consumption, pollutant emission, and total delay, whereas there is a significant decrease in toll plaza throughput and total system throughput. Fuel consumption is decreased by 39 per cent, pollutant emission is decreased by 47 per cent, total delay is decreased by 62 per cent, whereas toll plaza throughput is decreased by eight per cent and total system throughput is decreased by 7 per cent.

4.In Alternative 5, where all of the toll booths have been changed to OGS and the reverse lane has been removed, all MOEs have shown improvements significantly. Fuel consumption is decreased by 61 per cent, total system throughput is increased by two per cent, pollutant emission is decreased by 76 per cent, total delay is decreased by 95 per cent, and toll plaza throughput is increased by 2 percent.

5.Alternative 6, in which only the reverse lane has been removed, as similar to Alternative 5, has shown significant improvements for all MOEs. Fuel consumption is decreased by 63 per cent, total system throughput is increased by two per cent, pollutant emission is decreased by 75 per cent, total delay is decreased by 93 per cent, and toll plaza throughput is increased by 2 percent.

6.Alternative 7, closure of Etiler source, has shown no significant difference for fuel consumption, toll plaza throughput, and total system throughput, but has resulted with significantly less pollution and total delay values. Pollutant emission is decreased by seven percent and total delay is decreased by 14 percent.

With the comparison of the alternative designs that have created significant improvements, following findings are obtained;

• Considering fuel consumption, Alternative 6 is found to be the best design, but it has a slight and statistically significant difference than Alternative 5.

• Alternative 6 again is found to be the best design in term s of pollution and again has a slight but statistically significant difference than Alternative 5.

• Alternative 5 is the best design when total delay is considered, but it has a slight and statistically significant difference than Alternative 6.

• When toll plaza throughput is considered both Alternatives 5 and 6 are found to be the best designs, causing very similar improvements. There is no statistically significant difference between their values.

• When total system throughput is considered both Alternatives 5 and 6 are found to be the best designs, causing very similar improvements. There is no statistically significant difference between their values.

Considering the aforementioned findings, there are evident improvements in both Alternative 5 and Alternative 6. For Alternative 5, the reason of these evident improvements is the removal of the reverse lane. Although it is thought that adding the reverse lane would increase the capacity of the bridge, actually it is not. The application of the reverse lane creates two bottlenecks in the system. One point is the Kavacık intersection, where the reverse lane meets back TEM. At that point vehicles arriving from the four lanes of the FSM Bridge, vehicles entering TEM from the Kavacık source, and vehicles that drive back to TEM from the reverse lane merge to four lanes. An obvious bottleneck is created and congestion occurs. The second bottleneck is created at the entrance of the reverse lane where vehicles passing the OGS toll booths 19 and 20 enter the reverse lane. Since those vehicles can not move forward, queuing occurs behind the OGS toll booths. Again due to the weaving effect of the congestion at the merging point at

Kavacık intersection, congestion occurs on the FSM Bridge. Hence, vehicles passing the toll plaza experience congestion in the merging area due to the congestion on the FSM Bridge.

For Alternative 6, in addition to the removal of the reverse lane, all the toll booths are of OGS payment type. With the removal of the reverse lane, all vehicles passing the toll plaza continue driving without experiencing any congestion after the toll plaza. In addition to that, making all the toll booths of OGS payment type avoids queues occurring behind the toll plaza because the drivers pass the toll plaza without having to wait for paying tolls.

Between the alternatives 5 and 6, the application of the alternative 6 is more difficult. It will have an initial cost of installing new OGS toll booths. A powerful marketing strategy is necessary to increase the number of the OGS users. Besides, TEM is used by international trucks, which do not have OGS equipment and will cause problems if they want to use the bridge. Taking all these difficulties into consideration, alternative 5 would be easier to apply for the toll plaza. The decision maker should decide which of these alternatives should be applied taking all these difficulties, application costs, and bureaucracy, into consideration.

5.2. Recommendations

Recommendations for future work in this research area are listed below;

1.Enlarging the study area so that the effects of other sinks and sources of TEM can also be considered within the study.

2. To be able to collect more accurate and large amount of data, a data collection team with number of members at least equal to the number of sinks and must be formed, and technology based data collection methods must be used.

3.In order to be able to model a larger network and to avoid limitations on simulation capabilities, full licensed AIMSUN software, capable to assign all distribution functions for service times, should be provided.

4.To see the future operation conditions of the alternatives, affects of future traffic conditions can be considered.

5.Besides operational solutions suggestions, strategic solution suggestions may be searched, such as High Occupancy Vehicle (HOV) application, in which people working and living in the same areas are using one car for their transportation, instead of going to work single with their own cars. A detailed data collection, including the origin-destination information of drivers using the FSM Bridge, is necessary.

APPENDIX A – INPUT DATA

A.1. Toll Plaza Throughput Values

Table A.1. Toll plaza throughput values on 26.05.2006 Friday

FATIH SULTAN MEHMET BRIDGE TOLL PLAZA THROUGHPUT VALUES - 26.05.2006 FRIDAY																										
Toll Booth Type	Toll Booth No	00:00-00:59	01:00-01:59	02:00-02:59	03:00-03:59	04:00-04:59	05:00-05:59	06:00-06:59	07:00-07:59	08:00-08:59	09:00-09:59	10:00-10:59	11:00-11:59	12:00-12:59	13:00-13:59	14:00-14:59	15:00-15:59	16:00-16:59	17:00-17:59	18:00-18:59	19:00-19:59	20:00-20:59	21:00-21:59	22:00-22:59	23:00-23:59	TOTAL
OGS	20	368	140	63	33	32	75	176	578	891	1020	1059	1018	1110	587	512	396	395	747	619	451	545	361	574	632	12382
	19	227	115	64	41	39	69	138	487	709	715	726	699	751	519	513	397	700	1099	921	864	995	527	501	386	12202
	18	177	94	50	25	30	51	93	354	565	548	444	452	484	521	348	258	582	625	469	500	432	251	298	264	7915
	17	80	26	14	10	7	18	31	248	423	358	295	295	318	438	383	344	762	870	641	716	684	355	192	93	7601
	16	19	8	5	0	3	3	14	91	179	177	92	103	117	350	592	608	896	1087	972	962	991	640	177	10	8096
	4	23	4	10	2	9	7	32	86	176	174	116	158	110	126	347	243	226	646	739	946	843	394	108	49	5574
	1	195	96	46	22	19	57	50	476	845	638	459	381	417	407	538	979	1107	963	821	880	838	839	594	492	12159
KGS	15	91	49	23	20	20	26	63	63	105	147	166	175	199	140	190	192	207	180	236	220	212	200	203	154	3281
	14	87	42	35	22	17	30	56	69	97	125	141	155	169	136	183	168	187	159	189	205	182	162	180	121	2917
	13	64	33	25	14	13	23	35	65	88	123	121	128	149	141	156	116	103	109	128	91	94	105	127	62	2113
	12	95	39	22	13	9	23	57	73	109	140	194	205	223	171	197	199	267	183	240	243	209	211	227	191	3540
	5	59	36	34	24	24	31	43	61	87	89	109	119	123	102	123	80	87	100	121	84	83	78	87	52	1836
CASH	11	104	0	0	0	0	0	0	0	0	0	270	321	286	283	285	211	300	385	307	316	323	282	218	190	4081
	10	295	94	0	0	0	0	0	0	0	271	294	307	304	311	294	226	298	371	256	356	361	287	261	240	4826
	9	145	0	0	0	0	0	188	0	0	303	322	346	328	303	273	222	272	301	173	136	53	285	233	227	4110
	8	284	252	107	62	2	0	0	303	394	291	291	298	314	278	263	311	315	398	366	332	356	344	247	281	6089
	7	218	78	203	57	9	193	121	258	321	290	288	320	323	298	309	281	318	362	341	346	351	333	305	266	6189
	6	258	154	91	106	173	48	219	242	316	264	293	318	308	260	285	339	357	390	386	370	364	366	334	237	6478
	3	221	171	22	90	101	168	120	208	178	148	197	215	232	159	261	278	320	269	204	147	332	288	269	288	4886
	2	86	4	30	0	0	0	0	0	132	182	219	215	227	224	305	359	420	347	83	296	381	397	369	384	4660
TOTAL		3096	1435	844	541	507	822	1436	3662	5615	6003	6096	6228	6492	5754	6357	6207	8119	9591	8212	8461	8629	6705	5504	4619	120935

A.2. Vehicle Arrivals to the Toll Booths between 20-25.05.2006

Table A.2. Toll plaza arrival values on 20-25.05.2006 between 17:00-18:00

20-25.05.2006 Traffic Flow Data 17:00-18:00							
		Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
TEM		7513	7856	10600	9057	8855	8925
Etiler Sink		745	779	1051	898	878	885
Etiler Source		850	889	1199	1025	1002	1010
Kavacık Sink		1862	1947	2626	2244	2194	2212
Kavacık Through		4910	5135	6927	5919	5787	5833
Kavacık Source		773	808	1090	931	911	918
Toll Booth Type	Toll Booth Number						
OGS	20	1009	1140	1583	1551	1542	620
	19	672	642	1192	1292	1187	867
	18	507	436	763	794	732	718
	17	339	213	626	636	599	912
	16	165	52	374	472	413	1136
	4	196	9	413	462	363	750
	1	481	381	872	870	947	960
KGS	15	162	160	126	129	132	139
	14	85	100	143	135	136	139
	13	60	31	122	118	127	150
	12	165	184	150	165	139	150
	5	89	36	79	86	119	121
CASH	11	363	384	305	0	19	214
	10	400	374	334	411	359	227
	9	339	394	333	377	426	341
	8	386	373	335	395	370	234
	7	327	349	302	396	332	371
	6	334	353	0	0	13	211
	3	359	420	182	290	232	237
	2	374	447	239	328	287	290

Table A.3. Toll plaza arrival values on 20-25.05.2006 between 18:00-19:00

20-25.05.2006 Traffic Flow Data 18:00-19:00							
		Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
TEM		5363	5082	9349	8017	8447	9279
Etiler Sink		612	580	1067	915	964	1059
Etiler Source		595	564	1037	889	937	1029
Kavacık Sink		1429	1354	2491	2136	2251	2473
Kavacık Through		2400	2275	4185	3589	3781	4153
Kavacık Source		831	787	1448	1242	1308	1437
Toll Booth Type	Toll Booth Number						
OGS	20	1125	971	1203	694	1318	752
	19	740	536	1248	861	1257	929
	18	495	445	945	786	953	718
	17	364	250	911	933	800	986
	16	163	90	896	1132	738	1145
	4	155	16	938	1031	792	1159
	1	483	404	1060	1203	1090	1196
KGS	15	160	139	178	204	168	196
	14	128	109	163	195	166	195
	13	98	32	190	172	183	180
	12	153	168	187	203	205	205
	5	69	34	168	137	134	175
CASH	11	400	415	99	2	0	338
	10	412	369	405	436	410	364
	9	403	368	389	400	451	247
	8	416	377	382	426	414	387
	7	351	343	370	413	351	208
	6	380	397	0	1	1	301
	3	401	407	198	250	227	91
	2	401	429	278	317	315	320

Table A.4. Toll plaza arrival values on 20-25.05.2006 between 19:00-20:00

20-25.05.2006 Traffic Flow Data 19:00-20:00							
		Saturday	Sunday	Monday	Tuesday	Wednesday	Thursday
TEM		7476	6722	13706	12836	12054	13735
Etiler Sink		516	464	946	886	832	948
Etiler Source		719	646	1318	1234	1159	1321
Kavacık Sink		2054	1847	3766	3527	3312	3774
Kavacık Through		4901	4407	8985	8415	7903	9004
Kavacık Source		687	618	1260	1180	1108	1263
Toll Booth Type	Toll Booth Number						
OGS	20	981	820	712	699	675	523
	19	694	541	1019	984	901	900
	18	476	400	857	551	942	510
	17	304	219	889	685	990	703
	16	144	83	1006	989	1115	1036
	4	160	83	831	980	882	1037
	1	431	336	789	815	764	1114
KGS	15	172	121	156	185	170	168
	14	108	100	146	184	156	164
	13	90	62	185	146	171	158
	12	140	118	165	169	163	145
	5	63	46	118	109	127	127
CASH	11	390	319	299	0	295	376
	10	381	400	248	425	379	65
	9	410	320	399	423	396	375
	8	409	349	379	471	311	377
	7	325	335	370	364	342	378
	6	357	364	4	2	3	391
	3	351	315	281	317	269	194
	2	393	340	265	310	239	290

A.3. Arrival Data

Table A.5. Toll plaza arrival rate values from TEM on 26.05.2006 between 17:00-18:00

Observation No.	Arrival Rate (veh/min)	Observation No.	Arrival Rate (veh/min)	Observation No.	Arrival Rate (veh/min)
1	116	**21**	148	**41**	158
2	130	**22**	150	**42**	158
3	131	**23**	150	**43**	158
4	131	**24**	151	**44**	159
5	131	**25**	151	**45**	159
6	131	**26**	152	**46**	159
7	132	**27**	152	**47**	160
8	134	**28**	153	**48**	160
9	139	**29**	153	**49**	161
10	139	**30**	153	**50**	161
11	140	**31**	154	**51**	161
12	141	**32**	154	**52**	163
13	141	**33**	155	**53**	163
14	141	**34**	155	**54**	164
15	141	**35**	155	**55**	164
16	142	**36**	156	**56**	166
17	143	**37**	156	**57**	166
18	145	**38**	156	**58**	167
19	146	**39**	157	**59**	167
20	148	**40**	157	**60**	168
Avg. = 150,9 veh/min Std. Dev. = 11,54 veh/min Max = 168 veh/min Min = 116 veh/min					

A.4. KGS and CASH Toll Booths Service Times

Table A.6. KGS toll booth service time data

03.06.2006 - Service Times (sec) - KGS					
No	**Toll Booth No: 5**	**Toll Booth No: 12**	**Toll Booth No: 13**	**Toll Booth No:14**	**Toll Booth No: 15**
1	1,6	4,8	3,5	3,3	1,0
2	4,9	3,1	2,6	1,8	10,5
3	2,3	3,0	2,2	3,8	2,6
4	1,9	4,0	2,7	2,3	1,2
5	2,7	3,7	3,2	4,8	1,6
6	2,7	3,1	3,2	3,5	3,1
7	5,4	2,5	4,1	5,0	1,7
8	6,4	5,5	3,7	2,5	4,4
9	4,0	4,2	4,9	3,7	3,8
10	3,4	3,5	4,8	3,7	4,8
11	3,7	3,1	4,9	1,5	2,8
12	2,7	11,2	6,8	2,3	2,5
13	2,4	3,5	3,5	5,5	4,3
14	1,4	12,8	3,1	4,4	10,8
15	1,8	3,5	1,9	3,6	2,2
Avg.	**3,16**	**4,76**	**3,67**	**3,44**	**3,81**
St. Dev.	**1,48**	**3,05**	**1,27**	**1,20**	**3,01**
Max.	**6,4**	**12,8**	**6,8**	**5,5**	**10,8**
Min	**1,4**	**2,5**	**1,9**	**1,5**	**1,0**
Avg. = 3,77 sec St. Dev. = 2,18 sec Max = 12,8 sec Min = 1,0 sec					

Table A.7. CASH toll booth service time data

03.06.2006 - Service Time (sec) - CASH								
No	Toll Booth No: 2	Toll Booth No: 3	Toll Booth No: 6	Toll Booth No: 7	Toll Booth No: 8	Toll Booth No: 9	Toll Booth No: 10	Toll Booth No: 11
1	2,0	8,5	4,3	5,2	1,5	5,2	1,5	10,7
2	8,6	6,5	1,5	3,7	5,7	8,3	1,4	4,5
3	1,7	4,9	1,5	3,2	5,1	5,0	6,1	10,2
4	4,6	7,8	2,5	9,0	2,8	11,0	8,9	6,6
5	3,3	2,7	13,4	10,5	9,0	6,4	5,9	9,4
6	1,5	17,6	12,5	1,6	8,3	3,6	1,9	6,4
7	6,2	4,5	4,5	10,4	8,2	4,6	1,4	4,9
8	7,6	5,3	2,2	1,5	5,4	5,8	3,1	8,2
9	5,5	3,6	1,7	14,3	6,8	7,6	1,9	5,4
10	16,9	8,8	2,2	2,3	2,5	6,2	6,5	1,7
11	1,5	11,7	2,5	3,3	4,0	2,3	2,2	6,1
12	1,5	3,1	1,3	5,7	5,6	4,5	2,2	11,1
13	4,4	1,5	5,4	8,1	9,0	1,2	2,6	5,0
14	4,1	5,6	5,4	8,1	2,7	5,5	3,0	6,3
15	3,2	7,2	3,1	5,8	4,0	2,5	5,8	1,5
16	3,5	6,2	2,3	1,3	4,4	5,8	1,6	3,2
17	1,4	5,3	4,7	8,2	15,2	3,8	1,2	9,8
18	5,3	10,5	4,0	1,7	5,7	1,4	9,5	4,0
19	5,2	10,0	4,4	13,8	4,4	3,3	3,6	11,5
20	1,6	14,6	10,7	4,0	2,4	2,4	3,3	12,5
21	4,6	1,8	4,1	14,1	2,0	6,1	15,8	8,7
22	4,7	2,7	1,8	4,7	3,3	4,0	5,4	1,5
23	2,3	3,1	4,1	7,5	6,6	2,2	4,1	3,7
24	5,5	5,6	7,0	5,9	3,3	5,7	5,4	11,6
25	1,5	10,3	12,8	1,2	10,9	1,3	1,6	10,8
26	5,5	5,6	7,0	5,9	3,3	5,7	5,4	11,6
27	1,3	10,3	1,8	1,2	10,9	2,0	1,3	10,8
28	3,4	4,4	1,3	10,9	4,5	6,5	13,0	4,6
29	6,7	5,2	7,5	2,0	2,9	14,4	2,1	2,5
30	7,9	3,0	1,6	5,2	2,0	2,4	2,7	5,9
31	1,4	3,6	16,2	9,6	8,2	3,6	2,0	7,4
32	7,9	3,5	6,1	4,5	2,1	3,6	2,7	5,9
33	1,2	2,6	1,5	5,6	3,8	3,3	6,9	1,5
34	2,3	12,3	3,6	1,7	13,6	1,3	4,7	4,6
35	3,8	4,5	3,9	5,5	8,9	13,9	1,8	5,1
36	10,4	5,1	6,5	4,4	3,3	4,7	5,3	8,6
37	2,6	13,4	1,6	6,2	5,2	8,7	1,4	2,4
38	11,5	7,8	7,9	9,3	2,7	5,6	3,0	5,4
39	1,9	3,2	3,0	7,1	3,2	4,5	1,5	5,3
40	4,0	5,6	9,0	2,7	4,0	4,4	15,2	5,7
41	8,1	8,1	5,8	1,6	8,2	1,4	13,8	4,0
42	5,4	2,2	13,0	2,1	2,7	1,8	2,7	6,9
Avg.	**4,61**	**6,41**	**5,18**	**5,74**	**5,43**	**4,85**	**4,56**	**6,50**
St. Dev.	**3,26**	**3,75**	**3,88**	**3,69**	**3,25**	**3,04**	**3,87**	**3,19**
Max.	**16,9**	**17,6**	**16,2**	**14,3**	**15,2**	**14,4**	**15,8**	**12,5**
Min	**1,2**	**1,5**	**1,3**	**1,2**	**1,5**	**1,2**	**1,2**	**1,5**
Avg. = 5,41 sec St. Dev. = 3,54 sec Max = 17,63 sec Min = 1,2 sec								

