# REAL TIME TRAFFIC MANAGEMENT USING CONNECTED VEHICLES: A CASE STUDY ON D100 HIGHWAY

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REAL TIME TRAFFIC MANAGEMENT USING CONNECTED VEHICLES: A CASE STUDY ON D100 HIGHWAY

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# ABSTRACT

## REAL TIME TRAFFIC MANAGEMENT USING CONNECTED VEHICLES: A CASE STUDY ON D100 HIGHWAY

Traffic congestion is one of the most crucial issue that have a negative impact on the economy and the environment of a city. The negative impacts of congestion become stronger with the increasing population and vehicle usage. Here, the metropolitan areas are the most problematic and sensitive areas by considering that they contain most of the population within itself. Even traffic congestion in a local region may be felt throughout the network and; therefore, it might deteriorate the overall traffic conditions of the road network of a city which makes metropolitans quite sensitive. The scale of this impact gets especially grander in overpopulated cities; thus, it becomes even a more critical issue. In this thesis, a real time traffic management method using connected vehicles is tested in a simulation environment with synthetic and D 100 Highway real traffic data. To test this method, a 5.4 km length network with 3 lanes was built in the SUMO (Simulation of Urban Mobility) environment. An incident was generated in each run to observe its impact on the traffic network. By changing the incident and the parameters of the connected vehicles, 189 different scenarios were tested. The results of these 189 scenarios show that the introduction of connected vehicles causes an increase up to 20.35% in terms of mean speed, a decrease up to 32.54% in terms of mean density and an increase up to 2.45% in terms of mean flow for the local system before the incident. Based on the 189 scenarios, the connected vehicles provide the maximum mean speed increase and mean density decrease when they control traffic flow 1750 meters behind the incident location.

# ÖZET

## BİRBİRİNE BAĞLI AKILLI ARAÇLAR İLE GERÇEK ZAMANLI TRAFİK YÖNETİMİ: D100 OTOYOLU ÇALIŞMASI

Trafik sıkışıklığı, bir şehrin ekonomisini ve çevresini olumsuz etkileyen en önemli konulardan biridir. Artan nüfus ve araç kullanımı ile tıkanıklığın olumsuz etkileri güçlenmektedir. Metropoller, popülasyonun çoğunluğunu barındırdığından, en problemli ve hassas bölgelerdir. Yerel bir bölgede trafik sıkışıklığı bile ağ genelinde hissedilebilir ve bu nedenle, bir şehrin karayolu ağının genel trafik koşullarını bozabilir. Kazanın yarattığı etkinin ölçeği özellikle aşırı nüfuslu şehirlerde daha da ağırlaşmakta ve böylece daha da kritik bir konu haline gelmektedir. Bu tezde, bağlı araçları kullanan gerçek zamanlı trafik yönetimi yöntemi, sentetik ve D100 Karayolu gerçek trafik verileri ile bir simülasyon ortamında test edilmiştir. Bu yöntemi test etmek için, SUMO (Kentsel Hareketlilik Benzetimi) ortamında 3 şeritli 5,4 km uzunluğunda bir ağ kurularak sentetik trafik akışının özellikleri ve bu trafik akışındaki araçlar tanımlanmıştır. Her senaryoda, trafik ağı üzerindeki etkisini gözlemlemek için, bir olay oluşturulmuştur. Her olayın ve bağlı araçların parametreleri değiştirilerek 189 farklı vaka test edilmiştir. Sentetik trafik veri seti kullanılarak yapılan bu 189 senaryonun sonuçlarına göre bağlı araçların, kaza öncesi bölgede, ortalama hız açısından %20,35'e kadar bir artışa, ortalama yoğunluk açısından %32,54'e kadar bir düşüşe ve ortalama akış açısından %2,45'e kadar bir artışa neden olduğu gözlemlenmiştir. Bağlı araçlar kazadan 1750 metre geride trafik akışını kontrol etmeye başladıklarında maksimum ortalama hız artışını ve ortalama yoğunluk azalışını sağlamaktadır.

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# LIST OF SYMBOLS

| | |
|---|---|
| $d$ | Distance |
| $D$ | Distance |
| $decel$ | Deceleration |
| $h$ | Time Headway |
| $k$ | Density |
| $N$ | Number of vehicles |
| $q$ | Flow |
| $Q$ | Flow |
| $S$ | Variance |
| $T$ | Period |
| $t$ | Time |
| $u$ | Speed |
| $X$ | Position |
| | |
| $\Delta$ | Difference |
| $\omega$ | Shockwave Speed |

# LIST OF ACRONYMS/ABBREVIATIONS

| | |
|---|---|
| BDI | Beliefs Desires Intentions Paradigm |
| CACC | Cooperative Adaptive Cruise Control |
| CV | Connected Vehicles |
| CVH | Connected Vehicle Harmonizer |
| SORT | Simple Online and Realtime Tracking System |
| SUMO | Simulation of Urban Mobility |
| V2I | Vehicle to Infrastructure Connection |
| V2V | Vehicle to Vehicle Connection |
| V2X | Vehicle to Everything Connection |
| VSL | Variable Speed Limit |
| YOLO | You Only Look Once Algorithm |

# 1. INTRODUCTION

Traffic congestion is one of the most crucial issues that have a negative impact not only on the economy and the environment but also on the physiology of the inhabitants of a city. It burdens extra stress to city dwellers especially in crowded metropolitan areas [1]. In addition to stress, there is a correlation between peak hour stress and some diseases as well [2]. Besides, the toxicity inside the car while waiting in the traffic can get 10 times more than a regular urban air [3]. The negative impacts of congestion become stronger with the increasing population and vehicle usage. Here, the metropolitan areas are the most problematic and sensitive areas by considering that they contain most of the population within itself. Even traffic congestion in a local region may be felt throughout the network and, therefore; it might deteriorate the overall traffic conditions of the road network of a city which makes metropolitans quite sensitive. The scale of this impact gets especially grander in overpopulated cities; thus, it becomes even a more critical issue.

Istanbul as an overpopulated megacity has one of the most congested traffic in the world [4]. With a population of over 15 million people [5], the demand for transportation is incredibly high. The congestion level is 53% that means an average driver spends around 53% extra time in the car compared to uncongested conditions. There are over 4.1 million vehicles in the city's traffic [6], which causes significant congestion throughout the different parts of the city. Other than Istanbul, many others suffer from excessive congestion including Moscow with 56%, Mexico City 52%, Dublin with 45%, and Tokyo with 41% congestion level. Moscow's traffic had an average speed of 18 kilometers per hour in 2018 and drivers lost 210 hours in congestion [7, 8]. Due to increasing population and demand around the world, alternative, technology-oriented, and sustainable solutions must be created and actions must be taken for the problem of traffic congestion. Here, sustainable transportation systems that can be an alternative to transportation by private vehicles and public transportation systems can be important solutions to traffic congestion. Yet, some performance indicators must be satisfied to obtain maximum efficiency from public transportation systems

[9]. Some of those indicators are directly related to the freely flowing traffic network such as average speed that affects travel time and public transportation efficiency respectively. Therefore, to reach the full potential of those systems, the conditions of traffic flow on the road networks also need to be improved. It is possible to use intelligent transportation systems for improving traffic conditions. Connected vehicles (CVs), which is a new and developing technology, can be very beneficial and can be used for this purpose. By using these tools, a real-time traffic management system can be implemented that is economical and sustainable.

## 1.1. Problem Statement

Traffic congestions causes significant economic and environmental issues, which are even more significant in highly populated cities. Public transportation systems and accessible alternative transportation modes are important solutions to these issues. However, in order to get the full benefit of these solutions, the traffic flow conditions must be improved. Using the latest technology, such as autonomous and connected vehicles, the traffic must be managed efficiently so that the delays and queues caused by the traffic congestions are minimized.

## 1.2. Goals & Objectives

The goal of this thesis is to test the real time traffic management method using connected vehicles. In order to achieve this goal, there are certain objectives that must be completed. These objectives are as follows:

(i) To construct a SUMO model [10] of the D 100 Highway,
(ii) To evaluate the real time traffic management method using connected vehicles on the study network with synthetic and real traffic flow data.

## 1.3. Literature Review

As one of the main problems in urban areas, traffic congestion is a problem that must be handled via traffic management systems. To have an efficient traffic management system and maximize the benefits of traffic managing, information about the traffic must be available and must be interpreted correctly. Traffic management is a field of transportation engineering concerned with overcoming problems in the traffic network by making use of various measures instead of resorting to construction activities such as building new roads or improving the existing infrastructure. In this regard, the focus is mostly on "improving the overall traffic efficiency" [10, 11].

(i) Collect data from the traffic.
(ii) Process this data.
(iii) Deliver services accordingly.

The initial step of data collection can be handled by gathering information from various sources such as vehicles, traffic lights, in-road and roadside sensors, publicly available web sources and participatory networks. The most commonly collected data are related to traffic history, traffic light scheduling, road occupancy and incidents [12]. Parking and bus information are other examples of data collection [13]. The methodology of handling the collected data in the second step might either be infrastructure-based (making use of sensors etc.) or not (i.e., vehicle to vehicle communication). Lastly, suitable solutions are proposed based on detected incidents or hazards in the previous step. Some applications of traffic management include ramp metering, providing dynamic route information, altering speed limits and dynamic lane management [12].

One of the main aims of implementing traffic management is to tackle congestion by monitoring the current situation in traffic [13]. In addition to congestion relief, reduction in travel times, improved safety and reduced "traffic incident response time" could be listed among the many benefits resulting from managing the traffic. When considering the "economical and productivity losses as well as environmental impacts"

resulting from congestion, it can be said that addressing this issue through traffic management has economic and environmental benefits [14]. Similarly, it might help improve urban air quality and diminish the health problems related to exposure to air pollution resulting from the traffic [15, 16]. Since the aim is to increase the efficiency of the existing infrastructure, traffic management stands out with its cost-effectiveness as well. Lastly, the gathered and processed information could be used to create cooperation between the stakeholders responsible from the city's transportation such as transport authorities, emergency services, and the private sector, thus enhancing the policymaking and implementation processes. To summarize, it can be said that currently, traffic management has an important role in ensuring safe, efficient and sustainable mobility.

Transportation technologies have come a long way since the first cities were developed. By integrating wireless communication, processing power and sensing technologies for traffic management systems, mobility, sustainability and reliability of the transportation systems increased substantially. The current trend is to search for improvement opportunities with innovations based on vehicles. Autonomous vehicles with advanced sensing technologies and fast decision-making systems have become one of the most important technologies in recent years. Combining these vehicles with vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and vehicle-to-everything (V2X) technologies, it is possible to maximize the efficiency of solutions for the current issues of traffic. Vehicles that benefit from these technologies are called connected vehicles. Due to these reasons, it is important to take precautions for obtaining actually sustainable and efficient solutions by using this latest technology. There are studies in which the impact of autonomous and connected vehicles on traffic is being evaluated.

In a study that directly investigates connected and autonomous vehicles on a freeway under realistic scenarios in Antwerp, traffic congestion and network capacity will be benefited from the connected vehicles by obtaining time headway and reaction time reduction [17]. Whereas the same couldn't be the fact for autonomous vehicles. Therefore, connectivity and cooperation will be an important part of future transportation whether automation exists or not. The behavior of connected vehicles is considered similar to the car following behaviors of cooperative adaptive cruise control

(CACC) technologies that take place widely in the literature with proven effectiveness in many aspects such as human behavior prediction, fuel consumption, and safety [18, 19, 20]. The study found that connected vehicles act as autonomous vehicles under low traffic conditions and don't have much of an effect, however, under high demand, they improve the performance of the network, prevent the occurrence of bottlenecks and increase the capacity and average speed. Still, the effects of connectivity and autonomy are mostly investigated together. Another aspect that affects traffic congestion is the traffic flow stability which is studied in research by using the influence of connected and autonomous vehicles [21]. It was observed that the breakdown flow rate increases as the market penetration rate of both of these types of vehicles increases.

Variable speed limit (VSL) applications are used widely as a traffic management system. By utilizing from connected vehicles in freeways and corridors, VSL can be achieved more efficiently [22]. As suggested in a study, VSL acts like a congestion mitigation tool especially for bottlenecks to keep the traffic flow in an optimal level for both recurrent and non-recurrent congestions. As a result, the congestion decreased up to 7-12 %. The difference in the decline depends on the level of penetration of the CVs. The main aim of the VSL applications is to harmonize the speed of the traffic between upstream and downstream to obtain a smooth flow throughout the road and to reduce shockwave propagation. A dissertation focuses on the dynamic speed limits based on shockwaves on recurrent freeway bottlenecks [23]. It investigates congestion propagation and shockwave movement to upstream location as a result of breakdowns. The model is made with V2I communication due to the absence of CV data on the field. According to study, at least 20% of market penetration is necessary to obtain satisfying results. Moreover, shockwave-based VSL systems are found to be more effective than other VSL types. A study develops an optimization program named Connected Vehicles Harmonizer (CVH) to specify recommended speeds for CVs in work zones [24]. The aim of the program is to minimize travel time by controlling the speed and shockwave propagation efficiently. The tests performed showed that the methodology results more than 13% delay reduction for a penetration rate higher than 80%. Yet, when the penetration rate decreases form 80 to 70%, the efficiency decreases by half. Another study aims to discover the effects of early shockwave detection and the

improvements that can be obtained from speed harmonization by focusing on CVs in a congested flow [25]. The results showed that remarkable improvements can be achieved to control, to delay and even to eliminate the congestion. It also found that there is an optimal upstream location to implement the speed limit depending on the shockwave. Another criteria was the compliance to the speed harmonization which then found to be sufficient to have 10% of compliance. As a result, the combination of VSL and connected vehicles can achieve 7-12% improvement for the congestion depending on the penetration rate, resulting a decrease in travel time [22].

In the analysis, different methods and tools are suggested in the literature to evaluate the efficiency of connected and autonomous vehicles under different conditions. Paramics Software is one of the most utilized simulation tools. As an example, a study conducted in Toronto focuses on microsimulation and quantitative analysis of the CVs on mobility, safety, and the environment by using Paramics Software [26]. Different penetration rates are compared by simulation and experimentation in 3 dimensional that covers informed non-CV vehicles, uninformed non-CV, and CV. As a result, connectivity plays an important role to improve mobility, to enhance safety and to reduce GHGs emissions. A multi-agent-based extension of MovSim which is an open-source microscopic traffic simulation platform was proposed for modeling the complex interaction between connected vehicles and regular vehicles. Furthermore, the connection between connected vehicles and infrastructure was also considered in this study [27]. The results of this work show that roadside units can be strong candidates for traffic management, enabling a decentralized control strategy to harmonize speeds and headways. An approach for modeling the traffic of autonomous and connected vehicles based on the Beliefs-Desires-Intentions (BDI) paradigm was proposed in a different study [28]. Connected vehicles stand out as mobile sensors within the field of traffic management due to their ability of vehicle-to-vehicle and vehicle-to-infrastructure communication. For instance, information on "the position, motion, timestamp, headway, brake status, activation of emergency lights, airbag deployment status" can easily be extracted from the data provided from sensors. Online optimal control of the connected vehicles was developed for efficient traffic flow at merging roads [29]. The presented framework optimized the acceleration profile of each vehicle and avoided causing any

incidents at these merging zones. Moreover, fuel consumption and travel times are reduced significantly with connected vehicles.

A simulation-based study focuses on the development and evaluation of a cooperative vehicle intersection control algorithm in the environment of the connected vehicle [30]. The benefit of V2I was mainly taken advantage of in this case. The simulations show that with the improved algorithm 99% and 33% of stop delay and total travel time reductions, respectively were achieved. Besides, a 44% reduction of CO2 and a 44% improvement in terms of fuel savings, air quality, and energy savings are obtained. Another study on the effects of vehicle-to-vehicle (V2V) communication by using Paramics concluded that the V2V is effective to improve safety and network travel time for high to moderate congestion levels [31]. The same finding about low to moderate congestion was also concluded in [17]. It mainly focuses on high incident areas which shows parallelism with this thesis. The incidents were detected and the vehicles are informed not only to change their route choice but also to increase awareness and decrease their speed and aggressiveness. Another study used Paramics micro-simulation program to detect the effects of V2V and V2I communication by implementing speed recommendations and re-routing guidance in urban-freeways [32]. The main aim was to find the optimum treatments to prevent crashes that causes by the upstream and downstream speed differences by using two types of market penetration, 30 and 50 % respectively. As a result, the travel time decreases linearly going from non V2V, 30% V2V and 50% V2V and the crash potential decreases in the 30% connected vehicle scenario.

Another study has focused on optimizing the coordination and control of connected and autonomous vehicles at urban traffic intersections [33]. The proposed system allowed the vehicles to cross intersections without the need for traffic lights and safety issues. The validation of this system was made through conducting a simulation study which models two intersections located in downtown Boston. In the simulation, 42.4% fuel consumption improvement and 37.3% travel time improvement are obtained. A platoon-based multi-agent intersection management system for connected vehicles is proposed in another study [34]. The proposed system evaluated for mobility and environment performance in SUMO simulation that contains only from autonomous

and connected vehicles. Compared to conventional traffic signal control systems, the average travel time and fuel consumption were improved. Besides, the communication load on the intersection management agent is reduced by 90%. Connected vehicles also have the potential to act as "actuators for traffic control" by receiving guidance from the traffic management center through infrastructure-to-vehicle communication and influence the traffic [21]. Yet, the work in this study is still in progress with additional extensions planned to be introduced in the future.

## 1.4. Organization of the Thesis

In section 2, the theoretical background used in this thesis are presented and explained. In section 3, the methodology of the real time traffic management method using connected vehicles, the simulation study and the case study are presented. Finally, in section 4 the conclusion and final comments are made.

# 2. THEORY

In this section, the theoretical background of this thesis are presented.

## 2.1. Traffic Flow Parameters

The fundamental parameters of traffic flow are: speed, flow and density. The details are presented in the next sections.

### 2.1.1. Speed

The definition of speed is the distance travelled by an object per unit time. In this case the object is a vehicle. The properties of speed are important aspects for inspecting the performance of a roadway. The variation in speed values are important for determining the fuel consumption and the emission values. When density and flow rate are low and all external conditions are ideal (i.e. weather, road geometry) the average speed of the vehicles traveling on that road segment converges towards free flow speed. When the flow reaches the capacity level, then the average speed of the vehicles becomes the optimum speed.

The speed values can be investigated in both microscopic and macroscopic manner.

The microscopic speed is defined as the rate of movement of a singular vehicle with the unit of distance over time and is represented as the following formula:

$$u_i = \frac{d_x}{d_t} \tag{2.1}$$

where is the $u_i$ Speed of the $i^{th}$ vehicle (meters/second), is the $d_x$ the distance travelled by vehicle $i$ (meters), is the $d_t$ the length of time (seconds).

Time mean speed is the value that is evaluated to examine the microscopic speed characteristics. It is calculated by calculating the arithmetic average of all vehicles passing a section of a road with the following formula:

$$\bar{u}_t = \frac{1}{N}\sum_{i=1}^{N} u_i \tag{2.2}$$

where $\bar{u}_t$ Time mean speed (meters/second), is the $u_i$ Speed of the $i^{th}$ vehicle (meters/second), is the $N$ total number of vehicles.

Macroscopic speed differs from microscopic speed due to the fact that it utilizes space mean speed instead of time mean speed. By calculating space mean speed, the average time that a vehicle spends on a particular length of a roadway is obtained. To do so the following equation is used:

$$\bar{u}_s = \frac{D}{\frac{1}{N}\sum_i t_i} \tag{2.3}$$

where $\bar{u}_s$ Space mean speed (meters/second), is the $D$ The distance that vehicles are investigated for (meters), is the $t_i$ The time it takes for vehicle $i$ to travel distance $D$ (seconds).

The relationship between time and space mean speed values is presented in the following formula which indicates that time mean speed will always be greater than the space mean speed:

$$\bar{u}_t = \bar{u}_s + \frac{S_s^2}{\bar{u}_s} \tag{2.4}$$

where $S_s^2$ Variance of space mean speed.

Knoop *et al.*, [35] determined that the space mean speed fits better on the fundamental diagram of traffic flow. It is also why that, in practice, engineers also tend to use space mean speed values rather than time mean speed values.

### 2.1.2. Flow

Flow is defined as the number of vehicles passing through a point in an interval and can be represented with the following formula:

$$q = \frac{N}{T} \tag{2.5}$$

where $N$ Number of vehicles counted, is the $T$ Vehicle counting period.

Another way of denoting the flow rate is to equate the total time to the sum of time headways between each vehicle:

$$q = \frac{N}{T} = \frac{N}{\sum_{i=1}^{N} h_i} = \frac{N}{N * \bar{h}} = \frac{1}{\bar{h}} \tag{2.6}$$

Time headway (seconds) is the time interval between the moment that the front bumper of leading vehicle arrives to a selected point on the road and the moment that the front bumper of the following vehicle arrives to the exact same point. The physical distance between these two front bumpers of these two vehicles is called space headway ($h^s$) which is in terms of meters.

There are three general categories of flow on a roadway [36]:

(i) Free flow traffic: Under this condition the drivers have the maximum freedom of travel with their desired speed values. There are minimum interactions between vehicles. This condition usually occurs under low density and high speed conditions.

(ii) Flow at capacity: Compared to free flow traffic conditions, the drivers under this condition of traffic are much more constrained. The headways between vehicles decrease significantly and thus there are much more interactions between drivers. This is considered to be the most efficient state.

(iii) Congested flow: This condition occurs when the density is very high and the flow and speed values are very low. It generally causes many stops in traffic. The non-moving vehicles are located bumper to bumper, meaning that the space headway is minimized.

Hall *et al.*, [37] proposed a speed-flow curve based on various real life measurements from different highways (Figure 2.1). In the figure there are three segments which all represent different states of traffic flow conditions. Segment 1, 2 and 3 are representing free flow traffic, flow at capacity and congested flow conditions respectively. Up until a certain flow rate the speed values are conserved so that the traffic is under free flow conditions. When there is a significant reduction in speed values for the same flow rate [38], as can be observed from the second segment, it can be deduced that the flow rate has converged to capacity flow values. Finally, on the third segment, the speed values are the lowest compared to other segments with also decreasing flow values. The most undesirable case occurs when both the speed and flow values converge to 0.

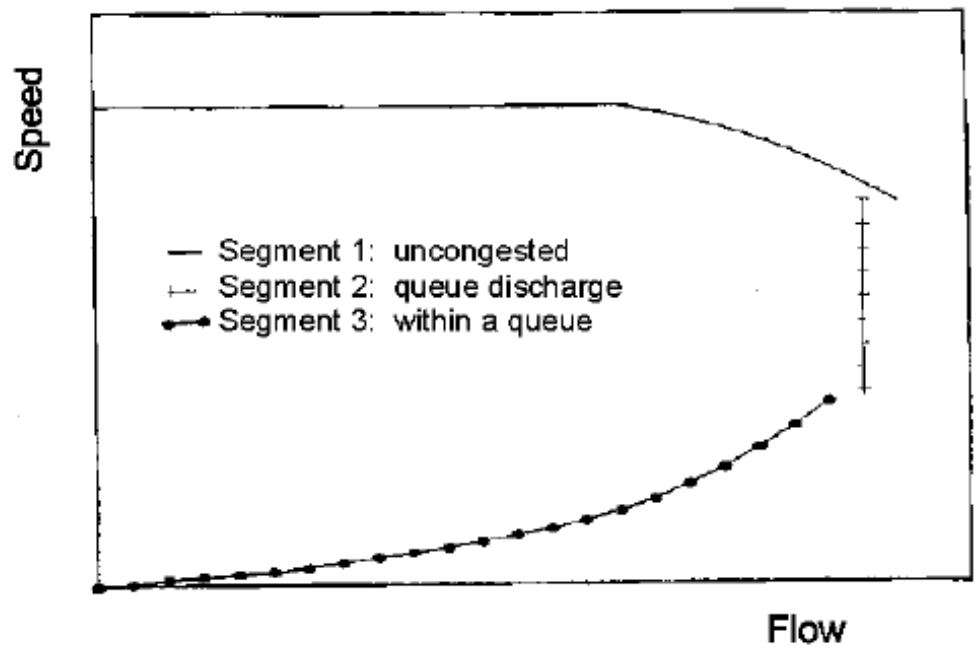


Figure 2.1. Speed-flow curve proposed by Hall *et al.* [37].

### 2.1.3. Density

Density ($k$) represents the number of vehicles on a unit length of a road. Traffic and road operators use mostly this parameter of the traffic flow for measuring the traffic performance. The density is a very has an inverse relationship with the average space headway ($\bar{h}_s$) value:

$$k = \frac{1}{\bar{h}_s} \tag{2.7}$$

In practice, due to the limited availability of sensors that collect traffic information, the occupancy value is used to determine the density levels. Occupancy is defined as the percentage of time that a detector is occupied by a vehicle for its given period of observation. Hall *et al.* [39] determined that the occupancy can be used as a traffic condition classifier, just as density. The occupancy is simply calculated as follows:

$$occupancy = \frac{\sum_{i=1}^{n} t_i}{t} \tag{2.8}$$

where $t_i$ the time that a ($i^{th}$) vehicle occupies the detector, is the $n$ total number of vehicles that passed through the detector, is the $t$ total duration of observation.

To calculate the density by using occupancy values, the following formula is used:

$$Density = \frac{occupancy}{Average\ vehicle\ length\,(m) + Detector\ length\,(m)} \tag{2.9}$$

The density value, when flow rate is equal to capacity, is called critical (optimum) density ($k_o$). When flow rate converges to zero, the density becomes the value that is called the jam density ($k_j$). When jam density is observed, the flow rate and speed values become zero, which indicates that there is a traffic jam. The field studies show that the critical density is half of the jam density value. Typical value of critical density is around 36 to 48 vehicles/mile/lane. Values between 185 to 250 vehicles/mile/lane

are generally observed for jam density values [40].

## 2.2. Traffic Stream Flow Fundamentals

With traffic steam models, fundamental relationships of macroscopic traffic stream characteristics for uninterrupted flow situations can be obtained. Flow, speed and density characteristics are obtained for free-flow and congested flow conditions where there are no flow interruptions (i.e. intersections).

For simplification, Greenshields [41] proposed to assume a linear speed-density relationship (Figure 2.2). Flow ($q$) is the number of vehicles passing a specified point or a short section in a pre-determined period of time in a single lane. It is expressed as an hourly rate on a per lane basis (veh/hr/ln) and has a special flow parameter called maximum flow or capacity ($q_m$). Speed ($u$), which is expressed in kilometers per hour (km/hr), stands for the average rate of motion. From the two types of speed values, which are space-mean-speed and time-mean-speed, space-mean-speed is utilized in this relationship [42]. Free-flow speed ($u_f$) and optimum speed ($u_0$) parameters are two unique speed parameters. The optimum speed value is observed when maximum flow conditions are available, whereas free-flow speed is observed when flow conditions approach zero under free-flow conditions. The final characteristic, density ($k$) is defined as the number of vehicles that are occupying a section of a roadway in a single lane and it is expressed on a per km per lane basis (veh/km/ln). The unique density parameters are jam density ($k_j$) and optimum density ($k0$)) which are defined as the density value which occurs when both flow and speed values approach zero and the density value which occurs when there are maximum flow conditions respectively. With traffic steam models, fundamental relationships of macroscopic traffic stream characteristics for uninterrupted flow situations can be obtained. Flow, speed and density characteristics are obtained for free flow and congested flow conditions where there are no flow interruptions (i.e. intersections).

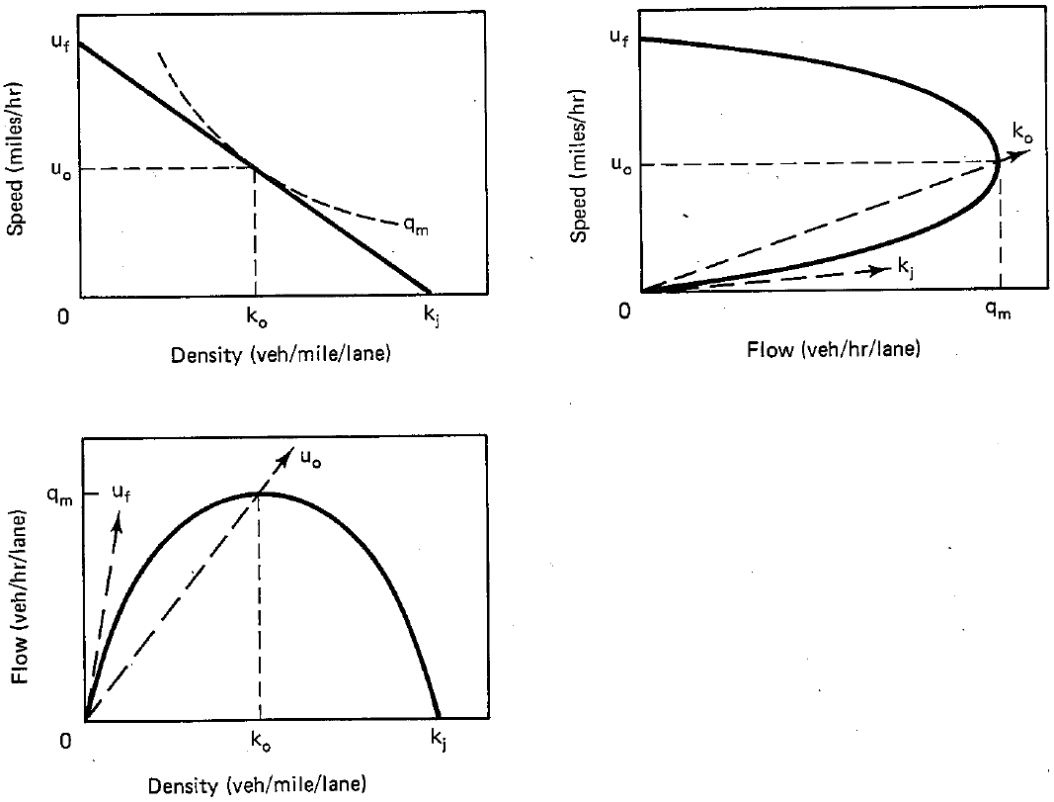


Figure 2.2. Basic stream flow diagrams [43].

Looking at the speed-density diagram in the basic stream flow diagrams, the assumption of linear relationship can be observed. The equation for this relationship is as follows:

$$u = u_f - \left(\frac{u_f}{k_j}\right) k \tag{2.10}$$

According to Equation 2.10, it can be observed that the speed value approaches free flow speed when density and flow approach zero. When density values increase, the speed values decrease up until the maximum flow value and speed and density approach their optimum values. After a certain point with the increase of density up until its maximum value, speed and flow values approach to zero. For deriving the flow-density relationship the following equation must be presented:

$$q = uk \tag{2.11}$$

Equation 2.11 shows that flow is equal to the product of speed and density values. By using these equations (Equation 2.10 and Equation 2.11), it is possible to derive the flow-density relationship, which is shown below the speed-density relation in Figure 2.2. By substituting $q/k$ for u the resulting flow - density equation is obtained:

$$q = u_f k - \left(\frac{u_f}{k_j}\right) k^2 \tag{2.12}$$

In case of very low-density scenarios, flow approaches zero whereas speed approaches free-flow speed. However, when flow increases, density increases whereas speed decreases. When optimum density is available, flow reaches its maximum value. In case of further increase in density, flow values will decrease and finally, become zero when jam density is reached. The speed values can be represented on the flow-density diagram by utilizing the slope of the radial lines extending up to the right from the origin. It can be observed that the slope of the flow-density curve becomes zero when maximum flow occurs $\left(\frac{dq}{dk} = 0 \text{when} k \xrightarrow{k_0}\right)$ and by utilizing this information the relationship between optimum and jam density can be derived, as shown below:

$$0 = u_f - \left(\frac{u_f}{k_j}\right) 2k_0 \tag{2.13}$$

$$k_0 = \frac{k_j}{2} \tag{2.14}$$

It should be noted that this relationship is valid when there is a linear speed-density relationship. In any case, the explanation above can be followed even when nonlinear relationships are encountered.

For speed-flow relationship, the equation can be derived by substituting $q/u$ for $k$ and inserting into Equation 2.15 , which transforms;

$$u = u_f - \left(\frac{u_f}{k_j}\right)\frac{q}{u} \tag{2.15}$$

into

$$q = \frac{k_j}{u_f}\left(u_f u - u^2\right) \tag{2.16}$$

The upper part of the speed-flow curve is called the free-flow regime whereas the lower part is called as the congested flow regime. When free-flow conditions are present, the speed values decrease as the flow level increases up until the maximum flow values. When density surpasses optimum density values, flow reductions and even further speed reductions are observed. Density can be represented by radial lines on the speed-flow diagram, just as the representation of speed on the flow-density diagram. As the lines become steeper, lower densities are observed and when the line vertical, the density becomes zero. With this information the relationship between optimum and free-flow speed can be derived as follows:

Since

$$u = u_f - \left(\frac{u_f}{k_j}\right)\frac{q}{u} \tag{2.17}$$

Then,

$$q_m = \frac{k_j}{u_f}\left(u_f u_0 - u_0^2\right) \tag{2.18}$$

Substituting $u_0 k_0$ for $q_m$, and $2k_0$ for $k_j$ yields,

$$u_0 k_0 = \frac{2k_0}{u_f}\left(u_f u_0 - u_0^2\right) \tag{2.19}$$

and finally solving Equation 2.19 for $u_0$ gives,

$$u_0 = \frac{u_f}{2} \tag{2.20}$$

By using Equation 2.14 and Equation 2.20 the maximum flow (capacity) can be determined as follows:

$$q_m = \frac{u_f k_j}{4} \tag{2.21}$$

Each of these relationships have their own particular benefit and use. Speed-density relationship has its theoretical use for its car-following theory formulations. Flow-density relationship is generally used for freeway control systems. Density is mostly used as a control parameter and flow is mainly an objective function. As an example, it can be said that there is no need for control in cases of low-density conditions due to the fact that the demand is being satisfied at a high level of service. As density increases and becomes closer to its optimum value, more control is required in order to maintain it below the optimum density values. The final relationship, which is speed-flow relationship, is primarily used during the design process to identify the trade-off between level of service and flow. In addition, *Highway Capacity Manual* [44] also utilizes this relationship. Based on the previously explained foundations, in later years several traffic stream models have been developed. Single-regime models can be given as an example, the first of which was developed by Greenshields in 1934 based on observing speed-density measurements which are obtained from aerial photographic studies [45]. Later on, multi-regime models were introduced to the literature. Edie proposed the idea of two-regime models in 1961 due to the poor performance of the Greenberg model under free-flow conditions [46].

The fundamental relationships that have been explained here will be utilized throughout the entirety of the thesis. In order to evaluate the performance of the developed rules, these relationships will be utilized.

## 2.3. Shockwaves in Traffic

Shockwaves in traffic are boundary conditions in space-time domain that create borders whenever there is a discontinuity in flow-density conditions. There are various types of shockwaves. These six types of shockwaves are backward forming, forward recovery, rear stationary, backward recovery, frontal stationary and forward forming shockwaves (Figure 2.3). It should also be noted that in the figure below, the density is at higher levels towards the center of the graphic and the densities decrease going outwards.

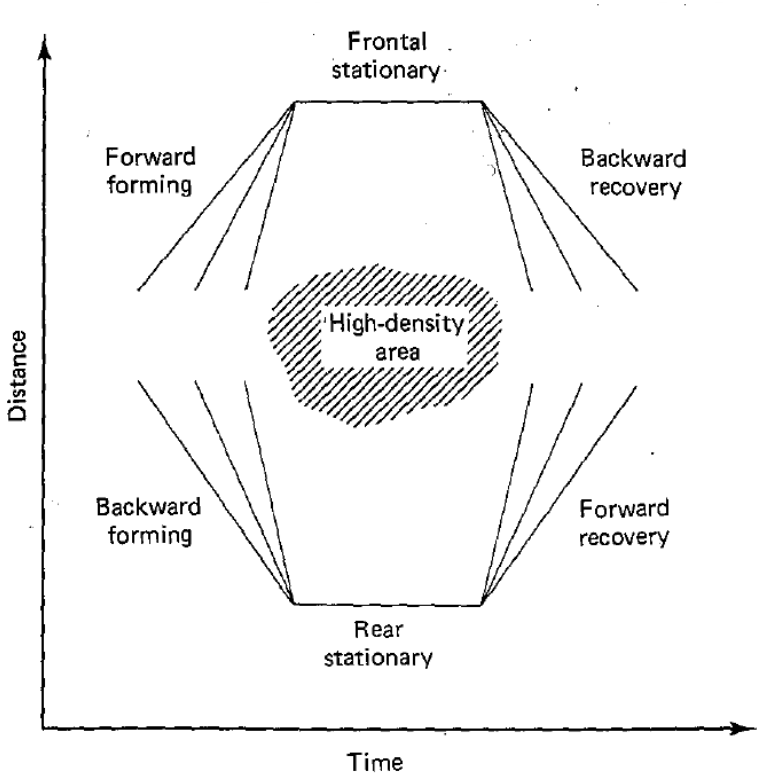


Figure 2.3. Types of shockwaves in traffic [43].

The terms backward and forward mean that the shockwave is moving in the opposite direction or along the direction of traffic respectively. The forming shockwave term implies that congestion is steadily spreading upstream. Backward forming shockwaves always form when there is a congestion occurring and the excess demand is being stored.

After backward forming shockwaves, forward recovery shockwave is the most encountered type of shockwave. This one occurs when there is a congestion but demand is decreasing and becoming even lower than the bottleneck capacity. In addition, the length of congestion is also being reduced. In the naming of this type the forward term means the shoc wave is moving along the traffic flow and the recovery term indicates that the free-flow conditions are spreading farther downstream.

Rear stationary shockwave can be observed when the arriving traffic demand is same as the flow in the congestion region for a given period of time. Its name implies that the shockwave is stationary and is located at the rear of the congested region. On the other hand, frontal stationary shockwave, while also being stationary, is located at the very front of the congested region.

Backward recovery shockwave can be observed when there is congestion but due to an increase in the bottleneck capacity, the discharge rate exceeds the flow rate inside the congested region. Finally, there is the forward forming shockwave, which is not very common in traffic.

Consider that there are two steady-state free-flow conditions $A$ and $B$ (Figure 2.4). The flow, density and speed of condition $A$ are denoted as $q_A$, $k_A$ and $u_A$ and for condition $B$, where in this case it will be assumed that the speed in this condition is higher than the previous condition, the flow density and speed will be denoted as $q_B$, $k_B$ and $u_B$. This scenario will provide a forward-moving shockwave along the direction of the traffic flow.

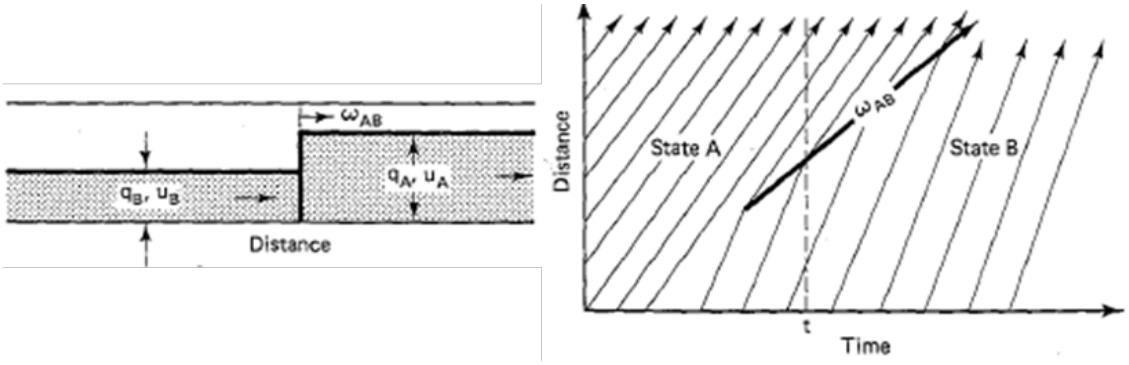


Figure 2.4. The fundamental graphics for shockwave analysis [43].

The boundary conditions state that the number of vehicles that are leaving the flow condition $B$ ($N_B$) and entering the flow condition $A$ ($N_A$) are equal. If the speed of vehicles in flow condition $A$ and $B$ are $(u_A - \omega_{AB})$ and $(u_B - \omega_{AB})$ respectively, then $N_A$ and $N_B$ can be calculated as follows:

$$N_A = q_A t = (u_A - \omega_{AB})\, k_A t \tag{2.22}$$

$$N_B = q_B t = (u_B - \omega_{AB})\, k_B t \tag{2.23}$$

Knowing that NA and NB are equal to each other, solving the equation for $\omega_{AB}$ will give the following equation:

$$\omega_{AB} = \frac{q_A - q_B}{k_A - k_B} \tag{2.24}$$

There are a number of assumptions in this theory which must be discussed in order to gain an insight on their impacts and provide potential refinements [43]:

(i) The capacity along the road sections and at a specific location for the entire duration of the analysis, is either considered to be constant or if there are any changes, they occur instantaneously.

(ii) The traffic demand is either constant or it changes instantaneously at a given time at a given location or there are no other entrances or exits other than the two extreme ends of the analyzed sections.

(iii) The flow-density relationship does not vary over time during the analysis or for the entire length of the studied section.

(iv) A single bottleneck is studied and queue collisions and splits are neglected.

(v) All vehicles in a given flow condition have the same speed and an instantaneous change in speed will only occur when they are located at the shockwave boundaries.

## 2.4. Density Contour Maps

Density contour maps are introduced by May (1963) [43] to illustrate spatial and temporal congestions on uninterrupted traffic facilities. May developed the map to analyze a section of Hollywood Freeway (Figure 2.5). Dataset used in density contour maps are the same datasets used to estimate travel times and traffic demands. With the help of density contour maps, it is possible to observe density, demand, flow and velocity changes in specific areas such as interchanges, upstream congestions, bottleneck areas.

On the horizontal axis of this map the distance values presented with the traffic moving from left to right. On the vertical axis the time values are presented and they increase from bottom to top. Each value that is on Figure 2.5 has the unit of veh/mile/ln. These density contour maps are very useful for determining the bottlenecks, estimating travel times, traffic demands and calculating and locating shockwaves.

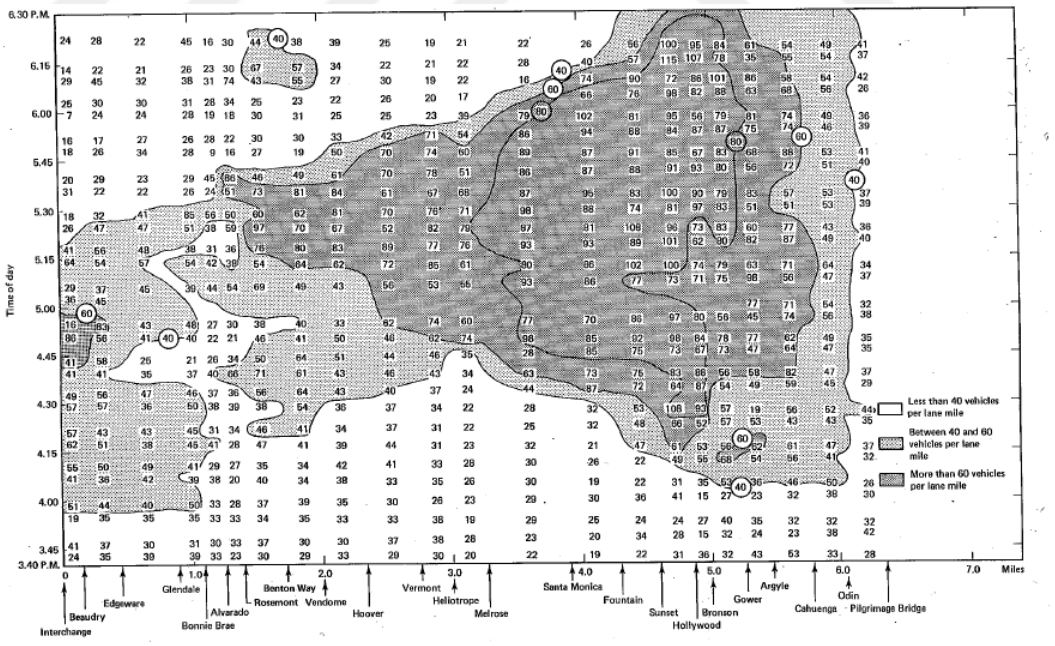


Figure 2.5. Hollywood Freeway density contour map [43].

## 2.5. Computer Vision

Computer vision provides the possibility of processing videos and images and obtaining very detailed data matrices that cannot be constructed manually. It has become a very popular data collection method due to the following reasons;

(i) Data either cannot be manipulated or can be cleaned easier compared to the other methods (GPS data, surveys, manual recordings etc.),
(ii) Data is more accurate and extra variables can be obtained (time, exact location, exact color)
(iii) Data can be cross checked with the visuals manually,
(iv) Frequency of obtained data can be chosen.

In this thesis, the YOLO V3 [47] system is used to process the video camera footages taken from the Istanbul Metropolitan Municipality Transport Management Center. YOLO V3 is based on the approach of SORT (Simple Online and Realtime Tracking) system.

SORT is an approach for multiple object tracking on a learned background with simple but very effective algorithms. Kalman filtering, which has recently become very popular, is the main detection algorithm of this approach. SORT is simply detecting the objects in every frame and by using the Hungarian measurement method it assigns a surrounding box to the detected object.

It is very time-consuming to process an entire video footage. In order to shorten the required time, Faster Region Convolutional Neural Networks (Figure 2.6) are chosen in SORT approach and 24 convolutions are selected for use in this thesis. With the help of the neural networks, first the background is learned by the agent. Later, new objects on the frame are identified and the centers of the boxes are determined. To match the object between cascade frames, by using predictions of the Kalman filtering, mass probability of being any location of the moving object in next frame is predicted. The probability decreases as the measured distances increase.

