Real-Time Predictive Traffic Signal Synchronization through VANET Communication

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A/A 2017/2018
Acknowledgements

I feel like it is difficult to address all the people who have helped me these past two years in Italy, the rewarding experience it has been. First, I thank prof Fusco Gaetano with who it has been my privilege to work with. It is my honour to have him as my mentor during my research. It was his lessons of traffic engineering during second semester I had grown passion about traffic engineering.

All of this would not be possible if it was not for Stefano Ricci. I sincerely thank him for believing in me and giving me an opportunity for studying at Sapienza University of Rome. The past few years have been a life changing experience for me in Italy. I thank Chiara Cholombaroni, Mattia Giovanni Crespi, Antonio Musso, Guido Gentile, Massimo Guarascio, Gabriele Malavasi, Luca Persia and Liana Ricci for their teachings, support and their cooperartion. I am truly grateful.

I thank my friends Eyad, George, Lorenzo, Nicola, Houshang, Federico, Marj, Amal, Agostino, Basak, Jobin, Jinjin, Alessandra, Matteo and Lory for their friendship, support and the encouragement. I thank Roberta and Natalia for sharing their office space with and guiding me during my research work for the past five months.

I cannot find the right words to describe my sister and my brother-in-law for their commitment and the help that I have received from her during my studies. I am indebted to my parents for having supported me in every way they could to help me finish my master’s in Italy.
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Introduction

This project presents various simulations in SUMO and gives an insight on how SUMO works according to the instructions given by the user. There is a strong demand for transportation in urban areas. The major part of the demand in the transportation is covered by the public sector. However, public transport sector cannot cover all the demand in the urban areas. Individual driver’s makeup the major part of the transportation. The traffic conditions in the city can be improved by various methods. Infrastructural modifications are not possible because of their cost effectiveness. The other way to control the the traffic is, by the use of traffic signal which are adaptive that recognize the vehicles on the network in real time and make adjustments to tackle certain traffic problems such as traffic jams and high delays.

There are two types of traffic signal control they are fixed time cycle control system and dynamic cycle control system. The phase timing plane of fixed time cycle controlling utilizes a predetermined cycle time. The dynamic cycle control system decides and modifies phase based on the traffic flow or density near the intersection. The detection of the vehicles is carried out by the V2I communication. The induction loop detector or lane area detector on the network are responsible for detecting the traffic flow density and means speed of the vehicle on the network. The traffic model with dynamic control system is simulated in SUMO- Simulation of urban mobility software. The networks were created on NETEDIT software which is available with SUMO. These network models are calibrated with the field data which is taken from the streets of Rome. Then this model is simulated, and same parameters are applied to another network to check the consistency of the model. The performance of traffic flow through consecutive intersections depends upon the coordination between them. The main goal of this system is to minimize the time lost by the vehicles running along the streets by real time traffic signal synchronization through VANET communication. The methods used in this report can be used as a starting point to start simulation in the SUMO. Additional research may be required to implement the methods provided in this report. The performance is analysed in terms of mean time loss, travel time, mean CO2 emissions and mean speed. The investigation and proposals in this report are a result of experience from traffic engineering and microsimulation models output. The chapters in this report are arranged in a chronological order. The last section appendix gives the insight of the traffic simulations in SUMO.
1. State of the art

1.1 Traffic characteristics

In the event that we need to think about the Traffic attributes and their expectations, it is appropriate to furnish at any rate their short posting with definitions and shared relations. The three fundamental characteristics in traffic flow theory are flow, speed, and density.

1.2 Traffic flow

Traffic flow can be additionally found in some literature named as flow, flow rate or volume. Nevertheless, all these terms can be used interchangeably. It is characterized as various vehicles passing a point in a given timeframe. It is typically communicated in units of vehicles per hour (vph). Other conceivable units are for example vehicles per hour per lane (vphpl), passenger car units per hour (pcu/hr), or passenger car units per hour per lane (pcphpl or in easier readable form pc/h/ln). The traffic flow counting equation is simple: where q is traffic flow (vph), n is number of vehicles passing a spot on the road in a given interval t. The special value of traffic flow is capacity c which defines the maximum hourly rate under prevailing roadway conditions. Since it is convenient to measure traffic flow in 15-minute intervals, a quantity called peak hour factor (PHF) is presented: Hence is obvious that PHF can theoretically be in the interval 0.25≤PHF≤1.0. Peak hour factor can be understood as an indicator of flow fluctuations within the hour. Introduction | 10

1.3 Speed

In light of various methodologies how to figure speed, there are two primary understandings they are time-mean speed and space-mean speed. Time-mean speed is defined as the average speed of vehicles passing a spot on a road. The standard notation is ut.

\[ U_s = \frac{\sum_{i=1}^{n} u_t}{n} \]

where:

- \( u_s \) is time-mean speed in km/h,
- \( u_t \) is speed of vehicle i measured at a point along a road, usually by a radar or laser gun (km/h),
- \( n \) is number of vehicles.

Space-mean speed is defined as the average travel speed of vehicles between two points at the distance D apart. It is computed as:

where:

- \( u_s \) is space-mean speed,
- \( D \) is the distance of two points on the road (km) is the average travel time (h).

Space-mean speed is more valuable with regards to traffic analysis and is resolved based on the time vital for a vehicle to move along some known length of a roadway. Consequently it is likewise meant basically as u.

Space-mean speed gives more accentuation to high \( u_i \), hence \( u_s \leq u_t \). The uncommon estimation of speed is free stream speed (FFS or \( u_f \)) which characterizes the space-mean speed.
on the specific piece of the street which is come to by an unhindered movement stream under winning roadway conditions. HCM2010 characterizes FFS as the mean speed of traveler autos working in stream under 1 000 pc/hr/ln. FFS is controlled by street geometry, cross area, nature of street surface, and every single mental factor having effect on drivers.

1.4 Density
Density is characterized as the quantity of vehicles per unit length of roadway at any instant. Density is usually denoted by k and its unit is vehicles per kilometre (veh/km) or vehicles per kilometre per lane (veh/km/ln). It is expressed as

$$k = \frac{n}{D}$$

where n is the quantity of vehicles involving length D of roadway at some predetermined time. It is difficult to measure density directly unless there is an option of aerial photography or satellite imaging. Along these lines it is all the more regularly evaluated in a roundabout way by estimating the inflow and surge of vehicles at a street segment after some time, however the underlying state must be known all things considered. The special case of density is so called jam density (kj), which is the maximum possible density on the roadway when the speed of the flow is nearly zero.

1.5 Relationships among traffic characteristics
If there is a requirement of analysis of traffic conditions, the macroscopic approach is used. The fundamental equation describing average conditions on a given link for a specific time period is:

$$q = u \times k$$

The equation assumes that the flow is uninterrupted and stable, i.e., all travelling at about the same speed. The fundamental diagram in the presented form assumes a linear speed-density model. That assumption is represented by Greenshields’s traffic stream model. However, it is not the only traffic stream model which can be used. Even their combinations creating multi-regime models might be applied. The benefit of using a linear representation of the speed-density relationship is that it provides a basic insight into the relationships among traffic flow, speed, and density interactions without clouding these insights by the additional complexity that a nonlinear speed-density relationship introduces. However, it is important to note that field studies have shown that the speed-density relationship $$u = f(k)$$ tends to be nonlinear at low densities and high densities. In fact, the overall speed-density relationship is better represented by three relationships: (1) a nonlinear relationship at low densities that has speed slowly declining from free flow value $$u_f$$, (2) a linear relationship over the large medium density region, and (3) a nonlinear relationship near jam density $$k_j$$ as the speed asymptotically approaches zero with increasing density. (Mannering, & Washburn).
Figure 1 Flow-density, speed-density and speed-flow relationships (Mannering and Washburn)

Figure 2 Flow-density, speed-density and speed-flow relationships (Wikipedia)
It is important to know that speed flow and density are not the only ones what can be measured or computed in the traffic flow assignments. One of the characteristic which is perceived by the end users (i.e. drivers) and affects their decisions about their trips is travel time (TT). TT is defined as a time taken by a vehicle to traverse a given section of a highway with length D. A valuable estimation of movement time may diminish cost impacts by a plausibility to keep away from joins with blockage and enhance a nature of carriage organizations by conveying their shipments in the required period of time. The estimation of TT at a specific direction isn’t influenced just by a street geometry, yet in addition by factors particular for the specific moment of the trek. These components are for instance real atmosphere and state of the carriageway, and doubtlessly additionally genuine level of administration in view of movement conditions. It is said as a rule that movement time is influenced by individuals, vehicles, and offices. There is a few alternatives how to quantify TT. The main gathering incorporates ways which record going of an auto through estimating focuses. While strategies from the second gathering use estimating tests moving in rush hour gridlock stream which record their advance. Cases of the main gathering may be tag strategy in any conceivable variation. It discovers distinction in entry time for vehicles touching base in focuses A and B. The suspicion for getting a pertinent outcome is that the timekeepers at the two focuses are synchronized. It should be possible physically by eyewitnesses in its fundamental shape. The more typical way is programmed coordinating of some ID of autos. As an ID can be considered plates read by sensors of programmed vehicle recognizable proof frameworks observing the stream or labels utilized as a part of electronic toll gathering frameworks (locally available units). A calculation of TT in light of information from implanted locators is another illustration having a place among these techniques. Presentation | 14 The second gathering utilizing a moving eyewitness is all the more intriguing in the terms of this theory. These strategies are for the most part in light of utilizing gliding autos as indicators. In view of activity stream hypothesis and level-of-benefit idea, as movement stream builds, speed diminishes, and in this way travel time increments. There have been produced a few connection execution capacities which exhibit a numerical connection between course travel time and course of traffic stream.