A.5. Splitting Percentages and Flows of 26.05.2006 Friday

Table A.8. Splitting percentages and flows between 17:00-18:00

17:00-18:00 Vehicle Class 1 Splitting Percentages			17:00-18:00 Vehicle Class 2 Splitting Percentages			17:00-18:00 Vehicle Class 3 Splitting Percentages		
Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)
108 to 112	9,8	48	108 to 112	6,3	23	108 to 112	6,8	8
108 to 110	45,4	224	108 to 110	52,0	190	108 to 110	83,3	100
108 to 109	44,8	221	108 to 109	41,7	152	108 to 109	9,8	12
140 to 212	10,0		140 to 212	10,0		140 to 212	100,0	
140 to 206	90,0		140 to 206	90,0		140 to 206	0,0	
146 to 142	17,5	733	146 to 142	10,1	77	146 to 142	0,0	0
146 to 140	24,1	1009	146 to 140	27,6	211	146 to 140	0,0	0
146 to 138	14,0	586	146 to 138	14,3	109	146 to 138	4,4	2
146 to 136	18,9	791	146 to 136	17,2	132	146 to 136	31,1	13
146 to 134	25,5	1068	146 to 134	30,8	236	146 to 134	64,4	26
149 to 144	9,1	643	149 to 144	14,1	255	149 to 144	0,0	0
149 to 146	59,3	4187	149 to 146	42,3	766	149 to 146	22,5	41
149 to 731	8,3	586	149 to 731	7,4	134	149 to 731	3,0	5
149 to 151	16,3	1151	149 to 151	16,0	290	149 to 151	8,5	15
149 to 108	7,0	494	149 to 108	20,2	366	149 to 108	66,0	119
161 to 124	14,5	167	161 to 124	19,4	56	161 to 124	23,5	4
161 to 122	15,9	183	161 to 122	19,1	55	161 to 122	35,3	5
161 to 120	17,2	198	161 to 120	20,6	60	161 to 120	5,9	1
161 to 118	18,9	218	161 to 118	15,0	43	161 to 118	0,0	0
161 to 116	17,2	198	161 to 116	15,2	44	161 to 116	11,8	2
161 to 114	16,3	188	161 to 114	10,8	31	161 to 114	23,5	4
220 to 222	29,8	274	220 to 222	30,1	32	220 to 222	50,0	0
220 to 224	70,2	644	220 to 224	69,9	74	220 to 224	50,0	0
731 to 132	24,4	143	731 to 132	21,0	28	731 to 132	33,3	2
731 to 130	24,0	141	731 to 130	28,0	38	731 to 130	16,7	1
731 to 128	24,8	145	731 to 128	19,6	26	731 to 128	16,7	1
731 to 126	26,8	157	731 to 126	31,5	42	731 to 126	33,3	2
10101885 to 10101894	25,0		10101885 to 10101894	25,0		10101885 to 10101894	25,0	
10101885 to 10101896	45,0		10101885 to 10101896	45,0		10101885 to 10101896	45,0	
10101885 to 10101888	30,0		10101885 to 10101888	30,0		10101885 to 10101888	30,0	
10478700 to 10101788	33,9	2183	10478700 to 10101788	29,4	447	10478700 to 10101788	69,6	136
10478700 to 10101885	66,1	4258	10478700 to 10101885	70,6	1075	10478700 to 10101885	30,4	59
10478707 to 206	100,0		10478707 to 206	100,0		10478707 to 206	0,0	
10478707 to 212	0,0		10478707 to 212	0,0		10478707 to 212	100,0	

Table A.9. Splitting percentages and flows between 18:00-19:00

18:00-19:00 Vehicle Class 1 Splitting Percentages			18:00-19:00 Vehicle Class 2 Splitting Percentages			18:00-19:00 Vehicle Class 3 Splitting Percentages		
Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)
108 to 112	10,0	48	108 to 112	6,30	17	108 to 112	6,80	8
108 to 110	61,1	295	108 to 110	85,70	230	108 to 110	83,30	96
108 to 109	28,9	140	108 to 109	8,00	21	108 to 109	9,80	11
140 to 212	5,0		140 to 212	5,00		140 to 212	100,00	
140 to 206	95,0		140 to 206	95,00		140 to 206	0,00	
146 to 142	17,5	639	146 to 142	10,10	75	146 to 142	0,00	0
146 to 140	24,1	880	146 to 140	27,60	205	146 to 140	0,00	0
146 to 138	14,0	511	146 to 138	14,30	106	146 to 138	4,40	2
146 to 136	18,9	690	146 to 136	17,20	128	146 to 136	31,10	12
146 to 134	25,5	932	146 to 134	30,80	229	146 to 134	64,40	25
149 to 144	10,5	746	149 to 144	16,10	293	149 to 144	0,00	0
149 to 146	51,4	3653	149 to 146	40,80	743	149 to 146	22,50	39
149 to 731	10,8	768	149 to 731	7,40	135	149 to 731	3,00	5
149 to 151	20,5	1457	149 to 151	21,00	383	149 to 151	8,50	15
149 to 108	6,8	483	149 to 108	14,70	268	149 to 108	66,00	116
161 to 124	14,5	211	161 to 124	19,40	74	161 to 124	23,50	3
161 to 122	15,9	232	161 to 122	19,10	73	161 to 122	35,30	5
161 to 120	17,2	251	161 to 120	20,60	79	161 to 120	5,90	1
161 to 118	18,9	275	161 to 118	15,00	57	161 to 118	0,00	0
161 to 116	17,2	251	161 to 116	15,20	58	161 to 116	11,80	2
161 to 114	16,3	237	161 to 114	10,80	41	161 to 114	23,50	3
220 to 222	21,0	169	220 to 222	21,20	44	220 to 222	50,00	0
220 to 224	79,0	635	220 to 224	78,80	162	220 to 224	50,00	0
731 to 132	24,4	187	731 to 132	21,00	28	731 to 132	33,30	2
731 to 130	24,0	184	731 to 130	28,00	38	731 to 130	16,70	1
731 to 128	24,8	190	731 to 128	19,60	26	731 to 128	16,70	1
731 to 126	26,8	206	731 to 126	31,50	42	731 to 126	33,30	2
10101885 to 10101894	25,0		10101885 to 10101894	25,00		10101885 to 10101894	25,00	
10101885 to 10101896	35,0		10101885 to 10101896	35,00		10101885 to 10101896	35,00	
10101885 to 10101888	40,0		10101885 to 10101888	40,00		10101885 to 10101888	40,00	
10478700 to 10101788	37,2	2160	10478700 to 10101788	37,70	473	10478700 to 10101788	69,70	
10478700 to 10101885	62,8	3647	10478700 to 10101885	62,30	781	10478700 to 10101885	30,30	
10478707 to 206	100,0		10478707 to 206	100,00		10478707 to 206	0,00	
10478707 to 212	0,0		10478707 to 212	0,00		10478707 to 212	100,00	

Table A.10. Splitting percentages and flows between 19:00-20:00

19:00-20:00 Vehicle Class 1 Splitting Percentages			19:00-20:00 Vehicle Class 2 Splitting Percentages			19:00-20:00 Vehicle Class 3 Splitting Percentages		
Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)	Turn Sections	Splitting Percentage (%)	Splitting Flow (veh)
108 to 112	7,0	57	108 to 112	5,3	11	108 to 112	6,8	3
108 to 110	62,1	503	108 to 110	85,7	182	108 to 110	83,3	31
108 to 109	30,9	250	108 to 109	9,0	19	108 to 109	9,8	4
140 to 212	15,0		140 to 212	15,0		140 to 212	100,0	
140 to 206	85,0		140 to 206	85,0		140 to 206	0,0	
146 to 142	17,5	579	146 to 142	10,1	94	146 to 142	2,2	1
146 to 140	24,1	798	146 to 140	27,6	257	146 to 140	2,2	1
146 to 138	14,0	463	146 to 138	14,3	133	146 to 138	4,4	3
146 to 136	18,9	625	146 to 136	17,2	160	146 to 136	31,1	20
146 to 134	25,5	844	146 to 134	30,8	286	146 to 134	60,0	38
149 to 144	7,4	500	149 to 144	5,5	90	149 to 144	0,0	0
149 to 146	49,0	3309	149 to 146	56,9	930	149 to 146	39,7	64
149 to 731	8,8	594	149 to 731	7,4	121	149 to 731	24,0	38
149 to 151	22,8	1540	149 to 151	17,2	281	149 to 151	13,3	21
149 to 108	12,0	810	149 to 108	13,0	212	149 to 108	23,0	37
161 to 124	14,5	223	161 to 124	19,4	55	161 to 124	23,5	5
161 to 122	15,9	245	161 to 122	19,1	54	161 to 122	35,3	8
161 to 120	17,2	265	161 to 120	20,6	58	161 to 120	5,9	1
161 to 118	18,9	291	161 to 118	15,0	42	161 to 118	0,0	0
161 to 116	17,2	265	161 to 116	15,2	43	161 to 116	11,8	3
161 to 114	16,3	251	161 to 114	10,8	30	161 to 114	23,5	5
220 to 222	20,5	150	220 to 222	20,6	19	220 to 222	50,0	0
220 to 224	79,5	580	220 to 224	79,4	73	220 to 224	50,0	0
731 to 132	24,4	145	731 to 132	21,0	25	731 to 132	33,3	13
731 to 130	24,0	143	731 to 130	28,0	34	731 to 130	16,7	6
731 to 128	24,8	147	731 to 128	19,6	24	731 to 128	16,7	6
731 to 126	26,8	159	731 to 126	31,5	38	731 to 126	33,3	13
10101885 to 10101894	25,0		10101885 to 10101894	25,0		10101885 to 10101894	25,0	
10101885 to 10101896	35,0		10101885 to 10101896	35,0		10101885 to 10101896	35,0	
10101885 to 10101888	40,0		10101885 to 10101888	40,0		10101885 to 10101888	40,0	
10478700 to 10101788	26,3	1619	10478700 to 10101788	26,8	432	10478700 to 10101788	70,8	116
10478700 to 10101885	73,7	4536	10478700 to 10101885	73,2	1180	10478700 to 10101885	29,2	48
10478707 to 206	100,0		10478707 to 206	100,0		10478707 to 206	0,0	
10478707 to 212	0,0		10478707 to 212	0,0		10478707 to 212	100,0	

APPENDIX B: SIMULATION TOLL BOOTH THROUGHPUTS FOR CALIBRATION

Table B.1. Toll booth throughputs obtained from the simulation of the existing system used for calibration

		Replication						
Exp		**1**	**2**	**3**	**4**	**5**	**AVG**	**STD DEV**
1	**OGS**	16999	16985	16723	16928	16848	16896,6	113,782
	KGS	2489	2576	2502	2536	2497	2520,0	36,076
	CASH	7165	7331	7249	7327	7228	7260,0	70,178
	TOTAL	**26653**	**26892**	**26474**	**26791**	**26573**	**26676,6**	**167,198**
2	**OGS**	16932	17020	16838	17142	17129	17012,2	129,739
	KGS	2555	2551	2466	2445	2469	2497,2	51,790
	CASH	7448	7386	7288	7260	7482	7372,8	97,042
	TOTAL	**26935**	**26957**	**26592**	**26847**	**27080**	**26882,2**	**182,320**
3	**OGS**	17072	17034	17013	17204	16989	17062,4	84,819
	KGS	2481	2518	2526	2475	2551	2510,2	31,886
	CASH	7505	7345	7395	7430	7244	7383,8	97,466
	TOTAL	**27058**	**26897**	**26934**	**27109**	**26784**	**26956,4**	**129,770**
4	**OGS**	16762	16910	16962	17003	16969	16921,2	95,014
	KGS	2342	2520	2552	2461	2538	2482,6	85,906
	CASH	7223	7459	7411	7309	7383	7357,0	92,542
	TOTAL	**26327**	**26889**	**26925**	**26773**	**26890**	**26760,8**	**249,209**
5	**OGS**	16938	16905	17148	17042	16975	17001,6	96,371
	KGS	2539	2443	2537	2487	2484	2498,0	40,447
	CASH	7268	7297	7206	7211	7356	7267,6	62,604
	TOTAL	**26745**	**26645**	**26891**	**26740**	**26815**	**26767,2**	**91,892**
6	**OGS**	17055	17080	16903	17129	16896	17012,6	106,650
	KGS	2498	2494	2388	2485	2568	2486,6	64,295
	CASH	7409	7298	7343	7127	7468	7329,0	130,079
	TOTAL	**26962**	**26872**	**26634**	**26741**	**26932**	**26828,2**	**137,761**
7	**OGS**	17303	17343	17245	17221	17190	17260,4	62,015
	KGS	2497	2582	2553	2539	2572	2548,6	33,306
	CASH	7710	7520	7500	7495	7639	7572,8	96,627
	TOTAL	**27510**	**27445**	**27298**	**27255**	**27401**	**27381,8**	**104,760**
8	**OGS**	17119	17108	17125	17262	17035	17129,8	82,278
	KGS	2582	2555	2509	2578	2545	2553,8	29,440
	CASH	7675	7706	7515	7641	7781	7663,6	97,856
	TOTAL	**27376**	**27369**	**27149**	**27481**	**27361**	**27347,2**	**121,121**
9	**OGS**	16535	17001	17035	17074	17078	16944,6	231,120
	KGS	2796	2528	2606	2483	2542	2591,0	122,764
	CASH	7590	7737	7627	7496	7463	7582,6	109,166
	TOTAL	**26921**	**27266**	**27268**	**27053**	**27083**	**27118,2**	**148,881**
10	**OGS**	17008	16862	15875	16856	16275	15321,0	481,876
	KGS	2234	2532	2833	2735	2711	2928,0	236,120
	CASH	8084	7590	7519	7567	7701	7302,0	228,967
	TOTAL	**27326**	**26984**	**26227**	**27158**	**26687**	**25551,0**	**433,189**
11	**OGS**	15168	15290	15740	15350	15365	15382,6	214,322
	KGS	3068	2896	2893	2936	2853	2929,2	82,962
	CASH	7572	7649	7739	7596	7480	7607,2	95,738
	TOTAL	**25808**	**25835**	**26372**	**25882**	**25698**	**25919,0**	**262,105**
12	**OGS**	15350	15349	14751	14629	14608	14937,4	380,136
	KGS	2936	2650	2916	2905	2910	2863,4	119,874
	CASH	7596	7858	7580	7602	7715	7670,2	117,865
	TOTAL	**25882**	**25857**	**25247**	**25136**	**25233**	**25471,0**	**366,388**

Table B.2. Simulation outputs for 0.1 sec and 0.2 sec simulation steps

Simulation Step	Outputs	Replication						
		1	2	3	4	5	AVG	STD DEV
0.1 sec	OGS Throughput (vehicles)	16939	17044	16943	17104	17066	17019,2	74,557
	KGS Throughput (vehicles)	2555	2547	2559	2598	2563	17019,2	74,557
	CASH Throughput (vehicles)	7325	7552	7319	7561	7338	2564,4	19,693
	TOTAL Throughput (vehicles)	26819	27143	26821	27263	26967	7419,0	125,748
	Fuel Consumption (l)	47312,87	50280,36	49685,07	41974,78	49138,02	27002,6	197,152
	Pollution (kg)	4494,354	4928,718	4851,033	3858,283	4794,619	47678,2	3376,102
	Total Delay (sec)	64489906	75097454	73515388	49496257	71726487	4585,4	438,517
	System Throughput (vehicle)	27003,6	26969,48	26517,08	27179,1	26845,65	66865098,4	10523180,617
0.2 sec	OGS Throughput (vehicles)	17008	16862	15875	16856	15321	16384,4	746,608
	KGS Throughput (vehicles)	2234	2532	2833	2735	2728	2612,4	238,070
	CASH Throughput (vehicles)	8084	7590	7519	7567	7302	7612,4	287,246
	TOTAL Throughput (vehicles)	27326	26984	26227	27158	25351	26609,2	819,238
	Fuel Consumption (l)	54558,02	50007,24	55245,46	49988,35	49782,79	51916,4	2737,491
	Pollution (kg)	5751,842	4996,44	5686,081	4900,518	4849,652	5236,9	443,809
	Total Delay (sec)	76147352	66143389	83126785	67463872	85460529	75668385,4	8800323,949
	System Throughput (vehicle)	25668	26220	26613	26886	26529	26383,2	465,032