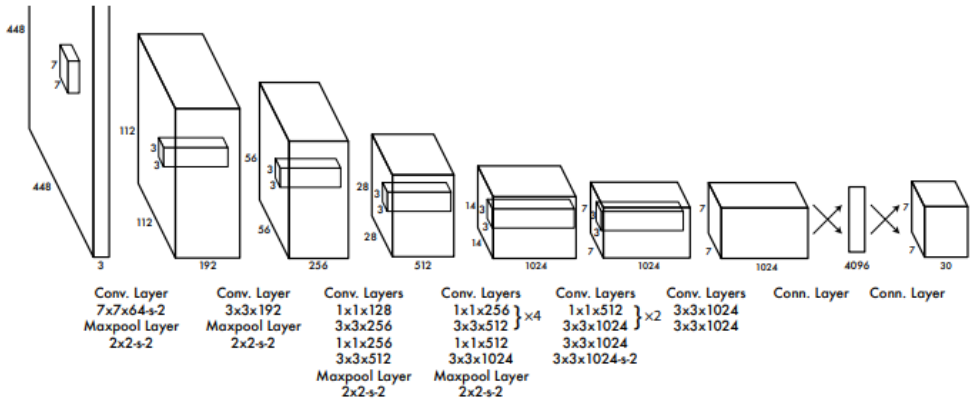


Figure 2.6. Convolutional neural network working principle.

YOLO is an open source object detection system presented in 2015 (Figure 2.7). One of the most distinguished features of YOLO is that it is much faster compared to the others. YOLO, You Only Look Once, is an algorithm that looks only once to the image to detect objects. It trains on the entire image and self-optimizes itself. With the help of Recurrent Neural Networks, which takes the past experiences into account to learn, both the test and training processes are performed simultaneously. Accuracy is further increased with V3 due to a more precise definition of the boxes surrounding the moving object.

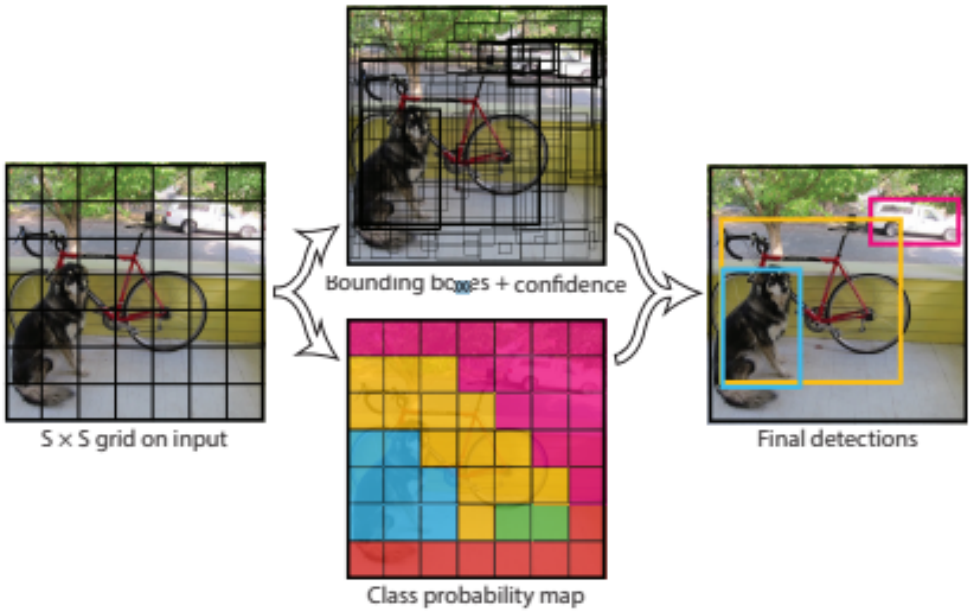


Figure 2.7. YOLO classification map.

# 3. METHODOLOGY

In this section; the real time traffic management method, the simulation environments, the tested scenarios with synthetic traffic flow and the case study are presented. The simulation results for both the case study and synthetic traffic flow scenarios are also presented. The flow chart of the methodology section is given below (Figure 3.1).

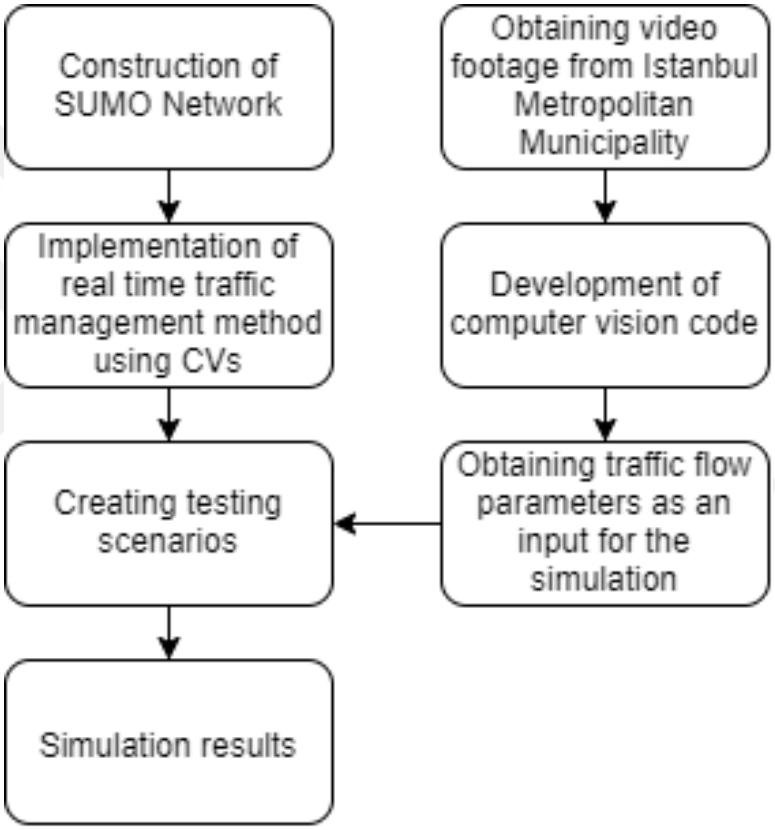


Figure 3.1. Flow chart of the methodology section.

## 3.1. Real Time Traffic Management Using Connected Vehicles

In this study, a real time traffic management method [48] which utilizes connected vehicles in traffic is tested using a simulation network built in SUMO. The aim of the method is to improve the traffic conditions of the network by decreasing the overall density values and increasing the speeds in the traffic flow. To do so the following assumptions are made:

(i) It is assumed that there are connected vehicles in the traffic flow that moves in groups of three for the thesis, which is equal to the number of lanes of the studied network.

(ii) It is assumed that when a traffic incident occurs, at the moment and near the location of the incident there is a connected vehicle during the incident. With this vehicle, the information of the generated shockwave speed due to the incident is immediately calculated and the information is transferred to the connected vehicles that are approaching the incident location.

(iii) When the incident occurs, it is assumed that at that moment there is another platoon of connected vehicles which is a certain distance away from the incident location. They adjust their speeds based on the information. The next platoon of vehicles also adjust their speeds when approaching the incident location if it is not cleared yet.

(iv) To control the traffic flow, when the connected vehicles come into a certain location, they block all lanes by slowing down to the calculated shockwave speed with a predetermined deceleration value.

## 3.2. Simulation Environment: SUMO Network

In this section; the properties of the SUMO network, the tested scenarios and the simulation results are presented. The SUMO network consists of the network geometry, vehicle and flow properties. The SUMO configuration file is formed by combining these factors.

### 3.2.1. Construction of SUMO Network

In this thesis, SUMO (version 1.4.0) software was used. A network of 5.3 km length was modeled with 3 lanes and lane width of 3.20 meters which is the default value for highway roads in SUMO (Figure 3.2). There are 3 main sections in this network:

(i) Entry (150 meters)

(ii) Main road (5000 meters)

(iii) Exit (150 meters).

All vehicles are assigned to move from the entry edge to the exit edge departing from the lane in which they have the most time before they need to make a lane change. By having this long network, the aim is to being able to observe the wide impact of both the incident and the connected vehicles.

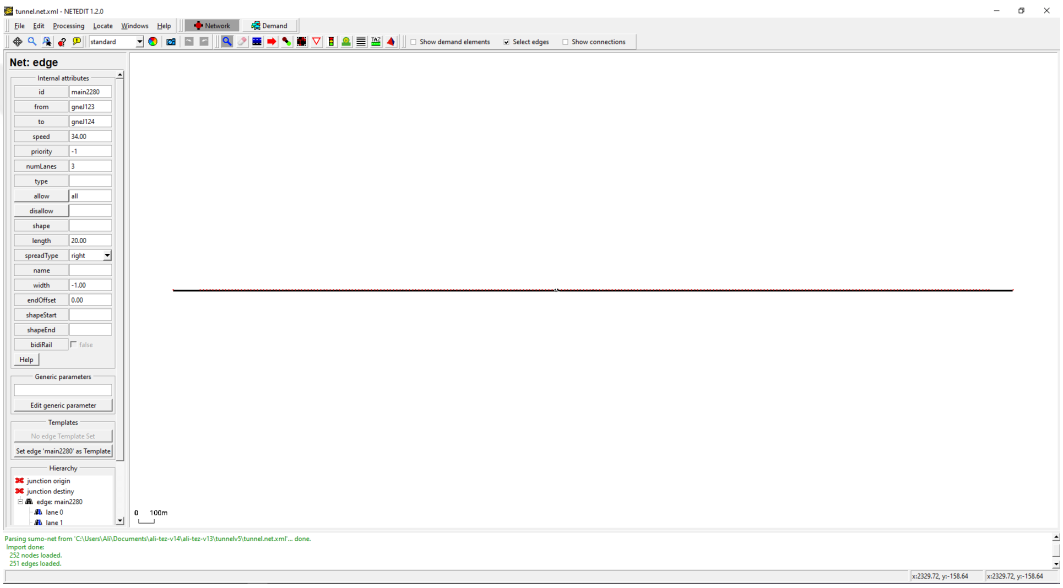


Figure 3.2. SUMO model of the study network.

In SUMO, it is possible to change the parameters of the vehicles that are traveling in the simulation. The selected parameters of the vehicle type is presented in the table below (Table D).

Table 3.1. Defined vehicle parameters in the SUMO.

| **Vehicle Parameter** | **Parameter Value** |
|---|---|
| Maximum acceleration | 2.6 $m/s^2$ |
| Maximum deceleration | 4.5 $m/s^2$ |
| Length of vehicle | 4.5 m |
| Maximum speed of vehicle | 120 km/hr |
| Speed factor | 0.9 |
| Speed deviation | 0.1 |
| Sigma | 0.5 |
| Minimum gap | 2.5 meters |

The maximum acceleration, deceleration values are the allowed values for the vehicles to change their speeds. In case they are commanded by the code to change their speeds with a value outside of this domain, than the program informs the user with a pop-up message with the information of what actual acceleration value was used and what was the severity of this speed change.

It is assumed that there are only passenger cars in this network, so that the network is more homogenous. The default value that SUMO uses is 5 meters. However, in order to observe more vehicles in a single run, it was reduced to 4.5 meters.

The maximum speed value is the maximum speed value that the vehicles are allowed to travel. With the given speed factor, it is assumed that the vehicles try to remain under the maximum value by 10%. The speed deviation which is by default 0.10 for passenger cars, is used.

The default car following model that the software uses is the Krauss model with some modifications [49]. Sigma is a parameter of this model, which is a value between 0 and 1. It denotes the driver imperfection. As the value comes closer to 0, the driver becomes more flawless. The default value of the software for this parameter is 0.5 and

in this study this value is used.

The minimum gap value is the distance between the following vehicle and the leading vehicle. The following vehicle follows the vehicle in front of it with a minimum gap of this value to avoid collision. The default value is 2.5 meters and in this study this value was also used as well.

With this type of vehicles, a flow is created for this simulation. The parameters of this flow are provided in the table below (Table 3.2).

Table 3.2. Defined flow parameters in the SUMO simulation software.

| **Flow Parameter** | **Parameter Value** |
|---|---|
| Vehicle type in flow | Passenger car |
| Flow starting time | 0 seconds |
| Flow end time | 3600 seconds |
| Number of vehicles in the flow | 2500 vehicle per hour |
| Departing edge name | entry |
| Destination edge name | exit |
| Departing position | Random |
| Departing lane | best |

The flow consists of only passenger cars. The simulation runs for an hour and within this time, 2500 vehicles are introduced into the network. This many vehicles are introduced to the network starting from 0 seconds to 3600 seconds. The first 15 minutes of this simulation is considered to be the warm up period and; thus, are excluded from the analyses.

The vehicles that are inserted to this network have the route of starting from the edge called “entry” and exiting the network from the edge called “exit”. Both of these edges are 150 meters long, as mentioned in the previous paragraphs.

Departing position parameter stands for the starting position of the departing vehicle. When this parameter is set as “random”, the departing vehicle can be inserted on any location of the departing edge. It does not retry to insert the vehicle if the first try fails. This means that the vehicle spawns on a random position on the “entry” edge. Considering that the headways of a traffic flow is not deterministic, this assumption was made.

Departing lane parameter stands for from which lane the departing vehicle starts its travel. “best” parameter value stands for the free lane of those who allow the vehicle the longest ride without the need to lane change.

### 3.2.2. Assumptions of the SUMO Network

In this study, some assumptions are made in order to obtain consistent and meaningful outputs. These assumptions are listed below:

(i) It is assumed that there are only passenger cars in this network, so that the network is more homogenous.

(ii) The average car length in this network is selected as 4.5 meters in order to fit more vehicles into this network at the same time.

(iii) The default value in SUMO for minimum allowed gap distance between the following and leading vehicles is 2.5 meters and in this study this value was also used as well.

(iv) Krauss model, which is the default car following model of SUMO, is used.

(v) Sigma which is a parameter of this model, denotes the driver imperfection and is set to be 0.5 which is also the default value that SUMO also uses.

(vi) The default values for speed factor and speed deviation values of SUMO are also used.

(vii) The connected vehicles in this thesis are assumed to be vehicles that are not autonomous. The drivers of these vehicles are normal people that are assigned by the municipality to manage the traffic to maximize the flow and average speed values and minimize the delays and queues.

(viii) The connected vehicles always travel in groups of 3. These groups of 3 arrive to the network with a predetermined period. This period is not deterministic and a randomization element was applied, which is explained in the next sections. After a group exits from the network, it is assumed that they try to return back to the start of the network using the quickest way.

(ix) It is assumed that when an incident occurs in the traffic, the connected vehicles are immediately informed about it. The connected vehicles also immediately know the shockwave speed that was created due to the incident and thus act accordingly.

### 3.2.3. Algorithm of the Simulation

The algorithm of this simulation when connected vehicles are introduced into the network, is presented below (Figure 3.3). The algorithm stays the same for the cases when there are no connected vehicles in the simulation network. The same principals for simulation a traffic incident still apply.

The simulation starts by setting the incident duration, incident lane, connected vehicle distance from the incident and arrival rate. The incident location and the time are always equal to 2520th meter of the main road and 1200th second (time step) of the simulation. These parameters are further explained in the section 3.2.4.

When the time step becomes equal or greater than the incident time (breaktime), the vehicle closest to the 2520th meter is commanded to stop and stay at that place for the duration of the incident. While the incident is still happening the simulation continues normally for scenarios in which there are no connected vehicles. However, if there are introduced connected vehicles into the simulation, then the behavior of those vehicles are as follows:

At the moment of incident 3 vehicles at the predetermined distance behind the incident (CVDistance) are selected and they safely change lanes so that they cover unique lanes. After that is done, they slow their speed until they reach to shockwave

speed. They use the following formula for calculating the duration ($t_stopDur$) of this slow down;

$$t_{stopDur} = \frac{u_i - u_f}{decel_{max}} \tag{3.1}$$

where $u_i$ is the initial speed, is the $u_fis$ the final speed (shockwave speed in this case), is the $decel_max$ is the maximum deceleration rate which was explained in section 3.2.1.

After these connected vehicles pass the incident location, they return back to their default state and continue to act within the rules of the default SUMO parameters. This process is repeated for the duration of the incident. After the incident is over, no more connected vehicles try to manipulate the traffic.

By changing the parameters for incident properties (incident duration and lane) and connected vehicle properties (connected vehicle distance from the incident and arrival rate), different scenarios are tested. The scenarios and measures of effectiveness for making comparisons are explained in the next sections.

```
Set seed for randomness, incident duration (incident Duration) and incident lane, arrival
rate for connected vehicle platoons and  the connected vehicle distance (CV Distance)
from the incident.
Calculate the introduction time for each platoon (introduction Time).
Set shockwave speed.
Set time step to 0, incident time (breaktime) to 1200, incident location (2520th meter of
the main road) and stopped Vehicle Exists to False.
Set incident No equal to 0.
Start SUMO through Tra CI with the provided seed.
While time step is less than 3601;
    If time step ≥ break time and incident No = 0;
        Find the vehicle on the incident lane which is closest to the incident location
        (breaking Vehicle),
        Assign breaking command to the breaking Vehicle and gradually stop and
        stay for the break duration,
        Set stopped Vehicle Exists=True.
        While stopped Vehicle Exists is True;
            If time step ≤ break time + incidentDuration;
                If time step ≥ introduction Time or time step = breaktime;
                Find 3 vehicle closest to the position CVDistance behind the
                incident location,
                    For each vehicle;
                        Command each vehicle to be on unique lanes,
                        Calculate the safe deceleration duration for slowing
                        down to the shockwave speed with the max
                        deceleration limit,
                        Record the IDs of the selected vehicles to the
                        connected vehicle list (CV List).
                    For each vehicle in CV List;
                        If the vehicle is in the simulation;
                            If vehicle passed the incident location;
                                Give the vehicle control back to SUMO,
                            Else
                                If vehicle speed is equal to the shockwave
                                speed;
                                    Continue to travel with shockwave
                                    speed.
                                Else
                                    Vehicle continues to slow down.
                        Else
                Else
            Else
                Incident No = incident No + 1,
                Set stopped Vehicle Exists to False.

    Else
Increase time step by 1.
```

Figure 3.3. Simulation algorithm when connected vehicles are introduced.

### 3.2.4. Testing Scenarios and Parameters

The scope of this thesis covers the scenarios that are given in the table below (Table 3.3). There are a total of 189 different scenarios tested. To test the real time traffic management method and to simulate that the vehicles act as they are connected and they know about the traffic event's impact, the simulations are conducted twice for the same scenario, after selecting the lane and duration of the incident which causes instant breakdown of a vehicle in the middle of the road on the selected lane for the selected duration. The simulation runs for an hour and the first 15 minutes are considered as the warm up period. The tested values for each scenario are presented in Table A.

Table 3.3. Tested scenarios and values.

| **Testing Parameters** | **Tested Values** |
|---|---|
| Duration of the incident | 5/10/15 minutes |
| The lane of incident | Left/Center/Right lane |
| The period of connected vehicles arriving to network | 10/15/20 minutes |
| The position of connected vehicle when traffic incident occurs | 500 meters up to 2000 meters with 250 meters increment |

The incident is simulated as a vehicle that changes its speed to 0 and stops at that position for the pre-determined time. The vehicle stops for 5, 10 and 15 minutes in different scenarios. As the duration of this incident increases, the traffic becomes more unrecoverable, especially around the 30 minute mark. Considering this fact and the duration of the simulation, the durations are selected as such.

The vehicle that breaks down can be in in either; right, middle or left. Connected vehicles try to steer the other vehicles away from the lane that the incident occurs so that the delays and queue lengths are minimized.

The connected vehicles arrive to the position behind the incident, which is pre-

determined, with the given period. Due to the fact that the headways are not deterministic, it is assumed that there is a potential delay up to 5 minutes, which is calculated by using a uniform distribution. Scenarios in which the headways of connected vehicles are 10, 15 and 20 minutes are be tested.

In this simulation, it is assumed that when the incident occurs, the connected vehicles, which are in groups of three, are always behind the incident location. These 3 connected vehicles, are always moving closely in groups. Even though they are not always traveling side by side, when they are commanded to manage the traffic in case of a incident, they always try to cover all 3 lanes. Scenarios in which the connected vehicles are 500 meters behind the incident are tested. This distance increases up to 2500 meters.

In the first run, the connected vehicles act as the rest of the traffic and does not interfere with the traffic. When the traffic incident, which is predetermined to be on the 2520th meter of the built network and 1200th second of the simulation, occurs and the run is completed, the density contour map of this scenario is generated. With the generated density and flow heatmaps, the shockwave speed that was caused by the traffic incident is calculated and this value is used in the second run to control the connected vehicle to change its speed to this value to control the traffic.

### 3.2.5. Shockwave Speed Calculation

Before calculating the shockwave speed, the capacity and the jam density of this network needed to be calculated. By placing sensors at the middle of the road, a simulation run with a flow value of 2500 veh/hr was conducted. These sensors collected information with 15 seconds intervals for the duration of the simulation. The collected information contains information such as, the number of vehicles that have passed, flow (veh/hr/ln), occupancy (%), arithmetic and harmonic mean speeds, average car length (Figure 3.4).

| begin | end | id | nVehContrib | flow | occupancy | speed | harmonicMe | length | nVehEntered | Density (veh/km/lane) |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 15 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 15 | 30 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 30 | 45 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 45 | 60 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 60 | 75 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 75 | 90 | main2520__0 | 1 | 240 | 0,95 | 31,52 | 31,52 | 4,5 | 1 | 1,117137153 |
| 90 | 105 | main2520__0 | 2 | 480 | 2,16 | 27,81 | 27,8 | 4,5 | 2 | 2,540017107 |
| 105 | 120 | main2520__0 | 1 | 240 | 1,23 | 24,31 | 24,31 | 4,5 | 1 | 1,44639863 |
| 120 | 135 | main2520__0 | 7 | 1680 | 8,28 | 25,37 | 25,36 | 4,5 | 7 | 9,736732242 |
| 135 | 150 | main2520__0 | 4 | 960 | 4,83 | 24,87 | 24,85 | 4,5 | 4 | 5,679760475 |
| 150 | 165 | main2520__0 | 7 | 1680 | 9,5 | 24,62 | 24,59 | 4,5 | 8 | 11,17137153 |
| 165 | 180 | main2520__0 | 3 | 720 | 2,57 | 25,55 | 25,54 | 4,5 | 2 | 3,022149983 |
| 180 | 195 | main2520__0 | 7 | 1680 | 8,44 | 24,92 | 24,89 | 4,5 | 7 | 9,924881658 |
| 195 | 210 | main2520__0 | 8 | 1920 | 8,97 | 26,77 | 26,76 | 4,5 | 8 | 10,5481266 |
| 210 | 225 | main2520__0 | 4 | 960 | 4,03 | 29,82 | 29,8 | 4,5 | 4 | 4,739013398 |
| 225 | 240 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 240 | 255 | main2520__0 | 8 | 1920 | 10,01 | 23,99 | 23,97 | 4,5 | 8 | 11,7710978 |
| 255 | 270 | main2520__0 | 5 | 1200 | 6,1 | 25,08 | 25,05 | 4,5 | 6 | 7,173196459 |
| 270 | 285 | main2520__0 | 6 | 1440 | 6,9 | 25,69 | 25,68 | 4,5 | 5 | 8,113943535 |
| 285 | 300 | main2520__0 | 3 | 720 | 3,66 | 24,61 | 24,59 | 4,5 | 3 | 4,303917875 |
| 300 | 315 | main2520__0 | 4 | 960 | 5,14 | 23,37 | 23,36 | 4,5 | 4 | 6,044299967 |
| 315 | 330 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 330 | 345 | main2520__0 | 8 | 1920 | 11,45 | 20,98 | 20,95 | 4,5 | 8 | 13,46444253 |
| 345 | 360 | main2520__0 | 10 | 2400 | 14,26 | 21,09 | 21,04 | 4,5 | 10 | 16,76881664 |
| 360 | 375 | main2520__0 | 6 | 1440 | 8 | 23,13 | 22,49 | 4,5 | 6 | 9,407470766 |
| 375 | 390 | main2520__0 | 3 | 720 | 3,42 | 26,34 | 26,33 | 4,5 | 3 | 4,021693752 |
| 390 | 405 | main2520__0 | 6 | 1440 | 7,52 | 23,97 | 23,94 | 4,5 | 6 | 8,84302252 |
| 405 | 420 | main2520__0 | 5 | 1200 | 6,23 | 24,09 | 24,06 | 4,5 | 5 | 7,326067859 |
| 420 | 435 | main2520__0 | 6 | 1440 | 7,43 | 24,23 | 24,22 | 4,5 | 6 | 8,737188474 |
| 435 | 450 | main2520__0 | 7 | 1680 | 8,04 | 26,19 | 26,14 | 4,5 | 7 | 9,454508119 |
| 450 | 465 | main2520__0 | 4 | 960 | 4,45 | 27 | 26,98 | 4,5 | 4 | 5,232905613 |
| 465 | 480 | main2520__0 | 2 | 480 | 2,32 | 25,87 | 25,87 | 4,5 | 2 | 2,728166522 |
| 480 | 495 | main2520__0 | 0 | 0 | 0 | -1 | -1 | -1 | 0 | 0 |
| 495 | 510 | main2520__0 | 8 | 1920 | 12,07 | 19,98 | 19,88 | 4,5 | 8 | 14,19352152 |

Figure 3.4. Traffic flow information collected by the sensors on the road network.

Using the occupancy, average car length and the length of the sensor (4 meters by default in SUMO), the density value was calculated with the following formula [43];

$$Density = \frac{5280\frac{ft}{mile} \times occupancy\,(\%)}{Detector\ length\,(ft) + Average\ car\ length\,(ft)} \tag{3.2}$$

The flow (veh/hr/ln) and the calculated density values (veh/km/ln) are plotted in a scatter plot. In the section 2.2, it was explained that the point where the fitted quadratic curve to this scatter plot provides the jam density value (Figure 2.2). From there, the jam density value for each lane at the detector location, which is also the incident location, was calculated. The mean value of the jam densities of these 3 lanes, which is equal to 67.66 veh/km/ln was used as the jam density of this network under this demand conditions (Table 3.4).

Table 3.4. Calculated jam density values for the network with synthetic flow conditions at the incident location.

| **Lane** | **Jam Density Value (veh/km/ln)** |
|---|---|
| Right | 75 |
| Middle | 110 |
| Left | 18 |

In this study, it is known that the location of the incident is always going to be on the 2520th meter on the main road link. When the incident occurs, it is assumed that the density in that section is equal to jam density and the flow is consequently equal to zero.

An example for the process of calculating the shockwave speed is provided. The modeled network is divided into 20 m length sections. A sketch for this example case on the network is presented in Figure 3.5. It is assumed that the section on the left has the flow and density values of 720 veh/hr/ln and 16.66 veh/km/ln, respectively when the incident happens. The section on the right, in which the incident occurs, has the flow and density values of 0 veh/hr/ln and 67.66 veh/km/ln (jam density) respectively when the incident happens.

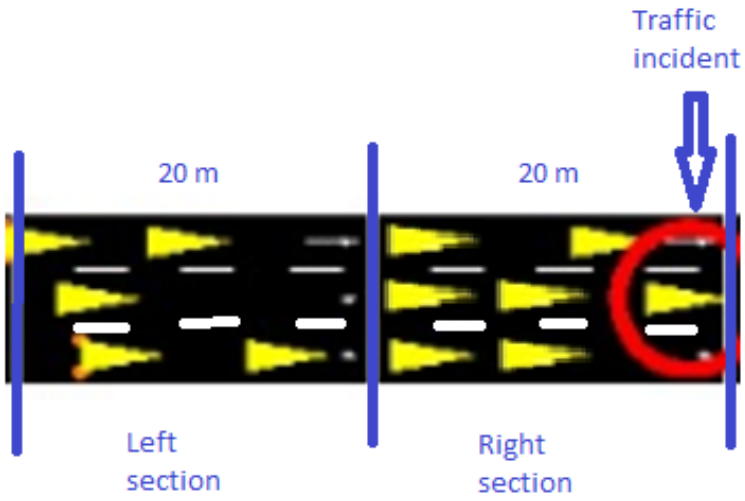


Figure 3.5. An example case where an incident occurs.

Equation 2.24 is used for calculating the shockwave speed. Using the information provided the result is calculated as follows:

$$\omega_{RL} = \frac{q_R - q_L}{k_R - k_L} = \frac{720 - 0}{16.66 - 67.66} = -14.11 \text{ km/hr} \tag{3.3}$$

It was calculated that the incident causes a shockwave with a speed of 14.11 km/hr backwards. In the second run of this simulation, in which there are connected vehicles, the connected vehicles reduce their speeds to this value when the incident happens. It must be noted that the shockwave speed is a dynamic value, which changes overtime. However, in this simulation only the initial shockwave speed is calculated which occurs at the moment of the incident. The calculated shockwave speeds for each scenario is provided in Table A.

### 3.2.6. Measures of Effectiveness

The parameters that are evaluated at the end of the simulation are as follows:

(i) Mean speed (km/hr): Mean speed ($u_{mean}$), namely time mean speed is used to evaluate the microscopic speed characteristics. To calculate this value the arithmetic average of all vehicles passing a section of a road is calculated with Equation 2.2. By collecting the speed values of each vehicle for each time step at every section on the road networkwide and local systemwide, the mean value for the duration of the simulation are calculated.

$$u_{mean} = \frac{1}{N} \sum_{i=1}^{N} u_i \tag{3.4}$$

where $N$ is the number of vehicles and $u_i$ is the speed of the $i_{th}$ vehicle.

(ii) Mean flow (veh/hr/ln): For a given period of time (15 seconds), the number of vehicles passing through a 20-meter-long section on the main road ($N$) are gathered

for each section. The arithmetic average number of vehicles passing through for each vehicle counting period is taken over 15 seconds with the following formula to obtain the mean flow value:

$$Q_{mean} = \frac{\text{N}}{\text{15 seconds}} \tag{3.5}$$

The obtained value, which has the unit of measure of vehicles/15 seconds is then converted to vehicle/hour (veh/hr). Finally, by dividing this value to the number of lanes, which is 3, the unit of measure becomes vehicle/hour/lane (veh/hr/ln).

(iii) Mean density (veh/km/ln)-($k_{mean}$) A snapshot of the simulation is be gathered every 15 seconds. In that snapshot, the number of vehicles counted on a 20-meter-long section on the main road is determined, which has the unit of measure of vehicle/20 m which is denoted by the following formula:

$$\text{k}_{mean}=\frac{\text{N}}{\text{20 meters}} \tag{3.6}$$

This value is then converted to vehicle/km by multiplying it by 50. Finally, by dividing this value to the number of lanes, which is 3, the unit of measure becomes vehicle/km/lane (veh/km/ln).

These parameters are evaluated both locally and networkwide. The distance D is defined as the distance between the incident location and connected vehicle position before the incident. The local system is defined as the 2 times the distance D, where it covers before and after the incident. (Figure 3.6). T-tests of the simulation results are conducted to see if the difference between the scenarios with and without connected vehicles are significant or not with a confidence level of 95%.

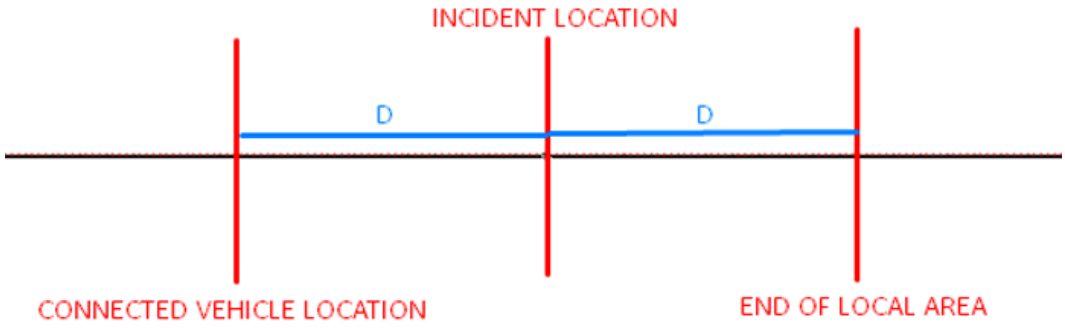


Figure 3.6. The sketch of the defined local system.

### 3.2.7. Simulation Results

The measures of effectiveness of the scenarios without connected vehicles are provided in Table b.1, Table b.2 and Table b.3. The measures of effectiveness of the scenarios with connected vehicles are provided in Table c.1, Table c.2 and Table c.3. The p-values of the t-test, which were made to evaluate statistical significance of introducing connected vehicles to the network, are provided in Table d.1, Table d.2 and Table d.3.

Mean speed and density values in the network for the first 10 scenarios when connected vehicles are introduced, are presented in the following table (Table 3.5). The explanation for the notation of the scenarios is as follows:

There are 4 components of a scenario. The first one is the duration of the incident in terms of minutes. “5min”, “10min” and “15min” stands for 5, 10 and 15 minutes lasting incidents respectively. The second term is for the incident lane. “0L”, “1L” and “2L” stands for right, mid and left lane respectively in which the incident occurs. The third term is the arrival rate of the connected vehicles arriving to the position behind the incident. When vehicles arrive to this position they start to change their speed to manipulate the traffic flow. As long as the incident lasts, the arriving connected vehicles continue to manipulate the traffic flow and when the incident is over they go

back to their default behavior. This third term can take the values “10min A”, “15min A” and “20min A” which stands for connected vehicles arriving to this position every, 10 15 and 20 minutes respectively. The fourth and final term is the position behind the incident that the vehicles start to manipulate the traffic flow. When there is an incident on the network, the connected vehicles arriving to this position start to adjust their speeds according to the rules of the simulation which were further explained in previous sections. By moving upstream from the traffic incident location by this amount of meters this location is determined. This parameter can take the following values: “500D”, “750D”, “1000D”, “1250D”, “1500D”, “1750D” and “2000D” which stands for 500, 750, 1000, 1250, 1500, 1750 and 2000 meters before the incident where the connected vehicles start to control the traffic flow. This notation is used for other tables as well.

Table 3.5. The mean speed and density values for the entire network.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 83.18 | 84.09 | 1.1 | 12.03 | 9.89 | -17.78 |
| 2 | (10min, 0L, 10min A, 500D) | 83.26 | 83.22 | -0.04 | 11.98 | 10.04 | -16.16 |
| 3 | (15min, 0L, 10min A, 500D) | 83.86 | 83.63 | -0.27 | 11.99 | 10.01 | -16.54 |
| 4 | (5min, 1L, 10min A, 500D) | 84.26 | 84.98 | 0.86 | 11.88 | 9.83 | -17.24 |
| 5 | (10min, 1L, 10min A, 500D) | 84.32 | 84.48 | 0.19 | 11.85 | 9.85 | -16.86 |
| 6 | (15min, 1L, 10min A, 500D) | 83.71 | 83.93 | 0.26 | 11.99 | 9.95 | -17.02 |
| 7 | (5min, 2L, 10min A, 500D) | 84.03 | 83.78 | -0.3 | 9.92 | 9.95 | 0.38 |
| 8 | (10min, 2L, 10min A, 500D) | 83.21 | 84.16 | 1.14 | 12.06 | 9.92 | -17.75 |
| 9 | (15min, 2L, 10min A, 500D) | 81.95 | 84.21 | 2.76 | 12.29 | 9.94 | -19.11 |
| 10 | (5min, 0L, 15min A, 500D) | 83.12 | 83.8 | 0.82 | 12.07 | 9.99 | -17.25 |

In terms of networkwide mean speed values, it was observed that up to a 3.09% increase, in the 144th scenario (15min, 2L, 10min A, 1750D), is gained with the introduction of connected vehicles into the network. In this scenario, the connected vehicles start to control the traffic from 1750 meters behind the traffic incident. The arrival rate of connected vehicles is 10 minutes and the incident lasts for 15 minutes on the left lane. The incident causes an initial shockwave speed of 25.09 km/hr. A t-test is conducted to determine if this difference in measure of effectiveness of concern with and without connected vehicles is significant or not and with a significance value that is very close to 0, it is safe to say that the difference, due to the introduction of connected vehicles, is significantly different.

The networkwide mean density in this scenario decreases by 19.29 percent with the introduction of connected vehicles. The results of the t-test also show, that the difference caused by the introduction of connected vehicles is also significant with a p-value of almost 0. Only in 9 of the 189 scenarios, the networkwide speed change is statistically insignificant with a confidence level of 95%.

In Figure 3.7 the networkwide mean speed values over time for the 144th scenario (15min, 2L, 10min A, 1750D) with and without connected vehicles in the network is presented. The starting point of both lines is the incident moment. In this scenario, the incident ends on the 2100th second. The graph shows that the introduction of connected vehicles homogenizes the mean speed values throughout the network. The difference between the mean speed values when there is an incident and when the incident is over, is reduced with the introduction of connected vehicles.

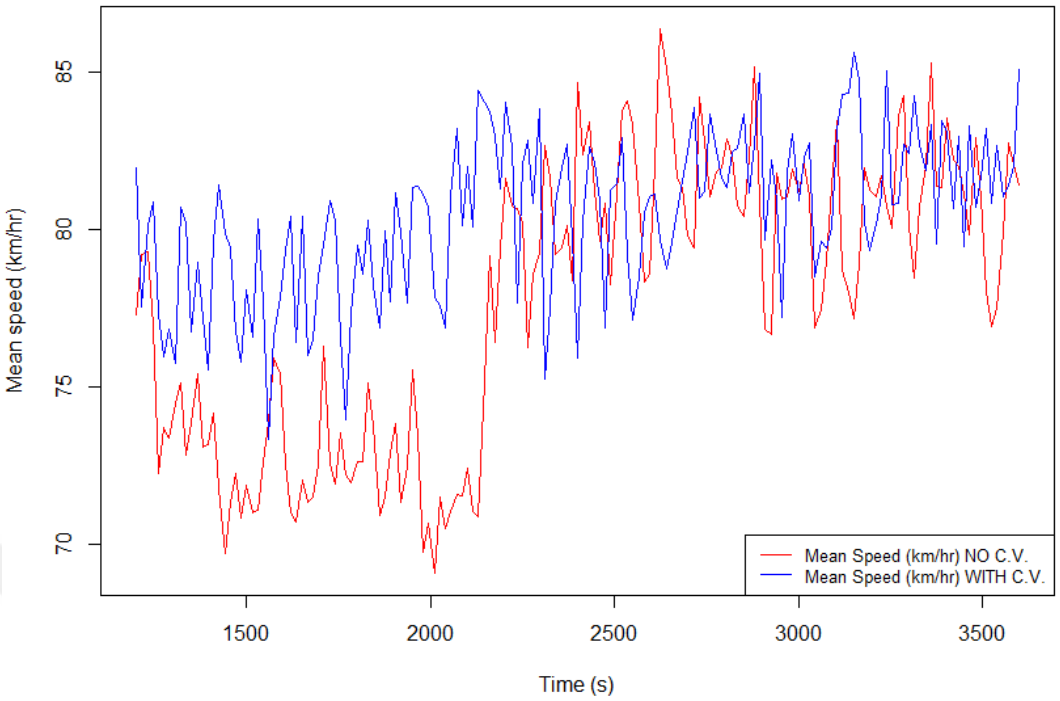


Figure 3.7. Mean speed values with and without connected vehicles before the incident location for the scenario 144 (15min, 2L, 10min A, 1750D).

The mean speed values throughout the network for different positions of connected vehicles are presented in the Figure 3.8. It can be observed that as the distance between the connected vehicle and the incident increases the mean speed values also increase in a non-monotonous manner.

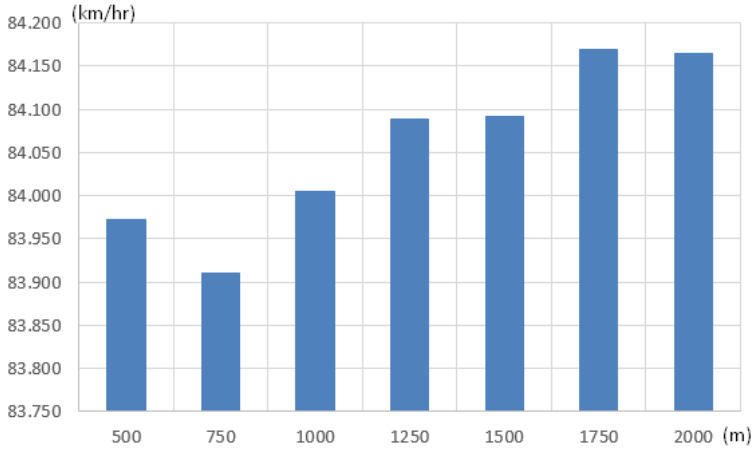


Figure 3.8. Mean speed values in the network for different positions of connected vehicles.

The mean density throughout the network decreases 19.61% and increases up to 0.47% with the introduction of connected vehicles. However, the mean density increase of 0.47% in the 88th scenario (5min, 2L, 10min A, 1250D), is tested with a t-test in order to check its significance and with a p-value of 0.542 it is determined to be insignificant. The decrease of mean density decrease of 19.61% in the 131th scenario (10min, 1L, 20min A, 1500D) was also tested for determining the level of significance and with a p-value of almost zero as a result of the t-test, the decrease of density is deemed to be very significant. In the 131th scenario the speed change with the introduction of connected vehicles is 2.91%. The t-test result shows that this change is also statistically significant. In 14 of the 189 scenarios, the networkwide density change is statistically insignificant with a confidence level of 95%.

In Figure 3.9, the density contour maps for the scenario 131 (10min, 1L, 20min A, 1500D) are presented. On the left figure, it can be observed that there is an increase in density values starting at the $1200^{th}$ second with is spreading both vertically and horizontally. The vertical change is representing the change in time, whereas the horizontal change is in terms of position. The horizontal spread of the highlighted area in the left figure is an indication of a forming queue. This highlighted area is nearly eliminated in the right figure, in which the connected vehicles are introduced. This result shows that the connected vehicles can prevent long queues to form and; thus, reduce the impact area of an incident.

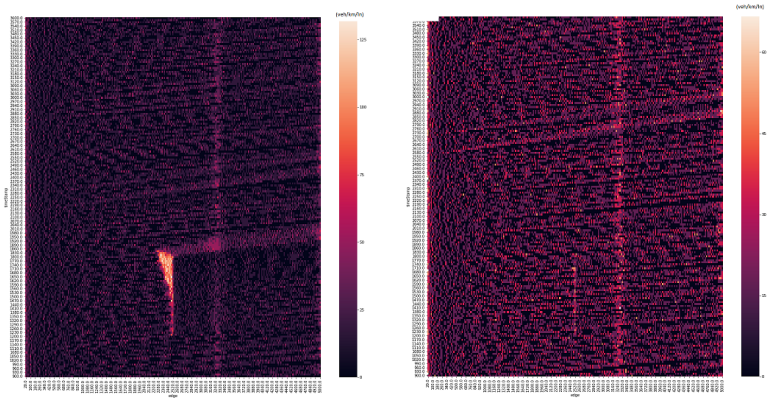

Figure 3.9. Density contour maps of scenario 131 (10min, 1L, 20min A, 1500D) with (right) and without (left) connected vehicles in the network.

In Figure 3.10, the density contour maps for scenarios 50 (10min, 1L, 20min A, 750D), 77 (10min, 1L, 20min A, 1000D), 104 (10min, 1L, 20min A, 1250D), 131 (10min, 1L, 20min A, 1500D), 158 (10min, 1L, 20min A, 1750D) and 185 (10min, 1L, 20min A, 2000D) are presented. In all of these scenarios there is an incident on the mid lane for 10 minutes and the arrival rate of connected vehicles is 20 minutes. The difference between these scenarios is the position where the connected vehicles start to control the traffic flow. Respectively, the distance between the incident and control position is 750, 1000, 1250, 1500, 1750 and 2000m. The highlighted area, where the density is much higher, is shrunk in all of these scenarios with the introduction of connected vehicles. In Table 3.6, the networkwide density change values are presented. The results show that all changes are statistically significant and the maximum density reduction occurs in scenario 131. The distance between the connected vehicles and incident in that scenario is 1500 meters. If connected vehicles start to control the traffic from a shorter distance then it may result in insufficient density reduction. However, if the control position is further away, then the road utilization may become inefficient.

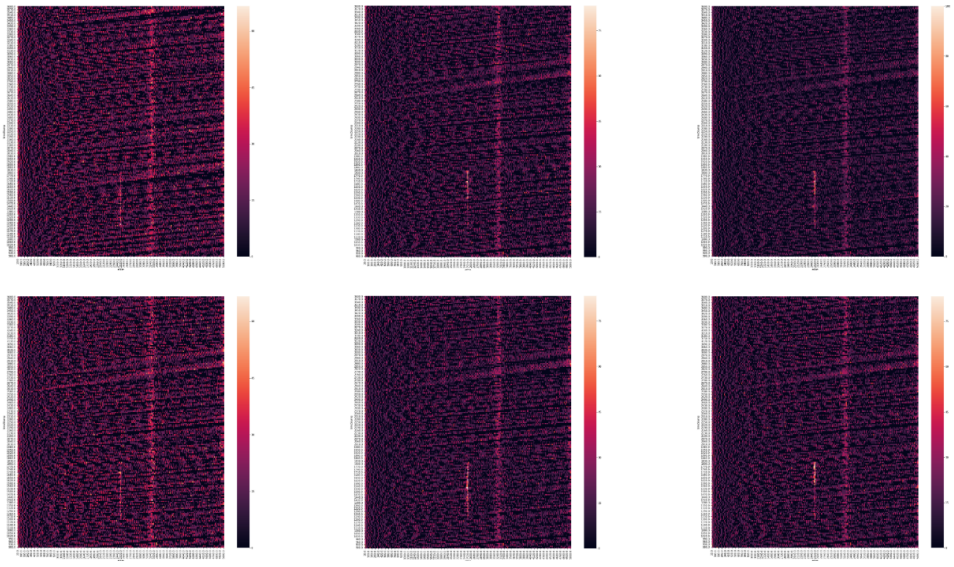

Figure 3.10. Density contour maps for scenarios 50 (10min, 1L, 20min A, 750D) (top left), 77 (10min, 1L, 20min A, 1000D) (top middle), 104 (10min, 1L, 20min A, 1250D) (top right), 131 (10min, 1L, 20min A, 1500D) (bottom left), 158 (10min, 1L, 20min A, 1750D) (bottom middle) and 185 (10min, 1L, 20min A, 2000D) (bottom right).