HCM2000 provides Akcelik Delay Function:

$$t = t_0 + D_0 + 0.25T \left[ (x - 1) + \sqrt{(x - 1)^2 + \frac{16/L^2}{T^2}} \right]$$

Where:

T is expected duration of demand
L is link length
D_o is the control delay
X is link demand to capacity ratio (v/c)
J is calibration parameter (-)

Federal highway authority uses its BPR function:

\[ t = \frac{L}{S} \left[ 1 + \alpha \left( \frac{v}{c} \right)^\beta \right] \]

Where:
T is time of a link,
L is the length of the link,
S is the free flow speed
V is link traffic flow (volume for which costs are computed) of a link,
C is capacity of the link,
\( \alpha, \beta \) are calibration parameters (typically \( \alpha=1, \beta=4 \))

### 1.7 Car following Model
Car following model describes the behaviour of the vehicle in a traffic flow on a lane. The following car maintains a safe distance from the lead car to avoid collisions (Gipps, 1981; Krauss, 1997; Treiber et al., 2000). The acceleration of a car depends upon the speed of the car before it (Gazis et al. 1961). There are different parameters that are used to describe various car following models. Acceleration is one of the parameters that is used to specify the acceleration of the vehicles. There is another parameter named desired speed this is the parameter described the drivers desired velocity. The driver accelerated until he reached the desired speed. The reaction time is the time taken by the driver to react to the changes in his environment, this parameter is usually taken as 1 sec as a standard value. Reaction times are also used in lane changing models. Desired headway is the space maintained by the follower from the leader. This is the taken by the follower to reach the leader’s same level of deceleration at same speeds in braking phase. The headway will be short if the driver is more aggressive. The minimum headway is independent of speed.

### 1.8 VANET
VANET stands for vehicular Ad-Hoc network. VANET is a bit of MANET (Mobile Ad-Hoc Networks). An Ad-Hoc network is a wireless network that is decentralised. Every vehicle acts as a node in Ad-Hoc network. Vehicle movement is limited to the roads and traffic rules on these roads, in order to have a continuous and reliable communication between the vehicle certain fixed infrastructure is deployed they are road side units mesh routers etc. Road side unit connects the vehicles to the infrastructure. There are two types of communications in VANET they are vehicle to vehicle communication and vehicle to infrastructure communication. Vehicles have some sensors inside them which detect the conditions on the road and convey this information to the authorities. So, authorities take necessary action in case of an accident or traffic jam. Vehicles provide various information to other vehicles and infrastructure
such as traffic density, road condition and vehicle speed. In the VANET every node stays connected and can freely move within the network coverage.

The nodes are mobile in VANETS and MANETS. The vehicle movement (node movement) in VANET is limited to the road infrastructure. VANET is an emerging technology that can integrate new generation wireless networks to nodes(vehicles). VANET utilizes Dedicated Short-Range Communication(DSRC), with cellular network, WIFI, satellite and WiMAX (Worldwide Interoperability for Microwave Access). The major application of VANET is ITS. VANET improves traffic efficiency and road safety.

**Figure 3: VANET**

The vehicles are equipped with onboard communication devices that are responsible for communication with the road side unit. The vehicles receive the information about their position from the GPS signal and convey it to the Road Side Unit. This communication helps in determining the flow, density and speed of the traffic and the authority can take necessary actions to improve these characteristics.

### 1.9 Signal Priority

Signal priority is an operational strategy which facilitates the movement of the prioritized vehicles through traffic signal-controlled intersections.
The general steps involved in signal priority are as follows:

The car approaching the intersection is detected at some point $P_d$ upstream of the intersection by various detection methods.

The system identifies the position of the vehicle with GPS and notifies the controller that this vehicle would like to receive priority at the intersection. The request will be processed by the system and grants priority according to the conditions defined. The traffic controller $C$ then gives the priority according to our strategy. Typically, if the intersection signals are already displaying a green phase for the approach being used by the priority car, the controller will extend the length of the green phase to enable the bus to pass through the intersection on that phase. If the intersection signals are displaying a red phase on the prioritized car approach, the controller will shorten the green phase on the cross street to provide an earlier green phase for the car approach.

When the car passes through the intersection, clearance is detected by the priority detection system $P_c$ and a communication is sent to the traffic controller that the bus has cleared the intersection.

On being notified that the car with the priority has cleared the intersection, the controller $C$ restores the normal signal timing through a predetermined logic.

### 1.9.1 Active priority

Active priority detects the vehicle that the priority has to be given and gives the priority to this vehicle by modifying the traffic signals in order to give priority to this system. There are different types of strategies which can be used within the traffic control environment to give priority. They are described below.

When a prioritized vehicle is approaching the intersection when the traffic signal of that artery is about to turn red but the traffic light is still green then a green extension strategy can be used to prolong the green time. This green extension is one of the most effective forms of signal priority since a green extension does not need any additional clearance intervals, yet allows a prioritized vehicle. This strategy reduces the waiting time time of the prioritised vehicle instead of waiting for an early green.
2. Simulation

The process of replicating real world in a computer model is called simulation. The models is used to study the behaviour of the components interacting in it. In the case of traffic simulation Infrastructure and traffic using this infrastructure are the components. Streets, traffic signals, railway lines, induction loop detectors etc components include infrastructure while traffic comprises of buses, trucks, pedestrians, bikes, passenger cars, trains and street cars. Traffic system performance is usually assessed by different measures of effectiveness (MOE) like queue length, system throughput, travel time, delay, etc. There are three types of traffic simulation which are based on the level of detail – macroscopic, mesoscopic and microscopic. A macroscopic model is the one in which traffic is considered as a stream and the level of detail is low. A mesoscopic model has a moderate level of detail with less interaction between the individual vehicles. The highest level of detail is given by the microscopic models and the vehicles are simulated on the basis of second by second. There are various parameters used in the microscopic models such as acceleration, deceleration, gap between the vehicles, reaction time and reaction time to make the interaction of vehicles in models as realistic as possible. Due to their ability to simulate individual vehicles in the network, only microscopic models are able to simulate transit signal priority applications at the individual intersection level. So, in this study we use the microscopic modelling. Simulation helps to develop a new system or redesign an old system by testing it on the computer before applying it on the field. It also can be used to test different scenarios which cannot be tested in real life such as transit signal priority in peak periods on urban arteries. Gives a practical method for testing and assessing distinctive situations Simulation is a fast way to test traffic scenarios than real life offers a knowledge into the qualities of traffic system operations that are vital, enabling the user to settle on an optimal choice.

2.1 Simulation tools

There are many types of simulation tools available in the market. SUMO was chosen because of its flexibility and availability. SUMO cannot make logical decisions during real time simulation. So, python has to be used along with SUMO. Python interacts with SUMO via TCP/IP as it get the data during real time traffic simulations and gives necessary commands to SUMO. SUMO acts as a server during the simulation.

2.1.1 SUMO

SUMO was developed at the German Aerospace Centre. SUMO is microscopic simulator, which means every vehicle is simulated. The vehicles stop for traffic lights, traffic stops, give way to high priority vehicles at an intersection while following their route. In this simulator vehicles can move freely, collision between vehicles and accidents are also simulated. Each vehicle has its own road and vehicle routing is dynamic. The vehicle behaviour is taken into consideration such as changing lanes during emergency deceleration etc. Roads in SUMO are shown as a plurality of lanes. Also, the vehicle width is fixed. And it does not take into account the different types of vehicles. SUMO allows modelling of intermodal traffic systems including road vehicles, public transport and pedestrians. SUMO software is famous for its ability to be manipulated at source code level. SUMO can be enhanced with custom models and provides various APIs to remotely control the simulation. Detectors can be used in the simulation of
SUMO to count the number of vehicles passed through a particular section. SUMO writes the output of a simulation into an xml format file. There are different types of outputs given by SUMO. The output syntax has to be written in the configuration file along with the input files. This output file can be opened in excel and the results can be seen over there. There are three files that are essential for a simulation run in SUMO. They are net file where the information about the network is stored, a route file where the information regarding the attributes of the car and the types of flows used in the simulation and the configuration file which creates the configuration for the simulation. This simulation can be run in SUMO-GUI for the graphical representation. The data flow in the simulation is shown in the figure below. SUMO can be used to simulate railway lines too. There are various types of simulation that can be carried out on SUMO such as bicycle, pedestrian, public transport, railway and waterway. Basic computer skills are required to operate the SUMO simulation software. Netgenerate is a c++ program used in SUMO to generate abstract road networks that can be used in the SUMO simulation software. In SUMO the networks can be imported from various programs such as OpenStreetMap, VISUM, Vissim, OpenDrive, MATsim and DirNavt eq. SUMO has some additional features such as Emissions, Electric Vehicles, Logistics, wireless device detection and emergency vehicles. Emergency vehicle over take the other vehicles and exceed the speed limit by 150%. The latest version of sumo is 0.30.0 which was released on 17/12/2017.

Figure 5: SUMO data flow

Sumo generates output files in XML-format by default. There are various types of output in SUMO such as vehicle-based, output from simulated detectors, network-based information and traffic lights-based information. There are five types of simulated detectors in SUMO. These simulated detectors include inductive loop detectors. SUMO can simulate various modes of transport and various types of vehicle, but a simple passenger car was chosen in this thesis for the simulation. In SUMO network can be built by NETEDIT tool from the scratch or network can be imported from the OSM website. This can be converted to .net.xml format by NETCONVERT tool in SUMO. The network file can be combined with polygon file and edge files to better visualize the network.
2.2 Detectors in SUMO

There are three types of detectors in SUMO. They are induction loop detectors, lane area detectors and multi-entry-exit detectors. Detectors are responsible for the detecting the vehicles on the network.

2.2.1 Induction loop detectors

An additional file has to be created along with the network file and this file has to be specified in the input as an additional file. There are certain attributed that have to be described in the additional file such as id-name(id) of the detector, lane id is the name of the lane on which the induction loop detector has to be placed upon, position-this is the position of the induction loop detector on the specified lane at a distance from the beginning of the lane and can be described in metres, frequency is the time period in which the induction loop detector aggregates the values and file-the output file will be written in the format along with the name specified in the attribute “file”.

Figure 6: SUMO-GUI
2.2.2 Lane area detector
The lane area detector can be used to capture the traffic on a lane or lanes. Lane area detectors are similar to vehicle tracking cameras. Lane area detector has all the attributes as the induction loop detector in addition it has a length attribute which can be described by the attributes pos and endPos. Lane area detector can be coupled with a traffic signal to generate actuated traffic signal. Lane area detectors have to be specified in an addition file which can be loaded in the simulation.

2.2.3 Multi-Entry-Exit Detectors
These detectors can be described in an additional file and can be loaded on to the simulation.
The about image shows the xml script for the entry exit detectors. This script should be written into an xml file. This xml file has to be loaded in additional files in configuration file. The above additional creates an output as out.xml.