APPENDIX C: VIDEO RECORDS AND SIMULATION SNAP-SHOTS OF QUEUE LENGTHS

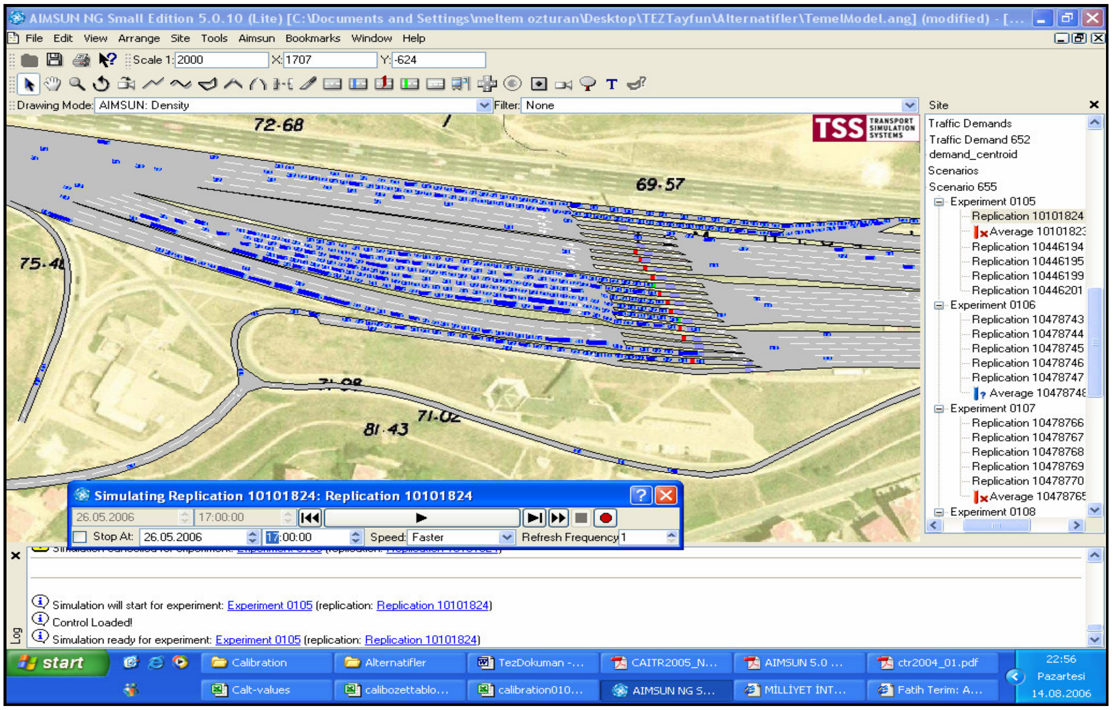


Figure C.1. Simulation snap-shot for 17:00 before toll plaza

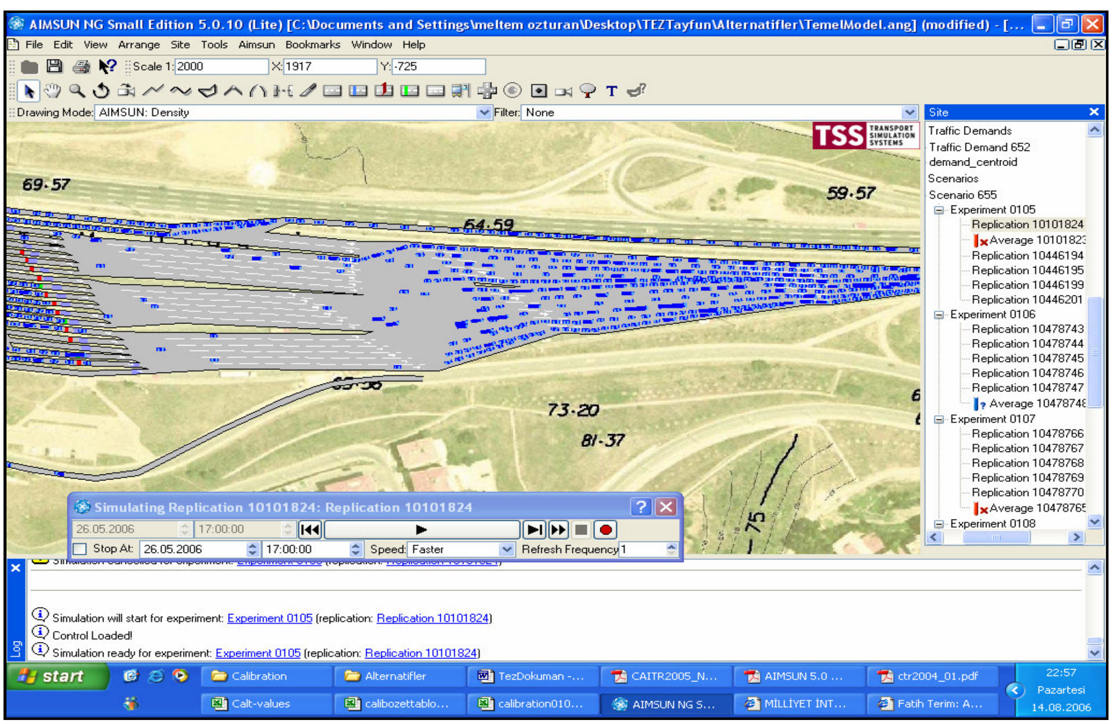


Figure C.2. Simulation snap-shot for 17:00 after toll plaza

Figure C.3. Video record snap-shot for 17:00 before toll plaza

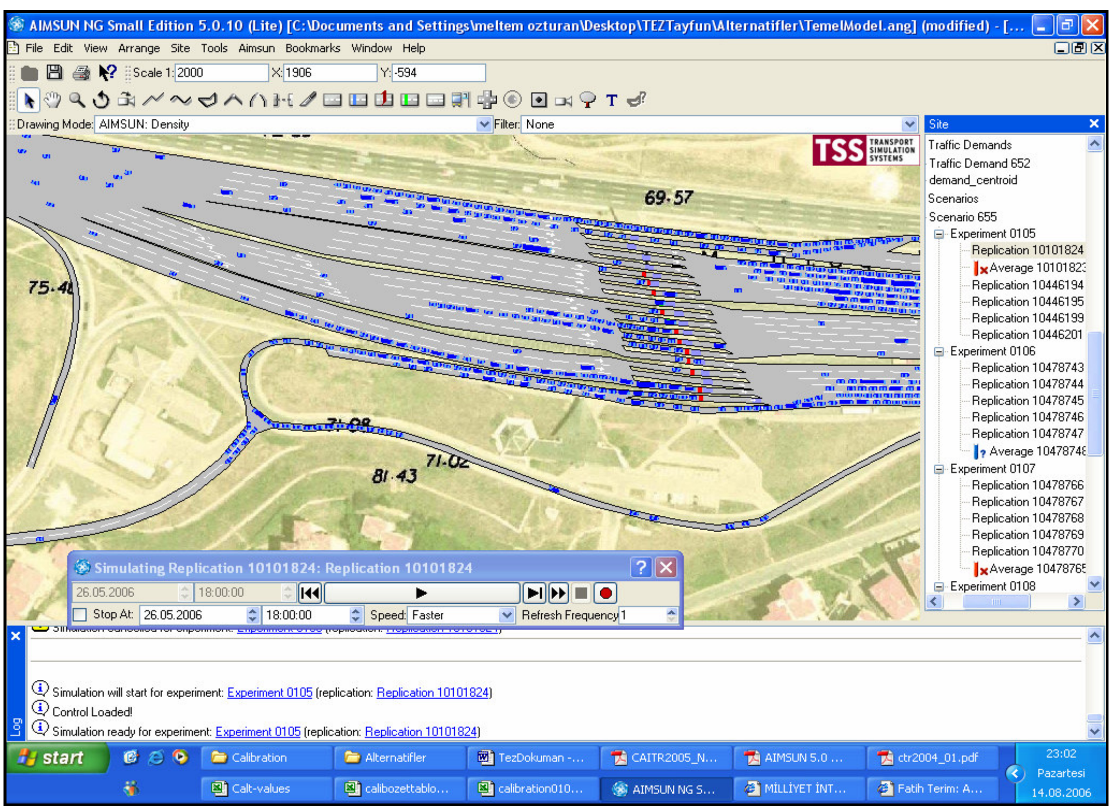


Figure C.4. Simulation snap-shot for 18:00 before toll plaza

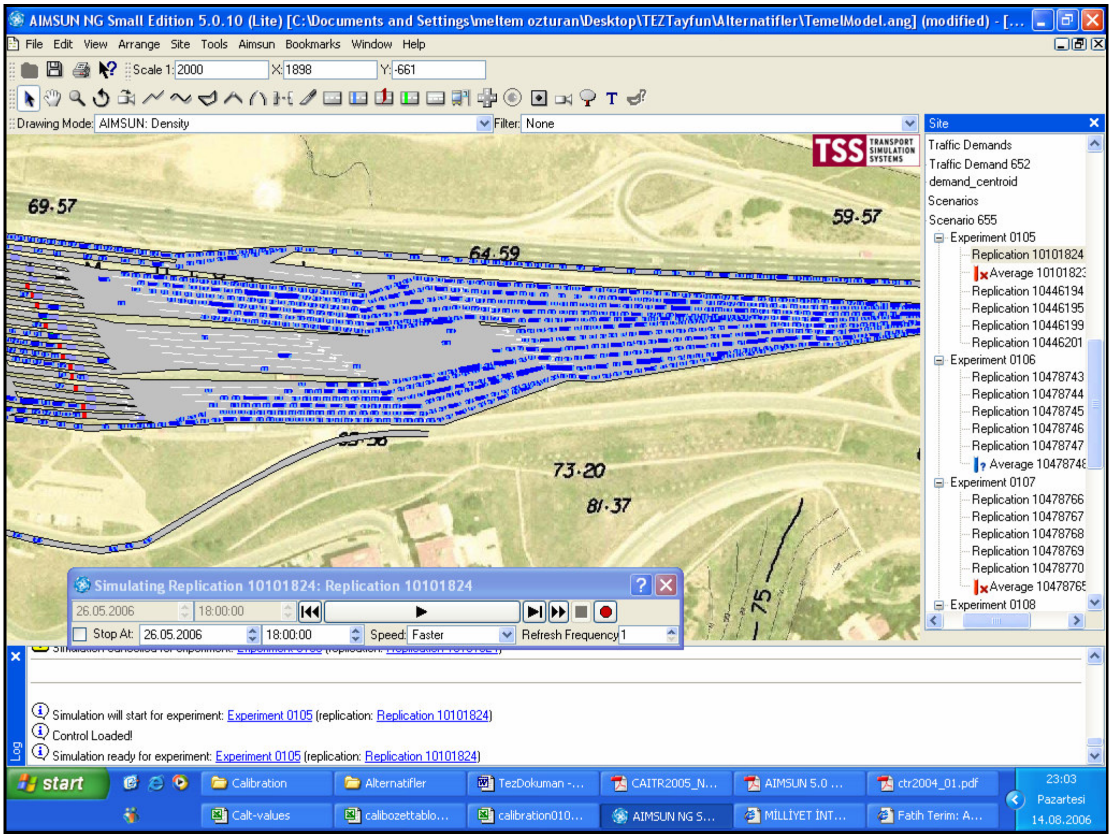


Figure C.5. Simulation snap-shot for 18:00 after toll plaza

Figure C.6. Video record snap-shot for 18:00 before toll plaza

Figure C.7. Video record snap-shot for 18:00 after toll plaza

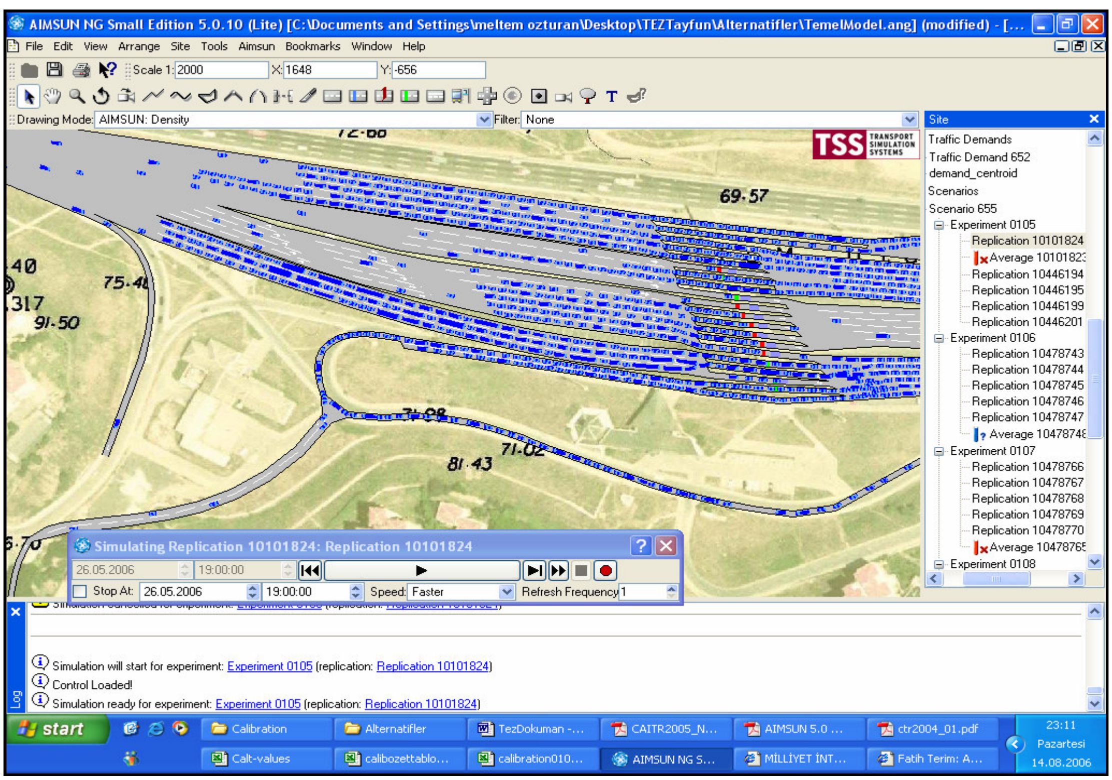


Figure C.8. Simulation snap-shot for 19:00 before toll plaza

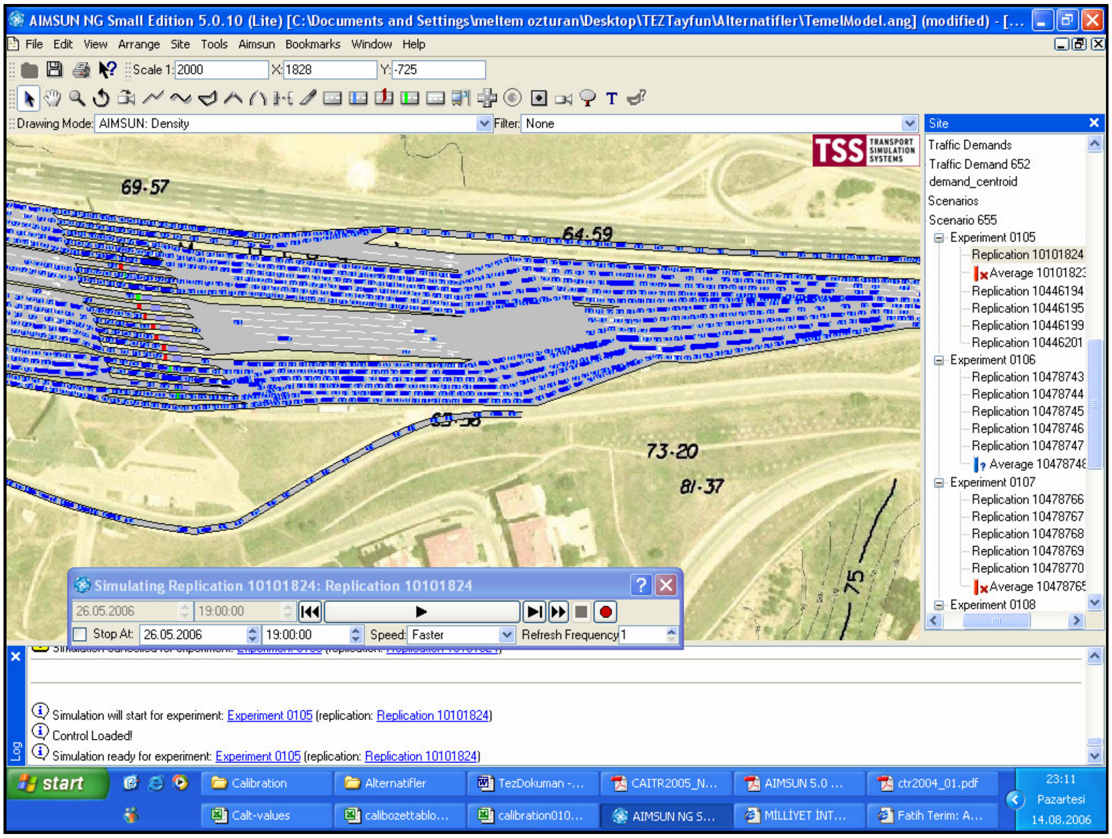


Figure C.9. Simulation snap-shot for 19:00 after toll plaza

Figure C.10. Video record snap-shot for 19:00 before toll plaza

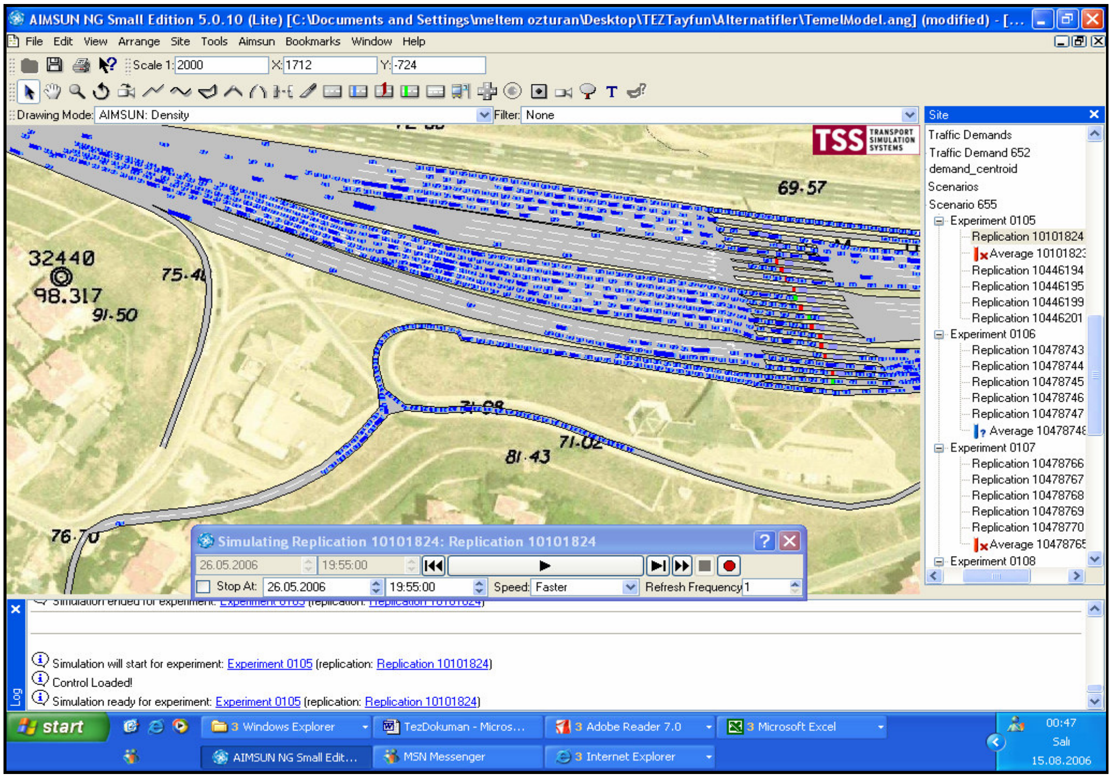


Figure C.11. Simulation snap-shot for 20:00 before toll plaza

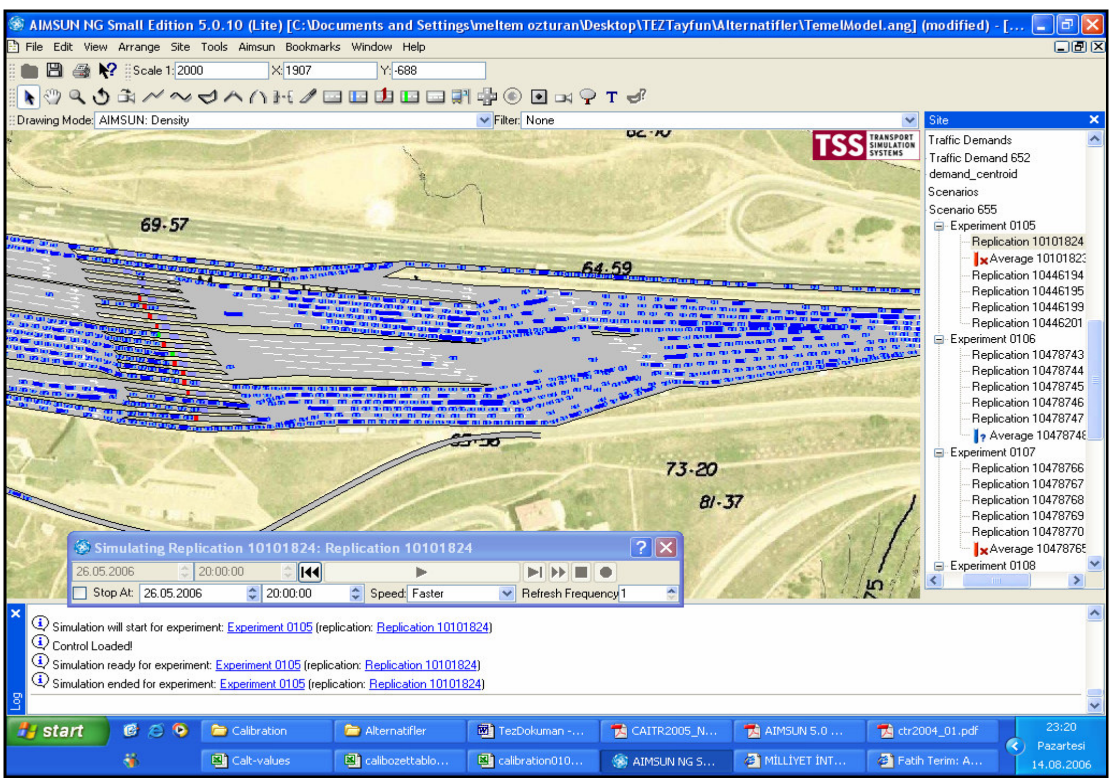


Figure C.12. Simulation snap-shot for 20:00 after toll plaza

Figure C.13. Video record snap-shot for 20:00 before toll plaza

APPENDIX D: SPLITTING PERCENTAGES OF ALTERNATIVES

D.1 ALTERNATIVE 1

Table D.1. Splitting percentages of Alternative 1 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		17:00-18:00 Vehicle Class 2 Splitting Percentages		17:00-18:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	9,8	108 to 112	6,3	108 to 112	6,8
108 to 110	45,4	108 to 110	52,0	108 to 110	83,3
108 to 109	44,8	108 to 109	41,7	108 to 109	9,8
140 to 212	10,0	140 to 212	10,0	140 to 212	100,0
140 to 206	90,0	140 to 206	90,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 151	16,3	149 to 151	16,0	149 to 151	8,5
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	29,8	220 to 222	30,1	220 to 222	50,0
220 to 224	70,2	220 to 224	69,9	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	45,0	10101885 to 10101896	45,0	10101885 to 10101896	45,0
10101885 to 10101888	30,0	10101885 to 10101888	30,0	10101885 to 10101888	30,0
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.2. Splitting percentages of Alternative 1 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110
18:00-19:00 Vehicle Class 1 Splitting Percentages		**18:00-19:00 Vehicle Class 2 Splitting Percentages**		**18:00-19:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	61,1	108 to 110	85,7	108 to 110	83,3
108 to 109	28,9	108 to 109	8,0	108 to 109	9,8
140 to 212	5,0	140 to 212	5,0	140 to 212	100,0
140 to 206	95,0	140 to 206	95,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 151	20,5	149 to 151	21,0	149 to 151	8,5
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	21,0	220 to 222	21,2	220 to 222	50,0
220 to 224	79,0	220 to 224	78,8	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	69,7
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,3
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.3. Splitting percentages of Alternative 1 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		19:00-20:00 Vehicle Class 2 Splitting Percentages		19:00-20:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	7,0	108 to 112	5,3	108 to 112	6,8
108 to 110	62,1	108 to 110	85,7	108 to 110	83,3
108 to 109	30,9	108 to 109	9,0	108 to 109	9,8
140 to 212	15,0	140 to 212	15,0	140 to 212	100,0
140 to 206	85,0	140 to 206	85,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	2,2
146 to 140	24,1	146 to 140	27,6	146 to 140	2,2
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	60,0
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 151	22,8	149 to 151	17,2	149 to 151	13,3
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	20,5	220 to 222	20,6	220 to 222	50,0
220 to 224	79,5	220 to 224	79,4	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,8
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	29,2
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