Table 3.6. Mean density changes and t-test significance values for scenarios 50, 77, 104, 131, 158 and 185.

| Scenario ID | Connected Vehicle Distance to The Incident (meters) | t-Test Significance Values | Mean Density (veh/km/ln) (Network) Percent Change (%) |
|---|---|---|---|
| 50 | 750 | 7.52E-155 | -18.42 |
| 77 | 1000 | 4.71E-172 | -19.44 |
| 104 | 1250 | 1.37E-174 | -19.54 |
| 131 | 1500 | 7.29E-175 | -19.61 |
| 158 | 1750 | 5.53E-165 | -19.09 |
| 185 | 2000 | 1.63E-171 | -19.45 |

In Figure 3.11, the networkwide mean density values are presented for the different positions of connected vehicles where they start to manipulate the traffic. As the distance between the incident and the connected vehicle's position increase the average density throughout the network decreases. The minimum density is observed when the connected vehicles start to control the traffic 1750 meters before the incident.

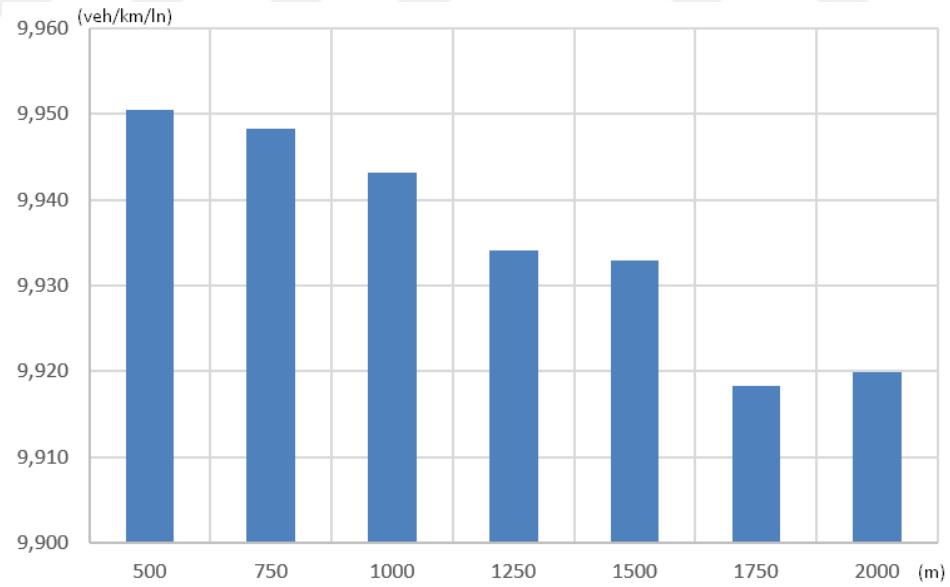


Figure 3.11. Mean density values in the network for different positions of connected vehicles.

Mean flow values in the network for the first 10 scenarios when connected vehicles are introduced, are presented in the following table (Table 3.13). The percent change

values of mean flow networkwide are not significant in 13 scenarios. The most increase in terms of networkwide mean flow is 0.34% in scenario 171 (15min, 2L, 10min A, 2000D). For the majority of the scenarios, the average flow rate decreases up to 18.68% in scenario 170 (10min, 2L, 10min A, 2000D). With the decrease of mean density values this result is not necessarily contradictory. The changes with the introduction of connected vehicles in scenario 170 and 171 are both statistically significant when checked with a t-test. In scenario 171, the density is decreased by 19.18% and the speed is increased by 2.82% networkwide with the introduction of connected vehicles. By decreasing the density and increasing the flow rate, the road can be utilized in a more efficient manner.

Table 3.7. The mean flow values for the entire network.

| **Scenario ID** | **Scenario Parameters** | **Mean Flow (veh/hr/ln) (w/o CV)** | **Mean Flow (veh/hr/ln) (w/ CV)** | **Percent Change (%)** |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 821.73 | 682.53 | -16.94 |
| 2 | (10min, 0L, 10min A, 500D) | 682.73 | 682.84 | 0.02 |
| 3 | (15min, 0L, 10min A, 500D) | 822.72 | 683.15 | -16.96 |
| 4 | (5min, 1L, 10min A, 500D) | 821.49 | 677.87 | -17.48 |
| 5 | (10min, 1L, 10min A, 500D) | 817.85 | 677.23 | -17.19 |
| 6 | (15min, 1L, 10min A, 500D) | 822.72 | 684.03 | -16.86 |
| 7 | (5min, 2L, 10min A, 500D) | 832.54 | 690.42 | -17.07 |
| 8 | (10min, 2L, 10min A, 500D) | 819.73 | 675.19 | -17.63 |

Table 3.1. The mean flow values for the entire network (cont.).

| Scenario ID | Scenario Parameters | Mean Flow (veh/hr/ln) (w/o CV) | Mean Flow (veh/hr/ln) (w/ CV) | Percent Change (%) |
|---|---|---|---|---|
| 9 | (15min, 2L, 10min A, 500D) | 820.47 | 681.65 | -16.92 |
| 10 | (5min, 0L, 15min A, 500D) | 813.72 | 672.39 | -17.37 |

In Figure 3.12, the networkwide mean flow values are presented for the different positions of connected vehicles where they start to manipulate the traffic. As the distance between the incident and the connected vehicle?s position increase the average density throughout the network decreases after 750 meters. The minimum and maximum flow rates are observed when the connected vehicles start to control the traffic 1750 and 750 meters before the incident respectively.

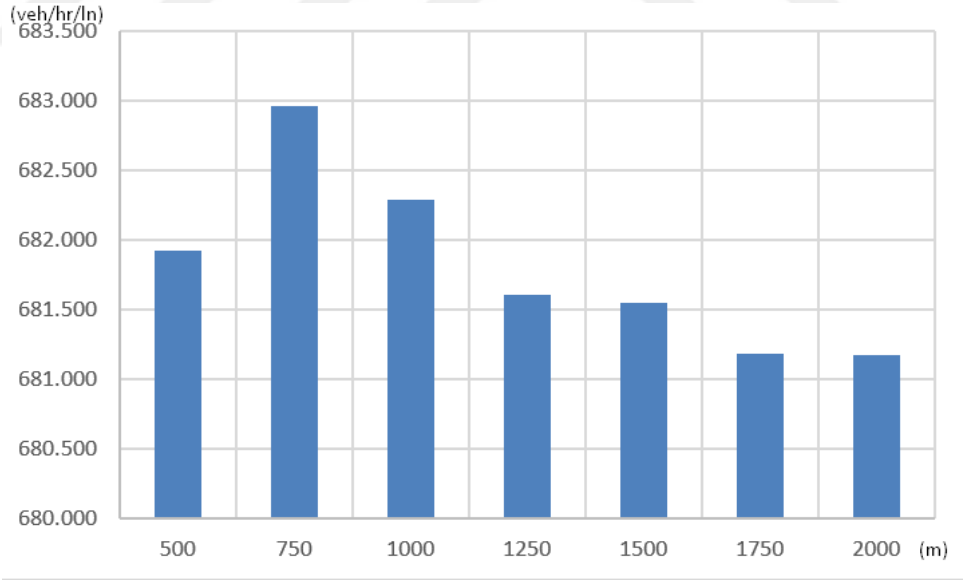


Figure 3.12. Mean flow values in the network for different positions of connected vehicles.

Mean speed and density values for the local area before the incident of the first 10 scenarios with connected vehicles, are presented in the following table (Table 3.14).

Table 3.8. The mean speed and density values for the for the local area before the incident.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 82.08 | 83.15 | 1.29 | 12.31 | 10.06 | -18.29 |
| 2 | (10min, 0L, 10min A, 500D) | 77.94 | 76.03 | -2.44 | 13.1 | 11.26 | -14.03 |
| 3 | (15min, 0L, 10min A, 500D) | 74.38 | 72.71 | -2.24 | 14 | 12.1 | -13.6 |
| 4 | (5min, 1L, 10min A, 500D) | 85.12 | 88.19 | 3.6 | 11.91 | 9.53 | -19.98 |
| 5 | (10min, 1L, 10min A, 500D) | 81.85 | 83.43 | 1.93 | 12.55 | 10.13 | -19.27 |
| 6 | (15min, 1L, 10min A, 500D) | 80.56 | 82.25 | 2.1 | 12.72 | 10.23 | -19.57 |
| 7 | (5min, 2L, 10min A, 500D) | 86.32 | 85.24 | -1.24 | 9.67 | 9.83 | 1.61 |
| 8 | (10min, 2L, 10min A, 500D) | 76.31 | 82.97 | 8.72 | 13.47 | 10.26 | -23.83 |
| 9 | (15min, 2L, 10min A, 500D) | 67.78 | 81.57 | 20.35 | 15.57 | 10.5 | -32.54 |
| 10 | (5min, 0L, 15min A, 500D) | 81.65 | 83.33 | 2.06 | 12.46 | 10.24 | -17.79 |

The maximum mean speed increase occurs in scenario 9 (15min, 2L, 10min A, 500D) by 20.35%. Compared to the networkwide mean speed change, it is significantly higher, which was 2.76%. From Figure 3.13 it can be observed that the drastic reduction in speed values in the area between the incident and the control position of the connected vehicles, does not occur at the same degree when the connected vehicles start to manipulate the traffic flow. The figure also shows that the speed is better harmonized with the introduction of connected vehicles, which means a more homogenous mean speed distribution. The applied t-test for checking if the change is statistically significant or not, shows that the change is indeed significant with a p-value of almost 0.

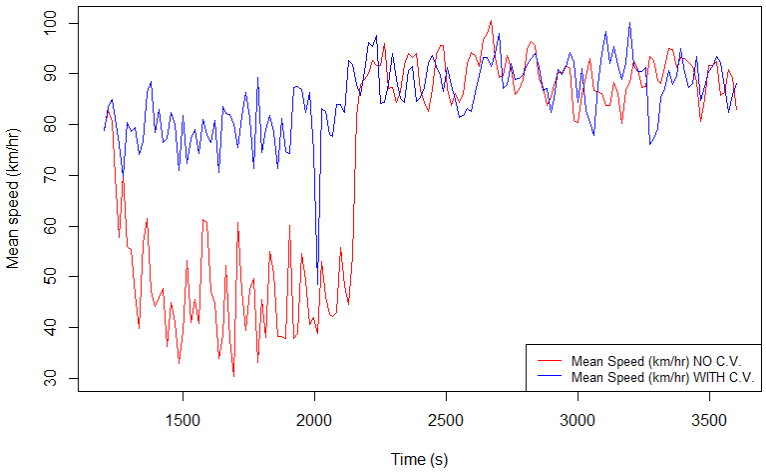


Figure 3.13. Mean speed values with and without CV before the incident location for the scenario 9 (15min, 2L, 10min A, 500D).

When the local area before the incident is evaluated, it is observed that again in the scenario 9 the density reduction is at its maximum value, which is 33%. Figure 3.14 also shows the reduction, with a density contour map. The highlighted area on the left figure, in which there are no connected vehicles is significantly reduced with the introduction of connected vehicles, which can be observed from the figure on the right. The area on the right shows that there is a queue formed but the length of it does not change very much over time. The area on the right shows that the length of the formed queue, based on the horizontal length of the highlighted area, is shorter with the introduction of connected vehicles.

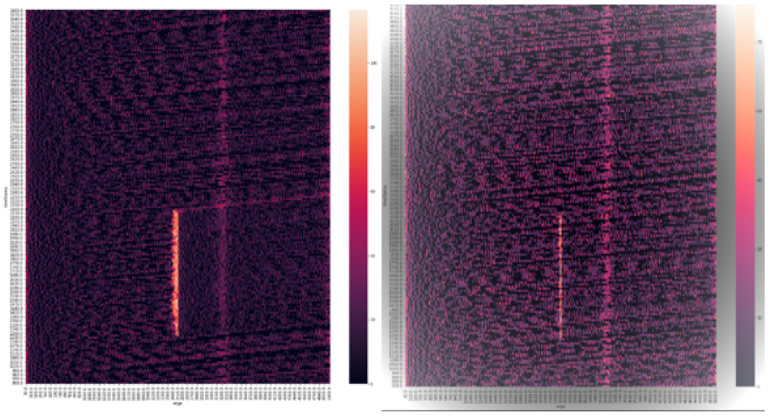

Figure 3.14. Density contour maps for scenario 9 (15min, 2L, 10min A, 500D) with (right) and without (left) connected vehicles.

Mean flow values for the local area before the incident of the first 10 scenarios when connected vehicles are introduced, are presented in the following table (Table 3.9). Up to a 2.45% increase is observed with the introduction of connected vehicles in to the network in scenario 91 (5min, 0L, 15min A, 1250D). In the same scenario, mean speed values in the local area before the incident is also increased by 2.08% and the density is reduced by 18%. All of these changes are determined to be statistically significant with a 95% level of confidence based on the results of t-test. This scenario shows that the connected vehicles can increase the efficiency of the local area before the incident with higher flow rates and speed values and lower density values.

Table 3.9. The mean flow values for the local area before the incident.

| **Scenario ID** | **Scenario Parameters** | **Mean Flow (veh/hr/ln) (w/o CV)** | **Mean Flow (veh/hr/ln) (w/ CV)** | **Percent Change (%)** |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 827.02 | 678.64 | -17.94 |
| 2 | (10min, 0L, 10min A, 500D) | 827.23 | 694.09 | -16.09 |
| 3 | (15min, 0L, 10min A, 500D) | 828.93 | 692.51 | -16.46 |
| 4 | (5min, 1L, 10min A, 500D) | 821.04 | 674.25 | -17.88 |
| 5 | (10min, 1L, 10min A, 500D) | 821.09 | 682.82 | -16.84 |
| 6 | (15min, 1L, 10min A, 500D) | 833.79 | 690.37 | -17.2 |
| 7 | (5min, 2L, 10min A, 500D) | 681.12 | 687.31 | 0.91 |
| 8 | (10min, 2L, 10min A, 500D) | 830.03 | 687.88 | -17.13 |
| 9 | (15min, 2L, 10min A, 500D) | 848.73 | 692.32 | -18.43 |
| 10 | (5min, 0L, 15min A, 500D) | 834.27 | 683.43 | -18.08 |

Mean speed and density values for the local area after the incident of the first 10 scenarios when connected vehicles are introduced, are presented in the following table (Table 3.10).

Table 3.10. The mean speed and density values for the for the local area after the incident.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 80.54 | 80.79 | 0.31 | 11.9 | 9.74 | -18.1 |
| 2 | (10min, 0L, 10min A, 500D) | 83.36 | 83.9 | 0.65 | 11.94 | 10.06 | -15.8 |
| 3 | (15min, 0L, 10min A, 500D) | 82.87 | 83.09 | 0.26 | 12.13 | 10.19 | -15.97 |
| 4 | (5min, 1L, 10min A, 500D) | 78.06 | 77.84 | -0.31 | 11.68 | 9.54 | -18.33 |
| 5 | (10min, 1L, 10min A, 500D) | 78.15 | 78.93 | 0.96 | 11.69 | 9.83 | -15.89 |
| 6 | (15min, 1L, 10min A, 500D) | 77.9 | 79.12 | 1.56 | 12.25 | 10.13 | -17.34 |
| 7 | (5min, 2L, 10min A, 500D) | 82.38 | 83.23 | 1.04 | 9.69 | 9.89 | 2.08 |
| 8 | (10min, 2L, 10min A, 500D) | 85.61 | 86.26 | 0.76 | 11.92 | 9.93 | -16.84 |
| 9 | (15min, 2L, 10min A, 500D) | 86.25 | 87.28 | 1.19 | 12.43 | 10.17 | -18.4 |
| 10 | (5min, 0L, 15min A, 500D) | 77.95 | 78.49 | 0.7 | 11.86 | 9.75 | -17.74 |

The maximum speed increase is observed in scenario 98 (10min, 2L, 15min A, 1250D), which is by 2.56% (Figure 3.15). The mean speed change in this scenario is statistically significant with a p-values of almost 0, based on the result of a t-test. In the scenario 45 (15min, 2L, 15min A, 750D), which is the scenario that the maximum density reduction is observed, the density decreases by 19.38%. This reduction, based on the result of the t-test, is significant, with a p-value that is very close to zero.

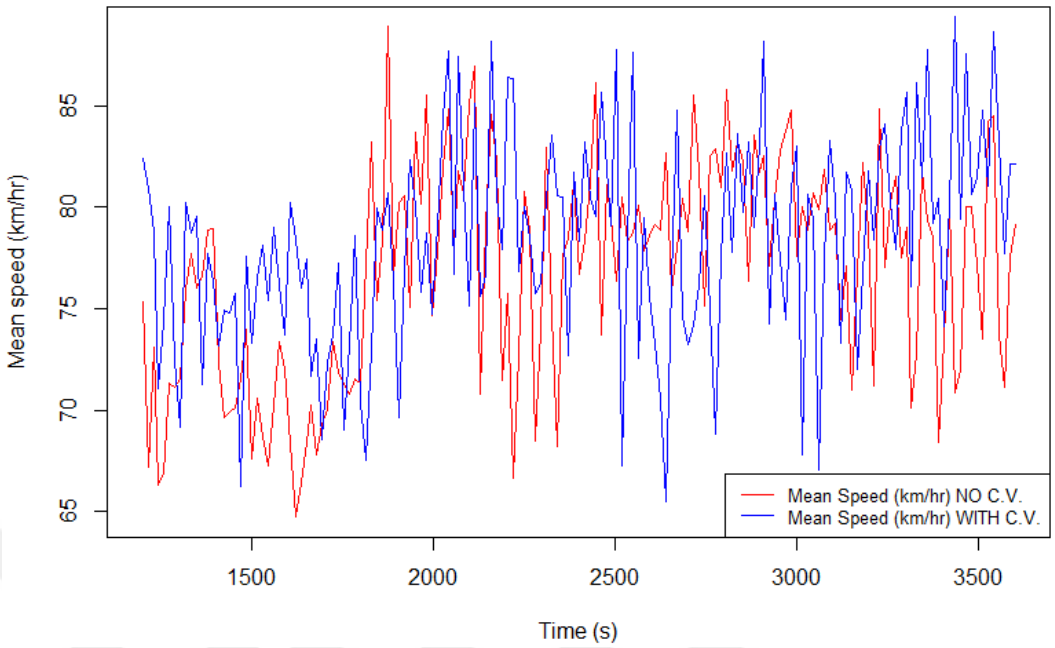


Figure 3.15. Mean speed values with and without connected vehicles before the incident location for the scenario 98 (10min, 2L, 15min A, 1250D).

Mean flow values for the local area before the incident of the first 10 scenarios when connected vehicles are introduced, are presented in the following table (Table 3.11). The maximum reduction of traffic flow occurs in scenario 172 (5min, 0L, 15min A, 2000D), by 18.45%. Whereas in scenario 88 (5min, 2L, 10min A, 1250D), the maximum flow increase can be observed, which is by 0.44%. The observed change in scenario 88 is not statistically significant. However, the reduction in scenario 172 is statistically significant.

Table 3.11. The mean flow values for the local area after the incident.

| Scenario ID | Scenario Parameters | Mean Flow (veh/hr/ln) (w/o CV) | Mean Flow (veh/hr/ln) (w/ CV) | Percent Change (%) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 828.38 | 679.26 | -18 |
| 2 | (10min, 0L, 10min A, 500D) | 811.73 | 681.95 | -15.99 |
| 3 | (15min, 0L, 10min A, 500D) | 811.15 | 677.73 | -16.45 |
| 4 | (5min, 1L, 10min A, 500D) | 814.51 | 670.58 | -17.67 |
| 5 | (10min, 1L, 10min A, 500D) | 806.71 | 675.13 | -16.31 |
| 6 | (15min, 1L, 10min A, 500D) | 824.24 | 681.44 | -17.32 |
| 7 | (5min, 2L, 10min A, 500D) | 685.54 | 687.75 | 0.32 |
| 8 | (10min, 2L, 10min A, 500D) | 814.8 | 677.99 | -16.79 |
| 9 | (15min, 2L, 10min A, 500D) | 823.34 | 682.56 | -17.1 |
| 10 | (5min, 0L, 15min A, 500D) | 832.87 | 682.89 | -18.01 |

The increase of mean speed values and decrease of density values show that the impact area of the incident can be reduced by decreasing the formed queue lengths and harmonizing the speed values. The reduction of flow values are mainly caused by the fact that connected vehicles are blocking all three lanes while adjusting their speed values. By doing so, the connected vehicles, delay the arrival of the incoming traffic to the beginning of the formed queue. However, this can cause underutilization of the road network. In real life cases, this strategy of the connected vehicles covering all lanes of the road will not be practically possible at all times. Therefore, this underutilization of the road network will not be a significant issue.

## 3.3. Case Study: D100 Highway

In this section, the method [48] is implemented using the traffic data of D100 Highway is presented. It must be noted that only the entry conditions of the real traffic flow on the D100 Highway was used in the implementation. Further explanations are provided in the next sections.

### 3.3.1. Data Collection

The study network (Figure 3.16) has 3 lanes with a speed limit of 120 km/hr. The location of the network and its boundaries are given in Figure 3.17. By using the computer vision algorithm explained in the Section 2.5., traffic flow parameters are collected with very high frequency of every 1/8 seconds.

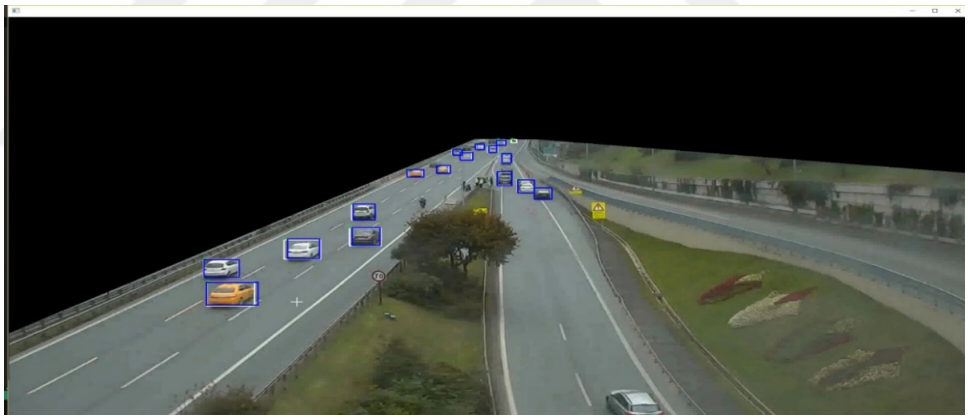

Figure 3.16. Study network, a section of D100 Highway.

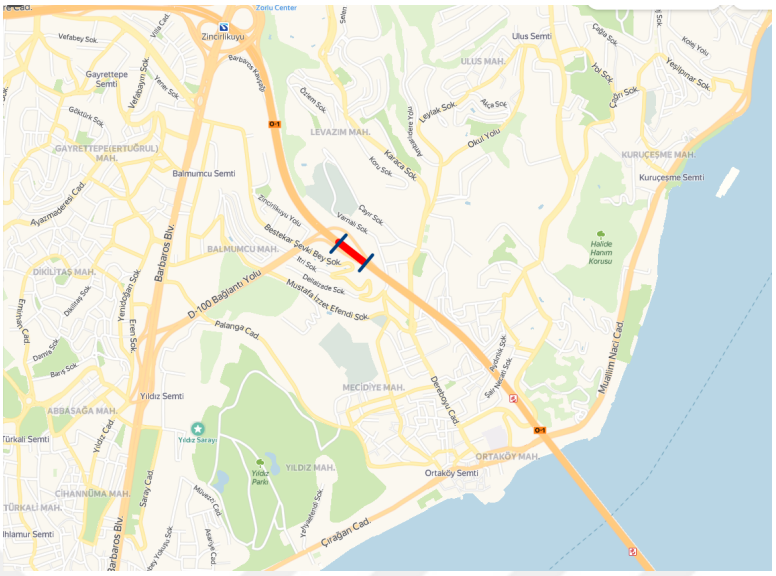


Figure 3.17. Location of the study network on D100 Highway [50].

The road was divided into regions in order to better identify the vehicle location while using the computer vision algorithm (Figure 3.18). The IDs of the regions are written in color red. Data is collected only from the regions 0, 1 and 2 in this implementation. From these regions the entry conditions of the vehicles into the given network are gathered and used as an input for the built SUMO network.

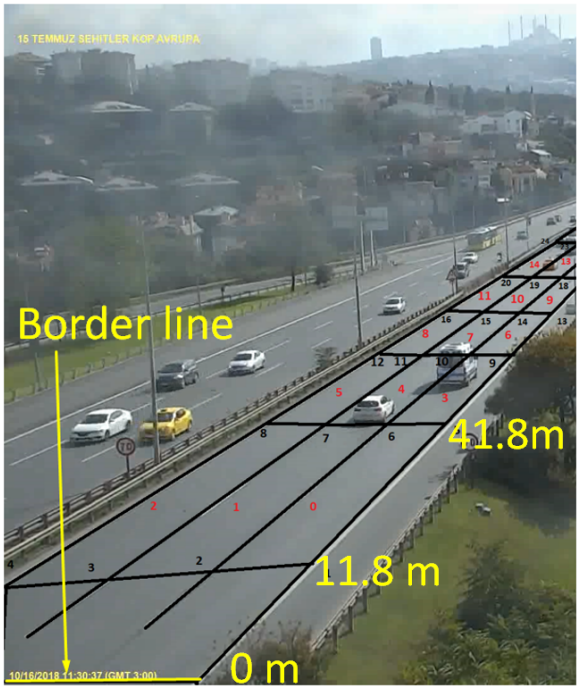


Figure 3.18. The regions of the study network.

The properties for the regions are presented in the table below (Table 3.12). The measured distance given in the table is measured from the border line that can be seen in Figure 3.18 These regions are used to identify the lane of the vehicles.

Table 3.12. The properties of the first three regions in the D100 Network.

| **Region** | **Start (m)** | **End (m)** | **Length (m)** |
|---|---|---|---|
| 0 | 11.8 | 41.8 | 30 |
| 1 | 11.8 | 41.8 | 30 |
| 2 | 11.8 | 41.8 | 30 |

The video footage of the date 11.10.2018 between the hours $11{:}30^{am}$ and $12{:}00^{pm}$ was used for this algorithm. The computer vision algorithm used required good light conditions and a traffic flow that is not very congested to avoid mislabeling the vehicles. The process of this algorithm took a very long time. It took between 13 to 13.5 hours to completely process a video footage of 2,5 hours. The video footage was also sped up and cropped (Figure 3.16) in order to accelerate the process and not to identify any other unnecessary objects in the footage. The video also labeled flying birds and moving trees due to wind as vehicles as well. The objects are not going to be included in the final dataset, if the duration of the detection is less than 1 or more than 600 seconds.

The information that were collected at the end of the video process were as follows:

(i) The ID of the detected vehicle (ID),
(ii) The frame that the vehicle was detected (Frame),
(iii) The X coordinate of the identified vehicle (NewCX),
(iv) The Y coordinate of the identified vehicle (CY),
(v) The located region of the detected vehicle (NewRegion),
(vi) The position of the detected vehicle measured from the bottom line in Figure 3.18 (Distance).

In order to accurately determine the location of the identified vehicle, the middle point on the bottom line of the blue rectangle is taken into account (Figure 3.17). This method proved to be the most accurate one when manual checks were made. The NewCX and CY parameters are the pixel coordinates that were collected with this computer vision algorithm. By using these pixel coordinates and analytical geometry, the regions (NewRegion) and thus the lanes, and the distance that is measured from the border line shown in Figure 3.19 were determined. A sample of the obtained data set is presented (Table 3.13).

Table 3.13. A sample of the obtained data set from the video footage of 11.10.2018 ($11{:}30^{am}$-$12{:}00^{pm}$ ).

| **ID** | **Frame** | **New CX** | **CY** | **New Region** | **Distance (meters)** |
|---|---|---|---|---|---|
| 8 | 3 | -999999 | 772.54 | 1 | 39.43 |
| 8 | 4 | -999999 | 752.57 | 1 | 39.43 |
| 8 | 5 | -999999 | 734.73 | 1 | 39.44 |
| 8 | 6 | -999999 | 717.67 | 1 | 39.45 |
| 8 | 7 | -999999 | 700.43 | 1 | 39.45 |
| 8 | 8 | -999999 | 684.64 | 1 | 39.46 |
| 31 | 27 | -999999 | 803.93 | 1 | 39.41 |
| 31 | 28 | -999999 | 777.27 | 1 | 39.42 |
| 31 | 29 | -999999 | 756.58 | 1 | 39.43 |
| 31 | 30 | -999999 | 735.77 | 1 | 39.44 |
| 31 | 31 | -999999 | 714.03 | 1 | 39.45 |
| 31 | 32 | -999999 | 693.88 | 1 | 39.46 |
| 58 | 66 | -999999 | 785.41 | 1 | 39.42 |

The detection time of the identified vehicle can be determined by using the Frame parameter. Each frame is equal to 0,125 seconds. The speed of a vehicle ($u$)) is calculated as follows. The distance between the vehicle's final ($X_{(i+1)}$) and the previous position ($X_i$) is calculated and then divided into the time difference ($\Delta t$) between these

positions. The following formula is used:

$$u = \frac{X_{i+1} - X_i}{\Delta t} \tag{3.7}$$

Average speed is calculated by recording the speed values of each vehicle every minute throughout the recording duration. The number of vehicles passing through as region is also calculated by counting the number of unique labels (ID) that are detected in each region (NewRegion). The collected values for regions 0, 1 and 2 for the first 13 minutes are presented in the table below (Table 3.14).

Table 3.14. Speed-flow data gathered from the video footage 11.10.2018 ($11{:}30^{am}$-$12{:}00^{pm}$ ).

| | **Region 0** | | **Region 1** | | **Region 2** | |
|---|---|---|---|---|---|---|
| **Minutes** | **Flow (veh/hr)** | **Speed (km/hr)** | **Flow (veh/hr)** | **Speed (km/hr)** | **Flow (veh/hr)** | **Speed (km/hr)** |
| 0 | 480 | 80 | 1329 | 89 | 1170 | 91 |
| 1 | 540 | 76 | 1595 | 81 | 2340 | 88 |
| 2 | 480 | 78 | 1861 | 85 | 2172 | 84 |
| 3 | 720 | 88 | 1329 | 85 | 1671 | 84 |
| 4 | 480 | 85 | 1595 | 83 | 1671 | 86 |
| 5 | 600 | 82 | 1529 | 84 | 1671 | 84 |
| 6 | 600 | 82 | 1595 | 88 | 1588 | 83 |
| 7 | 660 | 81 | 1595 | 85 | 1504 | 90 |
| 8 | 480 | 84 | 1396 | 89 | 919 | 93 |
| 9 | 420 | 85 | 1329 | 89 | 1755 | 87 |
| 10 | 240 | 83 | 1329 | 90 | 1755 | 89 |
| 11 | 360 | 80 | 1329 | 85 | 1337 | 93 |
| 12 | 420 | 90 | 1529 | 87 | 1504 | 95 |
| 13 | 600 | 85 | 1396 | 87 | 1003 | 90 |

Finally, the mean values of flow and speed are calculated for each region. These flow and speed values are used as inputs for the SUMO Network.

### 3.3.2. Simulation

For the case study, the simulation network built in the Section 3.2.1 was used with the assumptions provided in the Section 3.2.2. The data collected from the video footage was used as an input, namely the entry conditions. Mean flow and speed properties obtained from the video footage are presented in Table 3.15. By using the information provided in Table 3.14, the flow values of each lane at the entry section of the constructed SUMO network are determined. Also, the maximum mean speed value is used for the maximum speed value of the vehicles introduced to the stduy network. The defined vehicle parameters in Table D are not changed with the exception of "maxSpeed" parameter which is set to be the highest mean speed value among these 3 regions (88.80 km/hr). The flow parameters that were presented in Table 3.2 are used. However, the number of vehicles (mean flow value) that is introduced to the network for each lane are taken from the results of the computer vision algorithm.

Table 3.15. Entry conditions used for the case study in the SUMO Network.

| **Region 0 (Right Lane)** | | **Region 1 (Middle Lane)** | | **Region 2 (Left Lane)** | |
|---|---|---|---|---|---|
| **Mean Flow (veh/hr)** | **Mean Speed (km/hr)** | **Mean Flow (veh/hr)** | **Mean Speed (km/hr)** | **Mean Flow (veh/hr)** | **Mean Speed (km/hr)** |
| 586 | 82.87 | 1605 | 86.19 | 1795 | 88.8 |

For this case study, the tested scenarios are presented in the table below (Table 3.10). The incident that occurs in this network is at the same position ($2520^{th}$ meter) and at the same time ($1200^{th}$ second). The incident lasts 300 seconds and the arrival rate of connected vehicles to the given position when incident occurs is 10 minutes.

1500, 1000 and 500 meters of distances between connected vehicles and incident are tested for this study. The incident lane is also changed to all 3 lanes in different scenarios as well. The same measures of effectiveness explained in section 3.2.6 are also used as well. A t-test is conducted to see if the changes are significant or not with a confidence level of 95%. Finally, the seeds for all these scenarios are the same.

Table 3.16. Tested scenarios for the case study.

| **Scenario ID** | **Incident duration (Seconds)** | **Incident Lane** | **Period of Connected Vehicles Arriving to Network (Minutes)** | **Connected Vehicle Distance to The Incident (meters)** |
|---|---|---|---|---|
| 1 | 300 | Left | 10 | 1500 |
| 2 | 300 | Mid | 10 | 1500 |
| 3 | 300 | Right | 10 | 1500 |
| 8 | 300 | Left | 10 | 1000 |
| 4 | 300 | Right | 10 | 1000 |
| 6 | 300 | Mid | 10 | 1000 |
| 9 | 300 | Left | 10 | 500 |
| 7 | 300 | Mid | 10 | 500 |
| 5 | 300 | Right | 10 | 500 |

### 3.3.3. Simulation Results

For the traffic demand that is used in the case study, the jam densities at the section of the incident ($2520^{th}$ meter) were obtained for each lane, by placing a sensor at that position on each lane. The shockwave speeds are calculated by using the average jam density of the 3 lanes of the incident section. The calculated jam and critical density and flow capacity values for each lane are presented in the table below (Table 3.17).

Table 3.17. Properties of the study network under D100 Highway flow conditions.

| **Lane** | **Mean Flow (veh/hr/ln)** | **Jam Density (veh/km/ln)** |
|---|---|---|
| Left | 1795 | 106 |
| Middle | 1605 | 93 |
| Right | 586 | 50 |

The mean of these 3 jam density values (83 veh/km/ln) were used for calculating shockwave speeds. The shockwave speed for scenario 1 (5min, 2L, 10min A, 1500D), 8 (5min, 2L, 10min A, 1000D) and 9 (5min, 2L, 10min A, 500D) is 18.09 km/hr, for scenario 2 (5min, 1L, 10min A, 1500D), 6 (5min, 1L, 10min A, 1000D) and 7 (5min, 1L, 10min A, 500D) is 19.29 km/hr and for scenario 3 (5min, 0L, 10min A, 1500D), 4 (5min, 0L, 10min A, 1000D) and 5 (5min, 0L, 10min A, 500D) is 18.09 km/hr. These groups of scenarios are only differentiated by the lane that the incident occurs. Thus, for these groups of scenarios these same shockwave speeds were used.

The mean speed and density values in the network with the introduction of connected vehicles are presented in the table below (Table 3.18). The percent change values are tested for significance with a t-test to compare if the introduction of connected vehicles. For mean density percent change values, only scenario 5, 6 and 7 are statistically significant. For mean speed percent change values, only scenario 2, 4 and 9 are statistically insignificant.

Table 3.18. The mean speed and density values for the entire network.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 80.38 | 80.65 | 0.33 | 15.95 | 15.99 | 0.23 |
| 2 | (5min, 1L, 10min A, 1500D) | 80.68 | 80.72 | 0.04 | 15.89 | 15.84 | -0.34 |
| 3 | (5min, 0L, 10min A, 1500D) | 81.23 | 81.06 | -0.21 | 15.78 | 15.71 | -0.42 |
| 4 | (5min, 0L, 10min A, 1000D) | 81.23 | 81.27 | 0.04 | 15.78 | 15.69 | -0.57 |
| 5 | (5min, 0L, 10min A, 500D) | 81.23 | 81.73 | 0.61 | 15.78 | 15.53 | -1.61 |
| 6 | (5min, 1L, 10min A, 1000D) | 80.68 | 81.89 | 1.5 | 15.89 | 15.48 | -2.61 |
| 7 | (5min, 1L, 10min A, 500D) | 80.68 | 81.72 | 1.28 | 15.89 | 15.56 | -2.11 |
| 8 | (5min, 2L, 10min A, 1000D) | 80.38 | 80.69 | 0.39 | 15.95 | 15.77 | -1.13 |
| 9 | (5min, 2L, 10min A, 500D) | 80.38 | 80.42 | 0.04 | 15.95 | 15.85 | -0.65 |

Networkwide it was determined that generally there is an increase in terms of mean speed values in the network. The maximum increase, with a value of 1.50%, is observed in the scenario in which there is an accident in the mid lane and the connected vehicles are 1000 meters away from the incident location (Scenario 6: 5min, 1L, 10min A, 1000D). By testing this change with a t-test, the significance of this increase was evaluated. The p-value of this test was a value very close to 0 and; therefore, it was deemed significant. In terms of mean density percent change, the maximum decrease in the overall network was observed in the same scenario. The difference in mean density values of this scenario with and without connected vehicles was determined to be statistically significant based on the result of the t-test.

For the scenarios with an incident in the mid lane (Scenario 2: 5min, 1L, 10min A, 1500D, Scenario 6: 5min, 1L, 10min A, 1000D and Scenario 7: 5min, 1L, 10min A,

500D), as the distance between the incident and connected vehicles decrease, there is an speed increase in the network with the introduction of connected vehicles. However, the percent change values start to diminish after 1000 meters.

For scenarios in the right lane (Scenario 3: 5min, 0L, 10min A, 1500D, Scenario 4: 5min, 0L, 10min A, 1000D and Scenario 5: 5min, 0L, 10min A, 500D), as the distance between the connected vehicle and incident decrease, the percent change in the mean speed values throughout the network increases. An increase up to 0.61% was observed for these 3 scenarios. When its significance was checked with a t-test, it was observed that, with a p-value of almost 0, the change is statistically significant. The density values throughout the network also decreased as the distance D (explained in section 3.2.6) also decreases. Up to a 1.61% of decrease is observed and the t-test showed that this change is also statistically significant.

For scenarios in the left lane (Scenario 1: 5min, 2L, 10min A, 1500D, Scenario 8: 5min, 2L, 10min A, 1000D and Scenario 9: 5min, 2L, 10min A, 500D), in terms of mean speed change, the maximum increase (0.39%) is observed when connected vehicles are 1000 meters away from the incident location and start to control the traffic from that point. The density decreases the most in this same scenario as well by 1.13%. When these changes are checked for their levels of significance, the speed change came out to be significant whereas the density change was not.

The mean flow values in the network with the introduction of connected vehicles is presented in the table below (Table 3.19). All of these changes are statistically significant, based on the t-test results. The maximum increase of mean flow rate with the introduction of connected vehicles is in scenario 1 (5min, 2L, 10min A, 1500D), in which there is an incident on the left lane for 5 minutes and the connected vehicles are 1500 meters behind the location of the incident and they start to control the traffic flow from this point. For scenarios, with an incident on the left lane, the percent change values decrease as the distance for connected vehicles to control the traffic decreases. When an incident on the middle lane is observed, the flow of traffic decreases even with the introduction of connected vehicles. There is no clear pattern between the percent

change values and the distance between the connected vehicles and incident location. The minimum decrease is observed in scenario 2 (5min, 1L, 10min A, 1500D), in which the connected vehicles are 1500 meters behind the location of the incident and they start to control the traffic flow from this point. For the scenarios with an incident on the right lane the minimum decrease of flow value is observed in scenario 4 (5min, 0L, 10min A, 1000D), in which the connected vehicles are 1000 meters behind the location of the incident and they start to control the traffic flow from this point. It can be concluded based on networkwide results, that the flow values tend to decrease as the distance for connected vehicles to control the traffic decreases.

Table 3.19. The mean flow values for the entire network.

| Scenario ID | Scenario Parameters | Mean Flow (veh/hr/ln) (w/o CV) | Mean Flow (veh/hr/ln) (w/ CV) | Percent Change (%) |
|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 1088.34 | 1096.37 | 0.74 |
| 2 | (5min, 1L, 10min A, 1500D) | 1088.68 | 1083.52 | -0.47 |
| 3 | (5min, 0L, 10min A, 1500D) | 1090.5 | 1081.4 | -0.83 |
| 4 | (5min, 0L, 10min A, 1000D) | 1090.5 | 1083.02 | -0.69 |
| 5 | (5min, 0L, 10min A, 500D) | 1090.5 | 1078.65 | -1.09 |
| 6 | (5min, 1L, 10min A, 1000D) | 1088.68 | 1076.23 | -1.14 |
| 7 | (5min, 1L, 10min A, 500D) | 1088.68 | 1079.55 | -0.84 |
| 8 | (5min, 2L, 10min A, 1000D) | 1088.34 | 1081.33 | -0.64 |
| 9 | (5min, 2L, 10min A, 500D) | 1088.34 | 1081.69 | -0.61 |

Table 3.20 shows the average change values for networkwide mean density, flow and speed for the cases with same connected vehicle positions. The results show that the maximum networkwide density occurs when the connected vehicles are at 1500 meters behind the incident when they start to control the traffic flow. When mean

speed changes are observed, the maximum increase is observed when the connected vehicles are at 1000 or 1500 meters behind the incident when they start to control the traffic flow. Finally looking at mean flow changes, the minimum decrease of mean flow change occurs when connected vehicles are 500 meters behind the incident.

Table 3.20. Range of average change values of density, flow and speed for the scenarios with respect to different connected vehicle positions.

| Connected Vehicle Distance to The Incident (Meters) | Range of Mean Density Changes for the Scenarios (%) | Range of Mean Flow Changes for the Scenarios (%) | Range of Mean Speed Changes for the Scenarios (%) |
|---|---|---|---|
| 500 | -2.11 to -0.65 | -1.09 to -0.61 | 0.04 to 1.28 |
| 1000 | -2.61 to -0.57 | -0.69 to -1.14 | 0.04 to 1.50 |
| 1500 | -0.42 to 0.23 | -0.83 to 0.74 | -0.21 to 0.33 |

In Figure 3.19 the density contour maps of the scenario 3 (5min, 0L, 10min A, 1500D), 4 (5min, 0L, 10min A, 1000D) and 5 (5min, 0L, 10min A, 500D) are presented with the base scenario on the top left. In the base scenario, an incident on the right lane is occurring which lasts 5 minutes. The arrival rate of the connected vehicles are 10 minutes and the connected vehicles? control positions are 1500, 1000 and 500 meters behind the incident in scenario 3, 4 and 5 respectively. As the distance between the incident and the position where the connected vehicles start to control the traffic flow decreases, the change in networkwide mean density and flow values decreases and the mean speed values increases (Table 3.21). The highlighted areas in Figure 3.20 also shrink as the density values decrease throughout the network as well. This reduction indicates a more homogenous traffic flow and decreased queue lengths due to the incident (based on the reduced horizontal lengths of the highlighted areas).

Table 3.21. Networkwide average change values for the scenario 3 (5min, 0L, 10min A, 1500D), 4 (5min, 0L, 10min A, 1000D) and 5 (5min, 0L, 10min A, 500D).

| Scenario ID | Scenario Parameters | Mean Speed Percent Change (%) | Mean Density Percent Change (%) | Mean Flow Percent Change (%) |
|---|---|---|---|---|
| 3 | (5min, 0L, 10min A, 1500D) | -0.213 | -0.422 | -0.834 |
| 4 | (5min, 0L, 10min A, 1000D) | 0.045 | -0.574 | -0.686 |
| 5 | (5min, 0L, 10min A, 500D) | 0.612 | -1.61 | -1.087 |

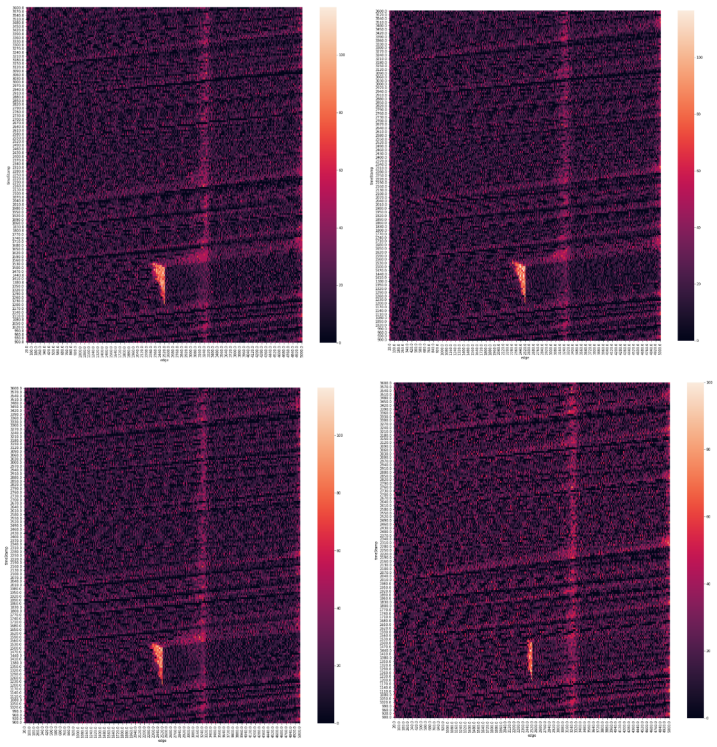

Figure 3.19. Density contour maps of a scenario with no connected vehicles and an incident on the right lane for 5 minutes (top left), scenario 3 (5min, 0L, 10min A, 1500D) (top right), 4 (5min, 0L, 10min A, 1000D) (bottom left) and 5 (5min, 0L, 10min A, 500D) (bottom right).