![Visualization of multi-entry-exit detectors](image)

**Figure 9: Visualization of multi-entry-exit detectors**

### 2.3 Traffic signal Lights in SUMO

Traffic light is one of the most effective ways of managing the traffic in SUMO. There are three types of traffic lights in SUMO. They are static, actuated and delay based. The static traffic signal has a pre-timed signal stated that it follows. The actuated traffic signal is coupled with lane area detector. In SUMO traffic lights are normally generated by NETCONVERT command during the development of the networks. It is possible to change the duration of the traffic light according to the real traffic light programs by using netedit or by editing the logic of the traffic light in the xml file of the network simulator.

#### 2.3.1 Static traffic signal

![Various colour states displayed by the traffic light in SUMO](image)

**Figure 10: Various colour states displayed by the traffic light in SUMO**
Table 1: Table describing colour states of the traffic signal in SUMO

2.3.2 Based on Time gaps
This control scheme is a gap-based actuated traffic control. This traffic signal prolongs the traffic phase whenever a continuous stream of traffic is detected. The traffic signal changes to next phase after maximum duration of the phase or after detecting a sufficient time gap between successive vehicle. The quantity of time gap can be described in the parameters. This traffic control scheme couples with the lane area detector.

2.3.3 Delay-based traffic signal
This traffic signal is based on time loss by the vehicles waiting at the intersection. There are various parameters that must be specified for this type of actuated signal. SUMO manual
suggests creating an additional file and specify that additional file containing the traffic light logic but we have found some errors by following this procedure, so it recommended to write the traffic light logic in the xml by finding the logic in the network xml file and replacing it with the delay based traffic signal parameters using the notepad++.

2.4 Open Street Map
OSM stands for open street map, OSM is a free and editable map of the world, released with an open-content license (OpenStreetMap Wiki, 2016a). According to Zilske et al. (2011), OSM data has proven to be a valuable data source for network creation. OSM offers in one source. Very high point coordinate accuracy, a strength of commercial data sources. OSM provides both geographic data and traffic signal information. OSM uses the elements node, way and relation, structured in an xml-format. A node is a single point in space defined by its latitude, longitude and id. A way connects two nodes, but ways are not only used for roads but all line elements present on a map. Relations group ways and nodes to logical entities such as buildings, rivers, forests, borders or public transit routes. OSM offers tags to define spatial public transit data such as routes and stops. OSM provides the means to define the actual path a vehicle takes. Instead of designing the network on the NETEDIT software. OSM data can be used to import real network on to SUMO. But, the OSM data has to be converted to xml format to be able to import into SUMO. Then Python can be used to assign flows on to this network.

2.5 Procedure to import OSM into SUMO
The working PC has to be installed with the following software such as SUMO Python Notepad++. In SUMO networks can be built using netedit software or they can be downloaded from the openstreetmap.org. we can manually select the area that we want to export from the OpenStreetMap.

The file that is exported from the OpenStreetMap is in the format of .osm. Microsoft Dos can be used to convert this file from .OSM format to .XML. In order to do that first the user has to run the DOS from there he has to navigate to the directory to where the SUMO software is installed. In this SUMO folder there is a folder named “bin”. In this bin folder you can find the start-command-line.bat.

The above command generates a file.rou.xml file. The next step is make a configuration file. In this file input files and time has to be specified. In order to create a configuration file. One can find a file named “test.sumo.cfg”. This file has to be copied into the map folder and then it has to edited using notepad++ with the following lines.
All files required for the simulation have been prepared now. The simulation can be run by the following command SUMO-gui test.SUMO.cfg.

### 2.6 NETEDIT

NETEDIT is visual GUI software provided with SUMO. This software can be used to design networks from the scratch. This software can also be used to modify existing networks. Edges can be created or deleted. Two junctions which are nearby each other can be joined together. Restricted lanes can be created for a particular vclass. Many additional elements can be created in this software they are induction loop detectors, lane area detectors, entry exit detectors, bus stop, charging station, vaporizer, container stop, rerouter, calibrator and variable speed sign. The shape of the network can be changed as per the preferences. This tool saves the network file in .xml format. There are nine modes by which the NETEDIT tool can be used.
2.7 Simulation Tests

In this case study the delay results on a single lane approach at a signalized intersection is determined. The length of the approach is 500m. The speed limit is 70 km/h. The traffic consists of passenger cars with a length of 4m. The signal has a cycle time of 90 seconds. The effective green is 50 seconds. SUMO implements the Messnne Teister algorithm for generating random numbers. The length of each simulation run was 900 seconds which corresponds to the HCM study length. The purpose of this simulation is to study the variation of delay according to car following model characteristics. The SUMO generates a huge amount of output data including mean speed, travel time, duration waiting time, max speed on a lane. The default lane capacity in SUMO is 2400veh/h/lane.

<table>
<thead>
<tr>
<th>Traffic demand (veh/hr)</th>
<th>HCM v/c ratio</th>
<th>Uniform delay (s)</th>
<th>Incremental delay (s)</th>
<th>Average control delay (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>0.1</td>
<td>9</td>
<td>0.3</td>
<td>9.2</td>
</tr>
<tr>
<td>480</td>
<td>0.2</td>
<td>9.4</td>
<td>0.4</td>
<td>10.2</td>
</tr>
<tr>
<td>960</td>
<td>0.4</td>
<td>9.88</td>
<td>1.1</td>
<td>12.5</td>
</tr>
<tr>
<td>1440</td>
<td>0.6</td>
<td>10.58</td>
<td>2.3</td>
<td>15.7</td>
</tr>
<tr>
<td>1920</td>
<td>0.8</td>
<td>11.58</td>
<td>5.8</td>
<td>21.8</td>
</tr>
<tr>
<td>2400</td>
<td>1</td>
<td>13.67</td>
<td>23.1</td>
<td>45.5</td>
</tr>
<tr>
<td>2880</td>
<td>1.2</td>
<td>20</td>
<td>42.3</td>
<td>78.3</td>
</tr>
</tbody>
</table>

Table 2: Traffic flow conditions obtained by the HCM methodology.
Now the length of the artery approaching the intersection has been varied by 300m, 500m, 750m and 1000m and the results are shown in the table below.

<table>
<thead>
<tr>
<th>Average delay SUMO(500m)</th>
<th>Average delay SUMO(300m)</th>
<th>Average delay SUMO(1000m)</th>
<th>Average delay SUMO(750m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.2</td>
<td>9.1</td>
<td>9.2</td>
<td>9.2</td>
</tr>
<tr>
<td>10.3</td>
<td>9.9</td>
<td>10.9</td>
<td>10.5</td>
</tr>
<tr>
<td>11.3</td>
<td>10.4</td>
<td>12.1</td>
<td>11.6</td>
</tr>
<tr>
<td>13.5</td>
<td>12.4</td>
<td>15.5</td>
<td>14.5</td>
</tr>
<tr>
<td>18.7</td>
<td>16.8</td>
<td>19.4</td>
<td>18.8</td>
</tr>
<tr>
<td>38.2</td>
<td>34.2</td>
<td>39.5</td>
<td>38.9</td>
</tr>
<tr>
<td>75.4</td>
<td>73.1</td>
<td>78.1</td>
<td>76.8</td>
</tr>
</tbody>
</table>

*Table 3: Simulation results*

There are eleven types of car following models that are currently implemented in SUMO. Some car following models describe the behaviour of the driver in all situations whereas some car following models describe drivers behaviour when following other vehicle. Most car following models use several schemes to describe the followers behaviour.

<table>
<thead>
<tr>
<th>Element Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>carFollowing-Krauss</td>
<td>The Krauß-model with some modifications which is the default model used in SUMO</td>
</tr>
<tr>
<td>carFollowing-Kraussorig1</td>
<td>The original Krauß-model</td>
</tr>
<tr>
<td>carFollowing-PWagner2009</td>
<td>This model uses Todoslev’s action points by Peter Wagner</td>
</tr>
<tr>
<td>carFollowing-BKerner</td>
<td>A Boris Kerner’s model</td>
</tr>
<tr>
<td>carFollowing-IDM</td>
<td>Martin Treiber’s intelligent driver model</td>
</tr>
<tr>
<td>carFollowing-IDMM</td>
<td>A variant of IDM</td>
</tr>
<tr>
<td>carFollowing-KraussPS</td>
<td>The default Krauß-model with road slope in consideration</td>
</tr>
<tr>
<td>carFollowing-KraussAB</td>
<td>Krauß-model with bounded acceleration</td>
</tr>
<tr>
<td>carFollowing-SmartSK</td>
<td>Variant of the Krauß-model</td>
</tr>
<tr>
<td>carFollowing-Wiedemann</td>
<td>A model by Wiedemann</td>
</tr>
<tr>
<td>carFollowing-Daniel</td>
<td>A model by Daniel Krajzewicz</td>
</tr>
</tbody>
</table>

*Table 4: Car following models available in SUMO*

First the Krauss car following model had been tested in SUMO.

The following car following models were studied in this study. They are described in the list below.

1. Krauss
2. IDM
4. Daniel
5. Kerner’s
The above picture shows a one-ways direction road section with two lanes. A circular network has been chosen to regulate the density. The length of this circuit is 1000 metres. All the car following models were used to study the behaviour of the vehicles on this network. The first model is the Krauss car following model. The parameters used in this model are taken as suggested by the SUMO website.

<table>
<thead>
<tr>
<th>Acceleration(m/s²)</th>
<th>Deceleration(m/s²)</th>
<th>Length(m)</th>
<th>Max speed(m/s)</th>
<th>Sigma</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5</td>
<td>4.5</td>
<td>4</td>
<td>13</td>
<td>0.5</td>
</tr>
</tbody>
</table>

The simulation was run for a duration of 60 minutes and the results are show in the fundamental diagram of Flow-Density, Speed-Flow and Speed-Density. All of the graphs displayed below show the relationship between the basic traffic parameters as expected.
The highest flow observed from the graph is 3195 Veh/hr where the density is 128 Veh/km. Hence the optimal density by Krauss following model is 128 Veh/km. The jam density is 260 Veh/km.
The traffic flows freely from 30 to 50 km/hr after which the bound flow ranges from 10 to 30 km/hr. The congestion starts when the traffic density exceed 180 Veh/km which leads to a traffic speed of less than 10Km/hr.

One can observe from the fundamental diagram of Krauss car following model the maximum flow which is around 3195 Veh/km and the critical velocity is 24 Km/hr.

Then the Krauss model has been computed outside SUMO in a mathematical software. In this scenario a vehicle on a single lane which with an initial speed of 20m/s comes to rest and then accelerates to 20m/s. The behavior of the following vehicles is calculated using the Krauss car following model mathematical formula. Their results are shown in the Space-Time, Speed

![Speed-Flow](image)
Time and Acceleration time graph below.