D.2 ALTERNATIVE 2

Table D.4. Splitting percentages of Alternative 2 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		17:00-18:00 Vehicle Class 2 Splitting Percentages		17:00-18:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	45,0	108 to 110	52,0	108 to 110	83,3
108 to 109	45,0	108 to 109	41,7	108 to 109	9,8
140 to 212	10,0	140 to 212	10,0	140 to 212	100,0
140 to 206	90,0	140 to 206	90,0	140 to 206	0,0
146 to 140	24,1	146 to 140	43,0	146 to 140	0,0
146 to 138	26,7	146 to 138	29,7	146 to 138	36,6
146 to 136	31,7	146 to 136	17,2	146 to 136	63,4
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 151	16,3	149 to 151	16,0	149 to 151	8,5
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
161 to 130	11,1	161 to 130	11,1	161 to 130	11,1
161 to 128	11,1	161 to 128	11,1	161 to 128	11,1
161 to 126	11,1	161 to 126	11,1	161 to 126	11,1
161 to 124	11,1	161 to 124	11,1	161 to 124	11,1
161 to 122	11,1	161 to 122	11,2	161 to 122	11,2
161 to 120	11,2	161 to 120	11,1	161 to 120	11,1
161 to 118	11,1	161 to 118	11,1	161 to 118	11,1
161 to 116	11,1	161 to 116	11,1	161 to 116	11,1
161 to 114	11,1	161 to 114	11,1	161 to 114	11,1
220 to 222	30,0	220 to 222	30,0	220 to 222	50,0
220 to 224	70,0	220 to 224	70,0	220 to 224	50,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 132	50,0	731 to 132	50,0	731 to 132	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	45,0	10101885 to 10101896	45,0	10101885 to 10101896	45,0
10101885 to 10101888	30,0	10101885 to 10101888	30,0	10101885 to 10101888	30,0
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.5. Splitting percentages of Alternative 2 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110

18:00-19:00 Vehicle Class 1 Splitting Percentages		18:00-19:00 Vehicle Class 2 Splitting Percentages		18:00-19:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	61,1	108 to 110	85,7	108 to 110	83,3
108 to 109	28,9	108 to 109	8,0	108 to 109	9,8
140 to 212	5,0	140 to 212	5,0	140 to 212	100,0
140 to 206	95,0	140 to 206	95,0	140 to 206	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	26,8	146 to 138	29,7	146 to 138	36,6
146 to 136	31,6	146 to 136	32,6	146 to 136	63,4
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 151	20,5	149 to 151	21,0	149 to 151	8,5
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
161 to 130	11,1	161 to 130	11,1	161 to 130	11,1
161 to 128	11,1	161 to 128	11,1	161 to 128	11,1
161 to 126	11,1	161 to 126	11,1	161 to 126	11,1
161 to 124	11,1	161 to 124	11,1	161 to 124	11,1
161 to 122	11,2	161 to 122	11,2	161 to 122	11,2
161 to 120	11,1	161 to 120	11,1	161 to 120	11,1
161 to 118	11,1	161 to 118	11,1	161 to 118	11,1
161 to 116	11,1	161 to 116	11,1	161 to 116	11,1
161 to 114	11,1	161 to 114	11,1	161 to 114	11,1
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 132	50,0	731 to 132	50,0	731 to 132	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.6. Splitting percentages of Alternative 2 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Turning Percentages		19:00-20:00 Vehicle Class 2 Turning Percentages		19:00-20:00 Vehicle Class 3 Turning Percentages	
Turn Sections	Turning Percentage (%)	Turn Sections	Turning Percentage (%)	Turn Sections	Turning Percentage (%)
108 to 112	7,0	108 to 112	5,3	108 to 112	6,8
108 to 110	62,1	108 to 110	85,7	108 to 110	83,3
108 to 109	30,9	108 to 109	9,0	108 to 109	9,8
140 to 212	15,0	140 to 212	15,0	140 to 212	100,0
140 to 206	85,0	140 to 206	85,0	140 to 206	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	2,2
146 to 138	26,7	146 to 138	29,7	146 to 138	34,4
146 to 136	31,7	146 to 136	32,6	146 to 136	61,2
146 to 142	17,5	146 to 142	10,1	146 to 142	2,2
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 151	22,8	149 to 151	17,2	149 to 151	13,3
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
161 to 130	11,1	161 to 130	11,1	161 to 130	11,1
161 to 128	11,1	161 to 128	11,1	161 to 128	11,1
161 to 126	11,1	161 to 126	11,1	161 to 126	11,1
161 to 124	11,1	161 to 124	11,1	161 to 124	11,1
161 to 122	11,1	161 to 122	11,2	161 to 122	11,2
161 to 120	11,2	161 to 120	11,1	161 to 120	11,1
161 to 118	11,1	161 to 118	11,1	161 to 118	11,1
161 to 116	11,1	161 to 116	11,1	161 to 116	11,1
161 to 114	11,1	161 to 114	11,1	161 to 114	11,1
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 132	50,0	731 to 132	50,0	731 to 132	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,0
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

D.3 ALTERNATIVE 3

Table D.7. Splitting percentages of Alternative 3 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115

17:00-18:00 Vehicle Class 1 Splitting Percentages		17:00-18:00 Vehicle Class 2 Splitting Percentages		17:00-18:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	45,0	108 to 110	52,0	108 to 110	83,3
108 to 109	45,0	108 to 109	41,7	108 to 109	9,8
140 to 212	10,0	140 to 212	10,0	140 to 212	100,0
140 to 206	90,0	140 to 206	90,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 151	16,3	149 to 151	16,0	149 to 151	8,5
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	30,0	220 to 222	30,0	220 to 222	50,0
220 to 224	70,0	220 to 224	70,0	220 to 224	50,0
224 to 10520415	89,4	224 to 10520415	90,2	224 to 10520415	50,0
224 to 10520417	10,6	224 to 10520417	9,8	224 to 10520417	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	45,0	10101885 to 10101896	45,0	10101885 to 10101896	45,0
10101885 to 10101888	30,0	10101885 to 10101888	30,0	10101885 to 10101888	30,0
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.8. Splitting percentages of Alternative 3 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110

18:00-19:00 Vehicle Class 1 Splitting Percentages		18:00-19:00 Vehicle Class 2 Splitting Percentages		18:00-19:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	61,1	108 to 110	85,7	108 to 110	83,3
108 to 109	28,9	108 to 109	8,0	108 to 109	9,8
140 to 212	5,0	140 to 212	5,0	140 to 212	100,0
140 to 206	95,0	140 to 206	95,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 151	20,5	149 to 151	21,0	149 to 151	8,5
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
224 to 10520415	92,3	224 to 10520415	93,6	224 to 10520415	50,0
224 to 10520417	7,7	224 to 10520417	6,4	224 to 10520417	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.9. Splitting percentages of Alternative 3 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		19:00-20:00 Vehicle Class 2 Splitting Percentages		19:00-20:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	7,0	108 to 112	5,3	108 to 112	6,8
108 to 110	62,1	108 to 110	85,7	108 to 110	83,3
108 to 109	30,9	108 to 109	9,0	108 to 109	9,8
140 to 212	15,0	140 to 212	15,0	140 to 212	100,0
140 to 206	85,0	140 to 206	85,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	2,2
146 to 140	24,1	146 to 140	27,6	146 to 140	2,2
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	60,0
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 151	22,8	149 to 151	17,2	149 to 151	13,3
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
224 to 10520415	93,9	224 to 10520415	92,4	224 to 10520415	50,0
224 to 10520417	6,1	224 to 10520417	7,6	224 to 10520417	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,0
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

D.4 ALTERNATIVE 4

Table D.10. Splitting percentages of Alternative 4 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		**17:00-18:00 Vehicle Class 2 Splitting Percentages**		**17:00-18:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 120	9,8	108 to 120	6,3	108 to 120	6,8
108 to 118	45,4	108 to 118	52,0	108 to 118	83,3
108 to 116	44,8	108 to 116	41,7	108 to 116	9,8
146 to 140	29,2	146 to 140	31,2	146 to 140	63,4
146 to 138	29,2	146 to 138	31,1	146 to 138	36,6
146 to 142	41,6	146 to 142	37,7	146 to 142	0,0
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
149 to 161	16,3	149 to 161	16,0	149 to 161	8,5
161 to 128	25,0	161 to 128	25,0	161 to 128	25,0
161 to 126	25,0	161 to 126	25,0	161 to 126	25,0
161 to 124	25,0	161 to 124	25,0	161 to 124	25,0
161 to 122	25,0	161 to 122	25,0	161 to 122	25,0
220 to 222	30,0	220 to 222	30,0	220 to 222	50,0
220 to 224	35,0	220 to 224	35,0	220 to 224	25,0
220 to 10478953	35,0	220 to 10478953	35,0	220 to 10478953	25,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 130	50,0	731 to 130	50,0	731 to 130	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	45,0	10101885 to 10101896	45,0	10101885 to 10101896	45,0
10101885 to 10101888	30,0	10101885 to 10101888	30,0	10101885 to 10101888	30,0
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	100,0
10478707 to 208	0,0	10478707 to 208	0,0	10478707 to 208	0,0

Table D.11. Splitting percentages of Alternative 4 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110
18:00-19:00 Vehicle Class 1 Splitting Percentages		**18:00-19:00 Vehicle Class 2 Splitting Percentages**		**18:00-19:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 120	10,0	108 to 120	6,3	108 to 120	6,8
108 to 118	61,1	108 to 118	85,7	108 to 118	83,3
108 to 116	28,9	108 to 116	8,0	108 to 116	9,8
146 to 140	29,2	146 to 140	31,2	146 to 140	63,4
146 to 138	29,2	146 to 138	31,1	146 to 138	36,6
146 to 142	41,6	146 to 142	37,7	146 to 142	0,0
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
149 to 161	20,5	149 to 161	21,0	149 to 161	8,5
161 to 128	25,0	161 to 128	25,0	161 to 128	25,0
161 to 126	25,0	161 to 126	25,0	161 to 126	25,0
161 to 124	25,0	161 to 124	25,0	161 to 124	25,0
161 to 122	25,0	161 to 122	25,0	161 to 122	25,0
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	39,5	220 to 224	39,5	220 to 224	25,0
220 to 10478953	39,5	220 to 10478953	39,5	220 to 10478953	25,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 130	50,0	731 to 130	50,0	731 to 130	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	100,0
10478707 to 208	0,0	10478707 to 208	0,0	10478707 to 208	0,0

Table D.12. Splitting percentages of Alternative 4 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		**19:00-20:00 Vehicle Class 2 Splitting Percentages**		**19:00-20:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 120	7,0	108 to 120	5,3	108 to 120	6,8
108 to 118	62,1	108 to 118	85,7	108 to 118	83,3
108 to 116	30,9	108 to 116	9,0	108 to 116	9,8
146 to 140	29,2	146 to 140	31,2	146 to 140	65,6
146 to 138	29,2	146 to 138	31,1	146 to 138	34,4
146 to 142	41,6	146 to 142	37,7	146 to 142	0,0
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
149 to 161	22,8	149 to 161	17,2	149 to 161	13,3
161 to 128	25,0	161 to 128	25,0	161 to 128	25,0
161 to 126	25,0	161 to 126	25,0	161 to 126	25,0
161 to 124	25,0	161 to 124	25,0	161 to 124	25,0
161 to 122	25,0	161 to 122	25,0	161 to 122	25,0
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	39,5	220 to 224	39,5	220 to 224	25,0
220 to 10478953	39,5	220 to 10478953	39,5	220 to 10478953	25,0
731 to 134	50,0	731 to 134	50,0	731 to 134	50,0
731 to 130	50,0	731 to 130	50,0	731 to 130	50,0
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,0
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	100,0
10478707 to 208	0,0	10478707 to 208	0,0	10478707 to 208	0,0

D.5 ALTERNATIVE 5

Table D.13. Splitting percentages of Alternative 5 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		**17:00-18:00 Vehicle Class 2 Splitting Percentages**		**17:00-18:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
149 to 144	9,10	149 to 144	14,1	149 to 144	0,0
149 to 142	5,10	149 to 142	4,8	149 to 142	0,0
149 to 140	5,10	149 to 140	4,8	149 to 140	0,0
149 to 138	5,10	149 to 138	4,8	149 to 138	6,2
149 to 136	5,10	149 to 136	4,8	149 to 136	6,3
149 to 134	5,10	149 to 134	4,8	149 to 134	6,2
149 to 132	5,10	149 to 132	4,8	149 to 132	6,3
149 to 130	5,10	149 to 130	4,8	149 to 130	6,2
149 to 128	5,10	149 to 128	4,8	149 to 128	6,3
149 to 126	5,10	149 to 126	4,8	149 to 126	6,2
149 to 124	5,00	149 to 124	4,8	149 to 124	6,3
149 to 122	5,00	149 to 122	4,8	149 to 122	6,2
149 to 120	5,00	149 to 120	4,8	149 to 120	6,3
149 to 118	5,00	149 to 118	4,8	149 to 118	6,2
149 to 116	5,00	149 to 116	4,7	149 to 116	6,3
149 to 114	5,00	149 to 114	4,7	149 to 114	6,2
149 to 112	5,00	149 to 112	4,7	149 to 112	6,3
149 to 110	5,00	149 to 110	4,7	149 to 110	6,2
149 to 109	5,00	149 to 109	4,7	149 to 109	6,3
220 to 222	50,00	220 to 222	50,0	220 to 222	50,0
220 to 224	50,00	220 to 224	50,0	220 to 224	50,0
10478700 to 10101788	33,90	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,10	10478700 to 10101885	70,6	10478700 to 10101885	30,4

Table D.14. Splitting percentages of Alternative 5 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110
18:00-19:00 Vehicle Class 1 Splitting Percentages		**18:00-19:00 Vehicle Class 2 Splitting Percentages**		**18:00-19:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 142	5,0	149 to 142	4,7	149 to 142	0,0
149 to 140	5,0	149 to 140	4,7	149 to 140	0,0
149 to 138	5,0	149 to 138	4,7	149 to 138	6,2
149 to 136	5,0	149 to 136	4,7	149 to 136	6,3
149 to 134	5,0	149 to 134	4,7	149 to 134	6,2
149 to 132	5,0	149 to 132	4,7	149 to 132	6,3
149 to 130	5,0	149 to 130	4,7	149 to 130	6,2
149 to 128	5,0	149 to 128	4,7	149 to 128	6,3
149 to 126	5,0	149 to 126	4,7	149 to 126	6,2
149 to 124	5,0	149 to 124	4,7	149 to 124	6,3
149 to 122	5,0	149 to 122	4,7	149 to 122	6,2
149 to 120	5,0	149 to 120	4,6	149 to 120	6,3
149 to 118	5,0	149 to 118	4,6	149 to 118	6,2
149 to 116	4,9	149 to 116	4,6	149 to 116	6,3
149 to 114	4,9	149 to 114	4,6	149 to 114	6,2
149 to 112	4,9	149 to 112	4,6	149 to 112	6,3
149 to 110	4,9	149 to 110	4,6	149 to 110	6,2
149 to 109	4,9	149 to 109	4,6	149 to 109	6,3
220 to 222	50,0	220 to 222	50,0	220 to 222	50,0
220 to 224	50,0	220 to 224	50,0	220 to 224	50,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0

Table D.15. Splitting percentages of Alternative 5 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		**19:00-20:00 Vehicle Class 2 Splitting Percentages**		**19:00-20:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
149 to 144	7,4	149 to 144	5,5	149 to 144	0
149 to 142	5,2	149 to 142	5,2	149 to 142	0
149 to 140	5,2	149 to 140	5,3	149 to 140	0
149 to 138	5,2	149 to 138	5,2	149 to 138	6,2
149 to 136	5,2	149 to 136	5,3	149 to 136	6,3
149 to 134	5,2	149 to 134	5,2	149 to 134	6,2
149 to 132	5,2	149 to 132	5,3	149 to 132	6,3
149 to 130	5,2	149 to 130	5,2	149 to 130	6,2
149 to 128	5,2	149 to 128	5,3	149 to 128	6,3
149 to 126	5,1	149 to 126	5,2	149 to 126	6,2
149 to 124	5,1	149 to 124	5,3	149 to 124	6,3
149 to 122	5,1	149 to 122	5,2	149 to 122	6,2
149 to 120	5,1	149 to 120	5,3	149 to 120	6,3
149 to 118	5,1	149 to 118	5,2	149 to 118	6,2
149 to 116	5,1	149 to 116	5,3	149 to 116	6,3
149 to 114	5,1	149 to 114	5,2	149 to 114	6,2
149 to 112	5,1	149 to 112	5,3	149 to 112	6,3
149 to 110	5,1	149 to 110	5,2	149 to 110	6,2
149 to 109	5,1	149 to 109	5,3	149 to 109	6,3
220 to 222	50	220 to 222	50	220 to 222	50
220 to 224	50	220 to 224	50	220 to 224	50
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30

D.6 ALTERNATIVE 6

Table D.16. Splitting percentages of Alternative 6 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7061	149	1810	149	181
198	459	198	53	198	0
1090	459	1090	53	1090	0
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		**17:00-18:00 Vehicle Class 2 Splitting Percentages**		**17:00-18:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	45,0	108 to 110	52,0	108 to 110	83,3
108 to 109	45,0	108 to 109	41,7	108 to 109	9,8
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 151	16,3	149 to 151	16,0	149 to 151	8,5
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	30,0	220 to 222	30,0	220 to 222	50,0
220 to 224	70,0	220 to 224	70,0	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4

Table D.17. Splitting percentages of Alternative 6 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7107	149	1822	149	175
198	402	198	103	198	0
1090	402	1090	103	1090	0
10101790	1157	10101790	143	10101790	110
18:00-19:00 Vehicle Class 1 Splitting Percentages		**18:00-19:00 Vehicle Class 2 Splitting Percentages**		**18:00-19:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	61,1	108 to 110	85,7	108 to 110	83,3
108 to 109	28,9	108 to 109	8,0	108 to 109	9,8
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 151	20,5	149 to 151	21,0	149 to 151	8,5
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0

Table D.18. Splitting percentages of Alternative 6 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	6754	149	1634	149	160
198	365	198	46	198	0
1090	365	1090	46	1090	0
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		**19:00-20:00 Vehicle Class 2 Splitting Percentages**		**19:00-20:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 112	7,0	108 to 112	5,3	108 to 112	6,8
108 to 110	62,1	108 to 110	85,7	108 to 110	83,3
108 to 109	30,9	108 to 109	9,0	108 to 109	9,8
146 to 142	17,5	146 to 142	10,1	146 to 142	2,2
146 to 140	24,1	146 to 140	27,6	146 to 140	2,2
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	60,0
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 151	22,8	149 to 151	17,2	149 to 151	13,3
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
220 to 222	21,0	220 to 222	21,0	220 to 222	50,0
220 to 224	79,0	220 to 224	79,0	220 to 224	50,0
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,0
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30,0