The mean speed and density changes for the local area before incident with the introduction of connected vehicles are presented in the table below (Table 3.22).

Table 3.22. The mean speed and density values before the incident.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 81.01 | 81.65 | 0.79 | 16 | 16 | 0 |
| 2 | (5min, 1L, 10min A, 1500D) | 81.5 | 81.63 | 0.17 | 15.93 | 15.84 | -1 |
| 3 | (5min, 0L, 10min A, 1500D) | 83.41 | 83.12 | -0.35 | 15.44 | 15.41 | 0 |
| 8 | (5min, 2L, 10min A, 1000D) | 78.52 | 79.97 | 1.84 | 16.65 | 16.11 | -3 |
| 6 | (5min, 1L, 10min A, 1000D) | 79.2 | 84.43 | 6.6 | 16.45 | 15.02 | -9 |
| 4 | (5min, 0L, 10min A, 1000D) | 82 | 82.29 | 0.35 | 15.82 | 15.62 | -1 |
| 9 | (5min, 2L, 10min A, 500D) | 72.13 | 72.35 | 0.3 | 18.55 | 18.24 | -2 |
| 5 | (5min, 0L, 10min A, 500D) | 78.33 | 82.34 | 5.11 | 16.77 | 15.62 | -7 |
| 7 | (5min, 1L, 10min A, 500D) | 73.31 | 81.82 | 11.61 | 18.16 | 15.69 | -14 |

The maximum increase in terms of mean speed change is observed in scenario 7 (5min, 1L, 10min A, 500D) in which there is an incident on the mid lane and connected vehicles are 500 meters behind the incident. The pattern of mean speed values can be observed in FFigure 3.20. From the figure it can be observed that the introduction of connected vehicles prevents the drastic speed change when there is an incident on the road (between $1200^{th}$ and $1500^{th}$ seconds).

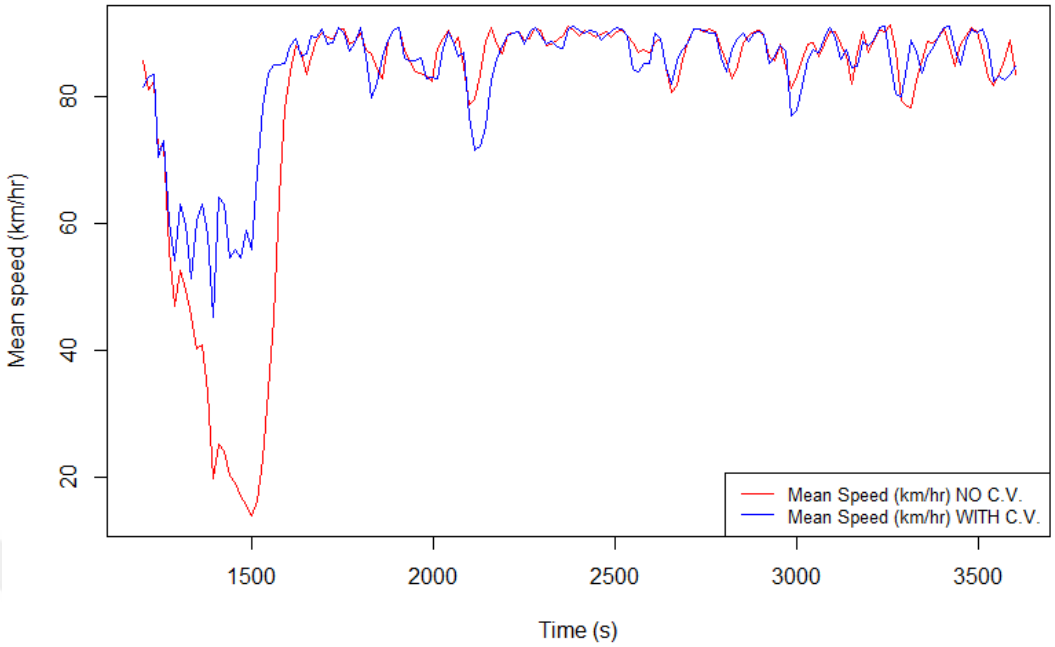


Figure 3.20. Mean speed values with and without connected vehicles before the incident location for the scenario 7 (5min, 1L, 10min A, 500D).

The mean flow values for the local area before the incident with the introduction of connected vehicles is presented in the table below (Table 3.23). The maximum flow increase is observed in the 1st scenario (5min, 2L, 10min A, 1500D), by 0.78%. The p-value obtained from a t-test is 0.031. It can be concluded that this change is significant with a confidence level of 95%.

Table 3.23. The mean flow changes for the local area before the incident.

| Scenario ID | Scenario Parameters | Mean Flow (veh/hr/lane) (w/o CV) | Mean Flow (veh/hr/lane) (w/ CV) | Percent Change (%) |
|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 1072.59 | 1080.98 | 0.78% |
| 2 | (5min, 1L, 10min A, 1500D) | 1070.65 | 1065.88 | -0.45% |
| 3 | (5min, 0L, 10min A, 1500D) | 1072.52 | 1064.06 | -0.79% |
| 4 | (5min, 0L, 10min A, 1000D) | 1075.93 | 1065.59 | -0.96% |
| 5 | (5min, 0L, 10min A, 500D) | 1084.16 | 1066.36 | -1.64% |
| 6 | (5min, 1L, 10min A, 1000D) | 1075.52 | 1054.04 | -2.00% |
| 7 | (5min, 1L, 10min A, 500D) | 1088.19 | 1067.74 | -1.88% |
| 8 | (5min, 2L, 10min A, 1000D) | 1078.73 | 1069.72 | -0.83% |
| 9 | (5min, 2L, 10min A, 500D) | 1098.39 | 1091.59 | -0.62% |

The mean speed and density values for the local area after the incident with the introduction of connected vehicles are presented in the table below (Table 3.24). The mean speeds in this local area increase up to 1.11% in the 7th scenario (5min, 1L, 10min A, 500D), which is statistically significant. The mean density in this local area decreases up to 2.82% in the 5th scenario (5min, 0L, 10min A, 500D). None of these changes, in terms of mean density in this local area, are statistically significant.

Table 3.24. The mean speed and density values for the local after the incident.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (w/o CV) | Mean Speed (km/hr) (w/ CV) | Mean Speed Percent Change (%) | Mean Density (veh/km/ln) (w/o CV) | Mean Density (veh/km/ln) (w/ CV) | Mean Density Percent Change (%) |
|---|---|---|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 77.06 | 77.23 | 0.225 | 16.644 | 16.658 | 0.09 |
| 2 | (5min, 1L, 10min A, 1500D) | 77.33 | 77.27 | -0.081 | 16.48 | 16.513 | 0.2 |
| 3 | (5min, 0L, 10min A, 1500D) | 77.12 | 77.17 | 0.054 | 16.598 | 16.468 | -0.78 |
| 4 | (5min, 0L, 10min A, 1000D) | 72.55 | 72.44 | -0.145 | 17.676 | 17.618 | -0.33 |
| 5 | (5min, 0L, 10min A, 500D) | 84.44 | 85.36 | 1.085 | 15.342 | 14.91 | -2.82 |
| 6 | (5min, 1L, 10min A, 1000D) | 72.87 | 73.53 | 0.899 | 17.559 | 17.286 | -1.55 |
| 7 | (5min, 1L, 10min A, 500D) | 84.6 | 85.53 | 1.105 | 15.293 | 15.03 | -1.71 |
| 8 | (5min, 2L, 10min A, 1000D) | 72.48 | 72.88 | 0.559 | 17.732 | 17.432 | -1.69 |
| 9 | (5min, 2L, 10min A, 500D) | 84.22 | 84.63 | 0.486 | 15.484 | 15.123 | -2.33 |

In Figure 3.21, the mean speed values for the local area after the incident is presented. For the duration of the incident the mean speed values are higher when the connected vehicles are introduced. When the incident is over and the connected vehicles stop to manipulate the traffic, no drastic changes in the mean speed values are observed.

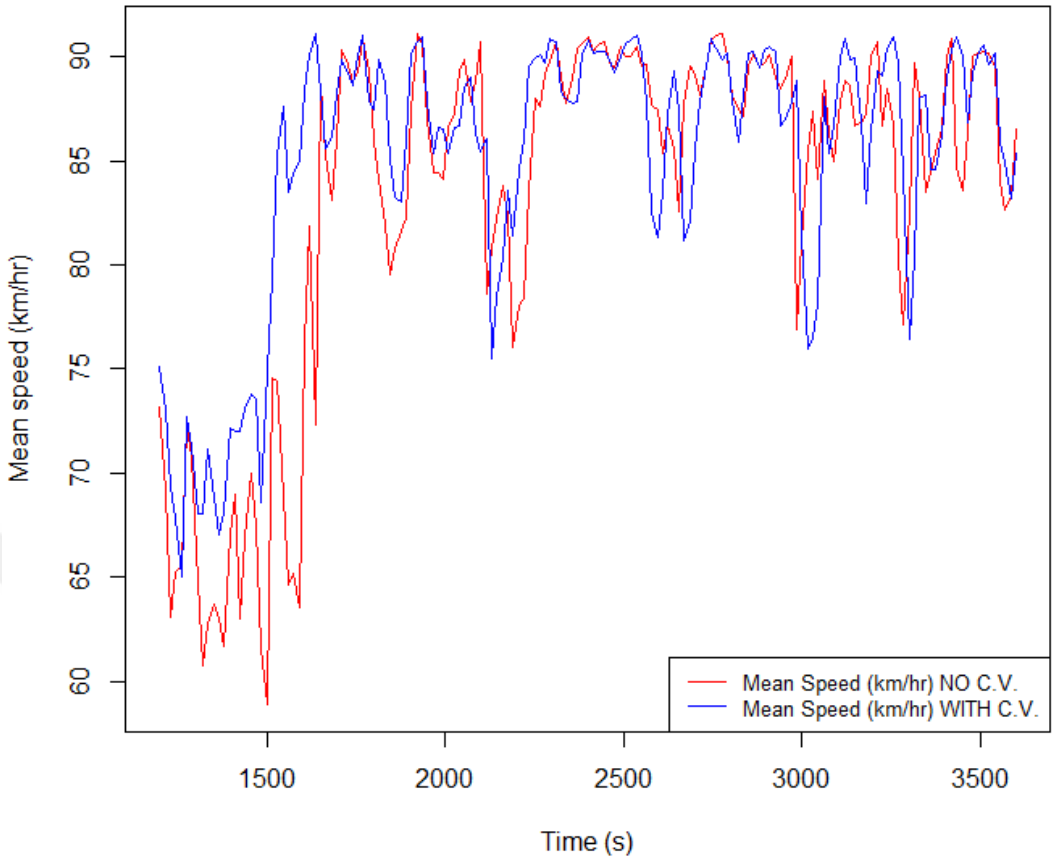


Figure 3.21. Mean speed values starting from the incident time for the local area after the incident for scenario 7 (5min, 1L, 10min A, 500D) with and without connected vehicles.

The mean flow values for the local area before the incident with the introduction of connected vehicles is presented in the table below (Table 3.25). The maximum flow increase is observed in the 1st scenario, by 0.70%. The p-value obtained from a t-test is 0.107. It can be concluded that this change is not significant .

Table 3.25. The mean flow changes for the local area after the incident.

| Scenario ID | Scenario Parameters | Mean Flow (veh/hr/ln) (w/o CV) | Mean Flow (veh/hr/ln) (w/ CV) | Percent Change (%) |
|---|---|---|---|---|
| 1 | (5min, 2L, 10min A, 1500D) | 1095.91 | 1103.62 | 0.7 |
| 2 | (5min, 1L, 10min A, 1500D) | 1095.4 | 1091.53 | -0.35 |
| 3 | (5min, 0L, 10min A, 1500D) | 1098.91 | 1088.32 | -0.96 |
| 4 | (5min, 0L, 10min A, 1000D) | 1130 | 1122.15 | -0.69 |
| 5 | (5min, 0L, 10min A, 500D) | 1075.07 | 1058.41 | -1.55 |
| 6 | (5min, 1L, 10min A, 1000D) | 1123.68 | 1110.91 | -1.14 |
| 7 | (5min, 1L, 10min A, 500D) | 1069.66 | 1054.34 | -1.43 |
| 8 | (5min, 2L, 10min A, 1000D) | 1126.46 | 1114.23 | -1.09 |
| 9 | (5min, 2L, 10min A, 500D) | 1074.96 | 1059.83 | -1.41 |

The p-values for difference in measures of effectiveness with and without connected vehicles of this case study are presented in the tables below (Table 3.26, Table 3.27 and Table 3.28).

Table 3.26. P-values for the differences of networkwide measures of effectiveness of the scenarios with and without connected vehicles.

| **Scenario ID** | **Mean Speed** | **Mean Flow** | **Mean Density** |
|---|---|---|---|
| 1 | 0.000 | 0.000 | 0.702 |
| 2 | 0.179 | 0.025 | 0.578 |
| 3 | 0.000 | 0.000 | 0.476 |
| 4 | 0.131 | 0.001 | 0.329 |
| 5 | 0.000 | 0.000 | 0.006 |
| 6 | 0.000 | 0.000 | 0.000 |
| 7 | 0.000 | 0.000 | 0.000 |
| 8 | 0.000 | 0.003 | 0.058 |
| 9 | 0.220 | 0.004 | 0.280 |

Table 3.27. P-values for the differences of measures of effectiveness before the incident in scenarios with and without connected vehicles.

| **Scenario ID** | **Mean Speed** | **Mean Flow** | **Mean Density** |
|---|---|---|---|
| 1 | 0.000 | 0.031 | 0.974 |
| 2 | 0.010 | 0.213 | 0.632 |
| 3 | 0.000 | 0.028 | 0.868 |
| 4 | 0.000 | 0.036 | 0.377 |
| 5 | 0.000 | 0.014 | 0.000 |
| 6 | 0.000 | 0.000 | 0.000 |
| 7 | 0.000 | 0.006 | 0.000 |
| 8 | 0.000 | 0.070 | 0.025 |
| 9 | 0.093 | 0.361 | 0.417 |

Table 3.28. P-values for the differences of measures of effectiveness after the incident in scenarios with and without connected vehicles.

| **Scenario ID** | **Mean Speed** | **Mean Flow** | **Mean Density** |
|---|---|---|---|
| 1 | 0.000 | 0.107 | 0.935 |
| 2 | 0.199 | 0.418 | 0.852 |
| 3 | 0.402 | 0.023 | 0.457 |
| 4 | 0.097 | 0.171 | 0.793 |
| 5 | 0.000 | 0.033 | 0.133 |
| 6 | 0.000 | 0.028 | 0.216 |
| 7 | 0.000 | 0.062 | 0.365 |
| 8 | 0.000 | 0.040 | 0.180 |
| 9 | 0.000 | 0.068 | 0.220 |

When evaluated networkwide , the introduction of connected vehicles causes a statistically significant difference in terms of mean speed values in 6 scenarios, in terms of mean flow in all scenarios and in terms of mean density in 3 scenarios.

When the systemwide local area before the incident is evaluated, 8 of the mean speed differences are statistically significant. In terms of mean flow and density terms, in 6 and 4 scenarios there is significant difference caused by the introduction of connected vehicles. In scenario 5 (5min, 0L, 10min A, 500D), 6 (5min, 1L, 10min A, 1000D) and 7 (5min, 1L, 10min A, 500D), there is a significant difference in all three measures of effectiveness with the introduction of connected vehicles. In scenario 5 and 7 the connected vehicles start to control the traffic 500 meters before the incident location. This causes a significant increase in mean speed values and a significant decrease in mean flow and density values. Also in scenario 6, with the control of connected vehicles 1000 meters before the incident, a significant decrease in terms of mean density and flow and a significant increase in terms of mean speed is observed. In the same scenarios, the difference in measures of effectiveness are also significant when evaluated networkwide . However, the difference and the effect is much higher when

these values are evaluated systemwide before the incident. As an example, in scenario 7, the difference of mean speed value is 1.03 km/hr networkwide , whereas this value changes to 8.51 km/hr when evaluated systemwide before the incident.

Finally, when the systemwide local area after the incident is evaluated, in 6 scenarios the mean speed values are significantly different when connected vehicles are introduced to the network, which are higher. In 4 scenarios there is a significant difference in terms of mean flow values and in no scenario, a significant difference in terms of mean density is observed.

# 4. CONCLUSION

In this thesis, a traffic management method using connected vehicles [48], is tested in a microscopic simulation environment, where there is an incident in the network, with synthetic and real traffic flow data. By calculating the shockwave speed that was caused by the incident on the road, and introducing connected vehicles into the network by changing their speeds to this calculated speed value, the traffic flow is managed. SUMO software was used as the simulation environment. SUMO (Version 1.4.0) is a microscopic, free and open source simulation software which gives the user the opportunity of enhancement with various APIs (Application Programming Interface) to remotely manipulate and control the simulation. A 5.4 km length network with 3 lanes was built in the SUMO environment. This network is used for both for the scenarios with synthetic traffic flow configurations and the real data obtained with the computer vision algorithm from the D100 Highway network. The measures of effectiveness, which are mean density, flow and speed, are considered for evaluating the effect of this method. These parameters are evaluated both networkwide and systemwide before and after the incident.

189 different scenarios were tested with a synthetic traffic flow configuration. Connected vehicles, with an arrival rate of 10, 15 or 20 minutes, control the traffic from 500, 750, 1000, 1250, 1500, 1750 or 2000 meters when there was an incident on the left, middle or right lane of the network for a duration of 5, 10 or 15 minutes in these scenarios. The synthetic traffic flow has a flow rate of 2500 veh/hr. These vehicles are placed on random positions of the entry section and their departing lane is the best lane, which stands for the free lane of those who allow the vehicle the longest ride without the need to lane change. The duration of each run is 1 hour and the first 15 minutes are considered as warm up period and thus, discarded.

The results of these 189 scenarios show that the introduction of connected vehicles causes an increase up to 20.35% in terms of mean speed, a decrease up to 32.54% in terms of mean density and an increase up to 2.45% in terms of mean flow for the local

system before the incident. When mean speed, density and flow values are evaluated for the local system after the incident, an increase of 2.56%, a decrease up to 19.38% and an increase up to 0.44% are observed with the introduction of connected vehicles into the network respectively. Networkwide, there is a decrease in terms of mean density up to 2.61% when there are connected vehicles controlling the traffic flow. The mean speed and flow values, networkwide , increases up to 3.09% and 0.34% respectively with the introduction of connected vehicles. These differences are tested with a t-test by comparing the same scenario with and without the connected vehicles in the network. Results of the t-test show that in 188 out of 189 scenarios there is at least one significant difference in terms of speed, density or flow that is caused by the introduction of connected vehicles, with a 95% level of confidence.

On the same network, using a real traffic data obtained from the D100 Highway using a computer vision algorithm 9 different scenarios were tested. In these scenarios there is an incident for 5 minutes and the arrival rate of connected vehicles are 10 minutes. The incident lane, which can be on either of the 3 lanes of this network and the distance from the incident where the connected vehicles begin controlling the network, which are 500, 1000 or 1500 meters, are the changing parameters. The results of these 9 scenarios show that the introduction of connected vehicles causes an increase up to 11.61% in terms of mean speed, a decrease up to 13.65% in terms of mean density and an increase up to 0.78% in terms of mean flow for the local system before the incident. When mean speed, density and flow values are evaluated for the local system after the incident, an increase of 1.11%, a decrease up to 2.82% and an increase up to 0.70% are observed with the introduction of connected vehicles into the network respectively. Networkwide , there is a decrease in terms of mean density up to 2.61% when there are connected vehicles controlling the traffic flow. The mean speed and flow values, networkwide , increases up to 1.50% and 0.74% respectively with the introduction of connected vehicles. None of the differences in terms of density at the local system after the incident are statistically significant.

The results show that:

(i) The introduction of connected vehicles can reduce the influence area of an incident by decreasing the queue lengths. They also influence the traffic flow behind them so that they delay their arrival to the beginning of the formed queue due to an incident.

(ii) Based on the 189 scenarios, the connected vehicles provide the maximum mean speed increase and mean density decrease when they control to traffic flow 1750 meters behind the incident location. As this distance changes from 500 meters up to 2000 meters, the mean speed values also increase.

(iii) When the distance between the control point of connected vehicles and the incident location decreases the mean flow values start to increase. The flow rate is at its peak value when the connected vehicles start to control the traffic at 1000 meters before the incident.

(iv) The changes in the local system after the incident are rather small compared to the changes in the local system before the incident, when connected vehicles are introduced to the network.

(v) Based on the results of the case study, as the distance between the point where connected vehicles control the traffic and the incident decrease, the mean density and flow values tend to decrease, whereas the mean speed values tend to increase.

The connected vehicles are useful for managing the traffic flow by making the speed values throughout the network more homogenous. They also cause the length of formed queues to shorten, which also reduces the impact area of an incident. By decreasing the impact area of an incident, the performance of the overall network can be improved in terms of safer traffic conditions and keeping the impact of an incident as minimal as possible. The duration and scale of the incident are also important factors. An incident that occurs in the middle lane causes much more traffic congestion compared to an incident on a left or right lane. Also, as the incident duration increases, the recovery probability of the traffic flow within a reasonable time period, after the incident is over, decreases. These primary results show that further improvements are possible. Future studies will include testing this method on a real highway network with

different real traffic demand data, without an incident. The fact that connected vehicles cover all 3 lanes while changing their speeds, can cause underutilization of the road network. Even though this behavior of connected vehicles are not always applicable in real life scenarios, different strategies in which the number of lanes covered by the connected vehicles are changed or by changing the duration of this speed change must be tested.

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# APPENDIX A: SIMULATION CASES FOR THE SYNTHETIC TRAFFIC FLOW CONDITIONS

Table A.1. Simulation cases for the synthetic traffic flow conditions.

| Scenario ID | Python Seed | Incident Duration (Seconds) | Incident Lane (0: Right, 1: Mid, 2:Left) | Arrival Rate of Connected Vehicles (seconds) | Connected Vehicle Distance to The Incident (meters) | Calculated Shockwave Speed (km/hr) |
|---|---|---|---|---|---|---|
| 1 | 1 | 300 | 0 | 600 | 500 | 27.93 |
| 2 | 2 | 600 | 0 | 600 | 500 | 16.56 |
| 3 | 3 | 900 | 0 | 600 | 500 | 9.46 |
| 4 | 4 | 300 | 1 | 600 | 500 | 23.54 |
| 5 | 5 | 600 | 1 | 600 | 500 | 15.69 |
| 6 | 6 | 900 | 1 | 600 | 500 | 41.94 |
| 7 | 7 | 300 | 2 | 600 | 500 | 31.68 |
| 8 | 8 | 600 | 2 | 600 | 500 | 21.96 |
| 9 | 9 | 900 | 2 | 600 | 500 | 25.09 |
| 10 | 10 | 300 | 0 | 900 | 500 | 11.8 |
| 11 | 11 | 600 | 0 | 900 | 500 | 14.18 |
| 12 | 12 | 900 | 0 | 900 | 500 | 10.62 |
| 13 | 13 | 300 | 1 | 900 | 500 | 32.61 |
| 14 | 14 | 600 | 1 | 900 | 500 | 25.63 |
| 15 | 15 | 900 | 1 | 900 | 500 | 15.69 |
| 16 | 16 | 300 | 2 | 900 | 500 | 34.95 |
| 17 | 17 | 600 | 2 | 900 | 500 | 10.62 |
| 18 | 18 | 900 | 2 | 900 | 500 | 9.468 |
| 19 | 19 | 300 | 0 | 1200 | 500 | 20.08 |
| 20 | 20 | 600 | 0 | 1200 | 500 | 12.52 |
| 21 | 21 | 900 | 0 | 1200 | 500 | 37.26 |
| 22 | 22 | 300 | 1 | 1200 | 500 | 12.99 |
| 23 | 23 | 600 | 1 | 1200 | 500 | 23.54 |
| 24 | 24 | 900 | 1 | 1200 | 500 | 12.99 |
| 25 | 25 | 300 | 2 | 1200 | 500 | 11.8 |
| 26 | 26 | 600 | 2 | 1200 | 500 | 14.18 |
| 27 | 27 | 900 | 2 | 1200 | 500 | 15.69 |
| 28 | 1 | 300 | 0 | 600 | 750 | 27.93 |
| 29 | 2 | 600 | 0 | 600 | 750 | 16.56 |
| 30 | 3 | 900 | 0 | 600 | 750 | 9.46 |
| 31 | 4 | 300 | 1 | 600 | 750 | 23.54 |
| 32 | 5 | 600 | 1 | 600 | 750 | 15.69 |
| 33 | 6 | 900 | 1 | 600 | 750 | 41.94 |
| 34 | 7 | 300 | 2 | 600 | 750 | 31.68 |
| 35 | 8 | 600 | 2 | 600 | 750 | 21.96 |
| 36 | 9 | 900 | 2 | 600 | 750 | 25.09 |
| 37 | 10 | 300 | 0 | 900 | 750 | 11.8 |
| 38 | 11 | 600 | 0 | 900 | 750 | 14.18 |
| 39 | 12 | 900 | 0 | 900 | 750 | 10.62 |
| 40 | 13 | 300 | 1 | 900 | 750 | 32.61 |
| 41 | 14 | 600 | 1 | 900 | 750 | 25.63 |
| 42 | 15 | 900 | 1 | 900 | 750 | 15.69 |
| 43 | 16 | 300 | 2 | 900 | 750 | 34.95 |
| 44 | 17 | 600 | 2 | 900 | 750 | 10.62 |
| 45 | 18 | 900 | 2 | 900 | 750 | 9.46 |
| 46 | 19 | 300 | 0 | 1200 | 750 | 20.08 |
| 47 | 20 | 600 | 0 | 1200 | 750 | 12.52 |
| 48 | 21 | 900 | 0 | 1200 | 750 | 37.26 |
| 49 | 22 | 300 | 1 | 1200 | 750 | 12.99 |
| 50 | 23 | 600 | 1 | 1200 | 750 | 23.54 |

Table A.1. Simulation cases for the synthetic traffic flow conditions (cont.).

| Scenario ID | Python Seed | Incident Duration (Seconds) | Incident Lane (0: Right, 1: Mid, 2:Left) | Arrival Rate of Connected Vehicles (seconds) | Connected Vehicle Distance to The Incident (meters) | Calculated Shockwave Speed (km/hr) |
|---|---|---|---|---|---|---|
| 51 | 24 | 900 | 1 | 1200 | 750 | 12.99 |
| 52 | 25 | 300 | 2 | 1200 | 750 | 11.8 |
| 53 | 26 | 600 | 2 | 1200 | 750 | 14.18 |
| 54 | 27 | 900 | 2 | 1200 | 750 | 15.69 |
| 55 | 1 | 300 | 0 | 600 | 1000 | 27.93 |
| 56 | 2 | 600 | 0 | 600 | 1000 | 16.56 |
| 57 | 3 | 900 | 0 | 600 | 1000 | 9.468 |
| 58 | 4 | 300 | 1 | 600 | 1000 | 23.54 |
| 59 | 5 | 600 | 1 | 600 | 1000 | 15.69 |
| 60 | 6 | 900 | 1 | 600 | 1000 | 41.94 |
| 61 | 7 | 300 | 2 | 600 | 1000 | 31.68 |
| 62 | 8 | 600 | 2 | 600 | 1000 | 21.96 |
| 63 | 9 | 900 | 2 | 600 | 1000 | 25.09 |
| 64 | 10 | 300 | 0 | 900 | 1000 | 11.8 |
| 65 | 11 | 600 | 0 | 900 | 1000 | 14.18 |
| 66 | 12 | 900 | 0 | 900 | 1000 | 10.62 |
| 67 | 13 | 300 | 1 | 900 | 1000 | 32.61 |
| 68 | 14 | 600 | 1 | 900 | 1000 | 25.63 |
| 69 | 15 | 900 | 1 | 900 | 1000 | 15.69 |
| 70 | 16 | 300 | 2 | 900 | 1000 | 34.95 |
| 71 | 17 | 600 | 2 | 900 | 1000 | 10.62 |
| 72 | 18 | 900 | 2 | 900 | 1000 | 9.46 |
| 73 | 19 | 300 | 0 | 1200 | 1000 | 20.08 |
| 74 | 20 | 600 | 0 | 1200 | 1000 | 12.52 |
| 75 | 21 | 900 | 0 | 1200 | 1000 | 37.2 |
| 76 | 22 | 300 | 1 | 1200 | 1000 | 12.96 |
| 77 | 23 | 600 | 1 | 1200 | 1000 | 23.54 |
| 78 | 24 | 900 | 1 | 1200 | 1000 | 12.99 |
| 79 | 25 | 300 | 2 | 1200 | 1000 | 11.8 |
| 80 | 26 | 600 | 2 | 1200 | 1000 | 14.18 |
| 81 | 27 | 900 | 2 | 1200 | 1000 | 15.69 |
| 82 | 1 | 300 | 0 | 600 | 1250 | 27.93 |
| 83 | 2 | 600 | 0 | 600 | 1250 | 16.56 |
| 84 | 3 | 900 | 0 | 600 | 1250 | 9.46 |
| 85 | 4 | 300 | 1 | 600 | 1250 | 23.54 |
| 86 | 5 | 600 | 1 | 600 | 1250 | 15.69 |
| 87 | 6 | 900 | 1 | 600 | 1250 | 41.94 |
| 88 | 7 | 300 | 2 | 600 | 1250 | 31.68 |
| 89 | 8 | 600 | 2 | 600 | 1250 | 21.96 |
| 90 | 9 | 900 | 2 | 600 | 1250 | 25.09 |
| 91 | 10 | 300 | 0 | 900 | 1250 | 11.8 |
| 92 | 11 | 600 | 0 | 900 | 1250 | 14.18 |
| 93 | 12 | 900 | 0 | 900 | 1250 | 10.62 |
| 94 | 13 | 300 | 1 | 900 | 1250 | 32.61 |
| 95 | 14 | 600 | 1 | 900 | 1250 | 25.63 |
| 96 | 15 | 900 | 1 | 900 | 1250 | 15.69 |
| 97 | 16 | 300 | 2 | 900 | 1250 | 34.95 |
| 98 | 17 | 600 | 2 | 900 | 1250 | 10.62 |
| 99 | 18 | 900 | 2 | 900 | 1250 | 9.46 |
| 100 | 19 | 300 | 0 | 1200 | 1250 | 20.08 |

Table A.1. Simulation cases for the synthetic traffic flow conditions (cont.).

| Scenario ID | Python Seed | Incident Duration (Seconds) | Incident Lane (0: Right, 1: Mid, 2:Left) | Arrival Rate of Connected Vehicles (seconds) | Connected Vehicle Distance to The Incident (meters) | Calculated Shockwave Speed (km/hr) |
|---|---|---|---|---|---|---|
| 101 | 20 | 600 | 0 | 1200 | 1250 | 12.52 |
| 102 | 21 | 900 | 0 | 1200 | 1250 | 37.26 |
| 103 | 22 | 300 | 1 | 1200 | 1250 | 12.99 |
| 104 | 23 | 600 | 1 | 1200 | 1250 | 23.54 |
| 105 | 24 | 900 | 1 | 1200 | 1250 | 12.99 |
| 106 | 25 | 300 | 2 | 1200 | 1250 | 11.8 |
| 107 | 26 | 600 | 2 | 1200 | 1250 | 14.18 |
| 108 | 27 | 900 | 2 | 1200 | 1250 | 15.69 |
| 109 | 1 | 300 | 0 | 600 | 1500 | 27.93 |
| 110 | 2 | 600 | 0 | 600 | 1500 | 16.56 |
| 111 | 3 | 900 | 0 | 600 | 1500 | 9.46 |
| 112 | 4 | 300 | 1 | 600 | 1500 | 23.54 |
| 113 | 5 | 600 | 1 | 600 | 1500 | 15.69 |
| 114 | 6 | 900 | 1 | 600 | 1500 | 41.94 |
| 115 | 7 | 300 | 2 | 600 | 1500 | 31.68 |
| 116 | 8 | 600 | 2 | 600 | 1500 | 21.96 |
| 117 | 9 | 900 | 2 | 600 | 1500 | 25.09 |
| 118 | 10 | 300 | 0 | 900 | 1500 | 11.8 |
| 119 | 11 | 600 | 0 | 900 | 1500 | 14.18 |
| 120 | 12 | 900 | 0 | 900 | 1500 | 10.62 |
| 121 | 13 | 300 | 1 | 900 | 1500 | 32.61 |
| 122 | 14 | 600 | 1 | 900 | 1500 | 25.63 |
| 123 | 15 | 900 | 1 | 900 | 1500 | 15.69 |
| 124 | 16 | 300 | 2 | 900 | 1500 | 34.95 |
| 125 | 17 | 600 | 2 | 900 | 1500 | 10.62 |
| 126 | 18 | 900 | 2 | 900 | 1500 | 9.468 |
| 127 | 19 | 300 | 0 | 1200 | 1500 | 20.08 |
| 128 | 20 | 600 | 0 | 1200 | 1500 | 12.52 |
| 129 | 21 | 900 | 0 | 1200 | 1500 | 37.26 |
| 130 | 22 | 300 | 1 | 1200 | 1500 | 12.99 |
| 131 | 23 | 600 | 1 | 1200 | 1500 | 23.54 |
| 132 | 24 | 900 | 1 | 1200 | 1500 | 12.99 |
| 133 | 25 | 300 | 2 | 1200 | 1500 | 11.8 |
| 134 | 26 | 600 | 2 | 1200 | 1500 | 14.18 |
| 135 | 27 | 900 | 2 | 1200 | 1500 | 15.69 |
| 136 | 1 | 300 | 0 | 600 | 1750 | 27.93 |
| 137 | 2 | 600 | 0 | 600 | 1750 | 16.56 |
| 138 | 3 | 900 | 0 | 600 | 1750 | 9.46 |
| 139 | 4 | 300 | 1 | 600 | 1750 | 23.54 |
| 140 | 5 | 600 | 1 | 600 | 1750 | 15.69 |
| 141 | 6 | 900 | 1 | 600 | 1750 | 41.94 |
| 142 | 7 | 300 | 2 | 600 | 1750 | 31.68 |
| 143 | 8 | 600 | 2 | 600 | 1750 | 21.96 |
| 144 | 9 | 900 | 2 | 600 | 1750 | 25.09 |
| 145 | 10 | 300 | 0 | 900 | 1750 | 11.8 |
| 146 | 11 | 600 | 0 | 900 | 1750 | 14.18 |
| 147 | 12 | 900 | 0 | 900 | 1750 | 10.62 |
| 148 | 13 | 300 | 1 | 900 | 1750 | 32.61 |
| 149 | 14 | 600 | 1 | 900 | 1750 | 25.63 |
| 150 | 15 | 900 | 1 | 900 | 1750 | 15.69 |

Table A.1. Simulation cases for the synthetic traffic flow conditions (cont.).

| Scenario ID | Python Seed | Incident Duration (Seconds) | Incident Lane (0: Right, 1: Mid, 2:Left) | Arrival Rate of Connected Vehicles (seconds) | Connected Vehicle Distance to The Incident (meters) | Calculated Shockwave Speed (km/hr) |
|---|---|---|---|---|---|---|
| 151 | 16 | 300 | 2 | 900 | 1750 | 34.95 |
| 152 | 17 | 600 | 2 | 900 | 1750 | 10.62 |
| 153 | 18 | 900 | 2 | 900 | 1750 | 9.46 |
| 154 | 19 | 300 | 0 | 1200 | 1750 | 20.08 |
| 155 | 20 | 600 | 0 | 1200 | 1750 | 12.52 |
| 156 | 21 | 900 | 0 | 1200 | 1750 | 37.26 |
| 157 | 22 | 300 | 1 | 1200 | 1750 | 12.99 |
| 158 | 23 | 600 | 1 | 1200 | 1750 | 23.54 |
| 159 | 24 | 900 | 1 | 1200 | 1750 | 12.99 |
| 160 | 25 | 300 | 2 | 1200 | 1750 | 11.8 |
| 161 | 26 | 600 | 2 | 1200 | 1750 | 14.18 |
| 162 | 27 | 900 | 2 | 1200 | 1750 | 15.69 |
| 163 | 1 | 300 | 0 | 600 | 2000 | 27.93 |
| 164 | 2 | 600 | 0 | 600 | 2000 | 16.56 |
| 165 | 3 | 900 | 0 | 600 | 2000 | 9.46 |
| 166 | 4 | 300 | 1 | 600 | 2000 | 23.54 |
| 167 | 5 | 600 | 1 | 600 | 2000 | 15.69 |
| 168 | 6 | 900 | 1 | 600 | 2000 | 41.94 |
| 169 | 7 | 300 | 2 | 600 | 2000 | 31.68 |
| 170 | 8 | 600 | 2 | 600 | 2000 | 21.96 |
| 171 | 9 | 900 | 2 | 600 | 2000 | 25.09 |
| 172 | 10 | 300 | 0 | 900 | 2000 | 11.8 |
| 173 | 11 | 600 | 0 | 900 | 2000 | 14.18 |
| 174 | 12 | 900 | 0 | 900 | 2000 | 10.62 |
| 175 | 13 | 300 | 1 | 900 | 2000 | 32.61 |
| 176 | 14 | 600 | 1 | 900 | 2000 | 25.63 |
| 177 | 15 | 900 | 1 | 900 | 2000 | 15.69 |
| 178 | 16 | 300 | 2 | 900 | 2000 | 34.95 |
| 179 | 17 | 600 | 2 | 900 | 2000 | 10.62 |
| 182 | 20 | 600 | 0 | 1200 | 2000 | 12.52 |
| 183 | 21 | 900 | 0 | 1200 | 2000 | 37.26 |
| 184 | 22 | 300 | 1 | 1200 | 2000 | 12.99 |
| 185 | 23 | 600 | 1 | 1200 | 2000 | 23.54 |
| 186 | 24 | 900 | 1 | 1200 | 2000 | 12.99 |
| 187 | 25 | 300 | 2 | 1200 | 2000 | 11.8 |
| 188 | 26 | 600 | 2 | 1200 | 2000 | 14.18 |
| 189 | 27 | 900 | 2 | 1200 | 2000 | 15.69 |

# APPENDIX B: MEASURES OF EFFECTIVENESS FOR SCENARIOS WITHOUT THE CONNECTED VEHICLES

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles.