Table 6: Speed time graph of Krauss car following model

Table 7: Space time graph of Krauss car following model
During the simulation in SUMO one can visualize the network parameters. These network parameters are shown in the image displayed below:
2.7.2 IDM
IDM stands for intelligent driving model. This is a type of car following model which is time continuous used to simulate the traffic on freeway and urban traffic. The parameter specific to this model is Delta which is the acceleration exponent. The simulation was run for a duration of 60 minutes. The following parameters are used to simulate the traffic on the network shown in the figure above.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration(m/s²)</td>
<td>0.73</td>
</tr>
<tr>
<td>Deceleration(m/s²)</td>
<td>1.67</td>
</tr>
<tr>
<td>Length(m)</td>
<td>4</td>
</tr>
<tr>
<td>Max Speed(m/s)</td>
<td>13</td>
</tr>
<tr>
<td>Tau(Seconds)</td>
<td>1.5</td>
</tr>
<tr>
<td>Delta</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 8: IDM car following model parameters

The results are show in the fundamental diagram below

Figure 19 Flow Density fundamental diagram of IDM
The congestion for IDM car following model starts at 100veh/km.

It can be observed from the above speed flow fundamental diagram of IDM car following model that the critical velocity is around 38Km/hr.

2.7.3 Krauss Vs IDM
Next the simulation tests were run considering the same parameters for both the Krauss and IDM. The parameters are described in the table below

<table>
<thead>
<tr>
<th>Krauss</th>
<th>IDM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Acceleration = 1m/s²</td>
<td>Acceleration = 1m/s²</td>
</tr>
<tr>
<td>-----------</td>
<td>------------------</td>
</tr>
<tr>
<td>Deceleration = 2m/s²</td>
<td>Deceleration = 2m/s²</td>
</tr>
<tr>
<td>Max Speed = 13m/s</td>
<td>Max Speed = 13m/s</td>
</tr>
<tr>
<td>Sigma = 0.5</td>
<td>Length = 4m</td>
</tr>
<tr>
<td>Length = 4m</td>
<td>Tau = 1.5s</td>
</tr>
<tr>
<td></td>
<td>Delta = 4</td>
</tr>
</tbody>
</table>

Table 9: IDM and Krauss car following model with same parameters

The results of this test are show in the fundamental diagrams below
Both the Krauss and IDM car following models performed poorly when their parameters were changed. Krauss car following model has a maximum traffic flow of 4109 Veh/hr whereas IDM car following model has a maximum traffic flow of 3315 Veh/hr. When the parameters of both these car following models were altered they did not show the characteristics of a typical car following model. One can observe this issue from the velocity flow fundamental diagrams.

2.7.4 Daniel

The following parameters were used in testing the Daniel car following model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>1.5 m/s²</td>
</tr>
<tr>
<td>Decceleration</td>
<td>3.5 m/s²</td>
</tr>
<tr>
<td>Mingap</td>
<td>3 m/s²</td>
</tr>
<tr>
<td>Emergency deceleration</td>
<td>9.5 m/s²</td>
</tr>
<tr>
<td>Max speed</td>
<td>13 m/s</td>
</tr>
<tr>
<td>Tau</td>
<td>1 sec</td>
</tr>
</tbody>
</table>

*Table 10: Daniel car following model parameters*
The graph provides the relationship between the flow and density of a road section using the Daniel’s car following model. As is observed from the graph.
Figure 24: Speed flow fundamental diagram of Daniel Car following model

### 2.7.5 Kerner’s

The following parameters were used in testing the Kerner’s car following model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>1.5 m/s²</td>
</tr>
<tr>
<td>Deceleration</td>
<td>3.5 m/s²</td>
</tr>
<tr>
<td>Mingap</td>
<td>3 m/s²</td>
</tr>
<tr>
<td>Emergency deceleration</td>
<td>9.5 m/s²</td>
</tr>
<tr>
<td>Max speed</td>
<td>13 m/s</td>
</tr>
<tr>
<td>Tau</td>
<td>1 sec</td>
</tr>
</tbody>
</table>

*Table 11: Kerner’s car following model parameters*
Figure 25: Flow-Density fundamental diagram of Kerner car following model.

Figure 26: Speed density fundamental diagram of Kerner’s car following model.
Figure 27: Speed flow fundamental diagram of Kerner’s car following model

2.7.6 Peter Wagner

The following parameters were used in testing the Peter Wagner car following model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>1.5 m/s²</td>
</tr>
<tr>
<td>Deceleration</td>
<td>3.5 m/s²</td>
</tr>
<tr>
<td>Mingap</td>
<td>3 m/s²</td>
</tr>
<tr>
<td>Emergency deceleration</td>
<td>9.5 m/s²</td>
</tr>
<tr>
<td>Max speed</td>
<td>13 m/s</td>
</tr>
<tr>
<td>Tau</td>
<td>1 sec</td>
</tr>
</tbody>
</table>

Table 12: Peter Wagner’s car following model parameters
Figure 28: Flow density fundamental diagram of PWagner’s Car following model

Figure 29: PWagner car following model
2.7.7 Wiedemann
The following parameters were used in testing Wiedemann car following model.

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration</td>
<td>1.5 m/s²</td>
</tr>
<tr>
<td>Deceleration</td>
<td>3.5 m/s²</td>
</tr>
<tr>
<td>Mingap</td>
<td>3 m/s²</td>
</tr>
<tr>
<td>Emergency deceleration</td>
<td>9.5 m/s²</td>
</tr>
<tr>
<td>Max speed</td>
<td>13 m/s</td>
</tr>
<tr>
<td>Tau</td>
<td>1 sec</td>
</tr>
</tbody>
</table>

*Table 13: Wiedemann car following model parameters*
Figure 31: Wiedemann’s car following model

Figure 32: Speed-Density fundamental diagram of Wiedemann’s car following model
Figure 33: Speed Flow fundamental diagram of Weidemann car following model

SPEED TIME

Daniel  Kerner  Pwagner  Krauss  IDM  Wiedemann
2.8 Lane Changing Model
Traffic flows are influenced by lane changing model in addition to the car following model. There are three lane changing models that are available in SUMO. They are tested on a circular circuit of 1km length and consists of 3 lanes. There are three inductions loop detectors on each lane.

1. LC2013
2. SL2015
3. DK2008

Two models have been tested in this study They are LC2013 and SL2015.

2.8.1 LC2013
The flowing parameter were used in testing the lane change model

lcStrategic: The driver enthusiasm to change the lane. This vale ranges from 0 to infinite. Higher values will influence the driver change the lane early.

lcCooperative: The readiness to execute cooperative lane changing. Higher value leads to the driver being more cooperative to other drivers. The value ranges from 0 to 1. Default value is 1.

lcSpeedGain: The driver’s eagerness for executing lane change in order to gain speed. Higher value results in more lane changing. The value of this parameter changes from 0 to 1.

lcKeepRight: The willingness for following the rule keep right. The value ranges from 0 to infinite. The higher the values the earlier the lane change.

lcLookaheadLeft: This is driver’s ability to recognize the vehicles in a certain distance before changing the lane to the left. The value ranges from 0 to infinite and the default value is 2.

lcSpeedGainRight: Factor for configuring the threshold asymmetry when changing to the left or to the right for speed gain. Naturally the choice for changing to the right takes more consideration. Symmetry is achieved when set to 1.0. default: 0.1, range [0-inf]

All the above parameters were used in the model SL2015 too.
One can observe from the graph that the number of vehicles on the right lane are always high during the simulation. The number vehicles on the middle lane came close to the number of vehicles on the right lane at the 3000 sec instance. The number of vehicles on the left lane is always low as it the lane for the vehicles with high velocity.

2.8.2 SL2015

lcSublane: The enthusiasm for utilizing the Configure lateral alignment inside the path. Higher values will lead in drivers sacrificing speed for lateral alignment.

lcPushy: Ability to cut in laterally on other drivers. The value ranges from 0 to 1.

lcPushyGap: The minimum gap desired from the other drivers while impinging laterally on other drives. It ranges from 0 to minGapLat.

lcAssertive: The driver’s willingness to accept front and rear gaps on the target lane. It’s default value is 1. All positive real numbers can be used in this parameter.
lcImpatience: Time changing factor for altering lcAssertive and lcPushy. It ranges from -1 to 1. Default value is zero.

lcTimeToImpatience: Impatience grows whenever a manoeuvre to change lane is blocked. In this parameter the time to reach maximum impatience can be described. Default value is infinite (disables the growth of impatience).

lcAccelLat: Maximum lateral acceleration per second.

Figure 36: Speed Time diagram of SL2015 model

Figure 37: Throughput of SL2015
3. Case Study

The area selected for our study is that of a major road with a ring function that almost surrounds the west part of the district core. Viale Egeo allows you to travel outside the nucleus of the district without entering the same. This allows to regulate the flow of vehicles in the study area, however the level of congestion is high due to the presence of many offices and presence of underground stations and associated multi-level parking lots.

![Google map showing the studied intersection](image)

Selected intersections delimit half the pentagon that surrounding the district. We are in the western part of the Pentagon and in this part, the core of the district fastens to neighboring districts as the Torrino and Mostacciano. The increased flow of cars we have in the early hours of the morning and late in the afternoon as in the rest of the city. It is to be highlighted that most of the flow is due to the change of mode of transport to the Eur Magliana parking, and this worsens the traffic situation. The first phase of analysis has been prepared with a graphical table of the location of the Intersections and route.
Int. 1 Viale dell’Oceano Pacifico - Viale Avignone - Via-le Giorgio Ribotta
Int. 2 Viale dell’Oceano Pacifico - Viale della Tecnica - Viale grande Muraglia
Figure 39: Int. 1 Viale Oceano Pacifico - Viale Avignone - Via le Giorgio Ribotta

Figure 40: Int. 2 Viale Oceano Pacifico - Viale della Tecnica - Viale grande Muraglia
3.1 Operational Analysis of signalized junctions

HCM stands for highway capacity manual. The National Academy of Science in the United States publishes HCM. HCM contains various procedures for analysing and calculating the capacity, Level of service of the traffic systems such as freeway, bike lane, traffic intersection and pedestrians. There are several editions in the HCM. The fifth edition HCM 2010 has been used to compute the capacity and Level of Service for the intersections that we have selected.