D.7 ALTERNATIVE 7

Table D.19. Splitting percentages of Alternative 7 between 17:00-18:00

17:00-18:00 Vehicle Class 1 Input Flows		17:00-18:00 Vehicle Class 2 Input Flows		17:00-18:00 Vehicle Class 3 Input Flows	
Section	**Flow**	**Section**	**Flow**	**Section**	**Flow**
149	7979	149	1916	149	181
10101790	723	10101790	93	10101790	115
17:00-18:00 Vehicle Class 1 Splitting Percentages		**17:00-18:00 Vehicle Class 2 Splitting Percentages**		**17:00-18:00 Vehicle Class 3 Splitting Percentages**	
Turn Sections	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**	**Turn Sections**	**Splitting Percentage (%)**
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	45,0	108 to 110	52,0	108 to 110	83,3
108 to 109	45,0	108 to 109	41,7	108 to 109	9,8
140 to 212	10,0	140 to 212	10,0	140 to 212	100,0
140 to 206	90,0	140 to 206	90,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	9,1	149 to 144	14,1	149 to 144	0,0
149 to 146	59,3	149 to 146	42,3	149 to 146	22,5
149 to 731	8,3	149 to 731	7,4	149 to 731	3,0
149 to 151	16,3	149 to 151	16,0	149 to 151	8,5
149 to 108	7,0	149 to 108	20,2	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	45,0	10101885 to 10101896	45,0	10101885 to 10101896	45,0
10101885 to 10101888	30,0	10101885 to 10101888	30,0	10101885 to 10101888	30,0
10478700 to 10101788	33,9	10478700 to 10101788	29,4	10478700 to 10101788	69,6
10478700 to 10101885	66,1	10478700 to 10101885	70,6	10478700 to 10101885	30,4
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.20. Splitting percentages of Alternative 7 between 18:00-19:00

18:00-19:00 Vehicle Class 1 Input Flows		18:00-19:00 Vehicle Class 2 Input Flows		18:00-19:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7911	149	2028	149	175
10101790	1157	10101790	143	10101790	110
18:00-19:00 Vehicle Class 1 Splitting Percentages		18:00-19:00 Vehicle Class 2 Splitting Percentages		18:00-19:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	10,0	108 to 112	6,3	108 to 112	6,8
108 to 110	61,1	108 to 110	85,7	108 to 110	83,3
108 to 109	28,9	108 to 109	8,0	108 to 109	9,8
140 to 212	5,0	140 to 212	5,0	140 to 212	100,0
140 to 206	95,0	140 to 206	95,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	0,0
146 to 140	24,1	146 to 140	27,6	146 to 140	0,0
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	64,4
149 to 144	10,5	149 to 144	16,1	149 to 144	0,0
149 to 146	51,4	149 to 146	40,8	149 to 146	22,5
149 to 731	10,8	149 to 731	7,4	149 to 731	3,0
149 to 151	20,5	149 to 151	21,0	149 to 151	8,5
149 to 108	6,8	149 to 108	14,7	149 to 108	66,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	37,2	10478700 to 10101788	37,7	10478700 to 10101788	70,0
10478700 to 10101885	62,8	10478700 to 10101885	62,3	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

Table D.21. Splitting percentages of Alternative 7 between 19:00-20:00

19:00-20:00 Vehicle Class 1 Input Flows		19:00-20:00 Vehicle Class 2 Input Flows		19:00-20:00 Vehicle Class 3 Input Flows	
Section	Flow	Section	Flow	Section	Flow
149	7484	149	1726	149	160
10101790	663	10101790	15	10101790	108
19:00-20:00 Vehicle Class 1 Splitting Percentages		19:00-20:00 Vehicle Class 2 Splitting Percentages		19:00-20:00 Vehicle Class 3 Splitting Percentages	
Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)	Turn Sections	Splitting Percentage (%)
108 to 112	7,0	108 to 112	5,3	108 to 112	6,8
108 to 110	62,1	108 to 110	85,7	108 to 110	83,3
108 to 109	30,9	108 to 109	9,0	108 to 109	9,8
140 to 212	15,0	140 to 212	15,0	140 to 212	100,0
140 to 206	85,0	140 to 206	85,0	140 to 206	0,0
146 to 142	17,5	146 to 142	10,1	146 to 142	2,2
146 to 140	24,1	146 to 140	27,6	146 to 140	2,2
146 to 138	14,0	146 to 138	14,3	146 to 138	4,4
146 to 136	18,9	146 to 136	17,2	146 to 136	31,1
146 to 134	25,5	146 to 134	30,8	146 to 134	60,0
149 to 144	7,4	149 to 144	5,5	149 to 144	0,0
149 to 146	49,0	149 to 146	56,9	149 to 146	39,7
149 to 731	8,8	149 to 731	7,4	149 to 731	24,0
149 to 151	22,8	149 to 151	17,2	149 to 151	13,3
149 to 108	12,0	149 to 108	13,0	149 to 108	23,0
161 to 124	14,5	161 to 124	19,4	161 to 124	23,5
161 to 122	15,9	161 to 122	19,1	161 to 122	35,3
161 to 120	17,2	161 to 120	20,6	161 to 120	5,9
161 to 118	18,9	161 to 118	15,0	161 to 118	0,0
161 to 116	17,2	161 to 116	15,2	161 to 116	11,8
161 to 114	16,3	161 to 114	10,8	161 to 114	23,5
731 to 132	24,4	731 to 132	21,0	731 to 132	33,3
731 to 130	24,0	731 to 130	28,0	731 to 130	16,7
731 to 128	24,8	731 to 128	19,6	731 to 128	16,7
731 to 126	26,8	731 to 126	31,5	731 to 126	33,3
10101885 to 10101894	25,0	10101885 to 10101894	25,0	10101885 to 10101894	25,0
10101885 to 10101896	35,0	10101885 to 10101896	35,0	10101885 to 10101896	35,0
10101885 to 10101888	40,0	10101885 to 10101888	40,0	10101885 to 10101888	40,0
10478700 to 10101788	26,3	10478700 to 10101788	26,8	10478700 to 10101788	70,0
10478700 to 10101885	73,7	10478700 to 10101885	73,2	10478700 to 10101885	30,0
10478707 to 206	100,0	10478707 to 206	100,0	10478707 to 206	0,0
10478707 to 212	0,0	10478707 to 212	0,0	10478707 to 212	100,0

APPENDIX E: SIMULATION RESULTS OF ALTERNATIVE DESIGNS

E.1 ALTERNATIVE 1

Table E.1. Simulation results of Alternative 1

Rep	Pollutant Emission (kg)	
1	CO	5751,84
	HC	473,11
	NOx	121,48
2	CO	4783,69
	HC	384,40
	NOx	101,96
3	CO	5279,95
	HC	427,36
	NOx	111,98
4	CO	4996,44
	HC	404,96
	NOx	106,96
5	CO	5080,26
	HC	412,35
	NOx	107,64
6	CO	5686,08
	HC	464,54
	NOx	120,51
7	CO	5323,15
	HC	433,41
	NOx	113,22
8	CO	4900,52
	HC	395,90
	NOx	104,90
9	CO	4849,65
	HC	386,25
	NOx	103,32
10	CO	5041,20
	HC	404,58
	NOx	107,18

Rep	Fuel Consumption (l)
1	54558,02
2	50466,72
3	53034,10
4	50007,24
5	50828,23
6	55245,46
7	53725,27
8	49988,35
9	49782,79
10	51339,74

Rep	Throghput (veh)	Total System Throghput (veh)
1	25551,00	25668,00
2	27356,00	27541,00
3	26984,00	27028,00
4	27326,00	26220,00
5	26470,00	26290,00
6	26227,00	26613,00
7	27150,00	27299,00
8	27158,00	26886,00
9	26984,00	26529,00
10	26942,00	26951,00

Rep	Total Delay (sec)	Total Delay (hr)
1	85460529,00	23739,04
2	65394111,00	18165,03
3	75343821,00	20928,84
4	76147352,00	21152,04
5	72181157,00	20050,32
6	83126785,00	23090,77
7	76116504,00	21143,47
8	67463872,00	18739,96
9	66143389,00	18373,16
10	70138854,00	19483,02

E.2 ALTERNATIVE 2

Table E.2. Simulation results of Alternative 2

Rep	Pollutant Emission (kg)	
1	CO	5114,05
	HC	410,18
	NOx	108,30
2	CO	4668,13
	HC	367,13
	NOx	100,33
3	CO	5419,78
	HC	445,23
	NOx	115,04
4	CO	5096,16
	HC	409,60
	NOx	108,12
5	CO	5039,22
	HC	408,66
	NOx	107,18
6	CO	5230,56
	HC	422,57
	NOx	110,40
7	CO	5470,04
	HC	453,87
	NOx	115,68
8	CO	5233,55
	HC	423,92
	NOx	111,65
9	CO	5471,30
	HC	450,65
	NOx	115,52
10	CO	5421,87
	HC	446,22
	NOx	114,54

Rep	Fuel Consumption (l)
1	52307,33
2	50190,10
3	54898,12
4	51741,72
5	51578,60
6	52400,37
7	54129,75
8	53552,09
9	53632,91
10	53682,30

Rep	Throghput (veh)	Total System Throghput (veh)
1	26937,00	26805,00
2	27353,00	27528,00
3	26938,00	27261,00
4	26451,00	26461,00
5	26473,00	26613,00
6	26612,00	26621,00
7	26564,00	26656,00
8	26867,00	27056,00
9	26136,00	26059,00
10	25987,00	26060,00

Rep	Total Delay (sec)	Total Delay (hr)
1	71796421,00	19943,45
2	60952614,00	16931,28
3	78743127,00	21873,09
4	71571954,00	19881,10
5	71146194,00	19762,83
6	74860827,00	20794,67
7	81325859,00	22590,52
8	73890735,00	20525,20
9	80805355,00	22445,93
10	80061267,00	22239,24

E.3 ALTERNATIVE 3

Table E.3. Simulation results of Alternative 3

Rep	Pollutant Emission (kg)	
1	CO	5294,80
	HC	429,95
	NOx	112,39
2	CO	5489,77
	HC	449,51
	NOx	116,44
3	CO	5769,31
	HC	474,08
	NOx	121,91
4	CO	5190,12
	HC	420,93
	NOx	109,76
5	CO	5220,49
	HC	423,12
	NOx	110,87
6	CO	5627,49
	HC	458,49
	NOx	119,01
7	CO	5543,88
	HC	449,69
	NOx	116,83
8	CO	4973,53
	HC	398,31
	NOx	105,82
9	CO	4878,30
	HC	393,21
	NOx	103,70
10	CO	5320,27
	HC	428,47
	NOx	112,07

Rep	Fuel Consumption (l)
1	52702,97
2	54442,23
3	55036,49
4	51807,83
5	52640,04
6	55070,40
7	54340,23
8	51610,88
9	50276,09
10	52191,14

Rep	Throghput (veh)	Total System Throghput (veh)
1	26235,00	26274,00
2	26356,00	26537,00
3	25426,00	25442,00
4	26368,00	26298,00
5	26586,00	26777,00
6	25757,00	26154,00
7	25918,00	26143,00
8	27107,00	27215,00
9	26556,00	26655,00
10	26429,00	26316,00

Rep	Total Delay (sec)	Total Delay (hr)
1	75879142,00	21077,54
2	79885351,00	22190,38
3	86084005,00	23912,22
4	74402497,00	20667,36
5	74452578,00	20681,27
6	82388562,00	22885,71
7	81114788,00	22531,89
8	68749119,00	19096,98
9	67876280,00	18854,52
10	76456018,00	21237,78

E.4 ALTERNATIVE 4

Table E.4. Simulation results of Alternative 4

Rep	Pollutant Emission (kg)	
1	CO	2646,79
	HC	200,08
	NOx	57,49
2	CO	2667,58
	HC	201,47
	NOx	58,19
3	CO	2798,09
	HC	210,76
	NOx	60,99
4	CO	2805,29
	HC	210,64
	NOx	61,27
5	CO	2865,88
	HC	216,66
	NOx	62,35
6	CO	2794,32
	HC	210,51
	NOx	61,07
7	CO	2646,46
	HC	199,69
	NOx	57,65
8	CO	2727,76
	HC	204,22
	NOx	58,91
9	CO	2614,07
	HC	197,41
	NOx	56,79
10	CO	2683,14
	HC	201,47
	NOx	58,30

Rep	Fuel Consumption (l)
1	30874,53
2	31234,58
3	32717,69
4	32556,77
5	33149,80
6	32238,69
7	30719,68
8	31330,48
9	30275,00
10	31278,04

Rep	Throghput (veh)	Total System Throghput (veh)
1	24567,00	24746,00
2	24654,00	24782,00
3	24751,00	25250,00
4	24734,00	25090,00
5	24574,00	25143,00
6	24700,00	24825,00
7	24606,00	24585,00
8	24723,00	24815,00
9	24393,00	24353,00
10	24839,00	24883,00

Rep	Total Delay (sec)	Total Delay (hr)
1	27086965,00	7524,16
2	27098136,00	7527,26
3	28860440,00	8016,79
4	28786577,00	7996,27
5	30180199,00	8383,39
6	28712970,00	7975,83
7	26868828,00	7463,56
8	27998509,00	7777,36
9	26646789,00	7401,89
10	27128586,00	7535,72

E.5 ALTERNATIVE 5

Table E.5. Simulation results of Alternative 5

Rep	Pollutant Emission (kg)	
1	CO	1254,64
	HC	89,99
	NOx	27,02
2	CO	1242,01
	HC	90,08
	NOx	26,93
3	CO	1228,49
	HC	88,00
	NOx	26,36
4	CO	1222,22
	HC	87,83
	NOx	26,11
5	CO	1215,25
	HC	88,81
	NOx	26,25
6	CO	1236,07
	HC	89,33
	NOx	26,72
7	CO	1222,03
	HC	87,81
	NOx	26,14
8	CO	1245,62
	HC	89,35
	NOx	26,94
9	CO	1233,70
	HC	89,27
	NOx	26,74
10	CO	1236,10
	HC	89,49
	NOx	26,91

Rep	Fuel Consumption (l)
1	20414,10
2	20009,04
3	19965,47
4	19902,16
5	19520,13
6	20031,98
7	19836,66
8	20300,69
9	20079,50
10	20151,99

Rep	Throghput (veh)	Total System Throghput (veh)
1	27565,00	27657,00
2	27331,00	27383,00
3	27134,00	27251,00
4	27332,00	27474,00
5	27073,00	27051,00
6	27055,00	27155,00
7	27153,00	27305,00
8	27297,00	27352,00
9	27219,00	27374,00
10	27255,00	27260,00

Rep	Total Delay (sec)	Total Delay (hr)
1	3585390,00	995,94
2	3737974,00	1038,33
3	3473728,00	964,92
4	3455783,00	959,94
5	3607846,00	1002,18
6	3656085,00	1015,58
7	3492386,00	970,11
8	3557142,00	988,10
9	3555827,00	987,73
10	3554421,00	987,34

E.6 ALTERNATIVE 6

Table E.6. Simulation results of Alternative 6

Rep	Pollutant Emission (kg)	
1	CO	1288,24
	HC	95,54
	NOx	27,44
2	CO	1317,38
	HC	97,18
	NOx	27,77
3	CO	1263,50
	HC	93,90
	NOx	27,14
4	CO	1347,88
	HC	100,57
	NOx	28,78
5	CO	1294,73
	HC	96,39
	NOx	27,44
6	CO	1302,49
	HC	96,39
	NOx	27,41
7	CO	1273,90
	HC	94,63
	NOx	27,18
8	CO	1258,88
	HC	92,98
	NOx	26,94
9	CO	1233,82
	HC	90,53
	NOx	25,96
10	CO	1317,58
	HC	97,85
	NOx	28,10

Rep	Fuel Consumption (l)
1	19496,59
2	19664,56
3	19356,19
4	20090,51
5	19392,05
6	19386,19
7	19286,58
8	19312,25
9	18805,29
10	19763,86

Rep	Throghput (veh)	Total System Throghput (veh)
1	27444,00	27489,00
2	27396,00	27422,00
3	27032,00	27131,00
4	27400,00	27456,00
5	27263,00	27392,00
6	27350,00	27331,00
7	27178,00	27199,00
8	27203,00	27349,00
9	27082,00	27113,00
10	27265,00	27243,00

Rep	Total Delay (sec)	Total Delay (hr)
1	4908090,00	1363,36
2	5417398,00	1504,83
3	4743643,00	1317,68
4	5983808,00	1662,17
5	5287771,00	1468,83
6	5345849,00	1484,96
7	4896420,00	1360,12
8	4381036,00	1216,95
9	4194142,00	1165,04
10	5523612,00	1534,34

E.7 ALTERNATIVE 7

Table E.7. Simulation results of Alternative 7

Rep	Pollutant Emission (kg)	
1	CO	5386,50
	HC	428,68
	NOx	114,68
2	CO	4574,88
	HC	355,43
	NOx	98,14
3	CO	4816,02
	HC	377,48
	NOx	103,22
4	CO	4032,55
	HC	309,23
	NOx	86,84
5	CO	5075,40
	HC	400,16
	NOx	108,84
6	CO	4577,56
	HC	355,94
	NOx	98,12
7	CO	5113,82
	HC	405,38
	NOx	109,41
8	CO	4808,31
	HC	376,23
	NOx	103,34
9	CO	4873,09
	HC	383,14
	NOx	104,87
10	CO	4936,93
	HC	387,01
	NOx	105,80

Rep	Fuel Consumption (l)
1	53010,87
2	49403,85
3	50314,83
4	43893,46
5	52787,82
6	48075,07
7	51708,19
8	50061,56
9	50263,14
10	51541,00

Rep	Throghput (veh)	Total System Throghput (veh)
1	25509,00	25087,00
2	26927,00	27188,00
3	26455,00	26387,00
4	26682,00	26699,00
5	26004,00	26370,00
6	26877,00	26678,00
7	26025,00	25904,00
8	26714,00	26526,00
9	26657,00	26522,00
10	26722,00	26677,00

Rep	Total Delay (sec)	Total Delay (hr)
1	75283137,00	20911,98
2	58859508,00	16349,86
3	63623026,00	17673,06
4	49170028,00	13658,34
5	68695554,00	19082,10
6	58789450,00	16330,40
7	69752890,00	19375,80
8	62982989,00	17495,27
9	64260824,00	17850,23
10	65665688,00	18240,47

APPENDIX F: DETAILED HYPOTHESIS TESTING RESULTS BETWEEN ALTERNATIVES FOR MEASURES OF EFFECTIVENESS

F.1 ALTERNATIVE 1&2

Table F.1. Fuel consumption comparison between Alternatives 1&2

	Aternatives				
Replications	1	2			
1	*54558,02441*	*52307,33203*			
2	*50466,71875*	*50190,10059*			
3	*53034,10254*	*54898,11719*			
4	*50007,23926*	*51741,71582*			
5	*50828,2334*	*51578,60156*			
6	*55245,46094*	*52400,37305*			
7	*53725,26953*	*54129,74707*			
8	*49988,34766*	*53552,08984*			
9	*49782,78516*	*53632,91211*		**Gen. Avg.**	**52354,46**
10	*51339,7412*	*53682,29883*			
Avg.	**51897,5923**	**52811,32881**			
Std. Dev.	**2057,8135**	**1415,495612**			
Var.	**4234596,38**	**2003627,828**			
Avg.-Gen.Avg.	**-456,86826**	**456,8682623**			
SQR. (Avg.-Gen.Avg.)	**208728,609**	**208728,6091**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**3119112,105**				
Alpha	**0,05**				
t-critical	**2,1**				
Abs(1Avg-2Avg)	**913,7365245**				
Sp	**1766,10082**				
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical	
				Not rejected	
t-value	**1,15688581**				