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 83.18 | 826.81 | 12.03 |
| 2 | (10min, 0L, 10min A, 500D) | 83.26 | 819.88 | 11.98 |
| 3 | (15min, 0L, 10min A, 500D) | 83.86 | 813.72 | 11.99 |
| 4 | (5min, 1L, 10min A, 500D) | 84.26 | 820.49 | 11.88 |
| 5 | (10min, 1L, 10min A, 500D) | 84.32 | 815.67 | 11.85 |
| 6 | (15min, 1L, 10min A, 500D) | 83.71 | 823.38 | 11.99 |
| 7 | (5min, 2L, 10min A, 500D) | 84.03 | 682.74 | 9.92 |
| 8 | (10min, 2L, 10min A, 500D) | 83.21 | 820.48 | 12.06 |
| 9 | (15min, 2L, 10min A, 500D) | 81.95 | 821.72 | 12.29 |
| 10 | (5min, 0L, 15min A, 500D) | 83.12 | 829.26 | 12.07 |
| 11 | (10min, 0L, 15min A, 500D) | 82.78 | 820.99 | 12.11 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 12 | (15min, 0L, 15min A, 500D) | 82.75 | 818.43 | 12.12 |
| 13 | (5min, 1L, 15min A, 500D) | 82.42 | 827.11 | 12.21 |
| 14 | (10min, 1L, 15min A, 500D) | 83.96 | 819.73 | 11.92 |
| 15 | (15min, 1L, 15min A, 500D) | 83.23 | 822.29 | 12.02 |
| 16 | (5min, 2L, 15min A, 500D) | 83.73 | 822.72 | 11.95 |
| 17 | (10min, 2L, 15min A, 500D) | 83.03 | 824.53 | 12.07 |
| 18 | (15min, 2L, 15min A, 500D) | 82.17 | 832.55 | 12.23 |
| 19 | (5min, 0L, 20min A, 500D) | 83.3 | 821.77 | 12.01 |
| 20 | (10min, 0L, 20min A, 500D) | 83.73 | 817.93 | 11.96 |
| 21 | (15min, 0L, 20min A, 500D) | 82.21 | 821.74 | 12.18 |
| 22 | (5min, 1L, 20min A, 500D) | 84.6 | 817.86 | 11.83 |
| 23 | (10min, 1L, 20min A, 500D) | 82.48 | 821.49 | 12.25 |
| 24 | (15min, 1L, 20min A, 500D) | 83.29 | 821.26 | 11.98 |
| 25 | (5min, 2L, 20min A, 500D) | 84.28 | 818.56 | 11.88 |
| 26 | (10min, 2L, 20min A, 500D) | 83.72 | 686.34 | 10.01 |
| 27 | (15min, 2L, 20min A, 500D) | 81.59 | 832.01 | 12.28 |
| 28 | (5min, 0L, 10min A, 750D) | 83.18 | 826.81 | 12.03 |
| 29 | (10min, 0L, 10min A, 750D) | 83.26 | 819.88 | 11.98 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 30 | (15min, 0L, 10min A, 750D) | 83.86 | 813.72 | 11.99 |
| 31 | (5min, 1L, 10min A, 750D) | 84.26 | 820.49 | 11.88 |
| 32 | (10min, 1L, 10min A, 750D) | 84.32 | 815.67 | 11.85 |
| 33 | (15min, 1L, 10min A, 750D) | 83.71 | 823.38 | 11.99 |
| 34 | (5min, 2L, 10min A, 750D) | 84.03 | 682.74 | 9.92 |
| 35 | (10min, 2L, 10min A, 750D) | 83.21 | 820.48 | 12.06 |
| 36 | (15min, 2L, 10min A, 750D) | 81.95 | 821.72 | 12.29 |
| 37 | (5min, 0L, 15min A, 750D) | 83.12 | 829.26 | 12.07 |
| 38 | (10min, 0L, 15min A, 750D) | 82.78 | 820.99 | 12.11 |
| 39 | (15min, 0L, 15min A, 750D) | 82.75 | 818.43 | 12.12 |
| 40 | (5min, 1L, 15min A, 750D) | 82.42 | 827.11 | 12.21 |
| 41 | (10min, 1L, 15min A, 750D) | 83.96 | 819.73 | 11.92 |
| 42 | (15min, 1L, 15min A, 750D) | 83.23 | 822.29 | 12.02 |
| 43 | (5min, 2L, 15min A, 750D) | 83.73 | 822.72 | 11.95 |
| 44 | (10min, 2L, 15min A, 750D) | 83.03 | 824.53 | 12.07 |
| 45 | (15min, 2L, 15min A, 750D) | 82.17 | 832.55 | 12.23 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 46 | (5min, 0L, 20min A, 750D) | 83.3 | 821.77 | 12.01 |
| 47 | (10min, 0L, 20min A, 750D) | 83.73 | 817.93 | 11.96 |
| 48 | (15min, 0L, 20min A, 750D) | 82.21 | 821.74 | 12.18 |
| 49 | (5min, 1L, 20min A, 750D) | 84.6 | 817.86 | 11.83 |
| 50 | (10min, 1L, 20min A, 750D) | 82.48 | 821.49 | 12.25 |
| 51 | (15min, 1L, 20min A, 750D) | 83.29 | 821.26 | 11.98 |
| 52 | (5min, 2L, 20min A, 750D) | 84.28 | 818.56 | 11.88 |
| 53 | (10min, 2L, 20min A, 750D) | 83.72 | 686.34 | 10.01 |
| 54 | (15min, 2L, 20min A, 750D) | 81.59 | 832.01 | 12.28 |
| 55 | (5min, 0L, 10min A, 1000D) | 83.18 | 826.81 | 12.03 |
| 56 | (10min, 0L, 10min A, 1000D) | 83.26 | 819.88 | 11.98 |
| 57 | (15min, 0L, 10min A, 1000D) | 83.86 | 813.72 | 11.99 |
| 58 | (5min, 1L, 10min A, 1000D) | 84.26 | 820.49 | 11.88 |
| 59 | (10min, 1L, 10min A, 1000D) | 84.32 | 815.67 | 11.85 |
| 60 | (15min, 1L, 10min A, 1000D) | 83.71 | 823.38 | 11.99 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 61 | (5min, 2L, 10min A, 1000D) | 84.03 | 682.74 | 9.92 |
| 62 | (10min, 2L, 10min A, 1000D) | 83.21 | 820.48 | 12.06 |
| 63 | (15min, 2L, 10min A, 1000D) | 81.95 | 821.72 | 12.29 |
| 64 | (5min, 0L, 15min A, 1000D) | 83.12 | 829.26 | 12.07 |
| 65 | (10min, 0L, 15min A, 1000D) | 82.78 | 820.99 | 12.11 |
| 66 | (15min, 0L, 15min A, 1000D) | 82.75 | 818.43 | 12.12 |
| 67 | (5min, 1L, 15min A, 1000D) | 82.42 | 827.11 | 12.21 |
| 68 | (10min, 1L, 15min A, 1000D) | 83.96 | 819.73 | 11.92 |
| 69 | (15min, 1L, 15min A, 1000D) | 83.23 | 822.29 | 12.02 |
| 70 | (5min, 2L, 15min A, 1000D) | 83.73 | 822.72 | 11.95 |
| 71 | (10min, 2L, 15min A, 1000D) | 83.03 | 824.53 | 12.07 |
| 72 | (15min, 2L, 15min A, 1000D) | 82.17 | 832.55 | 12.23 |
| 73 | (5min, 0L, 20min A, 1000D) | 83.3 | 821.77 | 12.01 |
| 74 | (10min, 0L, 20min A, 1000D) | 83.73 | 817.93 | 11.96 |
| 75 | (15min, 0L, 20min A, 1000D) | 82.21 | 821.74 | 12.18 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 76 | (5min, 1L, 20min A, 1000D) | 84.6 | 817.86 | 11.83 |
| 77 | (10min, 1L, 20min A, 1000D) | 82.48 | 821.49 | 12.25 |
| 78 | (15min, 1L, 20min A, 1000D) | 83.29 | 821.26 | 11.98 |
| 79 | (5min, 2L, 20min A, 1000D) | 84.28 | 818.56 | 11.88 |
| 80 | (10min, 2L, 20min A, 1000D) | 83.72 | 686.34 | 10.01 |
| 81 | (15min, 2L, 20min A, 1000D) | 81.59 | 832.01 | 12.28 |
| 82 | (5min, 0L, 10min A, 1250D) | 83.18 | 826.81 | 12.03 |
| 83 | (10min, 0L, 10min A, 1250D) | 83.26 | 819.88 | 11.98 |
| 84 | (15min, 0L, 10min A, 1250D) | 83.86 | 813.72 | 11.99 |
| 85 | (5min, 1L, 10min A, 1250D) | 84.26 | 820.49 | 11.88 |
| 86 | (10min, 1L, 10min A, 1250D) | 84.32 | 815.67 | 11.85 |
| 87 | (15min, 1L, 10min A, 1250D) | 83.71 | 823.38 | 11.99 |
| 88 | (5min, 2L, 10min A, 1250D) | 84.03 | 682.74 | 9.92 |
| 89 | (10min, 2L, 10min A, 1250D) | 83.21 | 820.48 | 12.06 |
| 90 | (15min, 2L, 10min A, 1250D) | 81.95 | 821.72 | 12.29 |
| 91 | (5min, 0L, 15min A, 1250D) | 83.12 | 829.26 | 12.07 |
| 92 | (10min, 0L, 15min A, 1250D) | 82.78 | 820.99 | 12.11 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 93 | (15min, 0L, 15min A, 1250D) | 82.75 | 818.43 | 12.12 |
| 94 | (5min, 1L, 15min A, 1250D) | 82.42 | 827.11 | 12.21 |
| 95 | (10min, 1L, 15min A, 1250D) | 83.96 | 819.73 | 11.92 |
| 96 | (15min, 1L, 15min A, 1250D) | 83.23 | 822.29 | 12.02 |
| 97 | (5min, 2L, 15min A, 1250D) | 83.73 | 822.72 | 11.95 |
| 98 | (10min, 2L, 15min A, 1250D) | 83.03 | 824.53 | 12.07 |
| 99 | (15min, 2L, 15min A, 1250D) | 82.17 | 832.55 | 12.23 |
| 100 | (5min, 0L, 20min A, 1250D) | 83.3 | 821.77 | 12.01 |
| 101 | (10min, 0L, 20min A, 1250D) | 83.73 | 817.93 | 11.96 |
| 102 | (15min, 0L, 20min A, 1250D) | 82.21 | 821.74 | 12.18 |
| 103 | (5min, 1L, 20min A, 1250D) | 84.6 | 817.86 | 11.83 |
| 104 | (10min, 1L, 20min A, 1250D) | 82.48 | 821.49 | 12.25 |
| 105 | (15min, 1L, 20min A, 1250D) | 83.29 | 821.26 | 11.98 |
| 106 | (5min, 2L, 20min A, 1250D) | 84.28 | 818.56 | 11.88 |
| 107 | (10min, 2L, 20min A, 1250D) | 83.72 | 686.34 | 10.01 |
| 108 | (15min, 2L, 20min A, 1250D) | 81.59 | 832.01 | 12.28 |
| 109 | (5min, 0L, 10min A, 1500D) | 83.18 | 826.81 | 12.03 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 110 | (10min, 0L, 10min A, 1500D) | 83.26 | 819.88 | 11.98 |
| 111 | (15min, 0L, 10min A, 1500D) | 83.86 | 813.72 | 11.99 |
| 112 | (5min, 1L, 10min A, 1500D) | 84.26 | 820.49 | 11.88 |
| 113 | (10min, 1L, 10min A, 1500D) | 84.32 | 815.67 | 11.85 |
| 114 | (15min, 1L, 10min A, 1500D) | 83.71 | 823.38 | 11.99 |
| 115 | (5min, 2L, 10min A, 1500D) | 84.03 | 682.74 | 9.92 |
| 116 | (10min, 2L, 10min A, 1500D) | 83.21 | 820.48 | 12.06 |
| 117 | (15min, 2L, 10min A, 1500D) | 81.95 | 821.72 | 12.29 |
| 118 | (5min, 0L, 15min A, 1500D) | 83.12 | 829.26 | 12.07 |
| 119 | (10min, 0L, 15min A, 1500D) | 82.78 | 820.99 | 12.11 |
| 120 | (15min, 0L, 15min A, 1500D) | 82.75 | 818.43 | 12.12 |
| 121 | (5min, 1L, 15min A, 1500D) | 82.42 | 827.11 | 12.21 |
| 122 | (10min, 1L, 15min A, 1500D) | 83.96 | 819.73 | 11.92 |
| 123 | (15min, 1L, 15min A, 1500D) | 83.23 | 822.29 | 12.02 |
| 124 | (5min, 2L, 15min A, 1500D) | 83.73 | 822.72 | 11.95 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 125 | (10min, 2L, 15min A, 1500D) | 83.03 | 824.53 | 12.07 |
| 126 | (15min, 2L, 15min A, 1500D) | 82.17 | 832.55 | 12.23 |
| 127 | (5min, 0L, 20min A, 1500D) | 83.3 | 821.77 | 12.01 |
| 128 | (10min, 0L, 20min A, 1500D) | 83.73 | 817.93 | 11.96 |
| 129 | (15min, 0L, 20min A, 1500D) | 82.21 | 821.74 | 12.18 |
| 130 | (5min, 1L, 20min A, 1500D) | 84.6 | 817.86 | 11.83 |
| 131 | (10min, 1L, 20min A, 1500D) | 82.48 | 821.49 | 12.25 |
| 132 | (15min, 1L, 20min A, 1500D) | 83.29 | 821.26 | 11.98 |
| 133 | (5min, 2L, 20min A, 1500D) | 84.28 | 818.56 | 11.88 |
| 134 | (10min, 2L, 20min A, 1500D) | 83.72 | 686.34 | 10.01 |
| 135 | (15min, 2L, 20min A, 1500D) | 81.59 | 832.01 | 12.28 |
| 136 | (5min, 0L, 10min A, 1750D) | 83.18 | 826.81 | 12.03 |
| 137 | (10min, 0L, 10min A, 1750D) | 83.26 | 819.88 | 11.98 |
| 138 | (15min, 0L, 10min A, 1750D) | 83.86 | 813.72 | 11.99 |
| 139 | (5min, 1L, 10min A, 1750D) | 84.26 | 820.49 | 11.88 |
| 140 | (10min, 1L, 10min A, 1750D) | 84.32 | 815.67 | 11.85 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 141 | (15min, 1L, 10min A, 1750D) | 83.71 | 823.38 | 11.99 |
| 142 | (5min, 2L, 10min A, 1750D) | 84.03 | 682.74 | 9.92 |
| 143 | (10min, 2L, 10min A, 1750D) | 83.21 | 820.48 | 12.06 |
| 144 | (15min, 2L, 10min A, 1750D) | 81.95 | 821.72 | 12.29 |
| 145 | (5min, 0L, 15min A, 1750D) | 83.12 | 829.26 | 12.07 |
| 146 | (10min, 0L, 15min A, 1750D) | 82.78 | 820.99 | 12.11 |
| 147 | (15min, 0L, 15min A, 1750D) | 82.75 | 818.43 | 12.12 |
| 148 | (5min, 1L, 15min A, 1750D) | 82.42 | 827.11 | 12.21 |
| 149 | (10min, 1L, 15min A, 1750D) | 83.96 | 819.73 | 11.92 |
| 150 | (15min, 1L, 15min A, 1750D) | 83.23 | 822.29 | 12.02 |
| 151 | (5min, 2L, 15min A, 1750D) | 83.73 | 822.72 | 11.95 |
| 152 | (10min, 2L, 15min A, 1750D) | 83.03 | 824.53 | 12.07 |
| 153 | (15min, 2L, 15min A, 1750D) | 82.17 | 832.55 | 12.23 |
| 154 | (5min, 0L, 20min A, 1750D) | 83.3 | 821.77 | 12.01 |
| 155 | (10min, 0L, 20min A, 1750D) | 83.73 | 817.93 | 11.96 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 156 | (15min, 0L, 20min A, 1750D) | 82.21 | 821.74 | 12.18 |
| 157 | (5min, 1L, 20min A, 1750D) | 84.6 | 817.86 | 11.83 |
| 158 | (10min, 1L, 20min A, 1750D) | 82.48 | 821.49 | 12.25 |
| 159 | (15min, 1L, 20min A, 1750D) | 83.29 | 821.26 | 11.98 |
| 160 | (5min, 2L, 20min A, 1750D) | 84.28 | 818.56 | 11.88 |
| 161 | (10min, 2L, 20min A, 1750D) | 83.72 | 686.34 | 10.01 |
| 162 | (15min, 2L, 20min A, 1750D) | 81.59 | 832.01 | 12.28 |
| 163 | (5min, 0L, 10min A, 2000D) | 83.18 | 826.81 | 12.03 |
| 164 | (10min, 0L, 10min A, 2000D) | 83.26 | 819.88 | 11.98 |
| 165 | (15min, 0L, 10min A, 2000D) | 83.86 | 813.72 | 11.99 |
| 166 | (5min, 1L, 10min A, 2000D) | 84.26 | 820.49 | 11.88 |
| 167 | (10min, 1L, 10min A, 2000D) | 84.32 | 815.67 | 11.85 |
| 168 | (15min, 1L, 10min A, 2000D) | 83.71 | 823.38 | 11.99 |
| 169 | (5min, 2L, 10min A, 2000D) | 84.03 | 682.74 | 9.92 |
| 170 | (10min, 2L, 10min A, 2000D) | 83.21 | 820.48 | 12.06 |
| 171 | (15min, 2L, 10min A, 2000D) | 81.95 | 821.72 | 12.29 |

Table B.1. Networkwide measures of effectiveness of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Network)** | **Mean Flow (veh/hr/ ln) (Network)** | **Mean Density (veh/km/ln) (Network)** |
|---|---|---|---|---|
| 172 | (5min, 0L, 15min A, 2000D) | 83.12 | 829.26 | 12.07 |
| 173 | (10min, 0L, 15min A, 2000D) | 82.78 | 820.99 | 12.11 |
| 174 | (15min, 0L, 15min A, 2000D) | 82.75 | 818.43 | 12.12 |
| 175 | (5min, 1L, 15min A, 2000D) | 82.42 | 827.11 | 12.21 |
| 176 | (10min, 1L, 15min A, 2000D) | 83.96 | 819.73 | 11.92 |
| 177 | (15min, 1L, 15min A, 2000D) | 83.23 | 822.29 | 12.02 |
| 178 | (5min, 2L, 15min A, 2000D) | 83.73 | 822.72 | 11.95 |
| 179 | (10min, 2L, 15min A, 2000D) | 83.03 | 824.53 | 12.07 |
| 180 | (15min, 2L, 15min A, 2000D) | 82.17 | 832.55 | 12.23 |
| 181 | (5min, 0L, 20min A, 2000D) | 83.3 | 821.77 | 12.01 |
| 182 | (10min, 0L, 20min A, 2000D) | 83.73 | 817.93 | 11.96 |
| 183 | (15min, 0L, 20min A, 2000D) | 82.21 | 821.74 | 12.18 |
| 184 | (5min, 1L, 20min A, 2000D) | 84.6 | 817.86 | 11.83 |
| 185 | (10min, 1L, 20min A, 2000D) | 82.48 | 821.49 | 12.25 |
| 186 | (15min, 1L, 20min A, 2000D) | 83.29 | 821.26 | 11.98 |
| 187 | (5min, 2L, 20min A, 2000D) | 84.28 | 818.56 | 11.88 |
| 188 | (10min, 2L, 20min A, 2000D) | 83.72 | 686.34 | 10.01 |
| 189 | (15min, 2L, 20min A, 2000D) | 81.59 | 832.01 | 12.28 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles.

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 82.08 | 827.03 | 12.32 |
| 2 | (10min, 0L, 10min A, 500D) | 77.94 | 827.23 | 13.1 |
| 3 | (15min, 0L, 10min A, 500D) | 74.38 | 828.93 | 14.01 |
| 4 | (5min, 1L, 10min A, 500D) | 85.12 | 821.05 | 11.91 |
| 5 | (10min, 1L, 10min A, 500D) | 81.85 | 821.1 | 12.55 |
| 6 | (15min, 1L, 10min A, 500D) | 80.56 | 833.8 | 12.72 |
| 7 | (5min, 2L, 10min A, 500D) | 86.32 | 681.12 | 9.68 |
| 8 | (10min, 2L, 10min A, 500D) | 76.31 | 830.04 | 13.48 |
| 9 | (15min, 2L, 10min A, 500D) | 67.78 | 848.74 | 15.58 |
| 10 | (5min, 0L, 15min A, 500D) | 81.65 | 834.27 | 12.46 |
| 11 | (10min, 0L, 15min A, 500D) | 75.28 | 839.32 | 13.92 |
| 12 | (15min, 0L, 15min A, 500D) | 72.36 | 839.85 | 14.65 |
| 13 | (5min, 1L, 15min A, 500D) | 76.97 | 836.11 | 13.54 |
| 14 | (10min, 1L, 15min A, 500D) | 81.58 | 822.88 | 12.48 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 15 | (15min, 1L, 15min A, 500D) | 77.68 | 836.97 | 13.37 |
| 16 | (5min, 2L, 15min A, 500D) | 84.62 | 823.15 | 12.02 |
| 17 | (10min, 2L, 15min A, 500D) | 77.26 | 837.37 | 13.36 |
| 18 | (15min, 2L, 15min A, 500D) | 75.53 | 850.56 | 13.81 |
| 19 | (5min, 0L, 20min A, 500D) | 80.63 | 829.17 | 12.65 |
| 20 | (10min, 0L, 20min A, 500D) | 78.49 | 819.86 | 13.13 |
| 21 | (15min, 0L, 20min A, 500D) | 70.68 | 839.66 | 14.76 |
| 28 | (5min, 1L, 20min A, 500D) | 84.04 | 823.69 | 12.01 |
| 29 | (10min, 1L, 20min A, 500D) | 81.32 | 820.38 | 12.47 |
| 30 | (15min, 1L, 20min A, 500D) | 79.01 | 818.75 | 13.16 |
| 31 | (5min, 2L, 20min A, 500D) | 86.47 | 816.46 | 11.67 |
| 32 | (10min, 2L, 20min A, 500D) | 84.25 | 815.55 | 12.12 |
| 33 | (15min, 2L, 20min A, 500D) | 83.19 | 825.98 | 12.25 |
| 34 | (5min, 0L, 10min A, 750D) | 87.18 | 677.96 | 9.57 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 35 | (10min, 0L, 10min A, 750D) | 80.2 | 822.31 | 12.84 |
| 36 | (15min, 0L, 10min A, 750D) | 73.71 | 834.75 | 14.28 |
| 37 | (5min, 1L, 10min A, 750D) | 83.67 | 829.25 | 12.19 |
| 38 | (10min, 1L, 10min A, 750D) | 79.36 | 828.64 | 13.06 |
| 39 | (15min, 1L, 10min A, 750D) | 77.33 | 828.32 | 13.51 |
| 40 | (5min, 2L, 10min A, 750D) | 80.44 | 828.83 | 12.81 |
| 41 | (10min, 2L, 10min A, 750D) | 83.91 | 817.91 | 12.09 |
| 42 | (15min, 2L, 10min A, 750D) | 81.12 | 828.8 | 12.68 |
| 43 | (5min, 0L, 15min A, 750D) | 86 | 818.84 | 11.83 |
| 44 | (10min, 0L, 15min A, 750D) | 80.79 | 828.51 | 12.72 |
| 45 | (15min, 0L, 15min A, 750D) | 79.17 | 841.44 | 13.01 |
| 46 | (5min, 1L, 15min A, 750D) | 83.09 | 822.88 | 12.25 |
| 47 | (10min, 1L, 15min A, 750D) | 81.87 | 813.75 | 12.52 |
| 48 | (15min, 1L, 15min A, 750D) | 75.79 | 829.1 | 13.73 |
| 49 | (5min, 2L, 15min A, 750D) | 86.75 | 817.03 | 11.63 |
| 50 | (10min, 2L, 15min A, 750D) | 74.51 | 836.59 | 14.11 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 51 | (15min, 2L, 15min A, 750D) | 81.17 | 824.7 | 12.47 |
| 52 | (5min, 0L, 20min A, 750D) | 85.33 | 819.46 | 11.97 |
| 53 | (10min, 0L, 20min A, 750D) | 85.45 | 683.78 | 9.9 |
| 54 | (15min, 0L, 20min A, 750D) | 79.24 | 837.19 | 12.93 |
| 55 | (5min, 1L, 20min A, 750D) | 85.23 | 820.42 | 11.94 |
| 56 | (10min, 1L, 20min A, 750D) | 83.27 | 814.61 | 12.16 |
| 57 | (15min, 1L, 20min A, 750D) | 81.7 | 811.62 | 12.54 |
| 58 | (5min, 2L, 20min A, 750D) | 87.23 | 814.26 | 11.55 |
| 59 | (10min, 2L, 20min A, 750D) | 85.62 | 811.26 | 11.91 |
| 60 | (15min, 2L, 20min A, 750D) | 84.63 | 821.37 | 12.01 |
| 61 | (5min, 0L, 10min A, 1000D) | 87.72 | 675.95 | 9.57 |
| 62 | (10min, 0L, 10min A, 1000D) | 82.35 | 817.42 | 12.4 |
| 63 | (15min, 0L, 10min A, 1000D) | 77.23 | 825.79 | 13.43 |
| 64 | (5min, 1L, 10min A, 1000D) | 84.91 | 825.59 | 12 |
| 65 | (10min, 1L, 10min A, 1000D) | 81.71 | 821.2 | 12.54 |
| 66 | (15min, 1L, 10min A, 1000D) | 80.24 | 819.61 | 12.92 |
| 67 | (5min, 2L, 10min A, 1000D) | 82.35 | 823.36 | 12.43 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 68 | (10min, 2L, 10min A, 1000D) | 85.22 | 814.42 | 11.86 |
| 69 | (15min, 2L, 10min A, 1000D) | 83.1 | 823.17 | 12.33 |
| 70 | (5min, 0L, 15min A, 1000D) | 86.9 | 814.03 | 11.73 |
| 71 | (10min, 0L, 15min A, 1000D) | 82.79 | 822.4 | 12.36 |
| 72 | (15min, 0L, 15min A, 1000D) | 81.27 | 834.77 | 12.56 |
| 73 | (5min, 1L, 15min A, 1000D) | 84.54 | 818.68 | 11.99 |
| 74 | (10min, 1L, 15min A, 1000D) | 83.77 | 809.52 | 12.17 |
| 75 | (15min, 1L, 15min A, 1000D) | 78.69 | 823.2 | 13.06 |
| 76 | (5min, 2L, 15min A, 1000D) | 87.48 | 813.75 | 11.52 |
| 77 | (10min, 2L, 15min A, 1000D) | 77.88 | 827.52 | 13.43 |
| 78 | (15min, 2L, 15min A, 1000D) | 83.03 | 819.31 | 12.13 |
| 79 | (5min, 0L, 20min A, 1000D) | 86.4 | 815.38 | 11.73 |
| 80 | (10min, 0L, 20min A, 1000D) | 86.38 | 680.17 | 9.69 |
| 81 | (15min, 0L, 20min A, 1000D) | 81.19 | 831.85 | 12.57 |
| 82 | (5min, 1L, 20min A, 1000D) | 86.11 | 817.71 | 11.7 |
| 83 | (10min, 1L, 20min A, 1000D) | 84.62 | 810.45 | 11.94 |
| 84 | (15min, 0L, 10min A, 1250D) | 83.54 | 806.34 | 12.24 |
| 85 | (5min, 1L, 10min A, 1250D) | 87.88 | 811.04 | 11.51 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 86 | (10min, 1L, 10min A, 1250D) | 86.6 | 808 | 11.72 |
| 87 | (15min, 1L, 10min A, 1250D) | 85.71 | 817.2 | 11.85 |
| 88 | (5min, 2L, 10min A, 1250D) | 88.18 | 673.64 | 9.48 |
| 89 | (10min, 2L, 10min A, 1250D) | 83.84 | 813.18 | 12.12 |
| 90 | (15min, 2L, 10min A, 1250D) | 79.63 | 819.51 | 12.98 |
| 91 | (5min, 0L, 15min A, 1250D) | 85.82 | 822.02 | 11.8 |
| 92 | (10min, 0L, 15min A, 1250D) | 83.4 | 815.37 | 12.21 |
| 93 | (15min, 0L, 15min A, 1250D) | 82.22 | 813.12 | 12.52 |
| 94 | (5min, 1L, 15min A, 1250D) | 83.71 | 818.68 | 12.25 |
| 95 | (10min, 1L, 15min A, 1250D) | 86.21 | 810.92 | 11.72 |
| 96 | (15min, 1L, 15min A, 1250D) | 84.42 | 819.27 | 12.09 |
| 97 | (5min, 2L, 15min A, 1250D) | 87.61 | 810.33 | 11.54 |
| 98 | (10min, 2L, 15min A, 1250D) | 84.17 | 817.85 | 12.1 |
| 99 | (15min, 2L, 15min A, 1250D) | 82.73 | 828.82 | 12.35 |
| 100 | (5min, 0L, 20min A, 1250D) | 85.62 | 814.34 | 11.8 |
| 101 | (10min, 0L, 20min A, 1250D) | 85.12 | 806.33 | 11.97 |
| 102 | (15min, 0L, 20min A, 1250D) | 80.73 | 818.35 | 12.65 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 103 | (5min, 1L, 20min A, 1250D) | 88.1 | 809.79 | 11.44 |
| 104 | (10min, 1L, 20min A, 1250D) | 80.19 | 821.1 | 12.95 |
| 105 | (15min, 1L, 20min A, 1250D) | 84.27 | 814.64 | 11.95 |
| 106 | (5min, 2L, 20min A, 1250D) | 87.21 | 811.39 | 11.61 |
| 107 | (10min, 2L, 20min A, 1250D) | 87.14 | 676.65 | 9.65 |
| 108 | (15min, 2L, 20min A, 1250D) | 82.55 | 827.38 | 12.26 |
| 109 | (5min, 0L, 10min A, 1500D) | 86.9 | 813.5 | 11.58 |
| 110 | (10min, 0L, 10min A, 1500D) | 85.73 | 805.25 | 11.76 |
| 111 | (15min, 0L, 10min A, 1500D) | 84.95 | 801.66 | 12.02 |
| 112 | (5min, 1L, 10min A, 1500D) | 88.52 | 806.91 | 11.41 |
| 113 | (10min, 1L, 10min A, 1500D) | 87.43 | 804.11 | 11.58 |
| 114 | (15min, 1L, 10min A, 1500D) | 86.65 | 811.97 | 11.68 |
| 115 | (5min, 2L, 10min A, 1500D) | 88.68 | 671.18 | 9.42 |
| 116 | (10min, 2L, 10min A, 1500D) | 85.05 | 808.23 | 11.93 |
| 117 | (15min, 2L, 10min A, 1500D) | 81.48 | 812.89 | 12.64 |
| 118 | (5min, 0L, 15min A, 1500D) | 86.61 | 817.66 | 11.71 |
| 119 | (10min, 0L, 15min A, 1500D) | 84.71 | 809.37 | 12.01 |
| 120 | (15min, 0L, 15min A, 1500D) | 83.78 | 806.97 | 12.23 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 121 | (5min, 1L, 15min A, 1500D) | 84.82 | 813.78 | 11.98 |
| 122 | (10min, 1L, 15min A, 1500D) | 87.06 | 806.81 | 11.57 |
| 123 | (15min, 1L, 15min A, 1500D) | 85.47 | 814.31 | 11.9 |
| 124 | (5min, 2L, 15min A, 1500D) | 88.28 | 805.75 | 11.43 |
| 125 | (10min, 2L, 15min A, 1500D) | 85.3 | 812.79 | 11.89 |
| 126 | (15min, 2L, 15min A, 1500D) | 83.92 | 823.16 | 12.11 |
| 127 | (5min, 0L, 20min A, 1500D) | 86.5 | 809.94 | 11.69 |
| 128 | (10min, 0L, 20min A, 1500D) | 86.18 | 802.49 | 11.76 |
| 129 | (15min, 0L, 20min A, 1500D) | 82.32 | 813.07 | 12.39 |
| 130 | (5min, 1L, 20min A, 1500D) | 88.73 | 805.41 | 11.31 |
| 131 | (10min, 1L, 20min A, 1500D) | 82.01 | 814.19 | 12.58 |
| 132 | (15min, 1L, 20min A, 1500D) | 85.32 | 809.05 | 11.75 |
| 133 | (5min, 2L, 20min A, 1500D) | 88 | 806.59 | 11.49 |
| 134 | (10min, 2L, 20min A, 1500D) | 87.9 | 671.74 | 9.54 |
| 135 | (15min, 2L, 20min A, 1500D) | 83.64 | 821.7 | 12.11 |
| 136 | (5min, 0L, 10min A, 1750D) | 87.68 | 808.72 | 11.54 |
| 137 | (10min, 0L, 10min A, 1750D) | 86.77 | 799.77 | 11.58 |
| 138 | (15min, 0L, 10min A, 1750D) | 86.2 | 796.16 | 11.8 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 139 | (5min, 1L, 10min A, 1750D) | 89.21 | 802.36 | 11.32 |
| 140 | (10min, 1L, 10min A, 1750D) | 88.25 | 799.57 | 11.46 |
| 141 | (15min, 1L, 10min A, 1750D) | 87.57 | 806.55 | 11.55 |
| 142 | (5min, 2L, 10min A, 1750D) | 89.31 | 667.48 | 9.37 |
| 143 | (10min, 2L, 10min A, 1750D) | 86.2 | 802.56 | 11.77 |
| 144 | (15min, 2L, 10min A, 1750D) | 83.03 | 807.01 | 12.33 |
| 145 | (5min, 0L, 15min A, 1750D) | 87.44 | 812.24 | 11.59 |
| 146 | (10min, 0L, 15min A, 1750D) | 85.88 | 803.43 | 11.84 |
| 147 | (15min, 0L, 15min A, 1750D) | 85.13 | 801.03 | 11.99 |
| 148 | (5min, 1L, 15min A, 1750D) | 85.86 | 808.45 | 11.85 |
| 149 | (10min, 1L, 15min A, 1750D) | 87.9 | 802.17 | 11.47 |
| 150 | (15min, 1L, 15min A, 1750D) | 86.47 | 808.93 | 11.76 |
| 151 | (5min, 2L, 15min A, 1750D) | 88.99 | 800.59 | 11.34 |
| 152 | (10min, 2L, 15min A, 1750D) | 86.36 | 807.55 | 11.76 |
| 153 | (15min, 2L, 15min A, 1750D) | 85.04 | 816.77 | 11.94 |
| 154 | (5min, 0L, 20min A, 1750D) | 87.38 | 805.11 | 11.58 |
| 155 | (10min, 0L, 20min A, 1750D) | 87.16 | 798.25 | 11.62 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 156 | (15min, 0L, 20min A, 1750D) | 83.71 | 807.51 | 12.16 |
| 157 | (5min, 1L, 20min A, 1750D) | 89.44 | 800.26 | 11.23 |
| 158 | (10min, 1L, 20min A, 1750D) | 83.58 | 807.36 | 12.33 |
| 159 | (15min, 1L, 20min A, 1750D) | 86.34 | 802.97 | 11.63 |
| 160 | (5min, 2L, 20min A, 1750D) | 88.83 | 801.06 | 11.35 |
| 161 | (10min, 2L, 20min A, 1750D) | 88.69 | 667.32 | 9.44 |
| 162 | (15min, 2L, 20min A, 1750D) | 84.69 | 816.04 | 11.94 |
| 163 | (5min, 0L, 10min A, 2000D) | 88.61 | 801.75 | 11.4 |
| 164 | (10min, 0L, 10min A, 2000D) | 87.84 | 792.54 | 11.46 |
| 165 | (15min, 0L, 10min A, 2000D) | 87.42 | 789.27 | 11.64 |
| 166 | (5min, 1L, 10min A, 2000D) | 90.04 | 795.81 | 11.21 |
| 167 | (10min, 1L, 10min A, 2000D) | 89.2 | 793.02 | 11.34 |
| 168 | (15min, 1L, 10min A, 2000D) | 88.56 | 799.19 | 11.43 |
| 169 | (5min, 2L, 10m in A, 2000D) | 90.13 | 661.95 | 9.28 |
| 170 | (10min, 2L, 10min A, 2000D) | 87.37 | 794.98 | 11.59 |
| 171 | (15min, 2L, 10min A, 2000D) | 84.48 | 799.69 | 12.13 |
| 172 | (5min, 0L, 15min A, 2000D) | 88.39 | 804.88 | 11.46 |
| 173 | (10min, 0L, 15min A, 2000D) | 87.08 | 795.89 | 11.64 |

Table B.2. Measures of effectiveness in the local area before the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (Before the Incident)** | **Mean Flow (veh/hr/ln) (Before the Incident)** | **Mean Density (veh/km/ln) (Before the Incident)** |
|---|---|---|---|---|
| 174 | (15min, 0L, 15min A, 2000D) | 86.43 | 793.77 | 11.82 |
| 175 | (5min, 1L, 15min A, 2000D) | 86.96 | 801.18 | 11.67 |
| 176 | (10min, 1L, 15min A, 2000D) | 88.85 | 795.5 | 11.34 |
| 177 | (15min, 1L, 15min A, 2000D) | 87.55 | 801.58 | 11.61 |
| 178 | (5min, 2L, 15min A, 2000D) | 89.82 | 793.97 | 11.24 |
| 179 | (10min, 2L, 15min A, 2000D) | 87.45 | 800.53 | 11.59 |
| 180 | (15min, 2L, 15min A, 2000D) | 86.22 | 808.79 | 11.77 |
| 181 | (5min, 0L, 20min A, 2000D) | 88.37 | 798.18 | 11.42 |
| 182 | (10min, 0L, 20min A, 2000D) | 88.22 | 791.9 | 11.49 |
| 183 | (15min, 0L, 20min A, 2000D) | 85.07 | 799.99 | 11.93 |
| 184 | (5min, 1L, 20min A, 2000D) | 90.29 | 793.46 | 11.12 |
| 185 | (10min, 1L, 20min A, 2000D) | 85.06 | 799.15 | 12.09 |
| 186 | (15min, 1L, 20min A, 2000D) | 87.45 | 795.34 | 11.43 |
| 187 | (5min, 2L, 20min A, 2000D) | 89.77 | 793.83 | 11.22 |
| 188 | (10min, 2L, 20min A, 2000D) | 89.58 | 661.5 | 9.36 |
| 189 | (15min, 2L, 20min A, 2000D) | 85.82 | 808.46 | 11.78 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles.

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 86.26 | 828.39 | 11.9 |
| 2 | (10min, 0L, 10min A, 500D) | 86.36 | 811.73 | 11.95 |
| 3 | (15min, 0L, 10min A, 500D) | 87.1 | 811.15 | 12.13 |
| 4 | (5min, 1L, 10min A, 500D) | 87.97 | 814.52 | 11.69 |
| 5 | (10min, 1L, 10min A, 500D) | 87.75 | 806.71 | 11.7 |
| 6 | (15min, 1L, 10min A, 500D) | 86.2 | 824.24 | 12.26 |
| 7 | (5min, 2L, 10min A, 500D) | 86.79 | 685.54 | 9.69 |
| 8 | (10min, 2L, 10min A, 500D) | 86.48 | 814.81 | 11.94 |
| 9 | (15min, 2L, 10min A, 500D) | 84.86 | 823.34 | 12.47 |
| 10 | (5min, 0L, 15min A, 500D) | 86.22 | 832.88 | 11.86 |
| 11 | (10min, 0L, 15min A, 500D) | 86.15 | 818.17 | 12.03 |
| 12 | (15min, 0L, 15min A, 500D) | 85.62 | 818.73 | 12.12 |
| 13 | (5min, 1L, 15min A, 500D) | 85.8 | 824.28 | 11.78 |
| 14 | (10min, 1L, 15min A, 500D) | 86.91 | 810.85 | 11.7 |
| 15 | (15min, 1L, 15min A, 500D) | 86.09 | 815.54 | 12.18 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 16 | (5min, 2L, 15min A, 500D) | 87.05 | 816.12 | 11.61 |
| 17 | (10min, 2L, 15min A, 500D) | 85.31 | 825.58 | 12.07 |
| 18 | (15min, 2L, 15min A, 500D) | 84.89 | 830.68 | 12.31 |
| 19 | (5min, 0L, 20min A, 500D) | 86.08 | 824.38 | 11.77 |
| 20 | (10min, 0L, 20min A, 500D) | 87.6 | 810.03 | 11.69 |
| 21 | (15min, 0L, 20min A, 500D) | 85.68 | 816.52 | 12.31 |
| 22 | (5min, 1L, 20min A, 500D) | 88.13 | 811.54 | 11.67 |
| 23 | (10min, 1L, 20min A, 500D) | 86.31 | 818.21 | 11.81 |
| 24 | (15min, 1L, 20min A, 500D) | 85.86 | 819.69 | 12.24 |
| 25 | (5min, 2L, 20min A, 500D) | 87.67 | 813.7 | 11.58 |
| 26 | (10min, 2L, 20min A, 500D) | 86.14 | 686.26 | 9.98 |
| 27 | (15min, 2L, 20min A, 500D) | 83.71 | 836.58 | 12.47 |
| 28 | (5min, 0L, 10min A, 750D) | 76.65 | 859.62 | 13.2 |
| 29 | (10min, 0L, 10min A, 750D) | 76.99 | 845.2 | 13.09 |
| 30 | (15min, 0L, 10min A, 750D) | 77.97 | 840.77 | 13.15 |
| 31 | (5min, 1L, 10min A, 750D) | 78.09 | 846.11 | 12.95 |
| 32 | (10min, 1L, 10min A, 750D) | 78.45 | 836.79 | 12.81 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 33 | (15min, 1L, 10min A, 750D) | 77.47 | 853.19 | 13.2 |
| 34 | (5min, 2L, 10min A, 750D) | 76.8 | 711.86 | 10.84 |
| 35 | (10min, 2L, 10min A, 750D) | 76.91 | 848.32 | 13.2 |
| 36 | (15min, 2L, 10min A, 750D) | 75.87 | 853.75 | 13.67 |
| 37 | (5min, 0L, 15min A, 750D) | 76.41 | 862.93 | 13.2 |
| 38 | (10min, 0L, 15min A, 750D) | 76.44 | 851.95 | 13.33 |
| 39 | (15min, 0L, 15min A, 750D) | 76.4 | 851.71 | 13.38 |
| 40 | (5min, 1L, 15 min A, 750D) | 76.25 | 855.09 | 13.21 |
| 41 | (10min, 1L, 15min A, 750D) | 77.79 | 841.1 | 12.85 |
| 42 | (15min, 1L, 15min A, 750D) | 77.03 | 846.01 | 13.22 |
| 43 | (5min, 2L, 15min A, 750D) | 76.89 | 849.56 | 13.02 |
| 44 | (10min, 2L, 15min A, 750D) | 76.42 | 853.75 | 13.24 |
| 45 | (15min, 2L, 15min A, 750D) | 75.56 | 861.45 | 13.55 |
| 46 | (5min, 0L, 20min A, 750D) | 76.38 | 854.49 | 13.13 |
| 47 | (10min, 0L, 20min A, 750D) | 77.84 | 842.24 | 12.92 |
| 48 | (15min, 0L, 20min A, 750D) | 76.69 | 847.82 | 13.35 |
| 49 | (5min, 1L, 20min A, 750D) | 78.34 | 842.62 | 12.86 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 50 | (10min, 1L, 20min A, 750D) | 77.03 | 848.14 | 13.13 |
| 51 | (15min, 1L, 20min A, 750D) | 77.18 | 848.75 | 13.23 |
| 52 | (5min, 2L, 20min A, 750D) | 78.08 | 843.56 | 12.81 |
| 53 | (10min, 2L, 20min A, 750D) | 76.52 | 713.08 | 11.05 |
| 54 | (15min, 2L, 20min A, 750D) | 74.74 | 865.58 | 13.69 |
| 55 | (5min, 0L, 10min A, 1000D) | 75.12 | 866.15 | 13.45 |
| 56 | (10min, 0L, 10min A, 1000D) | 75.42 | 855.6 | 13.34 |
| 57 | (15min, 0L, 10min A, 1000D) | 76.21 | 851.12 | 13.4 |
| 58 | (5min, 1L, 10min A, 1000D) | 76.23 | 855.27 | 13.24 |
| 59 | (10min, 1L, 10min A, 1000D) | 76.55 | 847.21 | 13.12 |
| 60 | (15min, 1L, 10min A, 1000D) | 75.8 | 861.37 | 13.41 |
| 61 | (5min, 2L, 10min A, 1000D) | 75.34 | 717.99 | 11.11 |
| 62 | (10min, 2L, 10min A, 1000D) | 75.4 | 856.75 | 13.43 |
| 63 | (15min, 2L, 10min A, 1000D) | 74.59 | 860.94 | 13.78 |
| 64 | (5min, 0L, 15min A, 1000D) | 74.97 | 868.9 | 13.47 |
| 65 | (10min, 0L, 15min A, 1000D) | 74.97 | 861.24 | 13.56 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 66 | (15min, 0L, 15min A, 1000D) | 74.98 | 860.75 | 13.62 |
| 67 | (5min, 1L, 15min A, 1000D) | 74.83 | 864.39 | 13.51 |
| 68 | (10min, 1L, 15min A, 1000D) | 76.03 | 851.62 | 13.18 |
| 69 | (15min, 1L, 15min A, 1000D) | 75.48 | 855.11 | 13.43 |
| 70 | (5min, 2L, 15min A, 1000D) | 75.28 | 859.78 | 13.33 |
| 71 | (10min, 2L, 15min A, 1000D) | 74.99 | 862.67 | 13.49 |
| 72 | (15min, 2L, 15min A, 1000D) | 74.29 | 869.63 | 13.76 |
| 73 | (5min, 0L, 20min A, 1000D) | 74.99 | 861.45 | 13.41 |
| 74 | (10min, 0L, 20min A, 1000D) | 76.08 | 852.87 | 13.22 |
| 75 | (15min, 0L, 20min A, 1000D) | 75.16 | 857.46 | 13.61 |
| 76 | (5min, 1L, 20min A, 1000D) | 76.45 | 851.72 | 13.15 |
| 77 | (10min, 1L, 20min A, 1000D) | 75.47 | 857.84 | 13.38 |
| 78 | (15min, 1L, 20min A, 1000D) | 75.63 | 857.74 | 13.44 |
| 79 | (5min, 2L, 20min A, 1000D) | 76.26 | 852.48 | 13.19 |
| 80 | (10min, 2L, 20min A, 1000D) | 75.1 | 719.65 | 11.22 |
| 81 | (15min, 2L, 20min A, 1000D) | 73.67 | 872.01 | 13.8 |
| 82 | (5min, 0L, 10min A, 1250D) | 78.15 | 848.12 | 12.93 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 83 | (10min, 0L, 10min A, 1250D) | 78.5 | 839.37 | 12.88 |
| 84 | (15min, 0L, 10min A, 1250D) | 79.37 | 833.28 | 12.83 |
| 85 | (5min, 1L, 10min A, 1250D) | 79.29 | 837.1 | 12.72 |
| 86 | (10min, 1L, 10min A, 1250D) | 79.62 | 829.37 | 12.61 |
| 87 | (15min, 1L, 10min A, 1250D) | 78.87 | 842.77 | 12.95 |
| 88 | (5min, 2L, 10min A, 1250D) | 78.5 | 701.61 | 10.7 |
| 89 | (10min, 2L, 10min A, 1250D) | 78.55 | 838.37 | 12.92 |
| 90 | (15min, 2L, 10min A, 1250D) | 77.91 | 841.96 | 13.15 |
| 91 | (5min, 0L, 15min A, 1250D) | 78.04 | 850.12 | 12.94 |
| 92 | (10min, 0L, 15min A, 1250D) | 78.11 | 843.66 | 13.01 |
| 93 | (15min, 0L, 15min A, 1250D) | 78.17 | 842.37 | 13.04 |
| 94 | (5min, 1L, 15min A, 1250D) | 77.95 | 846.92 | 12.96 |
| 95 | (10min, 1L, 15min A, 1250D) | 79.09 | 834.5 | 12.68 |
| 96 | (15min, 1L, 15min A, 1250D) | 78.63 | 837.05 | 12.86 |
| 97 | (5min, 2L, 15min A, 1250D) | 78.33 | 843.22 | 12.83 |
| 98 | (10min, 2L, 15min A, 1250D) | 78.17 | 844.27 | 12.94 |
| 99 | (15min, 2L, 15min A, 1250D) | 77.44 | 852.08 | 13.19 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 100 | (5min, 0L, 20min A, 1250D) | 78.15 | 842 | 12.88 |
| 101 | (10min, 0L, 20min A, 1250D) | 79.14 | 835.51 | 12.71 |
| 102 | (15min, 0L, 20min A, 1250D) | 78.26 | 839.5 | 13.07 |
| 103 | (5min, 1L, 20min A, 1250D) | 79.52 | 833.79 | 12.65 |
| 104 | (10min, 1L, 20min A, 1250D) | 78.67 | 839.59 | 12.85 |
| 105 | (15min, 1L, 20min A, 1250D) | 78.79 | 839.37 | 12.93 |
| 106 | (5min, 2L, 20min A, 1250D) | 79.32 | 834.71 | 12.68 |
| 107 | (10min, 2L, 20min A, 1250D) | 78.28 | 703.62 | 10.78 |
| 108 | (15min, 2L, 20min A, 1250D) | 76.82 | 853.15 | 13.24 |
| 109 | (5min, 0L, 10min A, 1500D) | 79.99 | 837.79 | 12.57 |
| 110 | (10min, 0L, 10min A, 1500D) | 80.43 | 830.28 | 12.54 |
| 111 | (15min, 0L, 10min A, 1500D) | 81.4 | 822.34 | 12.5 |
| 112 | (5min, 1L, 10min A, 1500D) | 81.16 | 827.32 | 12.41 |
| 113 | (10min, 1L, 10min A, 1500D) | 81.54 | 819.81 | 12.3 |
| 114 | (15min, 1L, 10min A, 1500D) | 80.75 | 832.47 | 12.55 |
| 115 | (5min, 2L, 10min A, 1500D) | 80.43 | 692.57 | 10.36 |
| 116 | (10min, 2L, 10min A, 1500D) | 80.51 | 828.58 | 12.55 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 117 | (15min, 2L, 10min A, 1500D) | 80 | 831.06 | 12.73 |
| 118 | (5min, 0L, 15min A, 1500D) | 79.91 | 839.8 | 12.6 |
| 119 | (10min, 0L, 15min A, 1500D) | 80.07 | 833.29 | 12.65 |
| 120 | (15min, 0L, 15min A, 1500D) | 80.17 | 831.06 | 12.6 |
| 121 | (5min, 1L, 15min A, 1500D) | 79.86 | 837.68 | 12.66 |
| 122 | (10min, 1L, 15min A, 1500D) | 81 | 825.58 | 12.37 |
| 123 | (15min, 1L, 15min A, 1500D) | 80.55 | 826.91 | 12.55 |
| 124 | (5min, 2L, 15min A, 1500D) | 80.2 | 834.35 | 12.5 |
| 125 | (10min, 2L, 15min A, 1500D) | 80.15 | 833.54 | 12.58 |
| 126 | (15min, 2L, 15min A, 1500D) | 79.39 | 842.55 | 12.85 |
| 127 | (5min, 0L, 20min A, 1500D) | 80.12 | 831.13 | 12.51 |
| 128 | (10min, 0L, 20min A, 1500D) | 81.06 | 825.89 | 12.43 |
| 129 | (15min, 0L, 20min A, 1500D) | 80.22 | 829.32 | 12.6 |
| 130 | (5min, 1L, 20min A, 1500D) | 81.42 | 824.38 | 12.33 |
| 131 | (10min, 1L, 20min A, 1500D) | 80.66 | 829.48 | 12.51 |
| 132 | (15min, 1L, 20min A, 1500D) | 80.72 | 829.41 | 12.58 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 133 | (5min, 2L, 20min A, 1500D) | 81.21 | 825.63 | 12.34 |
| 134 | (10min, 2L, 20min A, 1500D) | 80.23 | 695.7 | 10.51 |
| 135 | (15min, 2L, 20min A, 1500D) | 78.76 | 842.81 | 12.87 |
| 136 | (5min, 0L, 10min A, 1750D) | 81.24 | 832.25 | 12.37 |
| 137 | (10min, 0L, 10min A, 1750D) | 81.69 | 825.86 | 12.34 |
| 138 | (15min, 0L, 10min A, 1750D) | 82.78 | 816.27 | 12.27 |
| 139 | (5min, 1L, 10min A, 1750D) | 82.38 | 822.46 | 12.22 |
| 140 | (10min, 1L, 10min A, 1750D) | 82.81 | 815.63 | 12.09 |
| 141 | (15min, 1L, 10min A, 1750D) | 81.99 | 827.48 | 12.36 |
| 142 | (5min, 2L, 10min A, 1750D) | 81.69 | 688.11 | 10.24 |
| 143 | (10min, 2L, 10min A, 1750D) | 81.81 | 824.07 | 12.32 |
| 144 | (15min, 2L, 10min A, 1750D) | 81.44 | 825.22 | 12.54 |
| 145 | (5min, 0L, 15min A, 1750D) | 81.13 | 834.51 | 12.38 |
| 146 | (10min, 0L, 15min A, 1750D) | 81.37 | 827.68 | 12.45 |
| 147 | (15min, 0L, 15min A, 1750D) | 81.53 | 824.92 | 12.44 |
| 148 | (5min, 1L, 15min A, 1750D) | 81.11 | 833.28 | 12.46 |
| 149 | (10min, 1L, 15min A, 1750D) | 82.28 | 821.34 | 12.2 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 150 | (15min, 1L, 15min A, 1750D) | 81.82 | 822.13 | 12.31 |
| 151 | (5min, 2L, 15min A, 1750D) | 81.45 | 829.79 | 12.35 |
| 152 | (10min, 2L, 15min A, 1750D) | 81.46 | 827.78 | 12.38 |
| 153 | (15min, 2L, 15min A, 1750D) | 80.69 | 837.91 | 12.62 |
| 154 | (5min, 0L, 20min A, 1750D) | 81.43 | 825.65 | 12.33 |
| 155 | (10min, 0L, 20min A, 1750D) | 82.33 | 821.23 | 12.18 |
| 156 | (15min, 0L, 20min A, 1750D) | 81.55 | 823.88 | 12.41 |
| 157 | (5min, 1L, 20min A, 1750D) | 82.7 | 819.95 | 12.16 |
| 158 | (10min, 1L, 20min A, 1750D) | 81.99 | 824.55 | 12.31 |
| 159 | (15min, 1L, 20min A, 1750D) | 82 | 824.49 | 12.34 |
| 160 | (5min, 2L, 20min A, 1750D) | 82.48 | 821.13 | 12.19 |
| 161 | (10min, 2L, 20min A, 1750D) | 81.51 | 692.18 | 10.35 |
| 162 | (15min, 2L, 20min A, 1750D) | 80.03 | 837.45 | 12.63 |
| 163 | (5min, 0L, 10min A, 2000D) | 82.12 | 828.67 | 12.22 |
| 164 | (10min, 0L, 10min A, 2000D) | 82.6 | 822.24 | 12.18 |
| 165 | (15min, 0L, 10min A, 2000D) | 83.78 | 812.6 | 12.08 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 166 | (5min, 1L, 10min A, 2000D) | 83.24 | 819.69 | 12.09 |
| 167 | (10min, 1L, 10min A, 2000D) | 83.7 | 813.09 | 11.98 |
| 168 | (15min, 1L, 10min A, 2000D) | 82.86 | 824.33 | 12.24 |
| 169 | (5min, 2L, 10min A, 2000D) | 82.6 | 685.23 | 10.12 |
| 170 | (10min, 2L, 10min A, 2000D) | 82.77 | 820.62 | 12.19 |
| 171 | (15min, 2L, 10min A, 2000D) | 82.46 | 821.43 | 12.31 |
| 172 | (5min, 0L, 15min A, 2000D) | 82.01 | 830.91 | 12.26 |
| 173 | (10min, 0L, 15min A, 2000D) | 82.3 | 823.1 | 12.26 |
| 174 | (15min, 0L, 15min A, 2000D) | 82.51 | 820.31 | 12.22 |
| 175 | (5min, 1L, 15min A, 2000D) | 81.98 | 830.19 | 12.31 |
| 176 | (10min, 1L, 15min A, 2000D) | 83.19 | 818.64 | 12.07 |
| 177 | (15min, 1L, 15min A, 2000D) | 82.71 | 818.87 | 12.18 |
| 178 | (5min, 2L, 15min A, 2000D) | 82.32 | 826.31 | 12.19 |
| 179 | (10min, 2L, 15min A, 2000D) | 82.37 | 824.23 | 12.2 |
| 180 | (15min, 2L, 15min A, 2000D) | 81.62 | 834.98 | 12.44 |
| 181 | (5min, 0L, 20min A, 2000D) | 82.38 | 821.78 | 12.17 |
| 182 | (10min, 0L, 20min A, 2000D) | 83.21 | 818.84 | 12.1 |