![Figure 41: HCM methodology](image)

3.2 Collecting Data

The input data were selected using survey following number of benchmarks, including: Geometric Conditions, Traffic Conditions, and signalization conditions. This is a scheme of the parameters collected during the inspections. Complete information regarding signalization is considered to perform the analysis. This information includes a phase diagram illustrating the phase plan, cycle length, green times, and change-and-clearance intervals. Lane groups operating under actuated control must be identified, including the existence of push-button pedestrian-actuated phases. If pedestrian timing requirements exist, the minimum green time for the phase is indicated and provided for in the signal timing. The methodology for signalized intersections is disaggregate; that is, it is designed to consider individual intersection approaches and individual lane groups within approaches. Segmenting the intersection into lane groups is a relatively simple process that considers both the geometry of the intersection and
the distribution of traffic movements. Traffic data can be collected by various techniques. The data can be fed into the system by means of special equipment called sensors. In addition, field visits do help to get the number of vehicles, signal timings, speed at a particular intersection. Highway capacity manual does provide input work sheet for the purpose of getting the data. This collected data helps us calculate the traffic demand, analysis of traffic and traffic control systems.
3.3 Operational analysis of intersection 1
Viale Oceano Pacifico - Viale Avignone - Via-le Giorgio Ribotta

**INPUT WORKSHEET**

<table>
<thead>
<tr>
<th>General Information</th>
<th>Site Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyst</td>
<td>Vivek Reddy Marreddi</td>
</tr>
<tr>
<td>Date Performed</td>
<td>16-mag</td>
</tr>
<tr>
<td>Intersection</td>
<td>Viale O. P</td>
</tr>
<tr>
<td>Area Type</td>
<td>CBD</td>
</tr>
<tr>
<td>Analysis Time Period</td>
<td>18.00 / 18.17</td>
</tr>
<tr>
<td>Jurisdiction</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>Partially Cloudy</td>
</tr>
<tr>
<td>Analysis Year</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Volume and Timing input</th>
<th>Eastbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td>VT (veh/h)</td>
<td>318</td>
<td>152</td>
<td>73</td>
</tr>
<tr>
<td>% Heavy Vehicles, % MV</td>
<td>0%</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td>Peak - Hour Factor, PHF</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>% Start-up lost time, %I (s)</td>
<td>/</td>
<td>/</td>
<td>P</td>
</tr>
<tr>
<td>Extension of effective green time, e (s)</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Arrival Type, AT</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Approach pedestrian volume, 2 x ped (p/h)</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Approach bicycle volume, 2 x bic (p/h)</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Parking (Y or N)</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Parking Maneuvres, Nm (Manouvers/h)</td>
<td>10</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Bus Stopping, Nb (buses/h)</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Min. timing for pedestrians, 3 x (s)</td>
<td>17.35</td>
<td>17.35</td>
<td>17.35</td>
</tr>
</tbody>
</table>

** SIGNAL PHASING PLAN **

| D | 1 |
| G | 2 |
| A | 3 |

| Cycle L | 102 |

Table 14: Input worksheet of car following model for intersection 1
Table 15: Saturation flow and level of service worksheets for intersection 1

Now the OSM data of this intersection is downloaded and loaded into SUMO. The resulted network image is shown below.
The resulted network that has been obtained from the SUMO has two intersections, because SUMO recognised Via dell’oceano pacifico-Viale Avignone as one intersection and Via dell’oceano pacifico-Viale Giorgio Ribotta as another intersection and signs both of them two separate traffic signals. There is a command in SUMO which is “--junctions.join” to join two intersections nearby and the resulted network is shown below.
In the above image the shows that the traffic light has been incorporated and shown with the signal phasing according to the field visit.
The phases column in the above image show the characters in which each character describes different states of traffic signals in the phase. There are three phases in this traffic signal setting. The following signal colours are used:
- r – red signal
- y – amber (yellow) signal
- G – Green signal

There is a need for eight different types of flows in this intersection. Next the vehicle flows through the intersection has been generated by the commands below.

```xml
<routes>
    <vType accel="1.0" decel="5.0" id="Car" length="2.0" maxSpeed="13.0" sigma="0.5s"/>
    <flow id="type1" color="1,1,0" begin="0" end="7200" vehsPerHour="318" type="Car">
        <route edges="gneE14 -119306556#2"/>
    </flow>
    <flow id="type2" color="1,1,0" begin="0" end="7200" vehsPerHour="152" type="Car">
        <route edges="gneE14 335286725#0"/>
    </flow>
    <flow id="type3" color="1,1,0" begin="0" end="7200" vehsPerHour="73" type="Car">
        <route edges="-335286725#0 gneE8"/>
    </flow>
    <flow id="type4" color="1,1,0" begin="0" end="7200" vehsPerHour="330" type="Car">
        <route edges="-335286725#0 -119306556#2"/>
    </flow>
    <flow id="type5" color="1,1,0" begin="0" end="7200" vehsPerHour="170" type="Car">
        <route edges="-335286725#0 -119306556#2"/>
    </flow>
    <flow id="type6" color="1,1,0" begin="0" end="7200" vehsPerHour="247" type="Car">
        <route edges="119306556#2 gneE8"/>
    </flow>
    <flow id="type7" color="1,1,0" begin="0" end="7200" vehsPerHour="352" type="Car">
        <route edges="119306556#2 335286725#0"/>
    </flow>
    <flow id="type8" color="1,1,0" begin="0" end="7200" vehsPerHour="601" type="Car">
        <route edges="119306556#2 335286725#0"/>
    </flow>
</routes>
```

The simulation was run using the above procedure. Sigma in the car following model describes the driver imperfection it ranges from 0 to 1. When the sigma is 0 the drivers vary their speed randomly. The average waiting time obtained from the simulation run using the above parameters if 49.6 seconds. The intersection delay obtained by the methodology of HCM is 61.8 seconds.
### 3.4 Operational analysis of intersection 2

Viale dell’Oceano Pacifico - Viale della Tecnica - Viale grande Muraglia

#### General information

<table>
<thead>
<tr>
<th>Analyst</th>
<th>Vivek Reddy Marreddi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date Performed</td>
<td>16-mag</td>
</tr>
<tr>
<td>CBD Central Business District</td>
<td></td>
</tr>
<tr>
<td>Analysis Time Period</td>
<td>18.00 / 18.17</td>
</tr>
<tr>
<td>Municipio IX, Roma Capitale</td>
<td></td>
</tr>
<tr>
<td>Weather</td>
<td>Partially Cloudy</td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
</tbody>
</table>

#### Volume and Timing Input

<table>
<thead>
<tr>
<th></th>
<th>Eastbound</th>
<th>Westbound</th>
<th>Northbound</th>
<th>Southbound</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Volume, V (veh/h)</strong></td>
<td>288</td>
<td>745</td>
<td>165</td>
<td>505</td>
</tr>
<tr>
<td>% Heavy Vehicles, % HV</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Peak - Hour Factor, PHF</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>Pretimed (P) or Actuated (A)</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Start-up lost time, t1 (s)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Extension of effective green time, e (s)</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Arrival Type, AT</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Approach pedestrian volume, 2%ped (p/h)</td>
<td>50</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Approach bicycle volume, 2%bic (p/h)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Parking (Y or N)</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Parking Maneuvers, Nm (Maneuvners/h)</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Bus Stopping, N (buses/h)</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>Min. timing for pedestrians, 3sGap (s)</td>
<td>17.35</td>
<td>17.35</td>
<td>17.35</td>
<td>17.35</td>
</tr>
</tbody>
</table>

#### Signal Phasing Plan

<table>
<thead>
<tr>
<th>D</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Timing</td>
<td>G</td>
<td>Y</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle L</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

52
For the second intersection a background satellite image of the intersection has been inserted into the network model for enhancing the visualization of the intersection.
Once the network and route files are ready the configuration file has to be written which is described below.

<configuration>
  <input>
    <net-file value="2.net.xml"/>
    <route-files value="4.rou.xml"/>
  </input>
  <output>
    <queue-output value="results.xml"/>
  </output>
  <processing>
    <ignore-route-errors value="true"/>
    <time>
      <begin value="0"/>
      <end value="1200"/>
    </time>
    <time-to-teleport value="-1"/>
  </processing>
</configuration>

SUMO software does not show the output results after the simulation has been run. The output results can be found in the output file results.xml. The average waiting time of a vehicle is 74.96 seconds. The intersection delay computed by HCM methodology is 82 seconds.
3.5 Integrated Network
In this scenario a network with both the intersection have been develop and simulated. The value of demand is the numbers used from the field visits. Multi entry exit detectors were used in on the viale Oceano Pacifico lane to detect the average waiting time of the vehicle passing through these intersections. The image shown below displays the entire network that was developed by converting the openstreet map.

![Converted network from OSM](image)
Now the synchronization between the two signals has to be developed to have minimum waiting time on the viale dell’Oceano Pacifico. The Offset between the cycles can be selected by using the formula described in the highway capacity manual and it is compared with results from the simulation runs on SUMO. On SUMO network exit entry detectors have been used to calculate measure the mean speed, Average waiting time along the viale dell’Oceano Pacifico. The program for the exit entry detectors has to be written into an additional file in the format of xml as always. This program forces the SUMO software to write the output into an xml file. The program for the exit entry detectors is shown below.

```xml
<additionals>
  <entryExitDetector id="Full" freq="100" file="fulle2e.xml"
    timeThreshold="10" speedThreshold="15">
    <detEntry lane="-335286725#2_1" pos="23"/>
    <detEntry lane="-335286725#2_1" pos="23"/>
    <detExit lane="119306574_1" pos="55"/>
    <detExit lane="119306574_0" pos="55"/>
  </entryExitDetector>
</additionals>
```

The travel time to pass these two intersections as determined by the simulation is 50.9 seconds. The average waiting time to pass the two interesctions on the Viale dell’Oceano Pacifico is 60.2 seconds. When both the intersections were synchronized the waiting time is 47 seconds which is a 21% reduction in travel time.
3.6 TraCI
Traffic control Interface, shortly known as TraCI. TraCI uses transmission control protocol based client/server architecture. It permits to recover values of simulated objects and logically control their behaviour on-line. SUMO acts as a server when TraCI is initiated. SUMO doesn’t control the road traffic simulations after TraCI is initiated, it waits for the external application to come over and take control of the simulation.