Table F.2. Pollution comparison between Alternatives 1&2

	Aternatives			
Replications	1	2		
1	*5751,842407*	*5114,046265*		
2	*4783,689331*	*4668,134521*		
3	*5279,945313*	*5419,784912*		
4	*4996,439575*	*5096,162231*		
5	*5080,259888*	*5039,220947*		
6	*5686,080566*	*5230,5625*		
7	*5323,151123*	*5470,035889*		
8	*4900,517822*	*5233,546875*		
9	*4849,6521*	*5471,299927*	**Gen. Avg.**	**5192,872**
10	*5041,2*	*5421,872925*		
Avg.	**5169,27781**	**5216,466699**		
Std. Dev.	**336,594557**	**251,7284889**		
Var.	**113295,896**	**63367,23211**		
Avg.-Gen.Avg.	**-23,594443**	**23,59444336**		
SQR. (Avg.-Gen.Avg.)	**556,697757**	**556,6977574**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**88331,56404**			
Alpha	**0,05**			
t-critical	**2,1**			
Abs(1Avg-2Avg)	**47,18888672**			
Sp	**297,2062651**			
Sqrt(1/n+1/m)	**0,447213595**		t<t-critical	
			Not rejected	
t-value	**0,35503141**			

Table F.3. Total delay comparison between Alternatives 1&2

	Aternatives			
Replications	1	2		
1	*85460529*	*71796421*		
2	*65394111*	*60952614*		
3	*75343821*	*78743127*		
4	*76147352*	*71571954*		
5	*72181157*	*71146194*		
6	*83126785*	*74860827*		
7	*76116504*	*81325859*		
8	*67463872*	*73890735*		
9	*66143389*	*80805355*	**Gen. Avg.**	**74133536,35**
10	*70138854*	*80061267*		
Avg.	**73751637,4**	**74515435,3**		
Std. Dev.	**6844681,01**	**6204327,903**		
Var.	**4,685E+13**	**3,84937E+13**		
Avg.-Gen.Avg.	**-381898,95**	**381898,95**		
SQR. (Avg.-Gen.Avg.)	**1,4585E+11**	**1,45847E+11**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**4,26717E+13**			
Alpha	**0,05**			
t-critical	**2,1**			
Abs(1Avg-2Avg)	**763797,9**			
Sp	**6532355,736**			
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical
				Not rejected
t-value	**0,261453**			

Table F.4. Toll plaza throughput comparison between Alternatives 1&2

		Aternatives			
Replications		1	2		
	1	*25551*	*26937*		
	2	*27356*	*27353*		
	3	*26984*	*26938*		
	4	*27326*	*26451*		
	5	*26470*	*26473*		
	6	*26227*	*26612*		
	7	*27150*	*26564*		
	8	*27158*	*26867*		
	9	*26984*	*26136*	**Gen. Avg.**	**26723,3**
	10	*26942*	*25987*		
Avg.		**26814,8**	**26631,8**		
Std. Dev.		**569,540907**	**406,4526213**		
Var.		**324376,844**	**165203,7333**		
Avg.-Gen.Avg.		**91,5**	**-91,5**		
SQR. (Avg.-Gen.Avg.)		**8372,25**	**8372,25**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**244790,2889**			
Alpha		**0,05**			
t-critical		**2,1**			
Abs(1Avg-2Avg)		**183**			
Sp		**494,7628613**			
Sqrt(1/n+1/m)		**0,447213595**		t<t-critical	
				Not rejected	
t-value		**0,82706378**			

Table F.5. Total system throughput comparison between Alternatives 1&2

	Aternatives			
Replications	1	2		
1	*25668*	*26805*		
2	*27541*	*27528*		
3	*27028*	*27261*		
4	*26220*	*26461*		
5	*26290*	*26613*		
6	*26613*	*26621*		
7	*27299*	*26656*		
8	*26886*	*27056*		
9	*26529*	*26059*	**Gen. Avg.**	**26707,25**
10	*26951*	*26060*		
Avg.	**26702,5**	**26712**		
Std. Dev.	**554,930877**	**474,9238535**		
Var.	**307948,278**	**225552,6667**		
Avg.-Gen.Avg.	**-4,75**	**4,75**		
SQR. (Avg.-Gen.Avg.)	**22,5625**	**22,5625**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**266750,4722**			
Alpha	**0,05**			
t-critical	**2,1**			
Abs(1Avg-2Avg)	**9,5**			
Sp	**516,4789175**			
Sqrt(1/n+1/m)	**0,447213595**		t<t-critical	
			Not rejected	
t-value	**0,04112974**			

F.2 ALTERNATIVE 1&3

Table F.6. Fuel consumption comparison between Alternatives 1&3

		Aternatives			
Replications		1	3		
	1	*54558,02441*	*52702,97266*		
	2	*50466,71875*	*54442,22559*		
	3	*53034,10254*	*55036,49414*		
	4	*50007,23926*	*51807,82813*		
	5	*50828,2334*	*52640,04004*		
	6	*55245,46094*	*55070,40234*		
	7	*53725,26953*	*54340,23047*		
	8	*49988,34766*	*51610,88086*		
	9	*49782,78516*	*50276,08887*	**Gen. Avg.**	**52454,71**
	10	*51339,7412*	*52191,13574*		
Avg.		**51897,5923**	**53011,82988**		
Std. Dev.		**2057,8135**	**1631,338325**		
Var.		**4234596,38**	**2661264,73**		
Avg.-Gen.Avg.		**-557,1188**	**557,1187994**		
SQR. (Avg.-Gen.Avg.)		**310381,357**	**310381,3566**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**3447930,556**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**1114,237599**			
Sp		**1856,860403**			
Sqrt(1/n+1/m)		**0,447213595**			t<t-critical
					Not rejected
t-value		**1,34178693**			

Table F.7. Pollution comparison between Alternatives 1&3

	Aternatives			
Replications	1	3		
1	*5751,842407*	*5294,804688*		
2	*4783,689331*	*5489,766968*		
3	*5279,945313*	*5769,307007*		
4	*4996,439575*	*5190,120239*		
5	*5080,259888*	*5220,494141*		
6	*5686,080566*	*5627,489014*		
7	*5323,151123*	*5543,881958*		
8	*4900,517822*	*4973,528198*		
9	*4849,6521*	*4878,297241*	**Gen. Avg.**	**5250,037**
10	*5041,2*	*5320,272583*		
Avg.	**5169,27781**	**5330,796204**		
Std. Dev.	**336,594557**	**282,2043659**		
Var.	**113295,896**	**79639,30413**		
Avg.-Gen.Avg.	**-80,759196**	**80,75919556**		
SQR. (Avg.-Gen.Avg.)	**6522,04767**	**6522,047667**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**96467,60005**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**161,5183911**			
Sp	**310,5923374**			
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical
				Not rejected
t-value	**1,16283005**			

Table F.8. Total delay comparison between Alternatives 1&3

	Aternatives			
Replications	1	3		
1	*85460529*	*75879142*		
2	*65394111*	*79885351*		
3	*75343821*	*86084005*		
4	*76147352*	*74402497*		
5	*72181157*	*74452578*		
6	*83126785*	*82388562*		
7	*76116504*	*81114788*		
8	*67463872*	*68749119*		
9	*66143389*	*67876280*	**Gen. Avg.**	**75240236**
10	*70138854*	*76456018*		
Avg.	**73751637,4**	**76728834**		
Std. Dev.	**6844681,01**	**5794490,598**		
Var.	**4,685E+13**	**3,35761E+13**		
Avg.-Gen.Avg.	**-1488598,3**	**1488598,3**		
SQR. (Avg.-Gen.Avg.)	**2,2159E+12**	**2,21592E+12**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**4,02129E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2977196,6**			
Sp	**6341363,397**			
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical
				Not rejected
t-value	**1,04980799**			

Table F.9. Toll plaza throughput comparison between Alternatives 1&3

	Aternatives			
Replications	1	3		
1	*25551*	*26235*		
2	*27356*	*26356*		
3	*26984*	*25426*		
4	*27326*	*26368*		
5	*26470*	*26586*		
6	*26227*	*25757*		
7	*27150*	*25918*		
8	*27158*	*27107*		
9	*26984*	*26556*	**Gen. Avg.**	**26544,3**
10	*26942*	*26429*		
Avg.	**26814,8**	**26273,8**		
Std. Dev.	**569,540907**	**474,3406652**		
Var.	**324376,844**	**224999,0667**		
Avg.-Gen.Avg.	**270,5**	**-270,5**		
SQR. (Avg.-Gen.Avg.)	**73170,25**	**73170,25**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**274687,9556**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**541**			
Sp	**524,1068169**			
Sqrt(1/n+1/m)	**0,447213595**		t>t-critical	
			Rejected	
t-value	**2,30814165**			

Table F.10. Total system throughput comparison between Alternatives 1&3

	Aternatives			
Replications	1	3		
1	*25668*	*26274*		
2	*27541*	*26537*		
3	*27028*	*25442*		
4	*26220*	*26298*		
5	*26290*	*26777*		
6	*26613*	*26154*		
7	*27299*	*26143*		
8	*26886*	*27215*		
9	*26529*	*26655*	**Gen. Avg.**	**26541,8**
10	*26951*	*26316*		
Avg.	**26702,5**	**26381,1**		
Std. Dev.	**554,930877**	**467,1712629**		
Var.	**307948,278**	**218248,9889**		
Avg.-Gen.Avg.	**160,7**	**-160,7**		
SQR. (Avg.-Gen.Avg.)	**25824,49**	**25824,49**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**263098,6333**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**321,4**			
Sp	**512,9314119**			
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical
				Not Rejected
t-value	**1,40110789**			

F.3 ALTERNATIVE 1&4

Table F.11. Fuel consumption comparison between Alternatives 1&4

	Aternatives				
Replications	1	4			
1	*54558,02441*	*30874,5293*			
2	*50466,71875*	*31234,58105*			
3	*53034,10254*	*32717,69141*			
4	*50007,23926*	*32556,76758*			
5	*50828,2334*	*33149,7959*			
6	*55245,46094*	*32238,69238*			
7	*53725,26953*	*30719,68359*			
8	*49988,34766*	*31330,4834*			
9	*49782,78516*	*30275,00293*		**Gen. Avg.**	**41767,56**
10	*51339,7412*	*31278,03516*			
Avg.	**51897,5923**	**31637,52627**			
Std. Dev.	**2057,8135**	**961,8884708**			
Var.	**4234596,38**	**925229,4303**			
Avg.-Gen.Avg.	**10130,033**	**-10130,033**			
SQR. (Avg.-Gen.Avg.)	**102617569**	**102617568,7**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**2579912,907**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**20260,06601**				
Sp	**1606,210729**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**28,2048202**				

Table F.12. Pollution comparison between Alternatives 1&4

	Aternatives				
Replications		1	4		
	1	*5751,842407*	*2646,793884*		
	2	*4783,689331*	*2667,581177*		
	3	*5279,945313*	*2798,086548*		
	4	*4996,439575*	*2805,289307*		
	5	*5080,259888*	*2865,880676*		
	6	*5686,080566*	*2794,316956*		
	7	*5323,151123*	*2646,456909*		
	8	*4900,517822*	*2727,764465*		
	9	*4849,6521*	*2614,071533*	**Gen. Avg.**	**3947,108**
	10	*5041,2*	*2683,135681*		
Avg.		**5169,27781**	**2724,937714**		
Std. Dev.		**336,594557**	**85,69176405**		
Var.		**113295,896**	**7343,078427**		
Avg.-Gen.Avg.		**1222,17005**	**-1222,17005**		
SQR. (Avg.-Gen.Avg.)		**1493699,63**	**1493699,63**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**60319,4872**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**2444,340099**			
Sp		**245,600259**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical Rejected
t-value		**22,2544986**			

Table F.13. Total delay comparison between Alternatives 1&4

		Aternatives			
Replications		1	4		
	1	*85460529*	*27086965*		
	2	*65394111*	*27098136*		
	3	*75343821*	*28860440*		
	4	*76147352*	*28786577*		
	5	*72181157*	*30180199*		
	6	*83126785*	*28712970*		
	7	*76116504*	*26868828*		
	8	*67463872*	*27998509*		
	9	*66143389*	*26646789*	**Gen. Avg.**	**50844219**
	10	*70138854*	*27128586*		
Avg.		**73751637,4**	**27936799,9**		
Std. Dev.		**6844681,01**	**1159396,3**		
Var.		**4,685E+13**	**1,3442E+12**		
Avg.-Gen.Avg.		**22907418,8**	**-22907418,8**		
SQR. (Avg.-Gen.Avg.)		**5,2475E+14**	**5,2475E+14**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**2,40969E+13**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**45814837,5**			
Sp		**4908862,29**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**20,8694164**			

Table F.14. Toll plaza throughput comparison between Alternatives 1&4

	Aternatives			
Replications	1	4		
1	*25551*	*24567*		
2	*27356*	*24654*		
3	*26984*	*24751*		
4	*27326*	*24734*		
5	*26470*	*24574*		
6	*26227*	*24700*		
7	*27150*	*24606*		
8	*27158*	*24723*		
9	*26984*	*24393*	**Gen. Avg.**	**25734,45**
10	*26942*	*24839*		
Avg.	**26814,8**	**24654,1**		
Std. Dev.	**569,540907**	**125,3018134**		
Var.	**324376,844**	**15700,54444**		
Avg.-Gen.Avg.	**1080,35**	**-1080,35**		
SQR. (Avg.-Gen.Avg.)	**1167156,12**	**1167156,123**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**170038,6944**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2160,7**			
Sp	**412,3574838**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**11,7167076**			

Table F.15. Total system throughput comparison between Alternatives 1&4

	Aternatives			
Replications	1	4		
1	*25668*	*24746*		
2	*27541*	*24782*		
3	*27028*	*25250*		
4	*26220*	*25090*		
5	*26290*	*25143*		
6	*26613*	*24825*		
7	*27299*	*24585*		
8	*26886*	*24815*		
9	*26529*	*24353*	**Gen. Avg.**	**25774,85**
10	*26951*	*24883*		
Avg.	**26702,5**	**24847,2**		
Std. Dev.	**554,930877**	**266,4548325**		
Var.	**307948,278**	**70998,17778**		
Avg.-Gen.Avg.	**927,65**	**-927,65**		
SQR. (Avg.-Gen.Avg.)	**860534,523**	**860534,5225**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**189473,2278**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**1855,3**			
Sp	**435,2852258**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**9,53070923**			

F.4 ALTERNATIVE 1&5

Table F.16. Fuel consumption comparison between Alternatives 1&5

		Aternatives			
Replications		1	5		
	1	*54558,02441*	*20414,09717*		
	2	*50466,71875*	*20009,04053*		
	3	*53034,10254*	*19965,46973*		
	4	*50007,23926*	*19902,15576*		
	5	*50828,2334*	*19520,13232*		
	6	*55245,46094*	*20031,97949*		
	7	*53725,26953*	*19836,66406*		
	8	*49988,34766*	*20300,69434*		
	9	*49782,78516*	*20079,49902*	**Gen. Avg.**	**35959,38**
	10	*51339,7412*	*20151,98877*		
Avg.		**51897,5923**	**20021,17212**		
Std. Dev.		**2057,8135**	**248,4739001**		
Var.		**4234596,38**	**61739,27903**		
Avg.-Gen.Avg.		**15938,2101**	**-15938,2101**		
SQR. (Avg.-Gen.Avg.)		**254026541**	**254026540,6**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**2148167,831**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**31876,42016**			
Sp		**1465,662932**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**48,6318108**			

Table F.17. Pollution comparison between Alternatives 1&5

	Aternatives			
Replications	1	5		
1	*5751,842407*	*1254,643433*		
2	*4783,689331*	*1242,009796*		
3	*5279,945313*	*1228,491852*		
4	*4996,439575*	*1222,218445*		
5	*5080,259888*	*1215,245392*		
6	*5686,080566*	*1236,067383*		
7	*5323,151123*	*1222,026001*		
8	*4900,517822*	*1245,61676*		
9	*4849,6521*	*1233,696747*	**Gen. Avg.**	**3201,445**
10	*5041,2*	*1236,103088*		
Avg.	**5169,27781**	**1233,61189**		
Std. Dev.	**336,594557**	**12,00368786**		
Var.	**113295,896**	**144,0885222**		
Avg.-Gen.Avg.	**1967,83296**	**-1967,83296**		
SQR. (Avg.-Gen.Avg.)	**3872366,56**	**3872366,564**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**56719,99225**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**3935,665923**			
Sp	**238,1595941**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**36,9517616**			

Table F.18. Total delay comparison between Alternatives 1&5

	Aternatives			
Replications	1	5		
1	*85460529*	*3585390*		
2	*65394111*	*3737974*		
3	*75343821*	*3473728*		
4	*76147352*	*3455783*		
5	*72181157*	*3607846*		
6	*83126785*	*3656085*		
7	*76116504*	*3492386*		
8	*67463872*	*3557142*		
9	*66143389*	*3555827*	**Gen. Avg.**	**38659648**
10	*70138854*	*3554421*		
Avg.	**73751637,4**	**3567658,2**		
Std. Dev.	**6844681,01**	**85756,03953**		
Var.	**4,685E+13**	**7354098316**		
Avg.-Gen.Avg.	**35091989,6**	**-35091989,6**		
SQR. (Avg.-Gen.Avg.)	**1,2314E+15**	**1,23145E+15**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**2,34285E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**70183979,2**			
Sp	**4840300,212**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**32,422813**			

Table F.19. Toll plaza throughput comparison between Alternatives 1&5

		Aternatives			
Replications		1	5		
	1	*25551*	*27565*		
	2	*27356*	*27331*		
	3	*26984*	*27134*		
	4	*27326*	*27332*		
	5	*26470*	*27073*		
	6	*26227*	*27055*		
	7	*27150*	*27153*		
	8	*27158*	*27297*		
	9	*26984*	*27219*	**Gen. Avg.**	**27028,1**
	10	*26942*	*27255*		
Avg.		**26814,8**	**27241,4**		
Std. Dev.		**569,540907**	**151,7250437**		
Var.		**324376,844**	**23020,48889**		
Avg.-Gen.Avg.		**-213,3**	**213,3**		
SQR. (Avg.-Gen.Avg.)		**45496,89**	**45496,89**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**173698,6667**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**426,6**			
Sp		**416,7717201**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**2,28879877**			

Table F.20. Total plaza throughput comparison between Alternatives 1&5

	Aternatives			
Replications	1	5		
1	*25668*	*27657*		
2	*27541*	*27383*		
3	*27028*	*27251*		
4	*26220*	*27474*		
5	*26290*	*27051*		
6	*26613*	*27155*		
7	*27299*	*27305*		
8	*26886*	*27352*		
9	*26529*	*27374*	**Gen. Avg.**	**27014,35**
10	*26951*	*27260*		
Avg.	**26702,5**	**27326,2**		
Std. Dev.	**554,930877**	**167,6575876**		
Var.	**307948,278**	**28109,06667**		
Avg.-Gen.Avg.	**-311,85**	**311,85**		
SQR. (Avg.-Gen.Avg.)	**97250,4225**	**97250,4225**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**168028,6722**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**623,7**			
Sp	**409,9130057**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**3,40227214**			

F.5 ALTERNATIVE 1&6

Table F.21. Fuel consumption comparison between Alternatives 1&6

	Aternatives				
Replications	1	6			
1	*54558,02441*	*19496,58936*			
2	*50466,71875*	*19664,55859*			
3	*53034,10254*	*19356,18945*			
4	*50007,23926*	*20090,50732*			
5	*50828,2334*	*19392,05371*			
6	*55245,46094*	*19386,19482*			
7	*53725,26953*	*19286,57764*			
8	*49988,34766*	*19312,25244*			
9	*49782,78516*	*18805,28613*		**Gen. Avg.**	**35676,5**
10	*51339,7412*	*19763,86328*			
Avg.	**51897,5923**	**19455,40728**			
Std. Dev.	**2057,8135**	**338,9919508**			
Var.	**4234596,38**	**114915,5427**			
Avg.-Gen.Avg.	**16221,0925**	**-16221,0925**			
SQR. (Avg.-Gen.Avg.)	**263123842**	**263123842**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**2174755,963**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**32442,18501**				
Sp	**1474,705382**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**49,1914737**				