Table B.3. Measures of effectiveness in the local area after the incident of the scenarios without the connected vehicles (cont.).

| **Scenario ID** | **Scenario Parameters** | **Mean Speed (km/hr) (After the Incident)** | **Mean Flow (veh/hr/ln) (After the Incident)** | **Mean Density (veh/km/ln) (After the Incident)** |
|---|---|---|---|---|
| 183 | (15min, 0L, 20min A, 2000D) | 82.48 | 820.22 | 12.24 |
| 184 | (5min, 1L, 20min A, 2000D) | 83.59 | 816.95 | 12.04 |
| 185 | (10min, 1L, 20min A, 2000D) | 82.95 | 820.95 | 12.17 |
| 186 | (15min, 1L, 20min A, 2000D) | 82.88 | 822.04 | 12.23 |
| 187 | (5min, 2L, 20min A, 2000D) | 83.37 | 818.24 | 12.05 |
| 188 | (10min, 2L, 20min A, 2000D) | 82.39 | 690.47 | 10.24 |
| 189 | (15min, 2L, 20min A, 2000D) | 80.9 | 834.34 | 12.48 |

# APPENDIX C: MEASURES OF EFFECTIVENESS FOR SCENARIOS WITH THE CONNECTED VEHICLES

Table C.1. Networkwide measures of effectiveness of the scenarios with the connected vehicles.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Network) | Mean Flow (veh/hr/ln) (Network) | Mean Density (veh/km/ln) (Network) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 84.09 | 680.4 | 9.89 |
| 2 | (10min, 0L, 10min A, 500D) | 83.22 | 683.4 | 10.04 |
| 3 | (15min, 0L, 10min A, 500D) | 83.63 | 676.21 | 10.01 |
| 4 | (5min, 1L, 10min A, 500D) | 84.98 | 678.86 | 9.83 |
| 5 | (10min, 1L, 10min A, 500D) | 84.48 | 677.83 | 9.85 |
| 6 | (15min, 1L, 10min A, 500D) | 83.93 | 684.9 | 9.95 |
| 7 | (5min, 2L, 10min A, 500D) | 83.78 | 685.06 | 9.95 |
| 8 | (10min, 2L, 10min A, 500D) | 84.16 | 681.66 | 9.92 |
| 9 | (15min, 2L, 10min A, 500D) | 84.21 | 683.26 | 9.94 |
| 10 | (5min, 0L, 15min A, 500D) | 83.8 | 684.94 | 9.99 |
| 11 | (10min, 0L, 15min A, 500D) | 83.63 | 680.53 | 9.98 |
| 12 | (15min, 0L, 15min A, 500D) | 83.44 | 677.58 | 10 |
| 13 | (5min, 1L, 15min A, 500D) | 83.78 | 686.16 | 10.03 |
| 14 | (10min, 1L, 15min A, 500D) | 85.1 | 675.36 | 9.79 |
| 15 | (15min, 1L, 15min A, 500D) | 83.9 | 686.12 | 9.98 |
| 16 | (5min, 2L, 15min A, 500D) | 83.99 | 682.97 | 9.94 |
| 17 | (10min, 2L, 15min A, 500D) | 84.3 | 682.91 | 9.9 |
| 18 | (15min, 2L, 15min A, 500D) | 82.9 | 690.91 | 10.1 |
| 19 | (5min, 0L, 20min A, 500D) | 84.37 | 681.96 | 9.9 |
| 20 | (10min, 0L, 20min A, 500D) | 84.1 | 677.36 | 9.91 |
| 21 | (15min, 0L, 20min A, 500D) | 83.52 | 680.24 | 9.99 |
| 22 | (5min, 1L, 20min A, 500D) | 84.52 | 678.21 | 9.91 |
| 23 | (10min, 1L, 20min A, 500D) | 84.52 | 680.24 | 9.99 |
| 24 | (15min, 1L, 20min A, 500D) | 83.77 | 681.42 | 9.94 |
| 25 | (5min, 2L, 20min A, 500D) | 85.19 | 678.02 | 9.81 |
| 26 | (10min, 2L, 20min A, 500D) | 83.39 | 688.05 | 10.05 |
| 27 | (15min, 2L, 20min A, 500D) | 82.56 | 687.34 | 10.07 |
| 28 | (5min, 0L, 10min A, 750D) | 83.74 | 685.16 | 10 |
| 29 | (10min, 0L, 10min A, 750D) | 83.72 | 682.79 | 10.01 |
| 30 | (15min, 0L, 10min A, 750D) | 83.22 | 681.59 | 10.02 |
| 31 | (5min, 1L, 10min A, 750D) | 83.83 | 686.08 | 10.02 |
| 32 | (10min, 1L, 10min A, 750D) | 83.98 | 681.85 | 9.92 |
| 33 | (15min, 1L, 10min A, 750D) | 84.24 | 682.19 | 9.92 |
| 34 | (5min, 2L, 10min A, 750D) | 84.46 | 681.3 | 9.87 |
| 35 | (10min, 2L, 10min A, 750D) | 84.05 | 683.17 | 9.92 |
| 36 | (15min, 2L, 10min A, 750D) | 83.72 | 683.82 | 9.99 |
| 37 | (5min, 0L, 15min A, 750D) | 84.5 | 680.45 | 9.86 |
| 38 | (10min, 0L, 15min A, 750D) | 84.39 | 679.03 | 9.89 |
| 39 | (15min, 0L, 15min A, 750D) | 82.91 | 682.36 | 10.14 |
| 40 | (5min, 1L, 15min A, 750D) | 84.21 | 685.25 | 9.93 |

Table C.1. Networkwide measures of effectiveness of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Network) | Mean Flow (veh/hr/ln) (Network) | Mean Density (veh/km/ln) (Network) |
|---|---|---|---|---|
| 41 | (10min, 1L, 15min A, 750D) | 84.35 | 683.1 | 9.89 |
| 42 | (15min, 1L, 15min A, 750D) | 83.42 | 691.3 | 10.04 |
| 43 | (5min, 2L, 15min A, 750D) | 84.72 | 681.18 | 9.86 |
| 44 | (10min, 2L, 15min A, 750D) | 84.29 | 683.79 | 9.92 |
| 45 | (15min, 2L, 15min A, 750D) | 84.64 | 677.03 | 9.84 |
| 46 | (5min, 0L, 20min A, 750D) | 83.55 | 684.48 | 9.98 |
| 47 | (10min, 0L, 20min A, 750D) | 84.7 | 676.59 | 9.85 |
| 48 | (15min, 0L, 20min A, 750D) | 83.12 | 683.48 | 10.02 |
| 49 | (5min, 1L, 20min A, 750D) | 83.6 | 689.25 | 10 |
| 50 | (10min, 1L, 20min A, 750D) | 82.65 | 688.09 | 10 |
| 51 | (15min, 1L, 20min A, 750D) | 83.99 | 680.11 | 9.96 |
| 52 | (5min, 2L, 20min A, 750D) | 84.54 | 680.58 | 9.87 |
| 53 | (10min, 2L, 20min A, 750D) | 83.83 | 682.77 | 9.95 |
| 54 | (15min, 2L, 20min A, 750D) | 83.2 | 683.07 | 9.96 |
| 55 | (5min, 0L, 10min A, 1000D) | 83.92 | 683.68 | 9.95 |
| 56 | (10min, 0L, 10min A, 1000D) | 84.13 | 683.08 | 9.94 |
| 57 | (15min, 0L, 10min A, 1000D) | 83.14 | 681.99 | 10.09 |
| 58 | (5min, 1L, 10min A, 1000D) | 84.52 | 684.15 | 9.89 |
| 59 | (10min, 1L, 10min A, 1000D) | 84.05 | 680.41 | 9.89 |
| 60 | (15min, 1L, 10min A, 1000D) | 84.26 | 682.5 | 9.9 |
| 61 | (5min, 2L, 10min A, 1000D) | 84.71 | 678.78 | 9.82 |
| 62 | (10min, 2L, 10min A, 1000D) | 83.52 | 687.89 | 9.98 |
| 63 | (15min, 2L, 10min A, 1000D) | 83.71 | 684.54 | 9.98 |
| 64 | (5min, 0L, 15min A, 1000D) | 83.83 | 683.87 | 9.99 |
| 65 | (10min, 0L, 15min A, 1000D) | 84.12 | 679.99 | 9.9 |
| 66 | (15min, 0L, 15min A, 1000D) | 83.4 | 677.55 | 10.02 |
| 67 | (5min, 1L, 15min A, 1000D) | 83.98 | 685.21 | 10 |
| 68 | (10min, 1L, 15min A, 1000D) | 84.72 | 675.19 | 9.84 |
| 69 | (15min, 1L, 15min A, 1000D) | 84.17 | 684.13 | 9.95 |
| 70 | (5min, 2L, 15min A, 1000D) | 83.84 | 684.16 | 9.96 |
| 71 | (10min, 2L, 15min A, 1000D) | 84.43 | 681.61 | 9.88 |
| 72 | (15min, 2L, 15min A, 1000D) | 83.32 | 689.42 | 10.05 |
| 73 | (5min, 0L, 20min A, 1000D) | 84.33 | 681.5 | 9.9 |
| 74 | (10min, 0L, 20min A, 1000D) | 84.31 | 677.02 | 9.88 |
| 75 | (15min, 0L, 20min A, 1000D) | 82.88 | 682.54 | 10.1 |
| 76 | (5min, 1L, 20min A, 1000D) | 84.96 | 680.71 | 9.85 |
| 77 | (10min, 1L, 20min A, 1000D) | 84.66 | 680.09 | 9.87 |
| 78 | (15min, 1L, 20min A, 1000D) | 83.77 | 681.24 | 9.95 |
| 79 | (5min, 2L, 20min A, 1000D) | 85.29 | 677.58 | 9.8 |
| 80 | (10min, 2L, 20min A, 1000D) | 83.79 | 685.66 | 9.99 |
| 81 | (15min, 2L, 20min A, 1000D) | 82.32 | 687.22 | 10.09 |
| 82 | (5min, 0L, 10min A, 1250D) | 84.19 | 680.92 | 9.88 |
| 83 | (10min, 0L, 10min A, 1250D) | 83.99 | 680.9 | 9.94 |
| 84 | (15min, 0L, 10min A, 1250D) | 83.74 | 676.81 | 10 |
| 85 | (5min, 1L, 10min A, 1250D) | 84.35 | 678.97 | 9.93 |
| 86 | (10min, 1L, 10min A, 1250D) | 83.96 | 677.05 | 9.93 |
| 87 | (15min, 1L, 10min A, 1250D) | 83.6 | 686.36 | 10.01 |
| 88 | (5min, 2L, 10min A, 1250D) | 83.76 | 685.05 | 9.96 |
| 89 | (10min, 2L, 10min A, 1250D) | 84.58 | 686.92 | 9.99 |
| 90 | (15min, 2L, 10min A, 1250D) | 84.48 | 681.86 | 9.91 |
| 91 | (5min, 0L, 15min A, 1250D) | 83.83 | 681.86 | 9.91 |
| 92 | (10min, 0L, 15min A, 1250D) | 84.02 | 681.31 | 9.93 |
| 93 | (15min, 0L, 15min A, 1250D) | 84.34 | 674.7 | 9.88 |
| 94 | (5min, 1L, 15min A, 1250D) | 83.8 | 685.88 | 10.03 |
| 95 | (10min, 1L, 15min A, 1250D) | 84.69 | 674.93 | 9.83 |
| 96 | (15min, 1L, 15min A, 1250D) | 84.26 | 682.45 | 9.92 |
| 97 | (5min, 2L, 15min A, 1250D) | 83.78 | 685.1 | 9.97 |
| 98 | (10min, 2L, 15min A, 1250D) | 84.32 | 682.61 | 9.9 |
| 99 | (15min, 2L, 15min A, 1250D) | 82.98 | 689.77 | 10.09 |
| 100 | (5min, 0L, 20min A, 1250D) | 84.09 | 682.12 | 9.94 |

Table C.1. Networkwide measures of effectiveness of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Network) | Mean Flow (veh/hr/ln) (Network) | Mean Density (veh/km/ln) (Network) |
|---|---|---|---|---|
| 101 | (10min, 0L, 20min A, 1250D) | 84.21 | 677.62 | 9.89 |
| 102 | (15min, 0L, 20min A, 1250D) | 83.32 | 682.96 | 10.03 |
| 103 | (5min, 1L, 20min A, 1250D) | 85.44 | 677.08 | 9.78 |
| 104 | (10min, 1L, 20min A, 1250D) | 84.83 | 677.88 | 9.86 |
| 105 | (15min, 1L, 20min A, 1250D) | 84.24 | 681.47 | 9.87 |
| 106 | (5min, 2L, 20min A, 1250D) | 85.12 | 678.54 | 9.84 |
| 107 | (10min, 2L, 20min A, 1250D) | 83.69 | 686.45 | 9.99 |
| 108 | (15min, 2L, 20min A, 1250D) | 82.8 | 685.74 | 10.03 |
| 109 | (5min, 0L, 10min A, 1500D) | 84.17 | 680.78 | 9.87 |
| 110 | (10min, 0L, 10min A, 1500D) | 83.87 | 681.22 | 9.96 |
| 111 | (15min, 0L, 10min A, 1500D) | 84.86 | 672.39 | 9.83 |
| 112 | (5min, 1L, 10min A, 1500D) | 84.75 | 680.99 | 9.87 |
| 113 | (10min, 1L, 10min A, 1500D) | 84.36 | 679.25 | 9.86 |
| 114 | (15min, 1L, 10min A, 1500D) | 83.81 | 684.6 | 10 |
| 115 | (5min, 2L, 10min A, 1500D) | 83.89 | 684.16 | 9.94 |
| 116 | (10min, 2L, 10min A, 1500D) | 84.72 | 678.54 | 9.84 |
| 117 | (15min, 2L, 10min A, 1500D) | 84.32 | 682.27 | 9.93 |
| 118 | (5min, 0L, 15min A, 1500D) | 83.8 | 684.82 | 10 |
| 119 | (10min, 0L, 15min A, 1500D) | 83.9 | 681.42 | 9.95 |
| 120 | (15min, 0L, 15min A, 1500D) | 83.44 | 676.41 | 10.02 |
| 121 | (5min, 1L, 15min A, 1500D) | 83.88 | 685.63 | 10.01 |
| 122 | (10min, 1L, 15min A, 1500D) | 85.08 | 675.39 | 9.77 |
| 123 | (15min, 1L, 15min A, 1500D) | 83.76 | 684.13 | 10.01 |
| 124 | (5min, 2L, 15min A, 1500D) | 83.87 | 684.21 | 9.96 |
| 125 | (10min, 2L, 15min A, 1500D) | 84.19 | 683.7 | 9.9 |
| 126 | (15min, 2L, 15min A, 1500D) | 83.1 | 691.52 | 10.08 |
| 127 | (5min, 0L, 20min A, 1500D) | 84.39 | 680.93 | 9.89 |
| 128 | (10min, 0L, 20min A, 1500D) | 84.32 | 676.52 | 9.87 |
| 129 | (15min, 0L, 20min A, 1500D) | 82.75 | 682.13 | 10.12 |
| 130 | (5min, 1L, 20min A, 1500D) | 85.33 | 678.03 | 9.8 |
| 131 | (10min, 1L, 20min A, 1500D) | 84.87 | 679.79 | 9.85 |
| 132 | (15min, 1L, 20min A, 1500D) | 84.05 | 680.56 | 9.89 |
| 133 | (5min, 2L, 20min A, 1500D) | 85.15 | 678.21 | 9.83 |
| 134 | (10min, 2L, 20min A, 1500D) | 83.56 | 686.4 | 10.03 |
| 135 | (15min, 2L, 20min A, 1500D) | 82.28 | 687.6 | 10.11 |
| 136 | (5min, 0L, 10min A, 1750D) | 84.03 | 681.66 | 9.89 |
| 137 | (10min, 0L, 10min A, 1750D) | 84 | 681.24 | 9.93 |
| 138 | (15min, 0L, 10min A, 1750D) | 84.73 | 673.09 | 9.84 |
| 139 | (5min, 1L, 10min A, 1750D) | 84.86 | 678.61 | 9.85 |
| 140 | (10min, 1L, 10min A, 1750D) | 84.39 | 678.58 | 9.86 |
| 141 | (15min, 1L, 10min A, 1750D) | 84.16 | 681.48 | 9.95 |
| 142 | (5min, 2L, 10min A, 1750D) | 83.92 | 683.13 | 9.94 |
| 143 | (10min, 2L, 10min A, 1750D) | 84.25 | 680.32 | 9.9 |
| 144 | (15min, 2L, 10min A, 1750D) | 84.48 | 681.24 | 9.92 |
| 145 | (5min, 0L, 15min A, 1750D) | 84.08 | 683.26 | 9.95 |
| 146 | (10min, 0L, 15min A, 1750D) | 84.29 | 680.01 | 9.89 |
| 147 | (15min, 0L, 15min A, 1750D) | 84.3 | 675.38 | 9.87 |
| 148 | (5min, 1L, 15min A, 1750D) | 84.05 | 685.25 | 9.98 |
| 149 | (10min, 1L, 15min A, 1750D) | 84.74 | 675.95 | 9.83 |
| 150 | (15min, 1L, 15min A, 1750D) | 83.67 | 684.68 | 10.02 |
| 151 | (5min, 2L, 15min A, 1750D) | 83.9 | 684.03 | 9.95 |
| 152 | (10min, 2L, 15min A, 1750D) | 84.34 | 682.51 | 9.89 |
| 153 | (15min, 2L, 15min A, 1750D) | 83.16 | 690.13 | 10.08 |
| 154 | (5min, 0L, 20min A, 1750D) | 84.62 | 678.39 | 9.86 |
| 155 | (10min, 0L, 20min A, 1750D) | 84.25 | 677.89 | 9.88 |
| 156 | (15min, 0L, 20min A, 1750D) | 83.52 | 682.57 | 10 |
| 157 | (5min, 1L, 20min A, 1750D) | 85.42 | 677.23 | 9.78 |
| 158 | (10min, 1L, 20min A, 1750D) | 84.42 | 680.6 | 9.91 |
| 159 | (15min, 1L, 20min A, 1750D) | 83.84 | 681.58 | 9.93 |
| 160 | (5min, 2L, 20min A, 1750D) | 85.17 | 678.25 | 9.81 |
| 161 | (10min, 2L, 20min A, 1750D) | 83.49 | 688.04 | 10.03 |

Table C.1. Networkwide measures of effectiveness of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Network) | Mean Flow (veh/hr/ln) (Network) | Mean Density (veh/km/ln) (Network) |
|---|---|---|---|---|
| 162 | (15min, 2L, 20min A, 1750D) | 82.49 | 686.72 | 10.05 |
| 163 | (5min, 0L, 10min A, 2000D) | 84.06 | 681.69 | 9.89 |
| 164 | (10min, 0L, 10min A, 2000D) | 83.95 | 681.58 | 9.94 |
| 165 | (15min, 0L, 10min A, 2000D) | 84.42 | 674.83 | 9.89 |
| 166 | (5min, 1L, 10min A, 2000D) | 84.77 | 679.8 | 9.86 |
| 167 | (10min, 1L, 10min A, 2000D) | 84.83 | 677.32 | 9.8 |
| 168 | (15min, 1L, 10min A, 2000D) | 83.81 | 684.45 | 9.98 |
| 169 | (5min, 2L, 10min A, 2000D) | 83.99 | 682.84 | 9.92 |
| 170 | (10min, 2L, 10min A, 2000D) | 84.4 | 678.93 | 9.88 |
| 171 | (15min, 2L, 10min A, 2000D) | 84.26 | 682.03 | 9.94 |
| 172 | (5min, 0L, 15min A, 2000D) | 84.83 | 676.96 | 9.83 |
| 173 | (10min, 0L, 15min A, 2000D) | 83.55 | 681.91 | 10 |
| 174 | (15min, 0L, 15min A, 2000D) | 84.3 | 674.86 | 9.88 |
| 175 | (5min, 1L, 15min A, 2000D) | 83.94 | 686.2 | 10 |
| 176 | (10min, 1L, 15min A, 2000D) | 84.59 | 677.69 | 9.87 |
| 177 | (15min, 1L, 15min A, 2000D) | 83.75 | 683.93 | 10.01 |
| 178 | (5min, 2L, 15min A, 2000D) | 83.93 | 683.15 | 9.94 |
| 179 | (10min, 2L, 15min A, 2000D) | 84.5 | 680.78 | 9.86 |
| 180 | (15min, 2L, 15min A, 2000D) | 83.18 | 690.42 | 10.07 |
| 181 | (5min, 0L, 20min A, 2000D) | 84.25 | 682.11 | 9.92 |
| 182 | (10min, 0L, 20min A, 2000D) | 84.36 | 675.63 | 9.87 |
| 183 | (15min, 0L, 20min A, 2000D) | 83.59 | 683.68 | 9.98 |
| 184 | (5min, 1L, 20min A, 2000D) | 85.27 | 677.21 | 9.81 |
| 185 | (10min, 1L, 20min A, 2000D) | 84.63 | 680.24 | 9.87 |
| 186 | (15min, 1L, 20min A, 2000D) | 84.06 | 679.43 | 9.91 |
| 187 | (5min, 2L, 20min A, 2000D) | 85.22 | 677.89 | 9.82 |
| 188 | (10min, 2L, 20min A, 2000D) | 83.67 | 686.99 | 10.01 |
| 189 | (15min, 2L, 20min A, 2000D) | 82.34 | 688.97 | 10.09 |

Table C.2. Measures of effectiveness in the local area before the incident of the scenarios with the connected vehicles.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Before the incident) | Mean Flow (veh/hr/ln) (Before the incident) | Mean Density (veh/km/ln) (Before the incident) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 83.15 | 678.64 | 10.07 |
| 2 | (10min, 0L, 10min A, 500D) | 76.03 | 694.09 | 11.26 |
| 3 | (15min, 0L, 10min A, 500D) | 72.71 | 692.51 | 12.1 |
| 4 | (5min, 1L, 10min A, 500D) | 88.19 | 674.25 | 9.53 |
| 5 | (10min, 1L, 10min A, 500D) | 83.43 | 682.82 | 10.13 |
| 6 | (15min, 1L, 10min A, 500D) | 82.25 | 690.37 | 10.23 |
| 7 | (5min, 2L, 10min A, 500D) | 85.24 | 687.31 | 9.83 |
| 8 | (10min, 2L, 10min A, 500D) | 82.97 | 687.89 | 10.27 |
| 9 | (15min, 2L, 10min A, 500D) | 81.57 | 692.32 | 10.51 |
| 10 | (5min, 0L, 15min A, 500D) | 83.33 | 683.43 | 10.25 |
| 11 | (10min, 0L, 15min A, 500D) | 77.82 | 688.82 | 11.08 |
| 12 | (15min, 0L, 15min A, 500D) | 73.34 | 691.02 | 11.8 |
| 13 | (5min, 1L, 15min A, 500D) | 84.92 | 686.22 | 9.96 |
| 14 | (10min, 1L, 15min A, 500D) | 87.28 | 677.03 | 9.72 |
| 15 | (15min, 1L, 15min A, 500D) | 83.82 | 685.76 | 10.18 |
| 16 | (5min, 2L, 15min A, 500D) | 86.3 | 680.22 | 9.71 |
| 17 | (10min, 2L, 15min A, 500D) | 84.84 | 690.27 | 9.97 |
| 18 | (15min, 2L, 15min A, 500D) | 79.69 | 702.63 | 10.69 |

Table C.2. Measures of effectiveness in the local area before the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Before the incident) | Mean Flow (veh/hr/ln) (Before the incident) | Mean Density (veh/km/ln) (Before the incident) |
|---|---|---|---|---|
| 19 | (5min, 0L, 20min A, 500D) | 84.49 | 682.79 | 9.99 |
| 20 | (10min, 0L, 20min A, 500D) | 78.82 | 690.37 | 10.84 |
| 21 | (15min, 0L, 20min A, 500D) | 76.45 | 689.55 | 11.2 |
| 22 | (5min, 1L, 20min A, 500D) | 80.39 | 679.3 | 10.6 |
| 23 | (10min, 1L, 20min A, 500D) | 80.39 | 689.55 | 11.2 |
| 24 | (15min, 1L, 20min A, 500D) | 79.79 | 689.89 | 10.87 |
| 25 | (5min, 2L, 20min A, 500D) | 87.41 | 672.42 | 9.67 |
| 26 | (10min, 2L, 20min A, 500D) | 82.31 | 692.6 | 10.32 |
| 27 | (15min, 2L, 20min A, 500D) | 81.25 | 693.67 | 10.55 |
| 28 | (5min, 0L, 10min A, 750D) | 84.42 | 686.43 | 10.04 |
| 29 | (10min, 0L, 10min A, 750D) | 81.53 | 686.34 | 10.51 |
| 30 | (15min, 0L, 10min A, 750D) | 79.35 | 686.41 | 10.8 |
| 31 | (5min, 1L, 10min A, 750D) | 86.3 | 681.06 | 9.8 |
| 32 | (10min, 1L, 10min A, 750D) | 84.49 | 687.47 | 10.04 |
| 33 | (15min, 1L, 10min A, 750D) | 84.21 | 685.98 | 10.08 |
| 34 | (5min, 2L, 10min A, 750D) | 86.95 | 677.43 | 9.71 |
| 35 | (10min, 2L, 10min A, 750D) | 85.87 | 679.56 | 9.77 |
| 36 | (15min, 2L, 10min A, 750D) | 83.52 | 689.94 | 10.2 |
| 37 | (5min, 0L, 15min A, 750D) | 86.18 | 677.74 | 9.77 |
| 38 | (10min, 0L, 15min A, 750D) | 84.48 | 678.99 | 10.11 |
| 39 | (15min, 0L, 15min A, 750D) | 77.07 | 689.93 | 11.27 |
| 40 | (5min, 1L, 15min A, 750D) | 86.79 | 679.77 | 9.63 |
| 41 | (10min, 1L, 15min A, 750D) | 87.5 | 680.29 | 9.62 |
| 42 | (15min, 1L, 15min A, 750D) | 85.49 | 685.62 | 9.73 |
| 43 | (5min, 2L, 15min A, 750D) | 88.14 | 674 | 9.49 |
| 44 | (10min, 2L, 15min A, 750D) | 85.98 | 683.71 | 9.78 |
| 45 | (15min, 2L, 15min A, 750D) | 85.25 | 678.77 | 9.88 |
| 46 | (5min, 0L, 20min A, 750D) | 84.25 | 681.43 | 10 |
| 47 | (10min, 0L, 20min A, 750D) | 85.2 | 674.79 | 9.91 |
| 48 | (15min, 0L, 20min A, 750D) | 80.29 | 691.1 | 10.69 |
| 49 | (5min, 1L, 20min A, 750D) | 86.05 | 685.12 | 9.73 |
| 50 | (10min, 1L, 20min A, 750D) | 85.37 | 687.76 | 9.79 |
| 51 | (15min, 1L, 20min A, 750D) | 83.17 | 684.82 | 10.27 |
| 52 | (5min, 2L, 20min A, 750D) | 87.58 | 676.42 | 9.65 |
| 53 | (10min, 2L, 20min A, 750D) | 84.33 | 683.56 | 10.01 |
| 54 | (15min, 2L, 20min A, 750D) | 83.4 | 683.09 | 10 |
| 55 | (5min, 0L, 10min A, 1000D) | 86.53 | 679.71 | 9.75 |
| 56 | (10min, 0L, 10min A, 1000D) | 85.82 | 680.23 | 9.87 |
| 57 | (15min, 0L, 10min A, 1000D) | 80.47 | 682.56 | 10.69 |
| 58 | (5min, 1L, 10min A, 1000D) | 89.06 | 675.51 | 9.38 |
| 59 | (10min, 1L, 10min A, 1000D) | 86.11 | 679.09 | 9.75 |
| 60 | (15min, 1L, 10min A, 1000D) | 87.27 | 678.8 | 9.63 |
| 61 | (5min, 2L, 10min A, 1000D) | 88.37 | 673.83 | 9.5 |
| 62 | (10min, 2L, 10min A, 1000D) | 86.01 | 684.67 | 9.75 |
| 63 | (15min, 2L, 10min A, 1000D) | 85.95 | 680.26 | 9.81 |
| 64 | (5min, 0L, 15min A, 1000D) | 85.7 | 679.36 | 9.84 |
| 65 | (10min, 0L, 15min A, 1000D) | 85.51 | 678.38 | 9.9 |
| 66 | (15min, 0L, 15min A, 1000D) | 80.63 | 677.21 | 10.62 |
| 67 | (5min, 1L, 15min A, 1000D) | 86.89 | 678.8 | 9.7 |
| 68 | (10min, 1L, 15min A, 1000D) | 86.45 | 673.21 | 9.76 |
| 69 | (15min, 1L, 15min A, 1000D) | 86.77 | 677.52 | 9.69 |
| 70 | (5min, 2L, 15min A, 1000D) | 87.34 | 676.32 | 9.59 |
| 71 | (10min, 2L, 15min A, 1000D) | 87.05 | 680.32 | 9.68 |
| 72 | (15min, 2L, 15min A, 1000D) | 84.92 | 688.14 | 9.96 |
| 73 | (5min, 0L, 20min A, 1000D) | 87.09 | 673.24 | 9.62 |
| 74 | (10min, 0L, 20min A, 1000D) | 85.01 | 676.1 | 10.01 |
| 75 | (15min, 0L, 20min A, 1000D) | 79.93 | 683.83 | 10.69 |
| 76 | (5min, 1L, 20min A, 1000D) | 88.27 | 673.24 | 9.51 |
| 77 | (10min, 1L, 20min A, 1000D) | 87.51 | 676.04 | 9.66 |
| 78 | (15min, 1L, 20min A, 1000D) | 84.25 | 678.35 | 10.03 |
| 79 | (5min, 2L, 20min A, 1000D) | 88.84 | 668.78 | 9.42 |
| 80 | (10min, 2L, 20min A, 1000D) | 86.41 | 681.19 | 9.7 |

Table C.2. Measures of effectiveness in the local area before the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Before the incident) | Mean Flow (veh/hr/ln) (Before the incident) | Mean Density (veh/km/ln) (Before the incident) |
|---|---|---|---|---|
| 81 | (15min, 2L, 20min A, 1000D) | 83.69 | 684.5 | 10.01 |
| 82 | (5min, 0L, 10min A, 1250D) | 87.29 | 673.37 | 9.62 |
| 83 | (10min, 0L, 10min A, 1250D) | 86.27 | 673.44 | 9.75 |
| 84 | (15min, 0L, 10min A, 1250D) | 83.21 | 671.7 | 10.29 |
| 85 | (5min, 1L, 10min A, 1250D) | 86.18 | 674.32 | 9.85 |
| 86 | (10min, 1L, 10min A, 1250D) | 83.84 | 679.81 | 10.14 |
| 87 | (15min, 1L, 10min A, 1250D) | 85.17 | 685.57 | 9.91 |
| 88 | (5min, 2L, 10min A, 1250D) | 87.77 | 675.97 | 9.53 |
| 89 | (10min, 2L, 10min A, 1250D) | 87.91 | 677.67 | 9.62 |
| 90 | (15min, 2L, 10min A, 1250D) | 87.43 | 674.42 | 9.66 |
| 91 | (5min, 0L, 15min A, 1250D) | 87.61 | 842.14 | 9.66 |
| 92 | (10min, 0L, 15min A, 1250D) | 86.74 | 676.31 | 9.78 |
| 93 | (15min, 0L, 15min A, 1250D) | 85.55 | 667.91 | 9.87 |
| 94 | (5min, 1L, 15min A, 1250D) | 87.59 | 675.62 | 9.59 |
| 95 | (10min, 1L, 15min A, 1250D) | 87.34 | 668.47 | 9.68 |
| 96 | (15min, 1L, 15min A, 1250D) | 87.39 | 675.46 | 9.61 |
| 97 | (5min, 2L, 15min A, 1250D) | 87.73 | 677.14 | 9.55 |
| 98 | (10min, 2L, 15min A, 1250D) | 87.75 | 676.98 | 9.55 |
| 99 | (15min, 2L, 15min A, 1250D) | 84.68 | 685.53 | 9.96 |
| 100 | (5min, 0L, 20min A, 1250D) | 87.13 | 671.54 | 9.66 |
| 101 | (10min, 0L, 20min A, 1250D) | 85.85 | 675.04 | 9.85 |
| 102 | (15min, 0L, 20min A, 1250D) | 83.87 | 677.63 | 10.06 |
| 103 | (5min, 1L, 20min A, 1250D) | 89.87 | 664.45 | 9.28 |
| 104 | (10min, 1L, 20min A, 1250D) | 88.15 | 671.79 | 9.52 |
| 105 | (15min, 1L, 20min A, 1250D) | 88.04 | 671.42 | 9.5 |
| 106 | (5min, 2L, 20min A, 1250D) | 89.08 | 667.58 | 9.41 |
| 107 | (10min, 2L, 20min A, 1250D) | 87.07 | 678.82 | 9.65 |
| 108 | (15min, 2L, 20min A, 1250D) | 85.66 | 678.2 | 9.79 |
| 109 | (5min, 0L, 10min A, 1500D) | 87.81 | 670.59 | 9.53 |
| 110 | (10min, 0L, 10min A, 1500D) | 86.28 | 673.56 | 9.74 |
| 111 | (15min, 0L, 10min A, 1500D) | 87.1 | 663.62 | 9.67 |
| 112 | (5min, 1L, 10min A, 1500D) | 89.66 | 669.32 | 9.37 |
| 113 | (10min, 1L, 10min A, 1500D) | 87.67 | 672.28 | 9.57 |
| 114 | (15min, 1L, 10min A, 1500D) | 86.66 | 676.46 | 9.7 |
| 115 | (5min, 2L, 10min A, 1500D) | 88.61 | 672.36 | 9.45 |
| 116 | (10min, 2L, 10min A, 1500D) | 88.86 | 665.08 | 9.39 |
| 117 | (15min, 2L, 10min A, 1500D) | 87.71 | 671.89 | 9.61 |
| 118 | (5min, 0L, 15min A, 1500D) | 87.56 | 672.96 | 9.59 |
| 119 | (10min, 0L, 15min A, 1500D) | 86.9 | 673.54 | 9.68 |
| 120 | (15min, 0L, 15min A, 1500D) | 83.87 | 668.34 | 10.14 |
| 121 | (5min, 1L, 15min A, 1500D) | 88.21 | 673.17 | 9.52 |
| 122 | (10min, 1L, 15min A, 1500D) | 89.63 | 664.43 | 9.34 |
| 123 | (15min, 1L, 15min A, 1500D) | 86.41 | 675.81 | 9.79 |
| 124 | (5min, 2L, 15min A, 1500D) | 88.43 | 672.95 | 9.45 |
| 125 | (10min, 2L, 15min A, 1500D) | 88.09 | 675.8 | 9.54 |
| 126 | (15min, 2L, 15min A, 1500D) | 86.45 | 681 | 9.71 |
| 127 | (5min, 0L, 20min A, 1500D) | 88.41 | 667.29 | 9.47 |
| 128 | (10min, 0L, 20min A, 1500D) | 86.79 | 670.08 | 9.67 |
| 129 | (15min, 0L, 20min A, 1500D) | 83.17 | 674.36 | 10.2 |
| 130 | (5min, 1L, 20min A, 1500D) | 90.19 | 663.16 | 9.28 |
| 131 | (10min, 1L, 20min A, 1500D) | 89.43 | 668.04 | 9.36 |
| 132 | (15min, 1L, 20min A, 1500D) | 87.39 | 669.82 | 9.62 |
| 133 | (5min, 2L, 20min A, 1500D) | 89.92 | 661.72 | 9.33 |
| 134 | (10min, 2L, 20min A, 1500D) | 87.17 | 675.02 | 9.66 |
| 135 | (15min, 2L, 20min A, 1500D) | 85.07 | 678.64 | 9.87 |
| 136 | (5min, 0L, 10min A, 1750D) | 88.33 | 668.9 | 9.48 |
| 137 | (10min, 0L, 10min A, 1750D) | 87.93 | 667.26 | 9.55 |
| 138 | (15min, 0L, 10min A, 1750D) | 88.24 | 657.72 | 9.55 |
| 139 | (5min, 1L, 10min A, 1750D) | 90.12 | 662.4 | 9.32 |
| 140 | (10min, 1L, 10min A, 1750D) | 88.64 | 666.03 | 9.45 |

Table C.2. Measures of effectiveness in the local area before the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (Before the incident) | Mean Flow (veh/hr/ln) (Before the incident) | Mean Density (veh/km/ln) (Before the incident) |
|---|---|---|---|---|
| 141 | (15min, 1L, 10min A, 1750D) | 88.14 | 667.52 | 9.58 |
| 142 | (5min, 2L, 10min A, 1750D) | 88.98 | 668.77 | 9.41 |
| 143 | (10min, 2L, 10min A, 1750D) | 88.85 | 663.89 | 9.41 |
| 144 | (15min, 2L, 10min A, 1750D) | 88.88 | 665.29 | 9.52 |
| 145 | (5min, 0L, 15min A, 1750D) | 88.73 | 667.46 | 9.45 |
| 146 | (10min, 0L, 15min A, 1750D) | 88.66 | 666.39 | 9.47 |
| 147 | (15min, 0L, 15min A, 1750D) | 87.58 | 661.32 | 9.6 |
| 148 | (5min, 1L, 15min A, 1750D) | 89.55 | 666.59 | 9.37 |
| 149 | (10min, 1L, 15min A, 1750D) | 88.9 | 664.87 | 9.46 |
| 150 | (15min, 1L, 15min A, 1750D) | 87.53 | 669.76 | 9.62 |
| 151 | (5min, 2L, 15min A, 1750D) | 89.08 | 668.7 | 9.39 |
| 152 | (10min, 2L, 15min A, 1750D) | 89.26 | 667.95 | 9.42 |
| 153 | (15min, 2L, 15min A, 1750D) | 87.15 | 676.38 | 9.64 |
| 154 | (5min, 0L, 20min A, 1750D) | 89.27 | 661.19 | 9.4 |
| 155 | (10min, 0L, 20min A, 1750D) | 87.86 | 667.33 | 9.59 |
| 156 | (15min, 0L, 20min A, 1750D) | 86.44 | 670.86 | 9.71 |
| 157 | (5min, 1L, 20min A, 1750D) | 91.01 | 657.13 | 9.17 |
| 158 | (10min, 1L, 20min A, 1750D) | 88.97 | 666.79 | 9.47 |
| 159 | (15min, 1L, 20min A, 1750D) | 87.68 | 667.44 | 9.58 |
| 160 | (5min, 2L, 20min A, 1750D) | 90.47 | 659.13 | 9.22 |
| 161 | (10min, 2L, 20min A, 1750D) | 88.08 | 672.43 | 9.52 |
| 162 | (15min, 2L, 20min A, 1750D) | 86.91 | 670.83 | 9.62 |
| 163 | (5min, 0L, 10min A, 2000D) | 89.3 | 662.82 | 9.37 |
| 164 | (10min, 0L, 10min A, 2000D) | 88.88 | 661.07 | 9.43 |
| 165 | (15min, 0L, 10min A, 2000D) | 88.61 | 655.33 | 9.5 |
| 166 | (5min, 1L, 10min A, 2000D) | 90.62 | 660.87 | 9.27 |
| 167 | (10min, 1L, 10min A, 2000D) | 90.66 | 658.31 | 9.24 |
| 168 | (15min, 1L, 10min A, 2000D) | 88.42 | 667.91 | 9.54 |
| 169 | (5min, 2L, 10min A, 2000D) | 90.01 | 662.57 | 9.3 |
| 170 | (10min, 2L, 10min A, 2000D) | 89.95 | 654.79 | 9.29 |
| 171 | (15min, 2L, 10min A, 2000D) | 89.48 | 660.7 | 9.41 |
| 172 | (5min, 0L, 15min A, 2000D) | 90.22 | 655.21 | 9.26 |
| 173 | (10min, 0L, 15min A, 2000D) | 87.79 | 664.75 | 9.62 |
| 174 | (15min, 0L, 15min A, 2000D) | 88.6 | 655.19 | 9.51 |
| 175 | (5min, 1L, 15min A, 2000D) | 90.07 | 663.7 | 9.29 |
| 176 | (10min, 1L, 15min A, 2000D) | 90.07 | 657.18 | 9.34 |
| 177 | (15min, 1L, 15min A, 2000D) | 88.43 | 663.59 | 9.53 |
| 178 | (5min, 2L, 15min A, 2000D) | 89.95 | 661.79 | 9.31 |
| 179 | (10min, 2L, 15min A, 2000D) | 90.28 | 660.31 | 9.29 |
| 180 | (15min, 2L, 15min A, 2000D) | 88.38 | 669.37 | 9.48 |
| 181 | (5min, 0L, 20min A, 2000D) | 89.78 | 660.41 | 9.34 |
| 182 | (10min, 0L, 20min A, 2000D) | 88.63 | 659.97 | 9.52 |
| 183 | (15min, 0L, 20min A, 2000D) | 88.01 | 663.47 | 9.53 |
| 184 | (5min, 1L, 20min A, 2000D) | 91.31 | 653.36 | 9.15 |
| 185 | (10min, 1L, 20min A, 2000D) | 90.29 | 660.16 | 9.3 |
| 186 | (15min, 1L, 20min A, 2000D) | 89.03 | 657.92 | 9.43 |
| 187 | (5min, 2L, 20min A, 2000D) | 91.5 | 652.5 | 9.13 |
| 188 | (10min, 2L, 20min A, 2000D) | 89.28 | 664.66 | 9.41 |
| 189 | (15min, 2L, 20min A, 2000D) | 87.51 | 667.79 | 9.56 |

Table C.3. Measures of effectiveness in the local area after the incident of the scenarios with the connected vehicles.