![Diagram showing the communication between the Client and SUMO during simulation](image)

*Figure 46: Figure showing the communication between the Client and SUMO during simulation*

The above picture shows the communication between the SUMO acting as a server with a client software. When the TraCI is initiated SUMO loads the scenario and waits for the client software then after the client software is connected the simulation can started by the play button in SUMO-GUI. The are many categories in TraCI package. Each package has a different function. They are edge, gui, Induction loop, junction, lane, lane area, multientry and exit, person, polygon, route, simulation, traffic light, vehicle, vehicle type, connection, constants, domain, exceptions and storage. Each category has various functions and they can be used in the python program according to their functionality.
3.7 TraCI traffic light

The above figure shows the intersection with a induction loop detector place on the north bound approach of the intersection. This intersection is used to detect the vehicles passing from north to south through the intersection. A python script has been written for this intersection to regulate the traffic signal. This python program opens the TraCI terminal in SUMO. Then detects if there are any vehicles on the induction loop. If there are no signals passing from north to south, then the East and west signals of the intersection remain green. As soon as the induction loop detects a vehicle, the python program that has been developed changes the state of the traffic signal so that the traffic signals to North and south remain green. As the phase finishes the traffic signal return to the previous state which is green signal on east and west approaches. TraCI means traffic control interface. Python program communicates with SUMO via TraCI. The communication between SUMO and python is bidirectional.
Start

Are there any vehicles on the induction loop detector?

Keep the traffic light green of east and west side of the intersection

Change the traffic signal state to green on both North and South side of the intersection

Simulation max time reached?

Stop
4. Traffic signal Synchronization

Traffic signal Synchronization is a technique to match the green times of the traffic signals along the street. This method is used where there is a high volume of traffic. Drivers lose patience when they have to stop at every intersection on the main street when there is few or no traffic on the side street. All the signals in the intersection should have the same cycle length.

![Figure 48: Traffic signal synchronization along four signals](image)

The above picture represents the traffic movement along the synchronized intersections on a time space graph. The blue lines show the traffic movement along the street. As soon the vehicle approaches the signal 2L the state of the traffic signal is already so no time is wasted at this intersection and the next two signals. Synchronization does not change the green time of the intersection.

4.1 A scenario with four intersections

A network was developed in NETEDIT with four intersections with a gap of 320 metres. All the four-traffic signal have the same cycle length. The active lane area detector of 300 metres length in front of the traffic signal gneJ12 as shown in the image below.
The signal gneJ12 is an actuated signal. The other signals are coordinated with gneJ12 signal. The coordination is done by the python communicating with SUMO via TraCI. Max-gap is the gap that the two consecutive vehicles. If max gap is greater than 3 metres and the time is greater
than the minimum phase duration the traffic light changes the phase. If the SUMO detects the continuous flow it keeps the traffic phase until maximum phase duration. The detectorRange is the distance before the traffic signal until which the detector is active. Here in this network the detectorRange is 300 metres. Lane area detectors are always used for actuated traffic light. Lane area detector is responsible giving the data about the vehicles that are approaching the traffic signal.
The simulation results show that there is 30% reduction in travel time, 60% reduction in time lost and 50% increase in mean speed. To the above scenario three additional schemes were tested on this network. Those include

A: Traffic signals with fixed time cycle
B: Traffic signals based on delay
C: Traffic signal based on continuous flow
D: Synchronized adaptive traffic signal with active detectors

<table>
<thead>
<tr>
<th>Scheme</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Travel Time(s)</td>
<td>180</td>
<td>170</td>
<td>176</td>
<td>146</td>
</tr>
<tr>
<td>Mean Time Loss(S)</td>
<td>81</td>
<td>71</td>
<td>95</td>
<td>51</td>
</tr>
<tr>
<td>Mean Speed(m/s)</td>
<td>7.69</td>
<td>8.17</td>
<td>7.1</td>
<td>10.6</td>
</tr>
<tr>
<td>CO2 Released(g)</td>
<td>382</td>
<td>365</td>
<td>378</td>
<td>311</td>
</tr>
</tbody>
</table>

Table 16 Comparison between different traffic schemes

As seen in the above table scheme D is the best performer in all the key performances shown above

4.2 A scenario with five intersections

An ideal network for testing the synchronization of signal is developed which contains five consecutive signalized intersections with equal space between them. The first signal from the east is an actuated signal which observes the traffic flow passing through the intersection and the other intersection are synchronized dynamically according to this actuated signal.
Figure 51: Network with five equidistant intersection

Figure 52: Mean travel time
Figure 53 Mean speed

Figure 54 Mean time loss
<table>
<thead>
<tr>
<th>Scheme</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Travel Time</td>
<td>218</td>
<td>199</td>
<td>210</td>
<td>179</td>
</tr>
<tr>
<td>Mean Time Loss</td>
<td>102</td>
<td>79</td>
<td>90</td>
<td>58</td>
</tr>
<tr>
<td>Mean Speed</td>
<td>7.01</td>
<td>8.1</td>
<td>7.6</td>
<td>10.2</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>463</td>
<td>427</td>
<td>453</td>
<td>381</td>
</tr>
</tbody>
</table>

Table 17: Comparison between different traffic control schemes

In terms of every KPI the scheme A performed poorly with respect to other schemes. The D scheme outperforms every other scheme mentioned in the table above.

### 4.3 A scenario with six intersections

This scenario has the same characteristics as the previous scenario, but this network has six signalized intersections. All the intersections on the network are equally spaced.

![Network with six equidistant intersections](image)

Figure 55: Network with six equidistant intersections

![Mean Time loss](image)

Figure 56 Mean time loss
Figure 57 Mean travel time

Figure 58 Mean speed

<table>
<thead>
<tr>
<th>Scheme</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Travel Time</td>
<td>266</td>
<td>227</td>
<td>230</td>
<td>179</td>
</tr>
<tr>
<td>Mean Time Loss</td>
<td>139</td>
<td>97</td>
<td>103</td>
<td>65</td>
</tr>
<tr>
<td>Mean Speed</td>
<td>6.4</td>
<td>9.6</td>
<td>9.3</td>
<td>10.2</td>
</tr>
<tr>
<td>CO₂ emissions</td>
<td>565</td>
<td>494</td>
<td>514</td>
<td>442</td>
</tr>
</tbody>
</table>

Table 18: Comparison between different traffic schemes
4.4 Adaptive traffic signal with regulating maximum speed of the street.
In this simulation environment, the traffic signals are adaptive with the maximum velocity of the arteries are dynamic. The green time of the traffic signal is divided into two section out of which the first section is fixed and the second section is dynamic. The figure below shows the timing of the green phase in SUMO.

I <phase duration="15" state="xGrG"/>
II <phase duration="10" minDur="1" maxDur="15" state="xGrG"/>
   <phase duration="4" state="rYrY"/>
   <phase duration="24" state="GxGr"/>
   <phase duration="4" state="YxYr"/>

*Figure 59: Phase timing*

During the second phase the traffic signal is adaptive. The simulation is initiated by TraCI and the python program regulates the maximum velocity of the street. The initial maximum velocity is 15 m/s during the phase II the maximum velocity of the street is extended to 20 m/s, when the phase II finishes the maximum velocity is return to initial value which is 15 m/s. The output is taken from the simulation by using a multi-entry-exit detector. The results are shown in the figures below. The simulation was run for a duration of 3600 seconds.

*Figure 60 Mean Speed*

As seen in the above figure the mean speed is always higher when there is a variable limit.
The meant travel time with the variable limit is always lower than the mean travel time at constant limit. Now during the simulation an alternative approach was chosen to increase the safety of the passengers because the approach speed at the intersection is high when the light changes to amber because of the increased speed limit. The phase timing is divided into three sections and they are shown in the picture below.

In this scheme the first and third sections are fixed timings and the second section is adaptive which is based on the traffic flow. The velocity of the streets is increased to 20 m/s when the phase is adaptive and then decreased to 15 m/s during the phase III. The results are shown in the pictures below. Multi entry exit detectors were used to generated output in this simulation.
<table>
<thead>
<tr>
<th></th>
<th>Fixed time signal with variable speed limit</th>
<th>Adaptive signal with variable speed limit and safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>sections</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>III</td>
</tr>
<tr>
<td>Control</td>
<td>Fixed</td>
<td>Flow responsive</td>
</tr>
<tr>
<td></td>
<td>Flow responsive</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>Fixed</td>
<td>Flow responsive</td>
</tr>
<tr>
<td>Maximum velocity(m/s)</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Phase time(sec)</td>
<td>15</td>
<td>1-15</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1-15</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

Table 20

![Mean speed graph](image)

*Figure 61 Mean speed*
Figure 62 Mean travel time

Figure 63 Comparison of mean speed between three schemes
The traffic scheme with additional safety phase did not show much difference so it is better to utilize this scheme.

<table>
<thead>
<tr>
<th>KPI</th>
<th>Signal with constant speed limit</th>
<th>Signal with variable limit</th>
<th>Signal with variable limit and safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean travel time(s)</td>
<td>61</td>
<td>53</td>
<td>54</td>
</tr>
<tr>
<td>Mean time loss(s)</td>
<td>20</td>
<td>18</td>
<td>19</td>
</tr>
<tr>
<td>Mean speed(m/s)</td>
<td>9.7</td>
<td>11.3</td>
<td>11.2</td>
</tr>
<tr>
<td>Mean CO₂ emissions</td>
<td>171</td>
<td>157</td>
<td>160</td>
</tr>
</tbody>
</table>

### 4.5 Adaptive signal based on the location of the vehicle

This adaptive signal changes the green time according to the location of the vehicle on the street if the infrastructure detects the vehicle at 400m from the intersection then the time green time is extended by 15 seconds so that the vehicle can pass the intersection freely. If there is no vehicle from 400m to 300m then the traffic signal control system checks whether there are any vehicle between 200m and 300m from the intersection. If there are any vehicles on the street the time is extended by 10 seconds. If there are no vehicle from 200m to 400m away from the intersection, then the system check whether there are any vehicle from 100m to 200m if there are any vehicle in this section the green time is extended by two seconds. Note that there are three sections in the green time phase, out of which the first and the third segments are fixed timings at which the maximum velocity on the street is maintained at 15m/s. The seconds segment is adaptive and the maximum velocity during this phase is increased to 20m/s. During the phase III if the timing of the adaptive phase is extended to 15 seconds the maximum velocity of the street was maintained at 20m/s otherwise it was reduced to 15m/s second.
Acceleration(a)=1m/s²
Deceleration(d)=5m/s²
Initial velocity(u)=15m/s
Final velocity(v)=20m/s
Distance between the vehicle and the traffic signal=400m
Distance travelled during acceleration(S)=$\frac{v^2-u^2}{2a}$
S=87.5m
Distance covered during cruising=300m
Time required for the vehicle to cross the intersection from 400m is 21sec
Time required by the vehicle at 300m from the intersection is 17 sec
Time required by the vehicle at 200m from the intersection is 7 secs
Using the calculations mentioned above the lane area detectors were activated on the network from a distance of 200m to 400m from the intersection.