Table F.22. Pollution comparison between Alternatives 1&6

	Aternatives			
Replications	1	6		
1	*5751,842407*	*1288,238708*		
2	*4783,689331*	*1317,377136*		
3	*5279,945313*	*1263,503296*		
4	*4996,439575*	*1347,876709*		
5	*5080,259888*	*1294,729797*		
6	*5686,080566*	*1302,491821*		
7	*5323,151123*	*1273,902954*		
8	*4900,517822*	*1258,883911*		
9	*4849,6521*	*1233,821899*	**Gen. Avg.**	**3229,559**
10	*5041,2*	*1317,580597*		
Avg.	**5169,27781**	**1289,840683**		
Std. Dev.	**336,594557**	**33,54359594**		
Var.	**113295,896**	**1125,172828**		
Avg.-Gen.Avg.	**1939,71856**	**-1939,71856**		
SQR. (Avg.-Gen.Avg.)	**3762508,11**	**3762508,11**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**57210,5344**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**3879,43713**			
Sp	**239,1872371**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**36,2673412**			

Table F.23. Total delay comparison between Alternatives 1&6

	Aternatives			
Replications	1	6		
1	*85460529*	*4908090*		
2	*65394111*	*5417398*		
3	*75343821*	*4743643*		
4	*76147352*	*5983808*		
5	*72181157*	*5287771*		
6	*83126785*	*5345849*		
7	*76116504*	*4896420*		
8	*67463872*	*4381036*		
9	*66143389*	*4194142*	**Gen. Avg.**	**39409907**
10	*70138854*	*5523612*		
Avg.	**73751637,4**	**5068176,9**		
Std. Dev.	**6844681,01**	**546669,7465**		
Var.	**4,685E+13**	**2,98848E+11**		
Avg.-Gen.Avg.	**34341730,3**	**-34341730,3**		
SQR. (Avg.-Gen.Avg.)	**1,1794E+15**	**1,17935E+15**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**2,35743E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**68683460,5**			
Sp	**4855332,429**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**31,6313844**			

Table F.24. Toll plaza throughput comparison between Alternatives 1&6

	Aternatives			
Replications	1	6		
1	*25551*	*27444*		
2	*27356*	*27396*		
3	*26984*	*27032*		
4	*27326*	*27400*		
5	*26470*	*27263*		
6	*26227*	*27350*		
7	*27150*	*27178*		
8	*27158*	*27203*		
9	*26984*	*27082*	**Gen. Avg.**	**27038,05**
10	*26942*	*27265*		
Avg.	**26814,8**	**27261,3**		
Std. Dev.	**569,540907**	**138,9284788**		
Var.	**324376,844**	**19301,12222**		
Avg.-Gen.Avg.	**-223,25**	**223,25**		
SQR. (Avg.-Gen.Avg.)	**49840,5625**	**49840,5625**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**171838,9833**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**446,5**			
Sp	**414,5346588**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**2,40849427**			

Table F.25. Total system throughput comparison between Alternatives 1&6

	Aternatives			
Replications	1	6		
1	*25668*	*27489*		
2	*27541*	*27422*		
3	*27028*	*27131*		
4	*26220*	*27456*		
5	*26290*	*27392*		
6	*26613*	*27331*		
7	*27299*	*27199*		
8	*26886*	*27349*		
9	*26529*	*27113*	**Gen. Avg.**	**27007,5**
10	*26951*	*27243*		
Avg.	**26702,5**	**27312,5**		
Std. Dev.	**554,930877**	**134,2404559**		
Var.	**307948,278**	**18020,5**		
Avg.-Gen.Avg.	**-305**	**305**		
SQR. (Avg.-Gen.Avg.)	**93025**	**93025**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**162984,3889**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**610**			
Sp	**403,7132508**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**3,37863933**			

F.6 ALTERNATIVE 1&7

Table F.26. Fuel consumption comparison between Alternatives 1&7

		Aternatives			
Replications		1	7		
	1	*54558,02441*	*53010,87207*		
	2	*50466,71875*	*49403,84863*		
	3	*53034,10254*	*50314,8291*		
	4	*50007,23926*	*43893,45703*		
	5	*50828,2334*	*52787,81641*		
	6	*55245,46094*	*48075,07129*		
	7	*53725,26953*	*51708,19043*		
	8	*49988,34766*	*50061,56055*		
	9	*49782,78516*	*50263,1416*	**Gen. Avg.**	**51001,79**
	10	*51339,7412*	*51541*		
Avg.		**51897,5923**	**50105,97871**		
Std. Dev.		**2057,8135**	**2657,072662**		
Var.		**4234596,38**	**7060035,134**		
Avg.-Gen.Avg.		**895,806787**	**-895,806787**		
SQR. (Avg.-Gen.Avg.)		**802469,799**	**802469,7989**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**5647315,758**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**1791,613573**			
Sp		**2376,408163**			
Sqrt(1/n+1/m)		**0,447213595**			t<t-critical
					Not rejected
t-value		**1,68580878**			

Table F.27. Pollution comparison between Alternatives 1&7

	Aternatives			
Replications	1	7		
1	*5751,842407*	*5386,499756*		
2	*4783,689331*	*4574,881836*		
3	*5279,945313*	*4816,022583*		
4	*4996,439575*	*4032,553101*		
5	*5080,259888*	*5075,401611*		
6	*5686,080566*	*4577,558716*		
7	*5323,151123*	*5113,820557*		
8	*4900,517822*	*4808,311035*		
9	*4849,6521*	*4873,09021*	**Gen. Avg.**	**4994,392**
10	*5041,2*	*4936,929077*		
Avg.	**5169,27781**	**4819,506848**		
Std. Dev.	**336,594557**	**369,3924118**		
Var.	**113295,896**	**136450,7539**		
Avg.-Gen.Avg.	**174,885482**	**-174,885482**		
SQR. (Avg.-Gen.Avg.)	**30584,9319**	**30584,93188**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**124873,3249**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**349,7709644**			
Sp	**353,3741996**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**2,21326756**			

Table F.28. Total delay comparison between Alternatives 1&7

	Aternatives			
Replications	1	7		
1	*85460529*	*75283137*		
2	*65394111*	*58859508*		
3	*75343821*	*63623026*		
4	*76147352*	*49170028*		
5	*72181157*	*68695554*		
6	*83126785*	*58789450*		
7	*76116504*	*69752890*		
8	*67463872*	*62982989*		
9	*66143389*	*64260824*	**Gen. Avg.**	**68729973**
10	*70138854*	*65665688*		
Avg.	**73751637,4**	**63708309,4**		
Std. Dev.	**6844681,01**	**7142391,776**		
Var.	**4,685E+13**	**5,10138E+13**		
Avg.-Gen.Avg.	**5021664**	**-5021664**		
SQR. (Avg.-Gen.Avg.)	**2,5217E+13**	**2,52171E+13**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**4,89317E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**10043328**			
Sp	**6995120,387**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**3,21046142**			

Table F.29. Toll plaza throughput comparison between Alternatives 1&7

		Aternatives			
Replications		1	7		
	1	25551	25509		
	2	27356	26927		
	3	26984	26455		
	4	27326	26682		
	5	26470	26004		
	6	26227	26877		
	7	27150	26025		
	8	27158	26714		
	9	26984	26657	Gen. Avg.	26636
	10	26942	26722		
Avg.		26814,8	26457,2		
Std. Dev.		569,540907	461,2470536		
Var.		324376,844	212748,8444		
Avg.-Gen.Avg.		178,8	-178,8		
SQR. (Avg.-Gen.Avg.)		31969,44	31969,44		
n		10	10		
1/n		0,1	0,1		
n-1		9	9		
m+n-2		18			
Sp2		268562,8444			
Alpha		0,05			
Tcritical		2,1			
Abs(1Avg-2Avg)		357,6			
Sp		518,2304935			
Sqrt(1/n+1/m)		0,447213595		t<t-critical	
				Not rejected	
t-value		1,54297734			

Table F.30. Total system throughput comparison between Alternatives 1&7

		Aternatives			
Replications		1	7		
	1	*25668*	*25087*		
	2	*27541*	*27188*		
	3	*27028*	*26387*		
	4	*26220*	*26699*		
	5	*26290*	*26370*		
	6	*26613*	*26678*		
	7	*27299*	*25904*		
	8	*26886*	*26526*		
	9	*26529*	*26522*	**Gen. Avg.**	**26553,15**
	10	*26951*	*26677*		
Avg.		**26702,5**	**26403,8**		
Std. Dev.		**554,930877**	**564,3115373**		
Var.		**307948,278**	**318447,5111**		
Avg.-Gen.Avg.		**149,35**	**-149,35**		
SQR. (Avg.-Gen.Avg.)		**22305,4225**	**22305,4225**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**313197,8944**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**298,7**			
Sp		**559,640862**			
Sqrt(1/n+1/m)		**0,447213595**			t<t-critical
					Not rejected
t-value		**1,19346808**			

F.7 ALTERNATIVE 4&5

Table F.31. Fuel consumption comparison between Alternatives 4&5

	Aternatives			
Replications	4	5		
1	*30874,5293*	*20414,09717*		
2	*31234,58105*	*20009,04053*		
3	*32717,69141*	*19965,46973*		
4	*32556,76758*	*19902,15576*		
5	*33149,7959*	*19520,13232*		
6	*32238,69238*	*20031,97949*		
7	*30719,68359*	*19836,66406*		
8	*31330,4834*	*20300,69434*		
9	*30275,00293*	*20079,49902*	**Gen. Avg.**	**25829,35**
10	*31278,03516*	*20151,98877*		
Avg.	**31637,5263**	**20021,17212**		
Std. Dev.	**961,888471**	**248,4739001**		
Var.	**925229,43**	**61739,27903**		
Avg.-Gen.Avg.	**5808,17708**	**-5808,17708**		
SQR. (Avg.-Gen.Avg.)	**33734920,9**	**33734920,94**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**493484,3547**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**11616,35415**			
Sp	**702,484416**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**36,9758488**			

Table F.32. Pollution comparison between Alternatives 4&5

	Aternatives			
Replications	4	5		
1	*2646,793884*	*1254,643433*		
2	*2667,581177*	*1242,009796*		
3	*2798,086548*	*1228,491852*		
4	*2805,289307*	*1222,218445*		
5	*2865,880676*	*1215,245392*		
6	*2794,316956*	*1236,067383*		
7	*2646,456909*	*1222,026001*		
8	*2727,764465*	*1245,61676*		
9	*2614,071533*	*1233,696747*	**Gen. Avg.**	**1979,275**
10	*2683,135681*	*1236,103088*		
Avg.	**2724,93771**	**1233,61189**		
Std. Dev.	**85,6917641**	**12,00368786**		
Var.	**7343,07843**	**144,0885222**		
Avg.-Gen.Avg.	**745,662912**	**-745,662912**		
SQR. (Avg.-Gen.Avg.)	**556013,178**	**556013,1783**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**3743,583474**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**1491,325824**			
Sp	**61,18483043**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**54,5021682**			

Table F.33. Total delay comparison between Alternatives 4&5

		Aternatives			
Replications		4	5		
	1	*27086965*	*3585390*		
	2	*27098136*	*3737974*		
	3	*28860440*	*3473728*		
	4	*28786577*	*3455783*		
	5	*30180199*	*3607846*		
	6	*28712970*	*3656085*		
	7	*26868828*	*3492386*		
	8	*27998509*	*3557142*		
	9	*26646789*	*3555827*	**Gen. Avg.**	**15752229**
	10	*27128586*	*3554421*		
Avg.		**27936799,9**	**3567658,2**		
Std. Dev.		**1159396,3**	**85756,03953**		
Var.		**1,3442E+12**	**7354098316**		
Avg.-Gen.Avg.		**12184570,9**	**-12184570,9**		
SQR. (Avg.-Gen.Avg.)		**1,4846E+14**	**1,48464E+14**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**6,75777E+11**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**24369141,7**			
Sp		**822056,5303**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**66,2862655**			

Table F.34. Toll plaza throughput comparison between Alternatives 4&5

	Aternatives			
Replications	4	5		
1	*24567*	*27565*		
2	*24654*	*27331*		
3	*24751*	*27134*		
4	*24734*	*27332*		
5	*24574*	*27073*		
6	*24700*	*27055*		
7	*24606*	*27153*		
8	*24723*	*27297*		
9	*24393*	*27219*	**Gen. Avg.**	**25947,75**
10	*24839*	*27255*		
Avg.	**24654,1**	**27241,4**		
Std. Dev.	**125,301813**	**151,7250437**		
Var.	**15700,5444**	**23020,48889**		
Avg.-Gen.Avg.	**-1293,65**	**1293,65**		
SQR. (Avg.-Gen.Avg.)	**1673530,32**	**1673530,323**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**19360,51667**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2587,3**			
Sp	**139,1420737**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**41,578931**			

Table F.35. Total system throughput comparison between Alternatives 4&5

	Aternatives			
Replications	4	5		
1	*24746*	*27657*		
2	*24782*	*27383*		
3	*25250*	*27251*		
4	*25090*	*27474*		
5	*25143*	*27051*		
6	*24825*	*27155*		
7	*24585*	*27305*		
8	*24815*	*27352*		
9	*24353*	*27374*	**Gen. Avg.**	**26086,7**
10	*24883*	*27260*		
Avg.	**24847,2**	**27326,2**		
Std. Dev.	**266,454833**	**167,6575876**		
Var.	**70998,1778**	**28109,06667**		
Avg.-Gen.Avg.	**-1239,5**	**1239,5**		
SQR. (Avg.-Gen.Avg.)	**1536360,25**	**1536360,25**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**49553,62222**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2479**			
Sp	**222,606429**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**24,9014035**			

F.8 ALTERNATIVE 4&6

Table F.36. Fuel consumption comparison between Alternatives 4&6

	Aternatives				
Replications	4	6			
1	*30874,5293*	*19496,58936*			
2	*31234,58105*	*19664,55859*			
3	*32717,69141*	*19356,18945*			
4	*32556,76758*	*20090,50732*			
5	*33149,7959*	*19392,05371*			
6	*32238,69238*	*19386,19482*			
7	*30719,68359*	*19286,57764*			
8	*31330,4834*	*19312,25244*			
9	*30275,00293*	*18805,28613*		**Gen. Avg.**	**25546,47**
10	*31278,03516*	*19763,86328*			
Avg.	**31637,5263**	**19455,40728**			
Std. Dev.	**961,888471**	**338,9919508**			
Var.	**925229,43**	**114915,5427**			
Avg.-Gen.Avg.	**6091,0595**	**-6091,0595**			
SQR. (Avg.-Gen.Avg.)	**37101005,8**	**37101005,8**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**520072,4865**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**12182,11899**				
Sp	**721,1605137**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**37,7725148**				

Table F.37. Pollution comparison between Alternatives 4&6

	Aternatives			
Replications	4	6		
1	*2646,793884*	*1288,238708*		
2	*2667,581177*	*1317,377136*		
3	*2798,086548*	*1263,503296*		
4	*2805,289307*	*1347,876709*		
5	*2865,880676*	*1294,729797*		
6	*2794,316956*	*1302,491821*		
7	*2646,456909*	*1273,902954*		
8	*2727,764465*	*1258,883911*		
9	*2614,071533*	*1233,821899*	**Gen. Avg.**	**2007,389**
10	*2683,135681*	*1317,580597*		
Avg.	**2724,93771**	**1289,840683**		
Std. Dev.	**85,6917641**	**33,54359594**		
Var.	**7343,07843**	**1125,172828**		
Avg.-Gen.Avg.	**717,548515**	**-717,548515**		
SQR. (Avg.-Gen.Avg.)	**514875,872**	**514875,8718**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**4234,125627**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**1435,097031**			
Sp	**65,07015927**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**49,3156087**			

Table F.38. Total delay comparison between Alternatives 4&6

	Aternatives				
Replications	4	6			
1	*27086965*	*4908090*			
2	*27098136*	*5417398*			
3	*28860440*	*4743643*			
4	*28786577*	*5983808*			
5	*30180199*	*5287771*			
6	*28712970*	*5345849*			
7	*26868828*	*4896420*			
8	*27998509*	*4381036*			
9	*26646789*	*4194142*		**Gen. Avg.**	**16502488**
10	*27128586*	*5523612*			
Avg.	**27936799,9**	**5068176,9**			
Std. Dev.	**1159396,3**	**546669,7465**			
Var.	**1,3442E+12**	**2,98848E+11**			
Avg.-Gen.Avg.	**11434311,5**	**-11434311,5**			
SQR. (Avg.-Gen.Avg.)	**1,3074E+14**	**1,30743E+14**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**8,21524E+11**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**22868623**				
Sp	**906379,4987**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**56,4176437**				

Table F.39. Toll plaza throughput comparison between Alternatives 4&6

	Aternatives			
Replications	4	6		
1	*24567*	*27444*		
2	*24654*	*27396*		
3	*24751*	*27032*		
4	*24734*	*27400*		
5	*24574*	*27263*		
6	*24700*	*27350*		
7	*24606*	*27178*		
8	*24723*	*27203*		
9	*24393*	*27082*	**Gen. Avg.**	**25957,7**
10	*24839*	*27265*		
Avg.	**24654,1**	**27261,3**		
Std. Dev.	**125,301813**	**138,9284788**		
Var.	**15700,5444**	**19301,12222**		
Avg.-Gen.Avg.	**-1303,6**	**1303,6**		
SQR. (Avg.-Gen.Avg.)	**1699372,96**	**1699372,96**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**17500,83333**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2607,2**			
Sp	**132,2907152**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**44,0686742**			

Table F.40. Total system throughput comparison between Alternatives 4&6

	Aternatives			
Replications	4	6		
1	*24746*	*27489*		
2	*24782*	*27422*		
3	*25250*	*27131*		
4	*25090*	*27456*		
5	*25143*	*27392*		
6	*24825*	*27331*		
7	*24585*	*27199*		
8	*24815*	*27349*		
9	*24353*	*27113*	**Gen. Avg.**	**26079,85**
10	*24883*	*27243*		
Avg.	**24847,2**	**27312,5**		
Std. Dev.	**266,454833**	**134,2404559**		
Var.	**70998,1778**	**18020,5**		
Avg.-Gen.Avg.	**-1232,65**	**1232,65**		
SQR. (Avg.-Gen.Avg.)	**1519426,02**	**1519426,023**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**44509,33889**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**2465,3**			
Sp	**210,9723652**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**26,1293861**			

F.9 ALTERNATIVE 4&7

Table F.41. Fuel consumption comparison between Alternatives 4&7

	Aternatives				
Replications	4	7			
1	*30874,5293*	*53010,87207*			
2	*31234,58105*	*49403,84863*			
3	*32717,69141*	*50314,8291*			
4	*32556,76758*	*43893,45703*			
5	*33149,7959*	*52787,81641*			
6	*32238,69238*	*48075,07129*			
7	*30719,68359*	*51708,19043*			
8	*31330,4834*	*50061,56055*			
9	*30275,00293*	*50263,1416*		**Gen. Avg.**	**40871,75**
10	*31278,03516*	*51541*			
Avg.	**31637,5263**	**50105,97871**			
Std. Dev.	**961,888471**	**2657,072662**			
Var.	**925229,43**	**7060035,134**			
Avg.-Gen.Avg.	**-9234,2262**	**9234,226221**			
SQR. (Avg.-Gen.Avg.)	**85270933,9**	**85270933,9**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**3992632,282**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**18468,45244**				
Sp	**1998,157222**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**20,6674003**				