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (After the incident) | Mean Flow (veh/hr/ln) (After the incident) | Mean Density (veh/km/ln) (After the incident) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 87.29 | 679.27 | 9.75 |
| 2 | (10min, 0L, 10min A, 500D) | 86.5 | 681.95 | 10.06 |
| 3 | (15min, 0L, 10min A, 500D) | 86.84 | 677.74 | 10.19 |
| 4 | (5min, 1L, 10min A, 500D) | 88.6 | 670.58 | 9.54 |
| 5 | (10min, 1L, 10min A, 500D) | 86.9 | 675.14 | 9.84 |
| 6 | (15min, 1L, 10min A, 500D) | 86.09 | 681.44 | 10.13 |
| 7 | (5min, 2L, 10min A, 500D) | 86.35 | 687.75 | 9.89 |
| 8 | (10min, 2L, 10min A, 500D) | 86.95 | 677.99 | 9.93 |
| 9 | (15min, 2L, 10min A, 500D) | 86.39 | 682.57 | 10.18 |
| 10 | (5min, 0L, 15min A, 500D) | 87.17 | 682.89 | 9.76 |
| 11 | (10min, 0L, 15min A, 500D) | 86.91 | 683.96 | 10.02 |
| 12 | (15min, 0L, 15min A, 500D) | 86.26 | 678.22 | 10.16 |
| 13 | (5min, 1L, 15min A, 500D) | 86.26 | 681.95 | 9.84 |
| 14 | (10min, 1L, 15min A, 500D) | 87.75 | 670.36 | 9.61 |
| 15 | (15min, 1L, 15min A, 500D) | 85.98 | 682.29 | 9.84 |
| 16 | (5min, 2L, 15min A, 500D) | 86.76 | 680.48 | 9.72 |
| 17 | (10min, 2L, 15min A, 500D) | 86.23 | 687.36 | 9.96 |
| 18 | (15min, 2L, 15min A, 500D) | 83.85 | 693.97 | 10.45 |
| 19 | (5min, 0L, 20min A, 500D) | 87.71 | 678.33 | 9.67 |
| 20 | (10min, 0L, 20min A, 500D) | 88.18 | 673.22 | 9.74 |
| 21 | (15min, 0L, 20min A, 500D) | 86.13 | 672.67 | 10.17 |
| 22 | (5min, 1L, 20min A, 500D) | 87.38 | 675.63 | 9.88 |
| 23 | (10min, 1L, 20min A, 500D) | 87.38 | 672.67 | 10.17 |
| 24 | (15min, 1L, 20min A, 500D) | 85.88 | 676.16 | 9.97 |
| 25 | (5min, 2L, 20min A, 500D) | 88.21 | 674.85 | 9.48 |
| 26 | (10min, 2L, 20min A, 500D) | 85.33 | 688.14 | 10.13 |
| 27 | (15min, 2L, 20min A, 500D) | 83.8 | 686.92 | 10.17 |
| 28 | (5min, 0L, 10min A, 750D) | 76.83 | 713.81 | 10.98 |
| 29 | (10min, 0L, 10min A, 750D) | 77.23 | 705.07 | 10.9 |
| 30 | (15min, 0L, 10min A, 750D) | 76.65 | 709.21 | 11.12 |
| 31 | (5min, 1L, 10min A, 750D) | 76.86 | 707.83 | 10.93 |
| 32 | (10min, 1L, 10min A, 750D) | 77.33 | 703.3 | 10.9 |
| 33 | (15min, 1L, 10min A, 750D) | 77.38 | 703.05 | 10.98 |
| 34 | (5min, 2L, 10min A, 750D) | 77.54 | 704.43 | 10.79 |
| 35 | (10min, 2L, 10min A, 750D) | 77.11 | 703.86 | 10.8 |
| 36 | (15min, 2L, 10min A, 750D) | 76.33 | 710.47 | 11.11 |
| 37 | (5min, 0L, 15min A, 750D) | 78.04 | 705.88 | 10.78 |
| 38 | (10min, 0L, 15min A, 750D) | 77.83 | 699.01 | 10.81 |
| 39 | (15min, 0L, 15min A, 750D) | 76.53 | 712.04 | 11.27 |
| 40 | (5min, 1L, 15min A, 750D) | 77.44 | 710.88 | 10.84 |
| 41 | (10min, 1L, 15min A, 750D) | 77.43 | 706.66 | 10.77 |
| 42 | (15min, 1L, 15min A, 750D) | 76.1 | 717.29 | 11.04 |
| 43 | (5min, 2L, 15min A, 750D) | 78.26 | 701.67 | 10.65 |
| 44 | (10min, 2L, 15min A, 750D) | 77.34 | 707.58 | 10.92 |
| 45 | (15min, 2L, 15min A, 750D) | 77.49 | 703.09 | 10.93 |
| 46 | (5min, 0L, 20min A, 750D) | 76.8 | 710.09 | 10.86 |
| 47 | (10min, 0L, 20min A, 750D) | 78.28 | 700.92 | 10.79 |
| 48 | (15min, 0L, 20min A, 750D) | 76.68 | 704.75 | 10.99 |
| 49 | (5min, 1L, 20min A, 750D) | 76.5 | 716.07 | 10.91 |
| 50 | (10min, 1L, 20min A, 750D) | 74.89 | 713.46 | 10.94 |
| 51 | (15min, 1L, 20min A, 750D) | 76.95 | 706.64 | 11.2 |
| 52 | (5min, 2L, 20min A, 750D) | 77.84 | 702.53 | 10.75 |
| 53 | (10min, 2L, 20min A, 750D) | 77.05 | 709.64 | 11.04 |
| 54 | (15min, 2L, 20min A, 750D) | 75.49 | 707.19 | 11.05 |

Table C.3. Measures of effectiveness in the local area after the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (After the incident) | Mean Flow (veh/hr/ln) (After the incident) | Mean Density (veh/km/ln) (After the incident) |
|---|---|---|---|---|
| 55 | (5min, 0L, 10min A, 1000D) | 75.47 | 716.75 | 11.14 |
| 56 | (10min, 0L, 10min A, 1000D) | 75.9 | 710.53 | 11.08 |
| 57 | (15min, 0L, 10min A, 1000D) | 75.51 | 714.53 | 11.29 |
| 58 | (5min, 1L, 10min A, 1000D) | 75.97 | 714.64 | 10.92 |
| 59 | (10min, 1L, 10min A, 1000D) | 75.93 | 712.18 | 11.06 |
| 60 | (15min, 1L, 10min A, 1000D) | 75.36 | 714.31 | 11.09 |
| 61 | (5min, 2L, 10min A, 1000D) | 76.08 | 709.79 | 10.91 |
| 62 | (10min, 2L, 10min A, 1000D) | 75.08 | 718.37 | 11.18 |
| 63 | (15min, 2L, 10min A, 1000D) | 75.07 | 712.3 | 11.19 |
| 64 | (5min, 0L, 15min A, 1000D) | 75.36 | 720.49 | 11.19 |
| 65 | (10min, 0L, 15min A, 1000D) | 75.89 | 711.27 | 11.12 |
| 66 | (15min, 0L, 15min A, 1000D) | 75.54 | 712.85 | 11.23 |
| 67 | (5min, 1L, 15min A, 1000D) | 75.46 | 716.92 | 11.17 |
| 68 | (10min, 1L, 15min A, 1000D) | 76.33 | 703.27 | 10.99 |
| 69 | (15min, 1L, 15min A, 1000D) | 75.66 | 716.1 | 11.16 |
| 70 | (5min, 2L, 15min A, 1000D) | 75.27 | 715.67 | 11.09 |
| 71 | (10min, 2L, 15min A, 1000D) | 75.89 | 714.68 | 11.11 |
| 72 | (15min, 2L, 15min A, 1000D) | 74.7 | 720.69 | 11.33 |
| 73 | (5min, 0L, 20min A, 1000D) | 75.93 | 712.69 | 11.04 |
| 74 | (10min, 0L, 20min A, 1000D) | 76.58 | 705.4 | 10.93 |
| 75 | (15min, 0L, 20min A, 1000D) | 75.03 | 717.81 | 11.4 |
| 76 | (5min, 1L, 20min A, 1000D) | 76.48 | 711.24 | 10.99 |
| 77 | (10min, 1L, 20min A, 1000D) | 76.11 | 713.32 | 11.05 |
| 78 | (15min, 1L, 20min A, 1000D) | 75.76 | 709.19 | 11.12 |
| 79 | (5min, 2L, 20min A, 1000D) | 76.55 | 710.24 | 10.95 |
| 80 | (10min, 2L, 20min A, 1000D) | 75.26 | 716.98 | 11.17 |
| 81 | (15min, 2L, 20min A, 1000D) | 73.86 | 717.56 | 11.39 |
| 82 | (5min, 0L, 10min A, 1250D) | 79.09 | 698.21 | 10.58 |
| 83 | (10min, 0L, 10min A, 1250D) | 79.02 | 697.57 | 10.7 |
| 84 | (15min, 0L, 10min A, 1250D) | 79.17 | 695.14 | 10.73 |
| 85 | (5min, 1L, 10min A, 1250D) | 79.84 | 694.58 | 10.63 |
| 86 | (10min, 1L, 10min A, 1250D) | 80.09 | 689.36 | 10.61 |
| 87 | (15min, 1L, 10min A, 1250D) | 78.8 | 698.09 | 10.8 |
| 88 | (5min, 2L, 10min A, 1250D) | 78.16 | 704.69 | 10.76 |
| 89 | (10min, 2L, 10min A, 1250D) | 79.09 | 705.4 | 10.73 |
| 90 | (15min, 2L, 10min A, 1250D) | 79.12 | 695.8 | 10.66 |
| 91 | (5min, 0L, 15min A, 1250D) | 78.55 | 747.55 | 10.66 |
| 92 | (10min, 0L, 15min A, 1250D) | 78.72 | 697.15 | 10.73 |
| 93 | (15min, 0L, 15min A, 1250D) | 79.5 | 690.01 | 10.62 |
| 94 | (5min, 1L, 15min A, 1250D) | 78.49 | 701.67 | 10.73 |
| 95 | (10min, 1L, 15min A, 1250D) | 79.63 | 687.19 | 10.53 |
| 96 | (15min, 1L, 15min A, 1250D) | 78.87 | 699.24 | 10.71 |
| 97 | (5min, 2L, 15min A, 1250D) | 78.48 | 698.62 | 10.64 |
| 98 | (10min, 2L, 15min A, 1250D) | 79.08 | 698.05 | 10.64 |
| 99 | (15min, 2L, 15min A, 1250D) | 77.77 | 704.1 | 10.89 |
| 100 | (5min, 0L, 20min A, 1250D) | 78.9 | 698.88 | 10.65 |
| 101 | (10min, 0L, 20min A, 1250D) | 79.86 | 690.18 | 10.55 |
| 102 | (15min, 0L, 20min A, 1250D) | 78.65 | 698.37 | 10.79 |
| 103 | (5min, 1L, 20min A, 1250D) | 79.92 | 693.16 | 10.42 |
| 104 | (10min, 1L, 20min A, 1250D) | 79.36 | 696.95 | 10.65 |
| 105 | (15min, 1L, 20min A, 1250D) | 78.65 | 696.03 | 10.55 |
| 106 | (5min, 2L, 20min A, 1250D) | 79.66 | 694.49 | 10.52 |
| 107 | (10min, 2L, 20min A, 1250D) | 78.26 | 703.22 | 10.74 |
| 108 | (15min, 2L, 20min A, 1250D) | 77.46 | 699.9 | 10.85 |
| 109 | (5min, 0L, 10min A, 1500D) | 81.05 | 689.96 | 10.3 |
| 110 | (10min, 0L, 10min A, 1500D) | 81.13 | 688.01 | 10.35 |
| 111 | (15min, 0L, 10min A, 1500D) | 82.11 | 677.44 | 10.26 |
| 112 | (5min, 1L, 10min A, 1500D) | 81.31 | 688.89 | 10.29 |
| 113 | (10min, 1L, 10min A, 1500D) | 81.27 | 683.85 | 10.31 |
| 114 | (15min, 1L, 10min A, 1500D) | 80.67 | 690.68 | 10.53 |
| 115 | (5min, 2L, 10min A, 1500D) | 80.31 | 693.24 | 10.39 |

Table C.3. Measures of effectiveness in the local area after the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (After the incident) | Mean Flow (veh/hr/ln) (After the incident) | Mean Density (veh/km/ln) (After the incident) |
|---|---|---|---|---|
| 116 | (10min, 2L, 10min A, 1500D) | 81.38 | 687.48 | 10.39 |
| 117 | (15min, 2L, 10min A, 1500D) | 80.94 | 689.07 | 10.43 |
| 118 | (5min, 0L, 15min A, 1500D) | 80.5 | 693.22 | 10.4 |
| 119 | (10min, 0L, 15min A, 1500D) | 80.85 | 687.57 | 10.39 |
| 120 | (15min, 0L, 15min A, 1500D) | 81.06 | 686.28 | 10.39 |
| 121 | (5min, 1L, 15min A, 1500D) | 80.51 | 693.02 | 10.49 |
| 122 | (10min, 1L, 15min A, 1500D) | 81.57 | 679.52 | 10.14 |
| 123 | (15min, 1L, 15min A, 1500D) | 80.8 | 691.85 | 10.48 |
| 124 | (5min, 2L, 15min A, 1500D) | 80.42 | 689.96 | 10.37 |
| 125 | (10min, 2L, 15min A, 1500D) | 80.84 | 691.1 | 10.39 |
| 126 | (15min, 2L, 15min A, 1500D) | 79.78 | 698.73 | 10.59 |
| 127 | (5min, 0L, 20min A, 1500D) | 81.17 | 689.88 | 10.34 |
| 128 | (10min, 0L, 20min A, 1500D) | 81.96 | 680.42 | 10.23 |
| 129 | (15min, 0L, 20min A, 1500D) | 80.36 | 690.48 | 10.55 |
| 130 | (5min, 1L, 20min A, 1500D) | 81.8 | 685.5 | 10.19 |
| 131 | (10min, 1L, 20min A, 1500D) | 81.39 | 688.49 | 10.29 |
| 132 | (15min, 1L, 20min A, 1500D) | 80.81 | 686.54 | 10.31 |
| 133 | (5min, 2L, 20min A, 1500D) | 81.52 | 688.29 | 10.31 |
| 134 | (10min, 2L, 20min A, 1500D) | 80.2 | 694.35 | 10.52 |
| 135 | (15min, 2L, 20min A, 1500D) | 79.06 | 693.11 | 10.6 |
| 136 | (5min, 0L, 10min A, 1750D) | 82.17 | 685.58 | 10.15 |
| 137 | (10min, 0L, 10min A, 1750D) | 82.25 | 685.21 | 10.23 |
| 138 | (15min, 0L, 10min A, 1750D) | 83.21 | 675.02 | 10.09 |
| 139 | (5min, 1L, 10min A, 1750D) | 82.79 | 682.64 | 10.13 |
| 140 | (10min, 1L, 10min A, 1750D) | 82.56 | 679.01 | 10.09 |
| 141 | (15min, 1L, 10min A, 1750D) | 82.46 | 684.3 | 10.27 |
| 142 | (5min, 2L, 10min A, 1750D) | 81.67 | 688.14 | 10.26 |
| 143 | (10min, 2L, 10min A, 1750D) | 82.29 | 685.29 | 10.22 |
| 144 | (15min, 2L, 10min A, 1750D) | 82.48 | 684.11 | 10.23 |
| 145 | (5min, 0L, 15min A, 1750D) | 82.22 | 687.44 | 10.22 |
| 146 | (10min, 0L, 15min A, 1750D) | 82.4 | 681.61 | 10.14 |
| 147 | (15min, 0L, 15min A, 1750D) | 82.81 | 677.58 | 10.14 |
| 148 | (5min, 1L, 15min A, 1750D) | 81.72 | 690.35 | 10.3 |
| 149 | (10min, 1L, 15min A, 1750D) | 82.97 | 674.89 | 10.08 |
| 150 | (15min, 1L, 15min A, 1750D) | 81.82 | 690.31 | 10.39 |
| 151 | (5min, 2L, 15min A, 1750D) | 81.75 | 685.6 | 10.23 |
| 152 | (10min, 2L, 15min A, 1750D) | 82.27 | 685.56 | 10.23 |
| 153 | (15min, 2L, 15min A, 1750D) | 81.17 | 693.27 | 10.41 |
| 154 | (5min, 0L, 20min A, 1750D) | 82.66 | 683.64 | 10.13 |
| 155 | (10min, 0L, 20min A, 1750D) | 82.97 | 678 | 10.08 |
| 156 | (15min, 0L, 20min A, 1750D) | 82.24 | 682.84 | 10.25 |
| 157 | (5min, 1L, 20min A, 1750D) | 83.16 | 682.03 | 10.04 |
| 158 | (10min, 1L, 20min A, 1750D) | 82.35 | 685.05 | 10.25 |
| 159 | (15min, 1L, 20min A, 1750D) | 82.02 | 684.43 | 10.22 |
| 160 | (5min, 2L, 20min A, 1750D) | 82.99 | 682.97 | 10.11 |
| 161 | (10min, 2L, 20min A, 1750D) | 81.45 | 692.61 | 10.33 |
| 162 | (15min, 2L, 20min A, 1750D) | 80.31 | 689.98 | 10.41 |
| 163 | (5min, 0L, 10min A, 2000D) | 83.1 | 682.21 | 10.01 |
| 164 | (10min, 0L, 10min A, 2000D) | 83.3 | 681.46 | 10.1 |
| 165 | (15min, 0L, 10min A, 2000D) | 84.04 | 672.74 | 10.01 |
| 166 | (5min, 1L, 10min A, 2000D) | 83.68 | 679.52 | 9.97 |
| 167 | (10min, 1L, 10min A, 2000D) | 83.56 | 675.92 | 9.91 |
| 168 | (15min, 1L, 10min A, 2000D) | 83.1 | 680.42 | 10.13 |
| 169 | (5min, 2L, 10min A, 2000D) | 82.62 | 684.6 | 10.12 |
| 170 | (10min, 2L, 10min A, 2000D) | 83.26 | 682.05 | 10.14 |
| 171 | (15min, 2L, 10min A, 2000D) | 83.15 | 682.94 | 10.16 |
| 172 | (5min, 0L, 15min A, 2000D) | 83.99 | 677.59 | 9.96 |
| 173 | (10min, 0L, 15min A, 2000D) | 83.11 | 680.19 | 10.08 |
| 174 | (15min, 0L, 15min A, 2000D) | 83.78 | 674.12 | 10.03 |

Table C.3. Measures of effectiveness in the local area after the incident of the scenarios with the connected vehicles (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (km/hr) (After the incident) | Mean Flow (veh/hr/ln) (After the incident) | Mean Density (veh/km/ln) (After the incident) |
|---|---|---|---|---|
| 175 | (5min, 1L, 15min A, 2000D) | 82.49 | 688.15 | 10.23 |
| 176 | (10min, 1L, 15min A, 2000D) | 83.49 | 676.9 | 10.04 |
| 177 | (15min, 1L, 15min A, 2000D) | 83.02 | 685.94 | 10.21 |
| 178 | (5min, 2L, 15min A, 2000D) | 82.49 | 683.96 | 10.11 |
| 179 | (10min, 2L, 15min A, 2000D) | 83.24 | 680.85 | 10.06 |
| 180 | (15min, 2L, 15min A, 2000D) | 81.89 | 693.32 | 10.32 |
| 181 | (5min, 0L, 20min A, 2000D) | 83.24 | 683.05 | 10.07 |
| 182 | (10min, 0L, 20min A, 2000D) | 84.22 | 671.82 | 9.92 |
| 183 | (15min, 0L, 20min A, 2000D) | 82.87 | 684.3 | 10.14 |
| 184 | (5min, 1L, 20min A, 2000D) | 84.12 | 678.39 | 9.95 |
| 185 | (10min, 1L, 20min A, 2000D) | 83.28 | 682.42 | 10.07 |
| 186 | (15min, 1L, 20min A, 2000D) | 83.09 | 680.71 | 10.11 |
| 187 | (5min, 2L, 20min A, 2000D) | 83.91 | 680.21 | 10.01 |
| 188 | (10min, 2L, 20min A, 2000D) | 82.47 | 689.96 | 10.2 |
| 189 | (15min, 2L, 20min A, 2000D) | 81.12 | 690.06 | 10.32 |

# APPENDIX D: P VALUES OF THE T TEST FOR THE CHANGES IN MEASURES OF EFFECTIVENESS WHEN CONNECTED VEHICLES ARE INTRODUCED

Table D.1. P-values of the t test for the changes in networkwide measures of effectiveness when connected vehicles are introduced.

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 4.26E-132 | 0.00E+00 | 2.48E-150 |
| 2 | (10min, 0L, 10min A, 500D) | 4.18E-01 | 0.00E+00 | 3.04E-118 |
| 3 | (15min, 0L, 10min A, 500D) | 4.85E-08 | 0.00E+00 | 1.31E-124 |
| 4 | (5min, 1L, 10min A, 500D) | 7.44E-86 | 0.00E+00 | 2.56E-140 |
| 5 | (10min, 1L, 10min A, 500D) | 2.30E-05 | 0.00E+00 | 7.39E-132 |
| 6 | (15min, 1L, 10min A, 500D) | 7.78E-09 | 0.00E+00 | 1.36E-136 |
| 7 | (5min, 2L, 10min A, 500D) | 5.47E-11 | 2.30E-01 | 6.22E-01 |
| 8 | (10min, 2L, 10min A, 500D) | 2.07E-134 | 0.00E+00 | 5.30E-147 |
| 9 | (15min, 2L, 10min A, 500D) | 0.00E+00 | 0.00E+00 | 4.60E-169 |
| 10 | (5min, 0L, 15min A, 500D) | 1.23E-72 | 0.00E+00 | 6.69E-141 |
| 11 | (10min, 0L, 15min A, 500D) | 4.40E-99 | 0.00E+00 | 7.20E-145 |
| 12 | (15min, 0L, 15min A, 500D) | 3.15E-63 | 0.00E+00 | 2.39E-138 |
| 13 | (5min, 1L, 15min A, 500D) | 7.01E-270 | 0.00E+00 | 2.63E-149 |
| 14 | (10min, 1L, 15min A, 500D) | 1.34E-200 | 0.00E+00 | 1.02E-152 |
| 15 | (15min, 1L, 15min A, 500D) | 1.30E-69 | 0.00E+00 | 7.18E-136 |
| 16 | (5min, 2L, 15min A, 500D) | 8.86E-12 | 0.00E+00 | 4.75E-134 |
| 17 | (10min, 2L, 15min A, 500D) | 2.21E-243 | 0.00E+00 | 4.47E-152 |
| 18 | (15min, 2L, 15min A, 500D) | 3.73E-80 | 0.00E+00 | 2.70E-146 |
| 19 | (5min, 0L, 20min A, 500D) | 6.41E-177 | 0.00E+00 | 1.94E-144 |
| 20 | (10min, 0L, 20min A, 500D) | 6.85E-21 | 0.00E+00 | 3.28E-136 |
| 21 | (15min, 0L, 20min A, 500D) | 1.63E-228 | 0.00E+00 | 1.82E-147 |
| 22 | (5min, 1L, 20min A, 500D) | 5.65E-02 | 0.00E+00 | 2.29E-121 |
| 23 | (10min, 1L, 20min A, 500D) | 0.00E+00 | 0.00E+00 | 2.03E-152 |
| 24 | (15min, 1L, 20min A, 500D) | 6.32E-36 | 0.00E+00 | 7.16E-134 |
| 25 | (5min, 2L, 20min A, 500D) | 5.17E-130 | 0.00E+00 | 1.55E-141 |
| 26 | (10min, 2L, 20min A, 500D) | 1.39E-17 | 3.87E-01 | 6.30E-01 |
| 27 | (15min, 2L, 20min A, 500D) | 3.58E-141 | 0.00E+00 | 1.73E-155 |
| 28 | (5min, 0L, 10min A, 750D) | 9.77E-51 | 0.00E+00 | 6.41E-135 |
| 29 | (10min, 0L, 10min A, 750D) | 7.21E-32 | 0.00E+00 | 4.20E-124 |
| 30 | (15min, 0L, 10min A, 750D) | 5.21E-56 | 0.00E+00 | 1.04E-123 |
| 31 | (5min, 1L, 10min A, 750D) | 8.50E-31 | 0.00E+00 | 5.88E-115 |
| 32 | (10min, 1L, 10min A, 750D) | 3.94E-20 | 0.00E+00 | 1.99E-122 |
| 33 | (15min, 1L, 10min A, 750D) | 8.23E-45 | 0.00E+00 | 1.63E-139 |
| 34 | (5min, 2L, 10min A, 750D) | 1.07E-28 | 4.51E-01 | 5.83E-01 |
| 35 | (10min, 2L, 10min A, 750D) | 9.04E-108 | 0.00E+00 | 2.96E-147 |
| 36 | (15min, 2L, 10min A, 750D) | 0.00E+00 | 0.00E+00 | 1.84E-165 |
| 37 | (5min, 0L, 15min A, 750D) | 4.69E-294 | 0.00E+00 | 4.03E-159 |
| 38 | (10min, 0L, 15min A, 750D) | 0.00E+00 | 0.00E+00 | 2.09E-158 |
| 39 | (15min, 0L, 15min A, 750D) | 8.42E-05 | 0.00E+00 | 1.62E-121 |
| 40 | (5min, 1L, 15min A, 750D) | 0.00E+00 | 0.00E+00 | 1.20E-162 |
| 41 | (10min, 1L, 15min A, 750D) | 3.17E-25 | 0.00E+00 | 4.48E-137 |
| 42 | (15min, 1L, 15min A, 750D) | 4.24E-07 | 0.00E+00 | 6.91E-129 |
| 43 | (5min, 2L, 15min A, 750D) | 1.18E-156 | 0.00E+00 | 2.15E-145 |
| 44 | (10min, 2L, 15min A, 750D) | 4.84E-243 | 0.00E+00 | 5.68E-149 |
| 45 | (15min, 2L, 15min A, 750D) | 0.00E+00 | 0.00E+00 | 2.09E-185 |

Table D.1. P-values of the t test for the changes in networkwide measures of effectiveness when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 46 | (5min, 0L, 20min A, 750D) | 4.57E-11 | 0.00E+00 | 5.61E-133 |
| 47 | (10min, 0L, 20min A, 750D) | 3.07E-139 | 0.00E+00 | 2.48E-143 |
| 48 | (15min, 0L, 20min A, 750D) | 2.85E-113 | 0.00E+00 | 1.48E-143 |
| 49 | (5min, 1L, 20min A, 750D) | 2.19E-161 | 0.00E+00 | 6.64E-112 |
| 50 | (10min, 1L, 20min A, 750D) | 7.57E-06 | 0.00E+00 | 7.52E-155 |
| 51 | (15min, 1L, 20min A, 750D) | 2.43E-73 | 0.00E+00 | 3.53E-131 |
| 52 | (5min, 2L, 20min A, 750D) | 1.35E-12 | 0.00E+00 | 2.08E-134 |
| 53 | (10min, 2L, 20min A, 750D) | 6.47E-03 | 6.33E-02 | 4.01E-01 |
| 54 | (15min, 2L, 20min A, 750D) | 0.00E+00 | 0.00E+00 | 5.74E-170 |
| 55 | (5min, 0L, 10min A, 1000D) | 2.30E-87 | 0.00E+00 | 1.57E-141 |
| 56 | (10min, 0L, 10min A, 1000D) | 1.25E-114 | 0.00E+00 | 8.35E-134 |
| 57 | (15min, 0L, 10min A, 1000D) | 3.40E-67 | 0.00E+00 | 1.73E-115 |
| 58 | (5min, 1L, 10min A, 1000D) | 3.99E-13 | 0.00E+00 | 3.10E-132 |
| 59 | (10min, 1L, 10min A, 1000D) | 8.68E-13 | 0.00E+00 | 2.80E-126 |
| 60 | (15min, 1L, 10min A, 1000D) | 7.87E-49 | 0.00E+00 | 1.78E-144 |
| 61 | (5min, 2L, 10min A, 1000D) | 1.74E-70 | 3.46E-02 | 2.11E-01 |
| 62 | (10min, 2L, 10min A, 1000D) | 1.27E-16 | 0.00E+00 | 4.57E-138 |
| 63 | (15min, 2L, 10min A, 1000D) | 0.00E+00 | 0.00E+00 | 7.80E-164 |
| 64 | (5min, 0L, 15min A, 1000D) | 5.23E-79 | 0.00E+00 | 4.51E-141 |
| 65 | (10min, 0L, 15min A, 1000D) | 1.21E-255 | 0.00E+00 | 8.02E-156 |
| 66 | (15min, 0L, 15min A, 1000D) | 9.45E-56 | 0.00E+00 | 8.44E-137 |
| 67 | (5min, 1L, 15min A, 1000D) | 0.00E+00 | 0.00E+00 | 1.23E-154 |
| 68 | (10min, 1L, 15min A, 1000D) | 9.20E-86 | 0.00E+00 | 1.36E-144 |
| 69 | (15min, 1L, 15min A, 1000D) | 2.10E-132 | 0.00E+00 | 2.60E-140 |
| 70 | (5min, 2L, 15min A, 1000D) | 2.16E-03 | 0.00E+00 | 1.70E-130 |
| 71 | (10min, 2L, 15min A, 1000D) | 6.84E-296 | 0.00E+00 | 7.69E-154 |
| 72 | (15min, 2L, 15min A, 1000D) | 4.01E-199 | 0.00E+00 | 6.60E-154 |
| 73 | (5min, 0L, 20min A, 1000D) | 1.48E-161 | 0.00E+00 | 4.17E-144 |
| 74 | (10min, 0L, 20min A, 1000D) | 4.21E-50 | 0.00E+00 | 1.13E-139 |
| 75 | (15min, 0L, 20min A, 1000D) | 2.53E-59 | 0.00E+00 | 2.54E-132 |
| 76 | (5min, 1L, 20min A, 1000D) | 9.67E-23 | 0.00E+00 | 1.97E-130 |
| 77 | (10min, 1L, 20min A, 1000D) | 0.00E+00 | 0.00E+00 | 4.71E-172 |
| 78 | (15min, 1L, 20min A, 1000D) | 8.31E-36 | 0.00E+00 | 1.48E-132 |
| 79 | (5min, 2L, 20min A, 1000D) | 2.86E-160 | 0.00E+00 | 3.68E-143 |
| 80 | (10min, 2L, 20min A, 1000D) | 1.00E-01 | 7.32E-01 | 7.89E-01 |
| 81 | (15min, 2L, 20min A, 1000D) | 4.82E-80 | 0.00E+00 | 5.18E-152 |
| 82 | (5min, 0L, 10min A, 1250D) | 3.22E-166 | 0.00E+00 | 6.90E-151 |
| 83 | (10min, 0L, 10min A, 1250D) | 5.47E-80 | 0.00E+00 | 7.65E-133 |
| 84 | (15min, 0L, 10min A, 1250D) | 4.87E-03 | 0.00E+00 | 3.12E-127 |
| 85 | (5min, 1L, 10min A, 1250D) | 1.47E-02 | 0.00E+00 | 6.75E-126 |
| 86 | (10min, 1L, 10min A, 1250D) | 6.29E-21 | 0.00E+00 | 9.55E-121 |
| 87 | (15min, 1L, 10min A, 1250D) | 2.94E-03 | 0.00E+00 | 1.73E-128 |
| 88 | (5min, 2L, 10min A, 1250D) | 2.30E-12 | 2.32E-01 | 5.43E-01 |
| 89 | (10min, 2L, 10min A, 1250D) | 4.48E-282 | 0.00E+00 | 1.99E-136 |
| 90 | (15min, 2L, 10min A, 1250D) | 0.00E+00 | 0.00E+00 | 3.82E-175 |
| 91 | (5min, 0L, 15min A, 1250D) | 8.21E-81 | 0.00E+00 | 3.01E-152 |
| 92 | (10min, 0L, 15min A, 1250D) | 6.93E-220 | 0.00E+00 | 5.93E-153 |
| 93 | (15min, 0L, 15min A, 1250D) | 0.00E+00 | 0.00E+00 | 1.94E-157 |
| 94 | (5min, 1L, 15min A, 1250D) | 3.19E-277 | 0.00E+00 | 5.02E-148 |
| 95 | (10min, 1L, 15min A, 1250D) | 1.20E-80 | 0.00E+00 | 4.29E-146 |
| 96 | (15min, 1L, 15min A, 1250D) | 3.37E-158 | 0.00E+00 | 8.61E-145 |
| 97 | (5min, 2L, 15min A, 1250D) | 1.89E-01 | 0.00E+00 | 7.89E-130 |
| 98 | (10min, 2L, 15min A, 1250D) | 1.26E-252 | 0.00E+00 | 9.45E-153 |
| 99 | (15min, 2L, 15min A, 1250D) | 1.94E-97 | 0.00E+00 | 3.73E-148 |
| 100 | (5min, 0L, 20min A, 1250D) | 4.85E-94 | 0.00E+00 | 9.04E-138 |
| 101 | (10min, 0L, 20min A, 1250D) | 3.07E-35 | 0.00E+00 | 1.03E-137 |
| 102 | (15min, 0L, 20min A, 1250D) | 4.81E-166 | 0.00E+00 | 4.87E-142 |
| 103 | (5min, 1L, 20min A, 1250D) | 5.36E-116 | 0.00E+00 | 1.21E-139 |
| 104 | (10min, 1L, 20min A, 1250D) | 0.00E+00 | 0.00E+00 | 1.37E-174 |
| 105 | (15min, 1L, 20min A, 1250D) | 3.05E-139 | 0.00E+00 | 7.52E-145 |

Table D.1. P-values of the t test for the changes in networkwide measures of effectiveness when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 106 | (5min, 2L, 20min A, 1250D) | 4.53E-111 | 0.00E+00 | 5.00E-138 |
| 107 | (10min, 2L, 20min A, 1250D) | 4.71E-01 | 9.54E-01 | 8.34E-01 |
| 108 | (15min, 2L, 20min A, 1250D) | 2.62E-215 | 0.00E+00 | 1.34E-161 |
| 109 | (5min, 0L, 10min A, 1500D) | 7.55E-158 | 0.00E+00 | 1.91E-153 |
| 110 | (10min, 0L, 10min A, 1500D) | 4.30E-55 | 0.00E+00 | 9.78E-131 |
| 111 | (15min, 0L, 10min A, 1500D) | 2.02E-138 | 0.00E+00 | 3.86E-150 |
| 112 | (5min, 1L, 10min A, 1500D) | 6.84E-41 | 0.00E+00 | 2.68E-133 |
| 113 | (10min, 1L, 10min A, 1500D) | 3.69E-01 | 0.00E+00 | 4.25E-130 |
| 114 | (15min, 1L, 10min A, 1500D) | 6.94E-03 | 0.00E+00 | 3.57E-130 |
| 115 | (5min, 2L, 10min A, 1500D) | 4.72E-04 | 4.63E-01 | 7.54E-01 |
| 116 | (10min, 2L, 10min A, 1500D) | 0.00E+00 | 0.00E+00 | 3.83E-159 |
| 117 | (15min, 2L, 10min A, 1500D) | 0.00E+00 | 0.00E+00 | 1.60E-171 |
| 118 | (5min, 0L, 15min A, 1500D) | 1.68E-71 | 0.00E+00 | 6.33E-140 |
| 119 | (10min, 0L, 15min A, 1500D) | 1.72E-175 | 0.00E+00 | 5.57E-149 |
| 120 | (15min, 0L, 15min A, 1500D) | 7.42E-63 | 0.00E+00 | 1.31E-136 |
| 121 | (5min, 1L, 15min A, 1500D) | 0.00E+00 | 0.00E+00 | 1.88E-151 |
| 122 | (10min, 1L, 15min A, 1500D) | 3.89E-194 | 0.00E+00 | 1.18E-155 |
| 123 | (15min, 1L, 15min A, 1500D) | 8.29E-43 | 0.00E+00 | 1.92E-131 |
| 124 | (5min, 2L, 15min A, 1500D) | 1.19E-04 | 0.00E+00 | 3.56E-130 |
| 125 | (10min, 2L, 15min A, 1500D) | 2.18E-205 | 0.00E+00 | 5.76E-151 |
| 126 | (15min, 2L, 15min A, 1500D) | 1.49E-133 | 0.00E+00 | 9.01E-150 |
| 127 | (5min, 0L, 20min A, 1500D) | 1.78E-181 | 0.00E+00 | 3.70E-145 |
| 128 | (10min, 0L, 20min A, 1500D) | 1.34E-51 | 0.00E+00 | 2.24E-141 |
| 129 | (15min, 0L, 20min A, 1500D) | 3.93E-38 | 0.00E+00 | 3.44E-129 |
| 130 | (5min, 1L, 20min A, 1500D) | 7.52E-88 | 0.00E+00 | 2.36E-136 |
| 131 | (10min, 1L, 20min A, 1500D) | 0.00E+00 | 0.00E+00 | 7.29E-175 |
| 132 | (15min, 1L, 20min A, 1500D) | 3.89E-88 | 0.00E+00 | 7.18E-141 |
| 133 | (5min, 2L, 20min A, 1500D) | 2.72E-119 | 0.00E+00 | 4.19E-139 |
| 134 | (10min, 2L, 20min A, 1500D) | 6.26E-05 | 9.76E-01 | 8.42E-01 |
| 135 | (15min, 2L, 20min A, 1500D) | 2.43E-70 | 0.00E+00 | 5.12E-149 |
| 136 | (5min, 0L, 10min A, 1750D) | 2.55E-118 | 0.00E+00 | 5.93E-151 |
| 137 | (10min, 0L, 10min A, 1750D) | 1.05E-81 | 0.00E+00 | 2.10E-134 |
| 138 | (15min, 0L, 10min A, 1750D) | 3.88E-107 | 0.00E+00 | 4.78E-149 |
| 139 | (5min, 1L, 10min A, 1750D) | 6.17E-59 | 0.00E+00 | 3.31E-137 |
| 140 | (10min, 1L, 10min A, 1750D) | 7.07E-02 | 0.00E+00 | 4.35E-131 |
| 141 | (15min, 1L, 10min A, 1750D) | 5.22E-32 | 0.00E+00 | 2.66E-137 |
| 142 | (5min, 2L, 10min A, 1750D) | 4.81E-03 | 8.39E-01 | 7.62E-01 |
| 143 | (10min, 2L, 10min A, 1750D) | 1.08E-163 | 0.00E+00 | 1.03E-149 |
| 144 | (15min, 2L, 10min A, 1750D) | 0.00E+00 | 0.00E+00 | 2.36E-173 |
| 145 | (5min, 0L, 15min A, 1750D) | 9.48E-143 | 0.00E+00 | 9.03E-147 |
| 146 | (10min, 0L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 1.05E-159 |
| 147 | (15min, 0L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 3.36E-158 |
| 148 | (5min, 1L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 7.56E-157 |
| 149 | (10min, 1L, 15min A, 1750D) | 2.83E-93 | 0.00E+00 | 4.27E-146 |
| 150 | (15min, 1L, 15min A, 1750D) | 1.13E-29 | 0.00E+00 | 2.79E-129 |
| 151 | (5min, 2L, 15min A, 1750D) | 7.10E-06 | 0.00E+00 | 5.09E-133 |
| 152 | (10min, 2L, 15min A, 1750D) | 2.46E-260 | 0.00E+00 | 4.52E-154 |
| 153 | (15min, 2L, 15min A, 1750D) | 3.82E-149 | 0.00E+00 | 2.03E-149 |
| 154 | (5min, 0L, 20min A, 1750D) | 3.22E-261 | 0.00E+00 | 1.54E-150 |
| 155 | (10min, 0L, 20min A, 1750D) | 4.70E-41 | 0.00E+00 | 1.19E-138 |
| 156 | (15min, 0L, 20min A, 1750D) | 3.89E-233 | 0.00E+00 | 1.73E-145 |
| 157 | (5min, 1L, 20min A, 1750D) | 9.09E-112 | 0.00E+00 | 5.34E-141 |
| 158 | (10min, 1L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 5.53E-165 |
| 159 | (15min, 1L, 20min A, 1750D) | 6.80E-46 | 0.00E+00 | 6.55E-135 |
| 160 | (5min, 2L, 20min A, 1750D) | 1.55E-124 | 0.00E+00 | 1.54E-140 |

Table D.1. P-values of the t test for the changes in networkwide measures of effectiveness when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 161 | (10min, 2L, 20min A, 1750D) | 4.83E-09 | 3.94E-01 | 8.16E-01 |
| 162 | (15min, 2L, 20min A, 1750D) | 6.95E-119 | 0.00E+00 | 1.09E-157 |
| 163 | (5min, 0L, 10min A, 2000D) | 3.07E-126 | 0.00E+00 | 4.37E-149 |
| 164 | (10min, 0L, 10min A, 2000D) | 4.40E-71 | 0.00E+00 | 4.17E-132 |
| 165 | (15min, 0L, 10min A, 2000D) | 1.06E-44 | 0.00E+00 | 4.03E-142 |
| 166 | (5min, 1L, 10min A, 2000D) | 6.32E-44 | 0.00E+00 | 7.44E-136 |
| 167 | (10min, 1L, 10min A, 2000D) | 3.34E-42 | 0.00E+00 | 2.36E-140 |
| 168 | (15min, 1L, 10min A, 2000D) | 6.85E-03 | 0.00E+00 | 1.10E-132 |
| 169 | (5min, 2L, 10min A, 2000D) | 2.77E-01 | 9.56E-01 | 9.23E-01 |
| 165 | (10min, 2L, 10min A, 2000D) | 1.06E-44 | 0.00E+00 | 4.03E-142 |
| 170 | (15min, 2L, 10min A, 2000D) | 1.35E-208 | 0.00E+00 | 1.23E-152 |
| 171 | (5min, 0L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 6.84E-171 |
| 172 | (10min, 0L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 2.50E-165 |
| 173 | (15min, 0L, 15min A, 2000D) | 1.05E-82 | 0.00E+00 | 1.74E-142 |
| 174 | (5min, 2L, 10min A, 1500D) | 0.00E+00 | 0.00E+00 | 3.24E-157 |
| 175 | (5min, 1L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 3.59E-153 |
| 176 | (10min, 1L, 15min A, 2000D) | 1.01E-60 | 0.00E+00 | 1.17E-140 |
| 177 | (15min, 1L, 15min A, 2000D) | 4.02E-40 | 0.00E+00 | 4.09E-131 |
| 178 | (5min, 2L, 15min A, 2000D) | 6.37E-08 | 0.00E+00 | 4.97E-134 |
| 179 | (10min, 2L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 2.93E-157 |
| 180 | (15min, 2L, 15min A, 2000D) | 2.59E-156 | 0.00E+00 | 1.17E-150 |
| 181 | (5min, 0L, 20min A, 2000D) | 2.27E-139 | 0.00E+00 | 8.58E-141 |
| 182 | (10min, 0L, 20min A, 2000D) | 4.01E-58 | 0.00E+00 | 1.19E-141 |
| 183 | (15min, 0L, 20min A, 2000D) | 2.08E-261 | 0.00E+00 | 6.28E-149 |
| 184 | (5min, 1L, 20min A, 2000D) | 3.67E-73 | 0.00E+00 | 1.68E-135 |
| 185 | (10min, 1L, 20min A, 2000D) | 0.00E+00 | 0.00E+00 | 1.63E-171 |
| 186 | (15min, 1L, 20min A, 2000D) | 6.95E-88 | 0.00E+00 | 1.83E-139 |
| 187 | (5min, 2L, 20min A, 2000D) | 1.52E-139 | 0.00E+00 | 7.55E-141 |
| 188 | (10min, 2L, 20min A, 2000D) | 1.64E-01 | 7.42E-01 | 9.66E-01 |
| 189 | (15min, 2L, 20min A, 2000D) | 1.16E-84 | 0.00E+00 | 5.99E-151 |

Table D.2. P-values of the t test for the changes in measures of effectiveness for the local area before the incident when connected vehicles are introduced.