<table>
<thead>
<tr>
<th>Fixed time signal</th>
<th>Adaptive signal based on vehicle’s location</th>
</tr>
</thead>
<tbody>
<tr>
<td>segments</td>
<td>I</td>
</tr>
<tr>
<td>Control</td>
<td>Fixed</td>
</tr>
<tr>
<td>Maximum velocity(m/s)</td>
<td>15</td>
</tr>
<tr>
<td>Phase time</td>
<td>15</td>
</tr>
</tbody>
</table>

*Table 22*

In the table shown below one can see the three sections. The segments II and III are divided into sections 1,2 and three. If the number of vehicles on the lane is less than $N_{min}$ the signal is turned to red. If the number of vehicles is greater than $N_{min}$ the green time is extended while simultaneously checking the position of the vehicles on the lane. In the section 2 the traffic signal is extended according to the position of the vehicles. The maximum velocity during section 1 and section two is always 20m/s, where the maximum velocity during section 3 will be 20m/s if the section 2 is extended otherwise the maximum velocity will be reduced to 15m/s
Figure 65: Adaptive traffic signal space time diagram
<table>
<thead>
<tr>
<th>KPI</th>
<th>Static Signal</th>
<th>Adaptive signal with variable speed limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean travel time(s)</td>
<td>61</td>
<td>56</td>
</tr>
<tr>
<td>Mean speed(m/s)</td>
<td>9.7</td>
<td>11.7</td>
</tr>
<tr>
<td>Mean time loss(s)</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Mean Co₂ emissions(g)</td>
<td>171</td>
<td>163</td>
</tr>
</tbody>
</table>

Table 23
4.6 Application on viale dell’Oceano Pacifico

Figure 66: Network converted from the OSM map data
The network converted from OSM has many other street this causes the SUMO software to lag a little bit, so the network was filtered by deleting the other lanes manually in the NETEDIT. The result is a just the Viale dell’Oceano Pacifico with the three intersections. The Figure 61 shown below demonstrates the filtered network.

<table>
<thead>
<tr>
<th>Number</th>
<th>Intersection</th>
<th>Distance(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Viale dell’Oceano Pacifico- Via Cristoforo Colombo</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Viale dell’Oceano Pacifico- Viale Giorgio Ribotta</td>
<td>450</td>
</tr>
<tr>
<td>3</td>
<td>Viale dell’Oceano Pacifico- Viale della Grande Muraglia</td>
<td>900</td>
</tr>
<tr>
<td>4</td>
<td>Viale dell’Oceano Indiano- Viale Egeo</td>
<td>1400</td>
</tr>
<tr>
<td>5</td>
<td>Viale Egeo-Via monte dell Finocchio</td>
<td>1900</td>
</tr>
</tbody>
</table>

Table 24: Table showing the distance starting from intersection1

Mean time loss by a vehicle is 30 seconds. The time required to pass the five intersections is 110 seconds.
4.7 Issues found during simulation

The map imported from the OpenStreetMap is not accurate. SUMO considers a large intersection as two intersections. Signal imported from OSM to SUMO do not have proper cycle times. During the simulation of car following models such Pwagner and Wiedemann there were some collisions occurred. Upon referring to the SUMO site forum. The collisions occurred were due to some errors in the simulation software. While testing the python algorithms in SUMO. There were some complications with the logics in the python algorithm as SUMO did not flag any errors and signals were in a constant phase. So, care should be taken while writing the logic in python. There were some problems with multi entry exit detectors due some vehicles exiting the network on other arteries. So, care should be taken while placing the entry exit detectors and the researcher should make sure that there are no other arteries between the entry and exit detector. The traffic lights logic cannot be used as an additional file as this gave some error. The simulation by TraCI does not respect the time described in the configuration file. The user has to specify the detectors in an additional xml file with all the characteristics of the detector in it. Instant Induction loops cannot be used by the TraCI. During the simulation some cars were involved in some collision, the SUMO website describes that the SUMO software uses collision free model, but the presence of some bugs or intentional configurations. SUMO teleports the vehicles if the vehicle has waited too long or involved in a collision. The teleported vehicle will be inserted as soon as there is a place available on the network. A vehicle may be teleported multiple times during the simulation, however the vehicle maintains the average speed on the network during the teleportation. SUMO cannot provide the offset, so the user has to calculate the offset manually. NETEDIT always creates the junctions as a type of priority, this causes vehicles to make unnecessary stops at those junctions. One can overcome this issue by modifying the type of the junction to internal, so vehicles maintain their velocity while passing this intersection. The emissions values generated by the full output shows that the vehicles emit 0mg during idling time, but this is not true as idling engines do create pollution. Converting the network from OSM is quite easy as it uses justs the NETCONVERT tool but correcting this network would take a lot of time as an example a network with 1000 junctions takes less than a minute using the SUMO converting tools and after that correcting would require at least three days.
5. Conclusion and future work

In chapter two several car following models and lane changing models were tested in SUMO. Krauss car following model in SUMO has the most variations of it in SUMO. These studies may help others in selecting the right car following model in SUMO according to ones criteria.

In chapter 5 the methodology used for traffic signal synchronization was described. The signal synchronization with adaptive traffic signal decreases a considerable amount of time loss on urban road arteries. Care should be taken while writing the algorithm in python as the while loop in the program. After studying and analysing several research articles on SUMO. I have concluded that many of the researchers do not share the inner working in building up the networks in SUMO and on TraCI in SUMO. This report would be an excellent guide to whoever starting to simulate in SUMO as this gives an idea on which car following model and what parameters can be used to get the desired result. This study suggests that the use of V2I communication to detect vehicles on the network and make necessary modifications to the traffic light according to the flow. There is a significant reduction in average waiting time, increase in average speed is being exposed by the simulation results. The simulation results of the scenario with six intersections show that there is an average 30% reduction in travel time. There is a 50% increase in mean speed and 60% decrease in time loss along through these intersections. There is a significant improvement in traffic conditions of urban arteries which utilized adaptive traffic signal with synchronization. Further research should be carried out to better understand this system in Python. There is a huge demand for traffic simulation now more than ever due to increased adaptation by various research institutions and government organizations. The simulations results obtained from these simulations can be compared with the real traffic to calibrate the parameters of the model. SUMO is a open source software and it’s uses are unlimited because this simulation software can be couple with any other software to perform the needs of the user. This other software include MATLAB, omnet++, Ns2, Unity3D, rFpro etc. Further research is required to integrate these methods into the existing traffic networks.
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Appendix
Type map

<polygonTypes>
  <polygonType id="waterway" name="water" color=".71,.82,.82" layer="-4"/>
  <polygonType id="natural" name="natural" color=".55,.77,.42" layer="-4"/>
  <polygonType id="natural.water" name="water" color=".71,.82,.82" layer="-4"/>
  <polygonType id="natural.wetland" name="water" color=".71,.82,.82" layer="-4"/>
  <polygonType id="natural.wood" name="forest" color=".55,.77,.42" layer="-4"/>
  <polygonType id="natural.land" name="land" color=".98,.87,.46" layer="-4"/>
  <polygonType id="landuse" name="landuse" color=".76,.76,.51" layer="-3"/>
  <polygonType id="landuse.forest" name="forest" color=".55,.77,.42" layer="-3"/>
  <polygonType id="landuse.park" name="park" color=".81,.96,.79" layer="-3"/>
  <polygonType id="landuse.residential" name="residential" color=".92,.92,.89" layer="-3"/>
  <polygonType id="landuse.commercial" name="commercial" color=".82,.82,.80" layer="-3"/>
  <polygonType id="landuse.industrial" name="industrial" color=".82,.82,.80" layer="-3"/>
  <polygonType id="landuse.military" name="military" color=".60,.60,.36" layer="-3"/>
  <polygonType id="landuse.farm" name="farm" color=".95,.95,.80" layer="-3"/>
  <polygonType id="landuse.greenfield" name="farm" color=".95,.95,.80" layer="-3"/>
  <polygonType id="landuse.village.green" name="farm" color=".95,.95,.80" layer="-3"/>
  <polygonType id="tourism" name="tourism" color=".81,.96,.79" layer="-2"/>
  <polygonType id="military" name="military" color=".60,.60,.36" layer="-2"/>
  <polygonType id="sport" name="sport" color=".31,.90,.49" layer="-2"/>
  <polygonType id="leisure" name="leisure" color=".81,.96,.79" layer="-2"/>
  <polygonType id="leisure.park" name="tourism" color=".81,.96,.79" layer="-2"/>
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<polygonType id="aerialway" name="aerialway" color=".20,.20,.20" layer="-2"/>
<polygonType id="shop" name="shop" color=".93,.78,1.0" layer="-1"/>
<polygonType id="historic" name="historic" color=".50,1.0,.50" layer="-1"/>
<polygonType id="man_made" name="building" color="1.0,.90,.90" layer="-1"/>
<polygonType id="building" name="building" color="1.0,.90,.90" layer="-1"/>
<polygonType id="amenity" name="amenity" color=".93,.78,.78" layer="-1"/>
<polygonType id="amenity.parking" name="parking" color=".72,.72,.70" layer="-1"/>
<polygonType id="highway" name="highway" color=".10,.10,.10" layer="-1" discard="true"/>
<polygonType id="boundary" name="boundary" color="1.0,.33,.33" layer="0" fill="false" discard="true"/>
<polygonType id="admin_level" name="admin_level" color="1.0,.33,.33" layer="0" fill="false" discard="true"/>
</polygonTypes>

Configuration

<input>

<net-file value="file.net.xml"/>

<route-files value="file.rou.xml"/>
</input>

<time>

<begin value="0"/>

<end value="3600"/>
</time>

<output>

<queue-output value="output.xml"/>
</output>
</configuration>
OSM

Then the user has to navigate to the directory where the network file is downloaded. Then the following command netconvert is used.