Table F.42. Pollution comparison between Alternatives 4&7

	Aternatives				
Replications	4	7			
1	*2646,793884*	*5386,499756*			
2	*2667,581177*	*4574,881836*			
3	*2798,086548*	*4816,022583*			
4	*2805,289307*	*4032,553101*			
5	*2865,880676*	*5075,401611*			
6	*2794,316956*	*4577,558716*			
7	*2646,456909*	*5113,820557*			
8	*2727,764465*	*4808,311035*			
9	*2614,071533*	*4873,09021*		**Gen. Avg.**	**3772,222**
10	*2683,135681*	*4936,929077*			
Avg.	**2724,93771**	**4819,506848**			
Std. Dev.	**85,6917641**	**369,3924118**			
Var.	**7343,07843**	**136450,7539**			
Avg.-Gen.Avg.	**-1047,2846**	**1047,284567**			
SQR. (Avg.-Gen.Avg.)	**1096804,96**	**1096804,965**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**71896,91617**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**2094,569135**				
Sp	**268,1360031**				
Sqrt(1/n+1/m)	**0,447213595**				t>t-critical
					Rejected
t-value	**17,4672514**				

Table F.43. Total delay comparison between Alternatives 4&7

	Aternatives			
Replications	4	7		
1	*27086965*	*75283137*		
2	*27098136*	*58859508*		
3	*28860440*	*63623026*		
4	*28786577*	*49170028*		
5	*30180199*	*68695554*		
6	*28712970*	*58789450*		
7	*26868828*	*69752890*		
8	*27998509*	*62982989*		
9	*26646789*	*64260824*	**Gen. Avg.**	**45822555**
10	*27128586*	*65665688*		
Avg.	**27936799,9**	**63708309,4**		
Std. Dev.	**1159396,3**	**7142391,776**		
Var.	**1,3442E+12**	**5,10138E+13**		
Avg.-Gen.Avg.	**-17885755**	**17885754,75**		
SQR. (Avg.-Gen.Avg.)	**3,199E+14**	**3,199E+14**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**2,6179E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**35771509,5**			
Sp	**5116539,849**			
Sqrt(1/n+1/m)	**0,447213595**		t>t-critical	
			Rejected	
t-value	**15,6331289**			

Table F.44. Toll plaza throughput comparison between Alternatives 4&7

		Aternatives			
Replications		4	7		
	1	*24567*	*25509*		
	2	*24654*	*26927*		
	3	*24751*	*26455*		
	4	*24734*	*26682*		
	5	*24574*	*26004*		
	6	*24700*	*26877*		
	7	*24606*	*26025*		
	8	*24723*	*26714*		
	9	*24393*	*26657*	**Gen. Avg.**	**25555,65**
	10	*24839*	*26722*		
Avg.		**24654,1**	**26457,2**		
Std. Dev.		**125,301813**	**461,2470536**		
Var.		**15700,5444**	**212748,8444**		
Avg.-Gen.Avg.		**-901,55**	**901,55**		
SQR. (Avg.-Gen.Avg.)		**812792,403**	**812792,4025**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**114224,6944**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**1803,1**			
Sp		**337,9714403**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**11,9295706**			

Table F.45. Total system throughput comparison between Alternatives 4&7

	Aternatives			
Replications	4	7		
1	*24746*	*25087*		
2	*24782*	*27188*		
3	*25250*	*26387*		
4	*25090*	*26699*		
5	*25143*	*26370*		
6	*24825*	*26678*		
7	*24585*	*25904*		
8	*24815*	*26526*		
9	*24353*	*26522*	**Gen. Avg.**	**25625,5**
10	*24883*	*26677*		
Avg.	**24847,2**	**26403,8**		
Std. Dev.	**266,454833**	**564,3115373**		
Var.	**70998,1778**	**318447,5111**		
Avg.-Gen.Avg.	**-778,3**	**778,3**		
SQR. (Avg.-Gen.Avg.)	**605750,89**	**605750,89**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**194722,8444**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**1556,6**			
Sp	**441,2741149**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**7,88775796**			

F.10 ALTERNATIVE 5&6

Table F.46. Fuel consumption comparison between Alternatives 5&6

		Aternatives			
Replications		5	6		
	1	*20414,09717*	*19496,58936*		
	2	*20009,04053*	*19664,55859*		
	3	*19965,46973*	*19356,18945*		
	4	*19902,15576*	*20090,50732*		
	5	*19520,13232*	*19392,05371*		
	6	*20031,97949*	*19386,19482*		
	7	*19836,66406*	*19286,57764*		
	8	*20300,69434*	*19312,25244*		
	9	*20079,49902*	*18805,28613*	**Gen. Avg.**	**19738,29**
	10	*20151,98877*	*19763,86328*		
Avg.		**20021,1721**	**19455,40728**		
Std. Dev.		**248,4739**	**338,9919508**		
Var.		**61739,279**	**114915,5427**		
Avg.-Gen.Avg.		**282,882422**	**-282,882422**		
SQR. (Avg.-Gen.Avg.)		**80022,4646**	**80022,46461**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**88327,41087**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**565,7648437**			
Sp		**297,199278**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**4,25670163**			

Table F.47. Pollution comparison between Alternatives 5&6

	Aternatives			
Replications	5	6		
1	*1254,643433*	*1288,238708*		
2	*1242,009796*	*1317,377136*		
3	*1228,491852*	*1263,503296*		
4	*1222,218445*	*1347,876709*		
5	*1215,245392*	*1294,729797*		
6	*1236,067383*	*1302,491821*		
7	*1222,026001*	*1273,902954*		
8	*1245,61676*	*1258,883911*		
9	*1233,696747*	*1233,821899*	**Gen. Avg.**	**1261,726**
10	*1236,103088*	*1317,580597*		
Avg.	**1233,61189**	**1289,840683**		
Std. Dev.	**12,0036879**	**33,54359594**		
Var.	**144,088522**	**1125,172828**		
Avg.-Gen.Avg.	**-28,114397**	**28,11439667**		
SQR. (Avg.-Gen.Avg.)	**790,4193**	**790,4193**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**634,6306753**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**56,22879333**			
Sp	**25,19187717**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**4,99095019**			

Table F.48. Total delay comparison between Alternatives 5&6

		Aternatives			
Replications		5	6		
	1	*3585390*	*4908090*		
	2	*3737974*	*5417398*		
	3	*3473728*	*4743643*		
	4	*3455783*	*5983808*		
	5	*3607846*	*5287771*		
	6	*3656085*	*5345849*		
	7	*3492386*	*4896420*		
	8	*3557142*	*4381036*		
	9	*3555827*	*4194142*	**Gen. Avg.**	**4317918**
	10	*3554421*	*5523612*		
Avg.		**3567658,2**	**5068176,9**		
Std. Dev.		**85756,0395**	**546669,7465**		
Var.		**7354098316**	**2,98848E+11**		
Avg.-Gen.Avg.		**-750259,35**	**750259,35**		
SQR. (Avg.-Gen.Avg.)		**5,6289E+11**	**5,62889E+11**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**1,53101E+11**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**1500518,7**			
Sp		**391281,1713**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**8,57506586**			

Table F.49. Toll plaza throughput comparison between Alternatives 5&6

		Aternatives			
Replications		5	6		
	1	*27565*	*27444*		
	2	*27331*	*27396*		
	3	*27134*	*27032*		
	4	*27332*	*27400*		
	5	*27073*	*27263*		
	6	*27055*	*27350*		
	7	*27153*	*27178*		
	8	*27297*	*27203*		
	9	*27219*	*27082*	**Gen. Avg.**	**27251,35**
	10	*27255*	*27265*		
Avg.		**27241,4**	**27261,3**		
Std. Dev.		**151,725044**	**138,9284788**		
Var.		**23020,4889**	**19301,12222**		
Avg.-Gen.Avg.		**-9,95**	**9,95**		
SQR. (Avg.-Gen.Avg.)		**99,0025**	**99,0025**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**21160,80556**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**19,9**			
Sp		**145,4675412**			
Sqrt(1/n+1/m)		**0,447213595**			t<t-critical
					Not rejected
t-value		**0,30589472**			

Table F.50. Total system throughput comparison between Alternatives 5&6

	Aternatives				
Replications	5	6			
1	*27657*	*27489*			
2	*27383*	*27422*			
3	*27251*	*27131*			
4	*27474*	*27456*			
5	*27051*	*27392*			
6	*27155*	*27331*			
7	*27305*	*27199*			
8	*27352*	*27349*			
9	*27374*	*27113*		**Gen. Avg.**	**27319,35**
10	*27260*	*27243*			
Avg.	**27326,2**	**27312,5**			
Std. Dev.	**167,657588**	**134,2404559**			
Var.	**28109,0667**	**18020,5**			
Avg.-Gen.Avg.	**6,85**	**-6,85**			
SQR. (Avg.-Gen.Avg.)	**46,9225**	**46,9225**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**23064,78333**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**13,7**				
Sp	**151,870943**				
Sqrt(1/n+1/m)	**0,447213595**			t<t-critical	
				Not rejected	
t-value	**0,2017116**				

F.11 ALTERNATIVE 5&7

Table F.51. Fuel consumption comparison between Alternatives 5&7

	Aternatives			
Replications	5	7		
1	*20414,09717*	*53010,87207*		
2	*20009,04053*	*49403,84863*		
3	*19965,46973*	*50314,8291*		
4	*19902,15576*	*43893,45703*		
5	*19520,13232*	*52787,81641*		
6	*20031,97949*	*48075,07129*		
7	*19836,66406*	*51708,19043*		
8	*20300,69434*	*50061,56055*		
9	*20079,49902*	*50263,1416*	**Gen. Avg.**	**35063,58**
10	*20151,98877*	*51541*		
Avg.	**20021,1721**	**50105,97871**		
Std. Dev.	**248,4739**	**2657,072662**		
Var.	**61739,279**	**7060035,134**		
Avg.-Gen.Avg.	**-15042,403**	**15042,4033**		
SQR. (Avg.-Gen.Avg.)	**226273897**	**226273896,9**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**3560887,206**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**30084,80659**			
Sp	**1887,031321**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Not rejected
t-value	**35,6494733**			

Table F.52. Pollution comparison between Alternatives 5&7

	Aternatives			
Replications	5	7		
1	*1254,643433*	*5386,499756*		
2	*1242,009796*	*4574,881836*		
3	*1228,491852*	*4816,022583*		
4	*1222,218445*	*4032,553101*		
5	*1215,245392*	*5075,401611*		
6	*1236,067383*	*4577,558716*		
7	*1222,026001*	*5113,820557*		
8	*1245,61676*	*4808,311035*		
9	*1233,696747*	*4873,09021*	**Gen. Avg.**	**3026,559**
10	*1236,103088*	*4936,929077*		
Avg.	**1233,61189**	**4819,506848**		
Std. Dev.	**12,0036879**	**369,3924118**		
Var.	**144,088522**	**136450,7539**		
Avg.-Gen.Avg.	**-1792,9475**	**1792,947479**		
SQR. (Avg.-Gen.Avg.)	**3214660,66**	**3214660,663**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**68297,42122**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**3585,894958**			
Sp	**261,3377531**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Not rejected
t-value	**30,6817702**			

Table F.53. Total delay comparison between Alternatives 5&7

		Aternatives		
Replications		5	7	
	1	*3585390*	*75283137*	
	2	*3737974*	*58859508*	
	3	*3473728*	*63623026*	
	4	*3455783*	*49170028*	
	5	*3607846*	*68695554*	
	6	*3656085*	*58789450*	
	7	*3492386*	*69752890*	
	8	*3557142*	*62982989*	
	9	*3555827*	*64260824*	**Gen. Avg. 33637984**
	10	*3554421*	*65665688*	
Avg.		**3567658,2**	**63708309,4**	
Std. Dev.		**85756,0395**	**7142391,776**	
Var.		**7354098316**	**5,10138E+13**	
Avg.-Gen.Avg.		**-30070326**	**30070325,6**	
SQR. (Avg.-Gen.Avg.)		**9,0422E+14**	**9,04224E+14**	
n		**10**	**10**	
1/n		**0,1**	**0,1**	
n-1		**9**	**9**	
m+n-2		**18**		
Sp2		**2,55106E+13**		
Alpha		**0,05**		
Tcritical		**2,1**		
Abs(1Avg-2Avg)		**60140651,2**		
Sp		**5050797,678**		
Sqrt(1/n+1/m)		**0,447213595**		t>t-critical
				Not rejected
t-value		**26,625217**		

Table F.54. Toll plaza throughput comparison between Alternatives 5&7

	Aternatives			
Replications	5	7		
1	*27565*	*25509*		
2	*27331*	*26927*		
3	*27134*	*26455*		
4	*27332*	*26682*		
5	*27073*	*26004*		
6	*27055*	*26877*		
7	*27153*	*26025*		
8	*27297*	*26714*		
9	*27219*	*26657*	**Gen. Avg.**	**26849,3**
10	*27255*	*26722*		
Avg.	**27241,4**	**26457,2**		
Std. Dev.	**151,725044**	**461,2470536**		
Var.	**23020,4889**	**212748,8444**		
Avg.-Gen.Avg.	**392,1**	**-392,1**		
SQR. (Avg.-Gen.Avg.)	**153742,41**	**153742,41**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**117884,6667**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**784,2**			
Sp	**343,3433655**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Not rejected
t-value	**5,1072037**			

Table F.55. Total system throughput comparison between Alternatives 5&7

	Aternatives			
Replications	5	7		
1	*27657*	*25087*		
2	*27383*	*27188*		
3	*27251*	*26387*		
4	*27474*	*26699*		
5	*27051*	*26370*		
6	*27155*	*26678*		
7	*27305*	*25904*		
8	*27352*	*26526*		
9	*27374*	*26522*	**Gen. Avg.**	**26865**
10	*27260*	*26677*		
Avg.	**27326,2**	**26403,8**		
Std. Dev.	**167,657588**	**564,3115373**		
Var.	**28109,0667**	**318447,5111**		
Avg.-Gen.Avg.	**461,2**	**-461,2**		
SQR. (Avg.-Gen.Avg.)	**212705,44**	**212705,44**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**173278,2889**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**922,4**			
Sp	**416,2670884**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**4,95486951**			

F.12 ALTERNATIVE 6&7

Table F.56. Fuel consumption comparison between Alternatives 6&7

	Aternatives				
Replications	6	7			
1	*19496,58936*	*53010,87207*			
2	*19664,55859*	*49403,84863*			
3	*19356,18945*	*50314,8291*			
4	*20090,50732*	*43893,45703*			
5	*19392,05371*	*52787,81641*			
6	*19386,19482*	*48075,07129*			
7	*19286,57764*	*51708,19043*			
8	*19312,25244*	*50061,56055*			
9	*18805,28613*	*50263,1416*		**Gen. Avg.**	**34780,69**
10	*19763,86328*	*51541*			
Avg.	**19455,4073**	**50105,97871**			
Std. Dev.	**338,991951**	**2657,072662**			
Var.	**114915,543**	**7060035,134**			
Avg.-Gen.Avg.	**-15325,286**	**15325,28572**			
SQR. (Avg.-Gen.Avg.)	**234864382**	**234864382,3**			
n	**10**	**10**			
1/n	**0,1**	**0,1**			
n-1	**9**	**9**			
m+n-2	**18**				
Sp2	**3587475,338**				
Alpha	**0,05**				
Tcritical	**2,1**				
Abs(1Avg-2Avg)	**30650,57144**				
Sp	**1894,063182**				
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical	
				Rejected	
t-value	**36,1850449**				

Table F.57. Pollution comparison between Alternatives 6&7

		Aternatives			
Replications		6	7		
	1	*1288,238708*	*5386,499756*		
	2	*1317,377136*	*4574,881836*		
	3	*1263,503296*	*4816,022583*		
	4	*1347,876709*	*4032,553101*		
	5	*1294,729797*	*5075,401611*		
	6	*1302,491821*	*4577,558716*		
	7	*1273,902954*	*5113,820557*		
	8	*1258,883911*	*4808,311035*		
	9	*1233,821899*	*4873,09021*	**Gen. Avg.**	**3054,674**
	10	*1317,580597*	*4936,929077*		
Avg.		**1289,84068**	**4819,506848**		
Std. Dev.		**33,5435959**	**369,3924118**		
Var.		**1125,17283**	**136450,7539**		
Avg.-Gen.Avg.		**-1764,8331**	**1764,833083**		
SQR. (Avg.-Gen.Avg.)		**3114635,81**	**3114635,809**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**68787,96337**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**3529,666165**			
Sp		**262,2745954**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**30,0927868**			

Table F.58. Total delay comparison between Alternatives 6&7

	Aternatives			
Replications	6	7		
1	*4908090*	*75283137*		
2	*5417398*	*58859508*		
3	*4743643*	*63623026*		
4	*5983808*	*49170028*		
5	*5287771*	*68695554*		
6	*5345849*	*58789450*		
7	*4896420*	*69752890*		
8	*4381036*	*62982989*		
9	*4194142*	*64260824*	**Gen. Avg.**	**34388243**
10	*5523612*	*65665688*		
Avg.	**5068176,9**	**63708309,4**		
Std. Dev.	**546669,746**	**7142391,776**		
Var.	**2,9885E+11**	**5,10138E+13**		
Avg.-Gen.Avg.	**-29320066**	**29320066,25**		
SQR. (Avg.-Gen.Avg.)	**8,5967E+14**	**8,59666E+14**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**2,56563E+13**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**58640132,5**			
Sp	**5065205,232**			
Sqrt(1/n+1/m)	**0,447213595**		t>t-critical	
			Rejected	
t-value	**25,88707**			

Table F.59. Toll plaza throughput comparison between Alternatives 6&7

		Aternatives			
Replications		6	7		
	1	*27444*	*25509*		
	2	*27396*	*26927*		
	3	*27032*	*26455*		
	4	*27400*	*26682*		
	5	*27263*	*26004*		
	6	*27350*	*26877*		
	7	*27178*	*26025*		
	8	*27203*	*26714*		
	9	*27082*	*26657*	**Gen. Avg.**	**26859,25**
	10	*27265*	*26722*		
Avg.		**27261,3**	**26457,2**		
Std. Dev.		**138,928479**	**461,2470536**		
Var.		**19301,1222**	**212748,8444**		
Avg.-Gen.Avg.		**402,05**	**-402,05**		
SQR. (Avg.-Gen.Avg.)		**161644,202**	**161644,2025**		
n		**10**	**10**		
1/n		**0,1**	**0,1**		
n-1		**9**	**9**		
m+n-2		**18**			
Sp2		**116024,9833**			
Alpha		**0,05**			
Tcritical		**2,1**			
Abs(1Avg-2Avg)		**804,1**			
Sp		**340,6244021**			
Sqrt(1/n+1/m)		**0,447213595**			t>t-critical
					Rejected
t-value		**5,27860673**			

Table F.60. Throughput comparison between Alternatives 6&7

	Aternatives			
Replications	6	7		
1	*27489*	*25087*		
2	*27422*	*27188*		
3	*27131*	*26387*		
4	*27456*	*26699*		
5	*27392*	*26370*		
6	*27331*	*26678*		
7	*27199*	*25904*		
8	*27349*	*26526*		
9	*27113*	*26522*	**Gen. Avg.**	**26858,15**
10	*27243*	*26677*		
Avg.	**27312,5**	**26403,8**		
Std. Dev.	**134,240456**	**564,3115373**		
Var.	**18020,5**	**318447,5111**		
Avg.-Gen.Avg.	**454,35**	**-454,35**		
SQR. (Avg.-Gen.Avg.)	**206433,922**	**206433,9225**		
n	**10**	**10**		
1/n	**0,1**	**0,1**		
n-1	**9**	**9**		
m+n-2	**18**			
Sp2	**168234,0056**			
Alpha	**0,05**			
Tcritical	**2,1**			
Abs(1Avg-2Avg)	**908,7**			
Sp	**410,1633889**			
Sqrt(1/n+1/m)	**0,447213595**			t>t-critical
				Rejected
t-value	**4,95391599**			

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