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 2.42E-17 | 3.74E-106 | 1.43E-15 |
| 2 | (10min, 0L, 10min A, 500D) | 1.11E-31 | 6.74E-80 | 8.97E-09 |
| 3 | (15min, 0L, 10min A, 500D) | 2.22E-20 | 2.38E-102 | 1.85E-08 |
| 4 | (5min, 1L, 10min A, 500D) | 6.89E-243 | 5.55E-100 | 4.96E-20 |
| 5 | (10min, 1L, 10min A, 500D) | 4.97E-34 | 1.17E-100 | 4.20E-17 |
| 6 | (15min, 1L, 10min A, 500D) | 1.05E-38 | 5.90E-103 | 1.73E-18 |
| 7 | (5min, 2L, 10min A, 500D) | 4.01E-28 | 3.39E-01 | 5.30E-01 |
| 8 | (10min, 2L, 10min A, 500D) | 0.00E+00 | 5.67E-89 | 5.37E-24 |
| 9 | (15min, 2L, 10min A, 500D) | 0.00E+00 | 1.07E-108 | 1.70E-45 |
| 10 | (5min, 0L, 15min A, 500D) | 1.11E-39 | 2.75E-100 | 2.90E-15 |
| 11 | (10min, 0L, 15min A, 500D) | 1.63E-53 | 1.51E-107 | 3.56E-18 |
| 12 | (15min, 0L, 15min A, 500D) | 3.41E-08 | 2.53E-106 | 3.67E-16 |
| 13 | (5min, 1L, 15min A, 500D) | 0.00E+00 | 4.90E-92 | 5.49E-31 |
| 14 | (10min, 1L, 15min A, 500D) | 0.00E+00 | 2.72E-109 | 1.53E-24 |
| 15 | (15min, 1L, 15min A, 500D) | 0.00E+00 | 6.72E-104 | 9.11E-28 |
| 16 | (5min, 2L, 15min A, 500D) | 1.87E-62 | 3.20E-95 | 6.04E-18 |
| 17 | (10min, 2L, 15min A, 500D) | 0.00E+00 | 2.51E-102 | 1.27E-29 |

Table D.2. P-values of the t test for the changes in measures of effectiveness for the local area before the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 18 | (15min, 2L, 15min A, 500D) | 2.64E-186 | 7.64E-90 | 8.72E-24 |
| 19 | (5min, 0L, 20min A, 500D) | 8.58E-202 | 1.40E-89 | 4.47E-20 |
| 20 | (10min, 0L, 20min A, 500D) | 3.59E-02 | 3.31E-91 | 6.20E-14 |
| 21 | (15min, 0L, 20min A, 500D) | 3.81E-250 | 8.17E-101 | 1.40E-24 |
| 22 | (5min, 1L, 20min A, 500D) | 0.00E+00 | 3.71E-94 | 5.85E-05 |
| 23 | (10min, 1L, 20min A, 500D) | 0.00E+00 | 1.28E-115 | 9.19E-31 |
| 24 | (15min, 1L, 20min A, 500D) | 1.45E-36 | 2.26E-96 | 3.49E-13 |
| 25 | (5min, 2L, 20min A, 500D) | 2.55E-286 | 2.03E-100 | 1.38E-19 |
| 26 | (10min, 2L, 20min A, 500D) | 2.04E-38 | 5.37E-01 | 4.64E-01 |
| 27 | (15min, 2L, 20min A, 500D) | 0.00E+00 | 5.06E-101 | 6.67E-24 |
| 28 | (5min, 0L, 10min A, 750D) | 2.26E-05 | 1.77E-133 | 1.24E-18 |
| 29 | (10min, 0L, 10min A, 750D) | 6.96E-02 | 5.03E-127 | 1.49E-15 |
| 30 | (15min, 0L, 10min A, 750D) | 8.83E-03 | 2.67E-140 | 1.90E-20 |
| 31 | (5min, 1L, 10min A, 750D) | 2.34E-02 | 8.00E-128 | 5.24E-18 |
| 32 | (10min, 1L, 10min A, 750D) | 7.20E-03 | 2.05E-122 | 1.48E-19 |
| 33 | (15min, 1L, 10min A, 750D) | 2.43E-26 | 5.85E-139 | 2.29E-21 |
| 34 | (5min, 2L, 10min A, 750D) | 1.83E-03 | 9.18E-01 | 4.71E-01 |
| 35 | (10min, 2L, 10min A, 750D) | 0.00E+00 | 6.34E-136 | 1.81E-36 |
| 36 | (15min, 2L, 10min A, 750D) | 0.00E+00 | 5.68E-141 | 3.64E-51 |
| 37 | (5min, 0L, 15min A, 750D) | 6.81E-170 | 1.94E-159 | 3.36E-27 |
| 38 | (10min, 0L, 15min A, 750D) | 0.00E+00 | 3.67E-161 | 1.72E-33 |
| 39 | (15min, 0L, 15min A, 750D) | 5.20E-02 | 1.04E-137 | 3.85E-17 |
| 40 | (5min, 1L, 15min A, 750D) | 0.00E+00 | 3.90E-143 | 1.27E-39 |
| 41 | (10min, 1L, 15min A, 750D) | 0.00E+00 | 7.12E-148 | 1.23E-29 |
| 42 | (15min, 1L, 15min A, 750D) | 0.00E+00 | 1.01E-142 | 7.29E-39 |
| 43 | (5min, 2L, 15min A, 750D) | 5.70E-204 | 2.92E-146 | 3.47E-27 |
| 44 | (10min, 2L, 15min A, 750D) | 0.00E+00 | 5.65E-144 | 2.81E-35 |
| 45 | (15min, 2L, 15min A, 750D) | 0.00E+00 | 3.14E-175 | 2.84E-39 |
| 46 | (5min, 0L, 20min A, 750D) | 3.77E-33 | 3.65E-127 | 4.74E-22 |
| 47 | (10min, 0L, 20min A, 750D) | 1.62E-217 | 1.22E-159 | 9.16E-29 |
| 48 | (15min, 0L, 20min A, 750D) | 3.06E-288 | 9.51E-126 | 2.77E-30 |
| 49 | (5min, 1L, 20min A, 750D) | 4.22E-22 | 1.14E-118 | 1.22E-18 |
| 50 | (10min, 1L, 20min A, 750D) | 0.00E+00 | 9.13E-145 | 4.69E-58 |
| 51 | (15min, 1L, 20min A, 750D) | 2.96E-80 | 5.09E-141 | 4.76E-20 |
| 52 | (5min, 2L, 20min A, 750D) | 8.28E-186 | 3.36E-147 | 1.84E-25 |
| 53 | (10min, 2L, 20min A, 750D) | 4.64E-34 | 9.66E-01 | 5.92E-01 |
| 54 | (15min, 2L, 20min A, 750D) | 0.00E+00 | 2.47E-163 | 1.69E-34 |
| 55 | (5min, 0L, 10min A, 1000D) | 5.58E-80 | 3.42E-195 | 5.61E-31 |
| 56 | (10min, 0L, 10min A, 1000D) | 1.04E-208 | 9.26E-179 | 7.06E-31 |
| 57 | (15min, 0L, 10min A, 1000D) | 9.33E-31 | 7.16E-191 | 3.27E-18 |
| 58 | (5min, 1L, 10min A, 1000D) | 1.81E-270 | 3.84E-186 | 2.16E-32 |
| 59 | (10min, 1L, 10min A, 1000D) | 2.92E-11 | 1.35E-193 | 3.35E-29 |
| 60 | (15min, 1L, 10min A, 1000D) | 0.00E+00 | 2.13E-203 | 1.37E-36 |
| 61 | (5min, 2L, 10min A, 1000D) | 8.24E-31 | 6.13E-01 | 6.72E-01 |
| 62 | (10min, 2L, 10min A, 1000D) | 0.00E+00 | 1.52E-166 | 4.56E-39 |
| 63 | (15min, 2L, 10min A, 1000D) | 0.00E+00 | 3.35E-205 | 1.92E-60 |
| 64 | (5min, 0L, 15min A, 1000D) | 1.18E-25 | 3.05E-200 | 9.36E-30 |
| 65 | (10min, 0L, 15min A, 1000D) | 0.00E+00 | 1.24E-204 | 5.14E-38 |
| 66 | (15min, 0L, 15min A, 1000D) | 2.47E-04 | 4.58E-205 | 5.33E-26 |
| 67 | (5min, 1L, 15min A, 1000D) | 0.00E+00 | 2.70E-192 | 2.64E-42 |
| 68 | (10min, 1L, 15min A, 1000D) | 2.57E-57 | 5.68E-215 | 2.76E-28 |
| 69 | (15min, 1L, 15min A, 1000D) | 0.00E+00 | 2.87E-210 | 2.32E-42 |
| 70 | (5min, 2L, 15min A, 1000D) | 1.09E-12 | 3.42E-189 | 5.51E-31 |
| 71 | (10min, 2L, 15min A, 1000D) | 0.00E+00 | 3.48E-207 | 2.99E-41 |
| 72 | (15min, 2L, 15min A, 1000D) | 0.00E+00 | 1.05E-192 | 3.62E-39 |
| 73 | (5min, 0L, 20min A, 1000D) | 1.41E-257 | 2.36E-195 | 3.10E-34 |
| 74 | (10min, 0L, 20min A, 1000D) | 4.88E-44 | 5.69E-205 | 8.05E-28 |
| 75 | (15min, 0L, 20min A, 1000D) | 1.22E-30 | 3.50E-178 | 3.34E-26 |
| 76 | (5min, 1L, 20min A, 1000D) | 6.59E-42 | 5.94E-198 | 1.76E-27 |
| 77 | (10min, 1L, 20min A, 1000D) | 0.00E+00 | 5.59E-228 | 4.61E-65 |
| 78 | (15min, 1L, 20min A, 1000D) | 4.67E-46 | 2.98E-217 | 9.87E-26 |
| 79 | (5min, 2L, 20min A, 1000D) | 0.00E+00 | 2.40E-208 | 5.56E-35 |
| 80 | (10min, 2L, 20min A, 1000D) | 6.30E-01 | 8.16E-01 | 9.25E-01 |

Table D.2. P-values of the t test for the changes in measures of effectiveness for the local area before the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 81 | (15min, 2L, 20min A, 1000D) | 3.33E-194 | 9.10E-202 | 2.74E-37 |
| 82 | (5min, 0L, 10min A, 1250D) | 2.10E-91 | 1.03E-270 | 4.09E-35 |
| 83 | (10min, 0L, 10min A, 1250D) | 6.28E-114 | 8.52E-243 | 1.70E-35 |
| 84 | (15min, 0L, 10min A, 1250D) | 1.69E-04 | 4.04E-282 | 2.99E-26 |
| 85 | (5min, 1L, 10min A, 1250D) | 1.25E-154 | 2.06E-239 | 6.30E-23 |
| 86 | (10min, 1L, 10min A, 1250D) | 1.21E-301 | 2.39E-239 | 1.58E-19 |
| 87 | (15min, 1L, 10min A, 1250D) | 3.52E-16 | 2.02E-234 | 9.31E-30 |
| 88 | (5min, 2L, 10min A, 1250D) | 3.72E-16 | 5.46E-01 | 7.53E-01 |
| 89 | (10min, 2L, 10min A, 1250D) | 0.00E+00 | 3.57E-220 | 2.23E-45 |
| 90 | (15min, 2L, 10min A, 1250D) | 0.00E+00 | 4.84E-285 | 2.74E-67 |
| 91 | (5min, 0L, 15min A, 1250D) | 1.81E-213 | 1.22E-05 | 8.36E-37 |
| 92 | (10min, 0L, 15min A, 1250D) | 0.00E+00 | 6.03E-255 | 2.25E-42 |
| 93 | (15min, 0L, 15min A, 1250D) | 0.00E+00 | 5.41E-289 | 5.97E-47 |
| 94 | (5min, 1L, 15min A, 1250D) | 0.00E+00 | 2.08E-238 | 4.93E-51 |
| 95 | (10min, 1L, 15min A, 1250D) | 5.28E-67 | 9.51E-291 | 1.20E-33 |
| 96 | (15min, 1L, 15min A, 1250D) | 0.00E+00 | 7.16E-268 | 9.89E-48 |
| 97 | (5min, 2L, 15min A, 1250D) | 1.74E-02 | 3.74E-231 | 8.54E-34 |
| 98 | (10min, 2L, 15min A, 1250D) | 0.00E+00 | 4.59E-270 | 2.30E-48 |
| 99 | (15min, 2L, 15min A, 1250D) | 5.79E-163 | 9.05E-240 | 1.29E-41 |
| 100 | (5min, 0L, 20min A, 1250D) | 6.26E-118 | 3.63E-235 | 2.14E-35 |
| 101 | (10min, 0L, 20min A, 1250D) | 3.83E-23 | 8.38E-251 | 9.29E-34 |
| 102 | (15min, 0L, 20min A, 1250D) | 9.31E-300 | 8.13E-242 | 6.71E-42 |
| 103 | (5min, 1L, 20min A, 1250D) | 0.00E+00 | 3.20E-275 | 4.98E-40 |
| 104 | (10min, 1L, 20min A, 1250D) | 0.00E+00 | 2.93E-302 | 4.11E-72 |
| 105 | (15min, 1L, 20min A, 1250D) | 0.00E+00 | 4.45E-287 | 3.30E-46 |
| 106 | (5min, 2L, 20min A, 1250D) | 1.60E-260 | 2.02E-259 | 1.01E-39 |
| 107 | (10min, 2L, 20min A, 1250D) | 2.10E-01 | 5.77E-01 | 9.70E-01 |
| 108 | (15min, 2L, 20min A, 1250D) | 0.00E+00 | 1.20E-267 | 6.66E-46 |
| 109 | (5min, 0L, 10min A, 1500D) | 3.70E-68 | 0.00E+00 | 7.06E-42 |
| 110 | (10min, 0L, 10min A, 1500D) | 3.23E-17 | 6.85E-288 | 9.63E-37 |
| 111 | (15min, 0L, 10min A, 1500D) | 4.12E-202 | 0.00E+00 | 4.26E-49 |
| 112 | (5min, 1L, 10min A, 1500D) | 7.31E-153 | 1.88E-307 | 4.24E-43 |
| 113 | (10min, 1L, 10min A, 1500D) | 1.09E-05 | 0.00E+00 | 3.73E-39 |
| 114 | (15min, 1L, 10min A, 1500D) | 8.73E-01 | 0.00E+00 | 1.14E-37 |
| 115 | (5min, 2L, 10min A, 1500D) | 1.39E-01 | 7.25E-01 | 8.26E-01 |
| 116 | (10min, 2L, 10min A, 1500D) | 0.00E+00 | 0.00E+00 | 3.93E-58 |
| 117 | (15min, 2L, 10min A, 1500D) | 0.00E+00 | 0.00E+00 | 1.23E-71 |
| 118 | (5min, 0L, 15min A, 1500D) | 1.20E-67 | 0.00E+00 | 1.72E-44 |
| 119 | (10min, 0L, 15min A, 1500D) | 9.27E-247 | 2.05E-303 | 6.61E-48 |
| 120 | (15min, 0L, 15min A, 1500D) | 2.58E-01 | 0.00E+00 | 1.94E-35 |
| 121 | (5min, 1L, 15min A, 1500D) | 0.00E+00 | 1.89E-302 | 1.67E-54 |
| 122 | (10min, 1L, 15min A, 1500D) | 0.00E+00 | 0.00E+00 | 6.01E-51 |
| 123 | (15min, 1L, 15min A, 1500D) | 1.47E-49 | 0.00E+00 | 6.34E-41 |
| 124 | (5min, 2L, 15min A, 1500D) | 8.15E-04 | 9.90E-291 | 1.67E-40 |
| 125 | (10min, 2L, 15min A, 1500D) | 0.00E+00 | 0.00E+00 | 2.07E-50 |
| 126 | (15min, 2L, 15min A, 1500D) | 0.00E+00 | 4.62E-304 | 2.34E-53 |
| 127 | (5min, 0L, 20min A, 1500D) | 3.57E-259 | 0.00E+00 | 4.85E-47 |
| 128 | (10min, 0L, 20min A, 1500D) | 2.51E-21 | 0.00E+00 | 8.88E-41 |
| 129 | (15min, 0L, 20min A, 1500D) | 1.00E-26 | 2.74E-303 | 4.43E-37 |
| 130 | (5min, 1L, 20min A, 1500D) | 5.38E-268 | 0.00E+00 | 7.32E-43 |
| 131 | (10min, 1L, 20min A, 1500D) | 0.00E+00 | 0.00E+00 | 1.03E-81 |
| 132 | (15min, 1L, 20min A, 1500D) | 3.46E-264 | 0.00E+00 | 2.07E-42 |
| 133 | (5min, 2L, 20min A, 1500D) | 0.00E+00 | 0.00E+00 | 4.24E-47 |
| 134 | (10min, 2L, 20min A, 1500D) | 1.69E-43 | 3.40E-01 | 4.22E-01 |
| 135 | (15min, 2L, 20min A, 1500D) | 6.72E-112 | 0.00E+00 | 3.35E-45 |
| 136 | (5min, 0L, 10min A, 1750D) | 4.89E-44 | 0.00E+00 | 3.40E-49 |
| 137 | (10min, 0L, 10min A, 1750D) | 3.82E-96 | 0.00E+00 | 2.11E-45 |
| 138 | (15min, 0L, 10min A, 1750D) | 1.64E-228 | 0.00E+00 | 2.80E-54 |
| 139 | (5min, 1L, 10min A, 1750D) | 1.08E-101 | 0.00E+00 | 1.16E-48 |
| 140 | (10min, 1L, 10min A, 1750D) | 8.13E-15 | 0.00E+00 | 1.26E-46 |
| 141 | (15min, 1L, 10min A, 1750D) | 3.28E-27 | 0.00E+00 | 1.80E-44 |
| 142 | (5min, 2L, 10min A, 1750D) | 7.59E-15 | 6.66E-01 | 7.49E-01 |
| 143 | (10min, 2L, 10min A, 1750D) | 0.00E+00 | 0.00E+00 | 4.34E-59 |

Table D.2. P-values of the t test for the changes in measures of effectiveness for the local area before the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (Network) | Mean Flow (Network) | Mean Density (Network) |
|---|---|---|---|---|
| 144 | (15min, 2L, 10min A, 1750D) | 0.00E+00 | 0.00E+00 | 5.33E-75 |
| 145 | (5min, 0L, 15min A, 1750D) | 1.04E-157 | 0.00E+00 | 1.51E-53 |
| 146 | (10min, 0L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 3.13E-60 |
| 147 | (15min, 0L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 3.68E-58 |
| 148 | (5min, 1L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 4.69E-67 |
| 149 | (10min, 1L, 15min A, 1750D) | 3.15E-90 | 0.00E+00 | 8.08E-47 |
| 150 | (15min, 1L, 15min A, 1750D) | 1.19E-78 | 0.00E+00 | 7.87E-51 |
| 151 | (5min, 2L, 15min A, 1750D) | 2.48E-02 | 0.00E+00 | 1.22E-46 |
| 152 | (10min, 2L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 1.95E-60 |
| 153 | (15min, 2L, 15min A, 1750D) | 0.00E+00 | 0.00E+00 | 4.11E-58 |
| 154 | (5min, 0L, 20min A, 1750D) | 3.29E-296 | 0.00E+00 | 1.10E-53 |
| 155 | (10min, 0L, 20min A, 1750D) | 2.59E-35 | 0.00E+00 | 1.29E-45 |
| 156 | (15min, 0L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 4.31E-58 |
| 157 | (5min, 1L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 4.38E-52 |
| 158 | (10min, 1L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 2.72E-76 |
| 159 | (15min, 1L, 20min A, 1750D) | 9.54E-133 | 0.00E+00 | 3.77E-46 |
| 160 | (5min, 2L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 1.15E-53 |
| 161 | (10min, 2L, 20min A, 1750D) | 7.90E-39 | 9.79E-02 | 5.51E-01 |
| 162 | (15min, 2L, 20min A, 1750D) | 0.00E+00 | 0.00E+00 | 3.29E-58 |
| 163 | (5min, 0L, 10min A, 2000D) | 2.67E-57 | 0.00E+00 | 2.05E-55 |
| 164 | (10min, 0L, 10min A, 2000D) | 2.59E-91 | 0.00E+00 | 6.51E-53 |
| 165 | (15min, 0L, 10min A, 2000D) | 8.89E-93 | 0.00E+00 | 2.09E-57 |
| 166 | (5min, 1L, 10min A, 2000D) | 9.07E-49 | 0.00E+00 | 8.60E-53 |
| 167 | (10min, 1L, 10min A, 2000D) | 1.44E-265 | 0.00E+00 | 8.37E-61 |
| 168 | (15min, 1L, 10min A, 2000D) | 4.21E-03 | 0.00E+00 | 1.80E-47 |
| 169 | (5min, 2L, 10min A, 2000D) | 3.70E-03 | 8.13E-01 | 8.10E-01 |
| 170 | (10min, 2L, 10min A, 2000D) | 0.00E+00 | 0.00E+00 | 4.52E-66 |
| 171 | (15min, 2L, 10min A, 2000D) | 0.00E+00 | 0.00E+00 | 9.61E-83 |
| 172 | (5min, 0L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 1.17E-66 |
| 173 | (10min, 0L, 15min A, 2000D) | 2.09E-36 | 0.00E+00 | 3.56E-50 |
| 174 | (15min, 0L, 15min A, 2000D) | 1.42E-287 | 0.00E+00 | 4.50E-64 |
| 175 | (5min, 1L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 1.15E-71 |
| 176 | (10min, 1L, 15min A, 2000D) | 2.34E-157 | 0.00E+00 | 3.13E-55 |
| 177 | (15min, 1L, 15min A, 2000D) | 2.48E-62 | 0.00E+00 | 7.35E-56 |
| 178 | (5min, 2L, 15min A, 2000D) | 7.48E-04 | 0.00E+00 | 2.20E-52 |
| 179 | (10min, 2L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 6.31E-68 |
| 180 | (15min, 2L, 15min A, 2000D) | 0.00E+00 | 0.00E+00 | 8.59E-67 |
| 181 | (5min, 0L, 20min A, 2000D) | 3.27E-202 | 0.00E+00 | 2.71E-57 |
| 182 | (10min, 0L, 20min A, 2000D) | 2.46E-14 | 0.00E+00 | 3.20E-50 |
| 183 | (15min, 0L, 20min A, 2000D) | 0.00E+00 | 0.00E+00 | 1.85E-66 |
| 184 | (5min, 1L, 20min A, 2000D) | 1.75E-157 | 0.00E+00 | 2.52E-54 |
| 185 | (10min, 1L, 20min A, 2000D) | 0.00E+00 | 0.00E+00 | 3.95E-87 |
| 186 | (15min, 1L, 20min A, 2000D) | 3.79E-209 | 0.00E+00 | 1.97E-52 |
| 187 | (5min, 2L, 20min A, 2000D) | 0.00E+00 | 0.00E+00 | 2.64E-61 |
| 188 | (10min, 2L, 20min A, 2000D) | 7.19E-12 | 2.45E-01 | 6.61E-01 |
| 189 | (15min, 2L, 20min A, 2000D) | 3.86E-234 | 0.00E+00 | 2.40E-62 |

Table D.3. P-values of the t test for the changes in measures of effectiveness for the local area after the incident when connected vehicles are introduced.

| Scenario ID | Scenario Parameters | Mean Speed (After Incident) | Mean Flow (After Incident) | Mean Density (After Incident) |
|---|---|---|---|---|
| 1 | (5min, 0L, 10min A, 500D) | 2.44E-45 | 3.33E-102 | 1.45E-16 |
| 2 | (10min, 0L, 10min A, 500D) | 1.15E-01 | 4.91E-80 | 2.91E-12 |

Table D.3. P-values of the t test for the changes in measures of effectiveness for the local area after the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (After Incident) | Mean Flow (After Incident) | Mean Density (After Incident) |
|---|---|---|---|---|
| 3 | (15min, 0L, 10min A, 500D) | 5.31E-03 | 3.89E-102 | 2.75E-12 |
| 4 | (5min, 1L, 10min A, 500D) | 4.05E-17 | 8.09E-97 | 2.33E-17 |
| 5 | (10min, 1L, 10min A, 500D) | 5.06E-21 | 2.38E-95 | 2.68E-12 |
| 6 | (15min, 1L, 10min A, 500D) | 2.46E-01 | 3.84E-105 | 2.18E-15 |
| 7 | (5min, 2L, 10min A, 500D) | 1.22E-07 | 7.39E-01 | 4.05E-01 |
| 8 | (10min, 2L, 10min A, 500D) | 4.34E-07 | 4.95E-93 | 1.62E-13 |
| 9 | (15min, 2L, 10min A, 500D) | 2.17E-52 | 3.51E-97 | 6.94E-16 |
| 10 | (5min, 0L, 15min A, 500D) | 3.78E-34 | 4.15E-95 | 4.08E-16 |
| 11 | (10min, 0L, 15min A, 500D) | 1.15E-16 | 2.06E-89 | 3.48E-14 |
| 12 | (15min, 0L, 15min A, 500D) | 9.62E-11 | 4.25E-111 | 2.64E-12 |
| 13 | (5min, 1L, 15min A, 500D) | 7.02E-08 | 5.37E-76 | 1.26E-13 |
| 14 | (10min, 1L, 15min A, 500D) | 6.73E-21 | 5.32E-100 | 6.99E-17 |
| 15 | (15min, 1L, 15min A, 500D) | 2.81E-01 | 2.31E-88 | 2.08E-18 |
| 16 | (5min, 2L, 15min A, 500D) | 2.57E-04 | 3.60E-78 | 1.91E-13 |
| 17 | (10min, 2L, 15min A, 500D) | 1.04E-23 | 1.50E-90 | 3.58E-15 |
| 18 | (15min, 2L, 15min A, 500D) | 4.58E-25 | 3.45E-86 | 2.05E-11 |
| 19 | (5min, 0L, 20min A, 500D) | 7.84E-94 | 4.37E-85 | 9.97E-16 |
| 20 | (10min, 0L, 20min A, 500D) | 2.58E-14 | 1.11E-105 | 8.00E-14 |
| 21 | (15min, 0L, 20min A, 500D) | 2.44E-05 | 2.17E-108 | 4.56E-14 |
| 22 | (5min, 1L, 20min A, 500D) | 3.43E-19 | 1.03E-88 | 1.03E-11 |
| 23 | (10min, 1L, 20min A, 500D) | 3.64E-32 | 4.50E-96 | 1.39E-09 |
| 24 | (15min, 1L, 20min A, 500D) | 8.77E-01 | 1.09E-110 | 2.35E-16 |
| 25 | (5min, 2L, 20min A, 500D) | 1.25E-12 | 4.11E-85 | 7.51E-16 |
| 26 | (10min, 2L, 20min A, 500D) | 1.04E-16 | 7.81E-01 | 5.66E-01 |
| 27 | (15min, 2L, 20min A, 500D) | 3.66E-01 | 1.41E-97 | 6.90E-17 |
| 28 | (5min, 0L, 10min A, 750D) | 6.37E-02 | 6.69E-134 | 1.94E-23 |
| 29 | (10min, 0L, 10min A, 750D) | 1.56E-02 | 3.91E-132 | 1.39E-22 |
| 30 | (15min, 0L, 10min A, 750D) | 7.47E-40 | 7.42E-141 | 5.07E-19 |
| 31 | (5min, 1L, 10min A, 750D) | 1.21E-36 | 5.73E-121 | 4.40E-20 |
| 32 | (10min, 1L, 10min A, 750D) | 1.15E-28 | 1.37E-122 | 1.82E-17 |
| 33 | (15min, 1L, 10min A, 750D) | 3.61E-01 | 2.18E-148 | 4.92E-23 |
| 34 | (5min, 2L, 10min A, 750D) | 7.25E-13 | 1.83E-01 | 8.33E-01 |
| 35 | (10min, 2L, 10min A, 750D) | 5.45E-02 | 4.36E-135 | 1.80E-26 |
| 36 | (15min, 2L, 10min A, 750D) | 9.62E-06 | 2.06E-144 | 1.48E-28 |
| 37 | (5min, 0L, 15min A, 750D) | 1.10E-63 | 5.28E-145 | 6.23E-28 |
| 38 | (10min, 0L, 15min A, 750D) | 5.70E-43 | 1.64E-158 | 1.72E-29 |
| 39 | (15min, 0L, 15min A, 750D) | 2.36E-01 | 1.05E-149 | 2.76E-20 |
| 40 | (5min, 1L, 15min A, 750D) | 2.35E-34 | 2.05E-108 | 2.43E-26 |
| 41 | (10min, 1L, 15min A, 750D) | 1.96E-04 | 1.26E-126 | 6.88E-22 |
| 42 | (15min, 1L, 15min A, 750D) | 4.28E-20 | 5.05E-112 | 7.31E-23 |
| 43 | (5min, 2L, 15min A, 750D) | 4.65E-45 | 3.46E-133 | 5.54E-27 |
| 44 | (10min, 2L, 15min A, 750D) | 8.28E-21 | 2.08E-135 | 1.92E-24 |
| 45 | (15min, 2L, 15min A, 750D) | 1.61E-82 | 1.52E-159 | 1.32E-30 |
| 46 | (5min, 0L, 20min A, 750D) | 1.49E-05 | 3.31E-120 | 9.47E-25 |
| 47 | (10min, 0L, 20min A, 750D) | 7.09E-06 | 1.60E-148 | 1.34E-21 |
| 48 | (15min, 0L, 20min A, 750D) | 9.51E-01 | 4.55E-153 | 2.40E-24 |
| 49 | (5min, 1L, 20min A, 750D) | 9.51E-83 | 1.25E-95 | 4.60E-19 |
| 50 | (10min, 1L, 20min A, 750D) | 1.18E-103 | 1.30E-100 | 5.07E-23 |
| 51 | (15min, 1L, 20min A, 750D) | 2.22E-02 | 2.02E-135 | 1.51E-18 |
| 52 | (5min, 2L, 20min A, 750D) | 1.24E-02 | 5.33E-125 | 1.39E-20 |
| 53 | (10min, 2L, 20min A, 750D) | 3.29E-07 | 5.33E-01 | 9.46E-01 |
| 54 | (15min, 2L, 20min A, 750D) | 1.84E-13 | 4.19E-156 | 4.06E-30 |
| 55 | (5min, 0L, 10min A, 1000D) | 1.77E-05 | 2.95E-187 | 2.54E-33 |
| 56 | (10min, 0L, 10min A, 1000D) | 3.87E-08 | 2.09E-188 | 1.31E-31 |
| 57 | (15min, 0L, 10min A, 1000D) | 1.42E-15 | 1.26E-198 | 1.26E-27 |
| 58 | (5min, 1L, 10min A, 1000D) | 2.16E-03 | 6.44E-165 | 1.53E-34 |
| 59 | (10min, 1L, 10min A, 1000D) | 4.82E-13 | 2.48E-175 | 1.50E-26 |
| 60 | (15min, 1L, 10min A, 1000D) | 2.90E-07 | 1.35E-190 | 1.84E-34 |
| 61 | (5min, 2L, 10min A, 1000D) | 2.77E-17 | 7.87E-02 | 2.63E-01 |
| 62 | (10min, 2L, 10min A, 1000D) | 1.24E-04 | 3.34E-165 | 1.57E-30 |

Table D.3. P-values of the t test for the changes in measures of effectiveness for the local area after the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (After Incident) | Mean Flow (After Incident) | Mean Density (After Incident) |
|---|---|---|---|---|
| 63 | (15min, 2L, 10min A, 1000D) | 6.12E-08 | 1.52E-193 | 3.32E-39 |
| 64 | (5min, 0L, 15min A, 1000D) | 2.01E-06 | 1.09E-177 | 7.68E-33 |
| 65 | (10min, 0L, 15min A, 1000D) | 2.22E-26 | 3.55E-206 | 5.17E-37 |
| 66 | (15min, 0L, 15min A, 1000D) | 2.47E-10 | 9.02E-220 | 4.10E-34 |
| 67 | (5min, 1L, 15min A, 1000D) | 5.80E-14 | 4.25E-158 | 5.30E-34 |
| 68 | (10min, 1L, 15min A, 1000D) | 5.54E-04 | 1.18E-213 | 4.91E-31 |
| 69 | (15min, 1L, 15min A, 1000D) | 4.82E-02 | 3.91E-178 | 5.29E-32 |
| 70 | (5min, 2L, 15min A, 1000D) | 9.16E-01 | 2.38E-162 | 3.28E-31 |
| 71 | (10min, 2L, 15min A, 1000D) | 1.17E-25 | 7.93E-197 | 7.79E-35 |
| 72 | (15min, 2L, 15min A, 1000D) | 1.68E-06 | 1.45E-193 | 3.85E-36 |
| 73 | (5min, 0L, 20min A, 1000D) | 1.14E-28 | 1.60E-174 | 5.91E-35 |
| 74 | (10min, 0L, 20min A, 1000D) | 3.07E-09 | 8.22E-217 | 8.25E-33 |
| 75 | (15min, 0L, 20min A, 1000D) | 1.24E-01 | 9.19E-191 | 1.53E-29 |
| 76 | (5min, 1L, 20min A, 1000D) | 7.26E-01 | 1.99E-164 | 1.84E-29 |
| 77 | (10min, 1L, 20min A, 1000D) | 1.35E-13 | 3.83E-173 | 2.42E-33 |
| 78 | (15min, 1L, 20min A, 1000D) | 1.47E-01 | 4.75E-213 | 3.00E-32 |
| 79 | (5min, 2L, 20min A, 1000D) | 4.90E-04 | 4.62E-165 | 1.37E-31 |
| 80 | (10min, 2L, 20min A, 1000D) | 6.91E-02 | 5.90E-01 | 7.67E-01 |
| 81 | (15min, 2L, 20min A, 1000D) | 2.42E-02 | 5.24E-200 | 8.45E-35 |
| 82 | (5min, 0L, 10min A, 1250D) | 3.11E-36 | 1.10E-247 | 4.09E-44 |
| 83 | (10min, 0L, 10min A, 1250D) | 2.55E-11 | 9.45E-222 | 2.52E-37 |
| 84 | (15min, 0L, 10min A, 1250D) | 1.12E-02 | 4.55E-255 | 4.85E-35 |
| 85 | (5min, 1L, 10min A, 1250D) | 4.07E-13 | 8.99E-230 | 1.69E-35 |
| 86 | (10min, 1L, 10min A, 1250D) | 7.03E-10 | 6.54E-267 | 4.20E-32 |
| 87 | (15min, 1L, 10min A, 1250D) | 3.56E-01 | 1.11E-255 | 2.41E-36 |
| 88 | (5min, 2L, 10min A, 1250D) | 1.55E-05 | 4.78E-01 | 7.19E-01 |
| 89 | (10min, 2L, 10min A, 1250D) | 4.10E-12 | 9.24E-191 | 4.93E-38 |
| 90 | (15min, 2L, 10min A, 1250D) | 4.22E-53 | 2.33E-255 | 5.06E-47 |
| 91 | (5min, 0L, 15min A, 1250D) | 1.86E-11 | 2.85E-58 | 7.29E-41 |
| 92 | (10min, 0L, 15min A, 1250D) | 1.59E-14 | 3.96E-243 | 6.81E-41 |
| 93 | (15min, 0L, 15min A, 1250D) | 5.43E-62 | 1.16E-294 | 7.18E-45 |
| 94 | (5min, 1L, 15min A, 1250D) | 1.81E-12 | 7.16E-190 | 5.10E-39 |
| 95 | (10min, 1L, 15min A, 1250D) | 3.60E-12 | 5.66E-271 | 3.55E-38 |
| 96 | (15min, 1L, 15min A, 1250D) | 2.14E-03 | 1.03E-224 | 2.21E-37 |
| 97 | (5min, 2L, 15min A, 1250D) | 5.38E-02 | 1.68E-210 | 1.45E-38 |
| 98 | (10min, 2L, 15min A, 1250D) | 9.88E-32 | 4.39E-246 | 1.51E-41 |
| 99 | (15min, 2L, 15min A, 1250D) | 3.27E-05 | 1.75E-250 | 4.88E-41 |
| 100 | (5min, 0L, 20min A, 1250D) | 6.59E-23 | 3.07E-194 | 5.46E-39 |
| 101 | (10min, 0L, 20min A, 1250D) | 6.86E-21 | 6.00E-272 | 1.33E-37 |
| 102 | (15min, 0L, 20min A, 1250D) | 6.14E-07 | 1.14E-246 | 1.64E-39 |
| 103 | (5min, 1L, 20min A, 1250D) | 1.10E-07 | 2.70E-210 | 1.15E-40 |
| 104 | (10min, 1L, 20min A, 1250D) | 9.42E-19 | 3.99E-220 | 1.55E-38 |
| 105 | (15min, 1L, 20min A, 1250D) | 8.60E-02 | 2.03E-234 | 5.32E-45 |
| 106 | (5min, 2L, 20min A, 1250D) | 9.87E-06 | 8.29E-203 | 2.72E-37 |
| 107 | (10min, 2L, 20min A, 1250D) | 7.60E-01 | 9.28E-01 | 7.85E-01 |
| 108 | (15min, 2L, 20min A, 1250D) | 2.13E-16 | 2.66E-250 | 4.55E-44 |
| 109 | (5min, 0L, 10min A, 1500D) | 2.86E-56 | 8.57E-299 | 3.86E-51 |
| 110 | (10min, 0L, 10min A, 1500D) | 4.39E-24 | 6.99E-276 | 2.59E-46 |
| 111 | (15min, 0L, 10min A, 1500D) | 1.35E-23 | 0.00E+00 | 5.39E-49 |
| 112 | (5min, 1L, 10min A, 1500D) | 2.90E-02 | 1.79E-236 | 1.26E-44 |
| 113 | (10min, 1L, 10min A, 1500D) | 1.08E-04 | 3.32E-277 | 2.40E-39 |
| 114 | (15min, 1L, 10min A, 1500D) | 2.31E-01 | 5.77E-293 | 2.51E-40 |
| 115 | (5min, 2L, 10min A, 1500D) | 1.10E-01 | 8.64E-01 | 8.23E-01 |
| 116 | (10min, 2L, 10min A, 1500D) | 2.14E-36 | 7.48E-286 | 1.85E-45 |
| 117 | (15min, 2L, 10min A, 1500D) | 4.25E-39 | 8.45E-278 | 1.04E-49 |
| 118 | (5min, 0L, 15min A, 1500D) | 3.50E-18 | 4.58E-252 | 1.89E-47 |
| 119 | (10min, 0L, 15min A, 1500D) | 1.39E-28 | 1.03E-285 | 5.17E-50 |
| 120 | (15min, 0L, 15min A, 1500D) | 5.94E-36 | 0.00E+00 | 2.84E-47 |
| 121 | (5min, 1L, 15min A, 1500D) | 7.92E-21 | 1.32E-235 | 6.48E-46 |
| 122 | (10min, 1L, 15min A, 1500D) | 4.01E-16 | 0.00E+00 | 2.02E-51 |
| 123 | (15min, 1L, 15min A, 1500D) | 4.37E-04 | 2.37E-249 | 2.85E-41 |
| 124 | (5min, 2L, 15min A, 1500D) | 2.12E-03 | 2.08E-253 | 1.08E-44 |

Table D.3. P-values of the t test for the changes in measures of effectiveness for the local area after the incident when connected vehicles are introduced (cont.).

| Scenario ID | Scenario Parameters | Mean Speed (After Incident) | Mean Flow (After Incident) | Mean Density (After Incident) |
|---|---|---|---|---|
| 125 | (10min, 2L, 15min A, 1500D) | 2.64E-23 | 8.37E-279 | 3.62E-46 |
| 126 | (15min, 2L, 15min A, 1500D) | 9.58E-09 | 1.34E-273 | 3.05E-49 |
| 127 | (5min, 0L, 20min A, 1500D) | 3.52E-53 | 1.96E-237 | 5.48E-46 |
| 128 | (10min, 0L, 20min A, 1500D) | 7.27E-39 | 0.00E+00 | 1.48E-48 |
| 129 | (15min, 0L, 20min A, 1500D) | 6.32E-02 | 2.28E-282 | 6.05E-40 |
| 130 | (5min, 1L, 20min A, 1500D) | 2.82E-08 | 1.22E-243 | 1.14E-45 |
| 131 | (10min, 1L, 20min A, 1500D) | 1.42E-25 | 5.98E-256 | 5.05E-48 |
| 132 | (15min, 1L, 20min A, 1500D) | 1.95E-01 | 6.76E-300 | 4.35E-50 |
| 133 | (5min, 2L, 20min A, 1500D) | 6.86E-06 | 7.76E-238 | 2.83E-41 |
| 134 | (10min, 2L, 20min A, 1500D) | 6.53E-01 | 7.36E-01 | 9.33E-01 |
| 135 | (15min, 2L, 20min A, 1500D) | 2.39E-05 | 1.06E-288 | 1.08E-48 |
| 136 | (5min, 0L, 10min A, 1750D) | 1.92E-52 | 0.00E+00 | 3.36E-58 |
| 137 | (10min, 0L, 10min A, 1750D) | 5.09E-19 | 7.61E-308 | 1.31E-50 |
| 138 | (15min, 0L, 10min A, 1750D) | 1.34E-11 | 0.00E+00 | 5.59E-55 |
| 139 | (5min, 1L, 10min A, 1750D) | 5.23E-11 | 1.51E-287 | 4.79E-51 |
| 140 | (10min, 1L, 10min A, 1750D) | 1.21E-04 | 0.00E+00 | 1.49E-46 |
| 141 | (15min, 1L, 10min A, 1750D) | 8.89E-14 | 0.00E+00 | 1.28E-50 |
| 142 | (5min, 2L, 10min A, 1750D) | 6.78E-01 | 9.93E-01 | 8.85E-01 |
| 143 | (10min, 2L, 10min A, 1750D) | 5.15E-14 | 0.00E+00 | 1.40E-50 |
| 144 | (15min, 2L, 10min A, 1750D) | 1.77E-58 | 0.00E+00 | 1.27E-59 |
| 145 | (5min, 0L, 15min A, 1750D) | 5.11E-71 | 6.90E-307 | 2.77E-54 |
| 146 | (10min, 0L, 15min A, 1750D) | 1.37E-59 | 0.00E+00 | 4.12E-62 |
| 147 | (15min, 0L, 15min A, 1750D) | 6.80E-88 | 0.00E+00 | 2.18E-59 |
| 148 | (5min, 1L, 15min A, 1750D) | 2.73E-22 | 2.08E-258 | 6.60E-54 |
| 149 | (10min, 1L, 15min A, 1750D) | 3.34E-27 | 0.00E+00 | 1.64E-53 |
| 150 | (15min, 1L, 15min A, 1750D) | 9.95E-01 | 4.17E-280 | 2.86E-42 |
| 151 | (5min, 2L, 15min A, 1750D) | 1.36E-06 | 2.12E-295 | 2.45E-52 |
| 152 | (10min, 2L, 15min A, 1750D) | 1.75E-37 | 0.00E+00 | 6.46E-53 |
| 153 | (15min, 2L, 15min A, 1750D) | 2.69E-14 | 0.00E+00 | 1.40E-55 |
| 154 | (5min, 0L, 20min A, 1750D) | 1.25E-86 | 1.47E-283 | 4.76E-56 |
| 155 | (10min, 0L, 20min A, 1750D) | 2.65E-25 | 0.00E+00 | 2.45E-51 |
| 156 | (15min, 0L, 20min A, 1750D) | 2.78E-27 | 0.00E+00 | 3.06E-52 |
| 157 | (5min, 1L, 20min A, 1750D) | 5.77E-14 | 3.09E-290 | 2.15E-53 |
| 158 | (10min, 1L, 20min A, 1750D) | 1.95E-08 | 9.05E-287 | 1.41E-48 |
| 159 | (15min, 1L, 20min A, 1750D) | 7.77E-01 | 0.00E+00 | 4.77E-51 |
| 160 | (5min, 2L, 20min A, 1750D) | 1.01E-16 | 3.03E-282 | 2.19E-50 |
| 161 | (10min, 2L, 20min A, 1750D) | 3.84E-01 | 9.10E-01 | 8.81E-01 |
| 162 | (15min, 2L, 20min A, 1750D) | 1.32E-05 | 1.92E-305 | 2.99E-55 |
| 163 | (5min, 0L, 10min A, 2000D) | 6.01E-71 | 0.00E+00 | 5.23E-66 |
| 164 | (10min, 0L, 10min A, 2000D) | 1.75E-34 | 0.00E+00 | 2.81E-57 |
| 165 | (15min, 0L, 10min A, 2000D) | 6.84E-06 | 0.00E+00 | 1.24E-57 |
| 166 | (5min, 1L, 10min A, 2000D) | 2.94E-15 | 0.00E+00 | 6.08E-61 |
| 167 | (10min, 1L, 10min A, 2000D) | 9.53E-03 | 0.00E+00 | 2.81E-59 |
| 168 | (15min, 1L, 10min A, 2000D) | 2.14E-05 | 0.00E+00 | 2.10E-59 |
| 169 | (5min, 2L, 10min A, 2000D) | 7.77E-01 | 8.53E-01 | 1.00E+00 |
| 170 | (10min, 2L, 10min A, 2000D) | 1.24E-17 | 0.00E+00 | 2.41E-56 |
| 171 | (15min, 2L, 10min A, 2000D) | 2.04E-32 | 0.00E+00 | 4.50E-61 |
| 172 | (5min, 0L, 15min A, 2000D) | 1.79E-273 | 0.00E+00 | 1.31E-70 |
| 173 | (10min, 0L, 15min A, 2000D) | 9.30E-45 | 0.00E+00 | 1.65E-64 |
| 174 | (15min, 0L, 15min A, 2000D) | 3.61E-106 | 0.00E+00 | 7.26E-63 |
| 175 | (5min, 1L, 15min A, 2000D) | 3.31E-19 | 4.70E-294 | 5.23E-58 |
| 176 | (10min, 1L, 15min A, 2000D) | 1.53E-07 | 0.00E+00 | 3.94E-57 |
| 177 | (15min, 1L, 15min A, 2000D) | 1.23E-07 | 0.00E+00 | 3.29E-51 |
| 178 | (5min, 2L, 15min A, 2000D) | 2.92E-03 | 0.00E+00 | 8.72E-59 |
| 179 | (10min, 2L, 15min A, 2000D) | 6.18E-52 | 0.00E+00 | 1.26E-61 |
| 180 | (15min, 2L, 15min A, 2000D) | 1.32E-06 | 0.00E+00 | 3.35E-60 |
| 181 | (5min, 0L, 20min A, 2000D) | 6.37E-52 | 4.50E-301 | 2.92E-58 |
| 182 | (10min, 0L, 20min A, 2000D) | 2.46E-71 | 0.00E+00 | 3.31E-64 |
| 183 | (15min, 0L, 20min A, 2000D) | 1.51E-11 | 0.00E+00 | 2.55E-57 |
| 184 | (5min, 1L, 20min A, 2000D) | 8.28E-21 | 0.00E+00 | 1.66E-59 |
| 185 | (10min, 1L, 20min A, 2000D) | 1.39E-08 | 0.00E+00 | 9.19E-59 |
| 186 | (15min, 1L, 20min A, 2000D) | 1.97E-04 | 0.00E+00 | 5.77E-60 |
| 187 | (5min, 2L, 20min A, 2000D) | 7.61E-22 | 2.86E-308 | 4.33E-56 |
| 188 | (10min, 2L, 20min A, 2000D) | 1.92E-01 | 8.83E-01 | 7.78E-01 |
| 189 | (15min, 2L, 20min A, 2000D) | 1.11E-04 | 0.00E+00 | 1.69E-60 |