The syntax for the following command is shown below

Netconvert --osm-files file.osm -o file.net.xml

In the above syntax the file.osm is converted to file.net.xml. The next step is to use a function known as polyconvert which imports geometrical shapes so that it can be viewed by the SUMO-gui. In this step we import polygons and their types of the structures in the map based on their color.

The above polygon types has to imported into a notemap++ file and to be saved in .xml format as file.xml.

Then the following syntax can be used to convert

Polyconvert --net-file file.net.xml --osm-files file.osm --type-file typemap.xml -o file.poly.xml

This created the polygon file which can be used to visualize infrastructure and habitation in the network

Python c:/SUMO/map/randomtrips.py -n file.net.xml -e 100 1

The simulation generated 1 to 100 trips.

Python c:/SUMO/map/randomtrips.py -n file.net.xml -r file.rou.xml -e 100 1

Then the above syntax gives an output file of file.poly.xml. There is file in the tools folder of the SUMO directory where you can find the randomtrips.py which generated random trips for our simulation. This file can be copied into the directory where the file.osm is located then the following command has to be used

Traffic light

The traffic signal logic for the simple node is given below.

<tlLogic id="gneJ1" type="static" programID="0" offset="0">
    <phase duration="48" state="GGrrGGrr"/>
    <phase duration="4" state="yyrryyrr"/>
    <phase duration="48" state="rrGGrrGG"/>
    <phase duration="4" state="rryyrryy"/>
</tlLogic>
The route file for the lane changing mode LC2013l is described below

```xml
<routes>
  <vType accel="1.5" decel="3.5" id="Car" length="4.0" mingap="3" emergencyDecel="9.5" maxSpeed="13.0" tau="1" lcKeepRight="1" lcCooperative="2" lcStrategic="0.5" laneChangeModel="LC2013"/>
  <flow id="type1" color="1,1,0" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE14 gneE15 gneE16 gneE17 gneE7 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 ">
    </route>
  </flow>
  <flow id="type2" color="1,1,0" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE14 gneE15 gneE16 gneE17 gneE7 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 ">
    </route>
  </flow>
  <flow id="type3" color="0,1,0" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE15 gneE16 gneE17 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 ">
    </route>
  </flow>
  <flow id="type4" color="1,0,1" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE16 gneE17 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 gneE7 ">
    </route>
  </flow>
  <flow id="type5" color="1,1,0" begin="0" end= "36060" vehsPerHour="100" type="Car">
    <route edges="gneE17 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 gneE7 gneE8 ">
    </route>
  </flow>
  <flow id="type6" color="1,0,0" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE7 gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 gneE8 gneE9 ">
    </route>
  </flow>
  <flow id="type7" color="1,0.5,0.5" begin="0" end= "3600" vehsPerHour="100" type="Car">
    <route edges="gneE8 gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 gneE8 gneE9 gneE11 ">
    </route>
  </flow>
</routes>
```
<flow id="type8" color="0.5,1.0" begin="0" end="36000" vehsPerHour="100" type="Car">
  <route edges="gneE9 gneE11 gneE12 gneE13 gneE14 gneE15 gneE16 gneE17 gneE7 gneE8 gneE9 gneE11 gneE12"/>
</flow>

<routes>
  <vType accel="1.0" decel="5.0" id="Car" length="3.0" maxSpeed="13.0" sigma="0.5"/>
  <flow id="type1" color="1,1,0" begin="0" end="7200" vehsPerHour="318" type="Car">
    <route edges="gneE14 -119306556#2"/>
  </flow>
  <flow id="type2" color="1,1,0" begin="0" end="7200" vehsPerHour="152" type="Car">
    <route edges="gneE14 335286725#0"/>
  </flow>
  <flow id="type3" color="1,1,0" begin="0" end="7200" vehsPerHour="73" type="Car">
    <route edges="-335286725#0 gneE8"/>
  </flow>
  <flow id="type4" color="1,1,0" begin="0" end="7200" vehsPerHour="330" type="Car">
    <route edges="-335286725#0 -119306556#2"/>
  </flow>
  <flow id="type5" color="1,1,0" begin="0" end="7200" vehsPerHour="170" type="Car">
    <route edges="-335286725#0 -119306556#2"/>
  </flow>
  <flow id="type6" color="1,1,0" begin="0" end="7200" vehsPerHour="247" type="Car">
    <route edges="119306556#2 gneE8"/>
  </flow>
  <flow id="type7" color="1,1,0" begin="0" end="7200" vehsPerHour="352" type="Car">
    <route edges="119306556#2 335286725#0"/>
  </flow>
  <flow id="type8" color="1,1,0" begin="0" end="7200" vehsPerHour="601" type="Car">
  </flow>
</routes>

Intersection 1

The demand for the intersection 1 is given in SUMO as observed from the field visits. The code below describes the parameters and the demand of the traffic flow.
The traffic signal logic written in the SUMO is described below. The phases and their timings imitate the traffic signal observed

```xml
<tlLogic id="Viale_oceano_pacifico-viale_Avignone" type="static" programID="0" offset="0">
    <phase duration="48" state="GGrGrrrrrGGG"/>
    <phase duration="4" state="YYrrrrryyy"/>
    <phase duration="68" state="GGGGgrrrrrr"/>
    <phase duration="4" state="yyyyyrrrrrr"/>
    <phase duration="24" state="rrrGGGGrtrr"/>
    <phase duration="4" state="rrrryyyyrrr"/>
</tlLogic>
```
Edge

There are various functions in this class. All these functions give the information about the road and the vehicles on the road.

1. adaptTraveltime(self, edgeID, time, begin=None, end=None)

This function is used for re-routing for the given edge. It is necessary to specify the begin and end of this time so this function will be applied only in that time otherwise the function will apply all the time.

Syntax:

\[
\text{TraCI.edge.adaptTraveltime(edgeID, begin=None, end=None)}
\]

2. getAdaptedTraveltime(self, edgeID, time)

This function gives the travel time in seconds used on an edge at a given time used for rerouting in double.

Syntax:
TraCI.edge.getAdaptedTraveltime()

3. getLaneNumber(self, edgeID)
This function returns the number of lanes of this edge as an integer.
Syntax:
TraCI.edge.getLaneNumber()

4. getLastStepHaltingNumber(self, edgeID)
This function returns the number of halting vehicle on given edge in the last time step as an integer.
Halt is a speed less than 0.1 m/s.
Syntax:
TraCI.edge.getLastStepHaltingNumber("edgeID")

5. getLastStepMeanSpeed(self, edgeID)
This function returns the average speed of the vehicles in m/s on a given edge in the last time step as double.
Syntax:
TraCI.edge.getLaststepMeanSpeed("edgeID")

6. getLastStepOccupancy(self, edgeID)
yields the occupancy in percentage for the last time step on the given edge as a double.
Syntax:
TraCI.edge.getLastStepOccupancy("edgeID")

7. getLastStepVehicleNumber(self, edgeID)
Returns the total number of vehicles for the last time step on the given edge.
Syntax:
TraCI.edge.getLastStepVehicleNumber()

8. getWaitingTime(self, edgeID)
This command gives the sum of the waiting time of all vehicles currently on the prescribed edge as a double value.
Syntax:
TraCI.edge.getWaitingTime("edgeID")

---

**Inductionloop**

1. getLaneID(self, loopID)
This function can be used to the ID of the lane on which the induction loop detector is placed upon.
Syntax:
TraCI.inductionloop.getLaneID("LaneID")
2. getLastStepMeanSpeed(self, loopID)

This returns the value of mean speed of m/s of vehicles on the induction loop detector in the last time step.

Syntax:
TraCI.inductionloop.getLastStepMeanSpeed()
3. getLastStepVehicleNumber(self, loopID)

This function returns the number of vehicles that were on the specified induction loop detector in the last time step.

4. getTimeSinceDetection(self, loopID)

This function returns the time in seconds since last detection.

Syntax:
TraCI.inductionloop.getTimeSinceDetection("loopID")
5. getPosition(self, loopID)

This command returns the measured position from beginning of the lane in meters.

Syntax:
TraCI.inductionloop.getPosition("loopID")

The above described commands can used also for the lane area detectors except the following command.

Lane
1. getLength(self, laneID)

Gives the length of the lane area detector in double

Syntax:
TraCI.lane.getLength("laneID")
2. getMaxSpeed(self, laneID)

getMaxSpeed(string)
This command returns a value in double the maximum allowed speed on the lane in m/s.

Syntax:
TraCI.lane.getMaxSpeed("laneID")
3. setMaxSpeed(self, laneID, speed)
setMaxSpeed(string, double)
This command can be used to set a fresh maximum speed on the specified lane
Syntax:
TraCI.lane.setMaxSpeed(“laneID”)

4.getEdgeID(self, laneID)
getEdgeID(string)
This command returns the id of the edge that the given lane belongs to.
Syntax:
TraCI.lane.getEdge(“laneID”)

Simulation
1. getArrivedNumber(self)
getArrivedNumber() -> integer
Returns the number of vehicles which arrived (have reached their destination and are removed from the road network) in this time step.

2. getCurrentTime(self)
getCurrentTime() -> integer
Returns the current simulation time in ms. Hence care should be taken while writing the python program as the simulation time is displayed in seconds.

3. getDeltaT(self)
getDeltaT()
Returns the length of one simulation step in milliseconds

4. getDepartedNumber(self)
getDepartedNumber()
Returns the number of vehicles which departed (were inserted into the road network) in this time step.

5. getMinExpectedNumber(self)
getMinExpectedNumber() -> integer
Returns the number of vehicles which are in the net plus the ones still waiting to start. This number may be smaller than the actual number of vehicles still to come because of delayed route file parsing. If the number is 0 however, it is guaranteed that all route files have been parsed completely and all vehicles have left the network.

Traffic Light
1. getCompleteRedYellowGreenDefinition(self, tlsID)
This function can be used to set the traffic definitions in SUMO
2. getControlledLanes(self, tlsID)
getControlledLanes(string) -> list

This function gives the list of all the lanes controlled by traffic light.

3. getPhase(self, tlsID)
getPhase(string)
Returns the phase of the traffic signal in integer form.

4. getPhaseDuration(self, tlsID)
getPhaseDuration(string) -> integer

Returns the duration of the current phase in integer.

5. getRedYellowGreenState(self, tlsID)
getRedYellowGreenState(string) -> string

This function return the state of the traffic light in the following format as Ggyyrro, here the lower case letters mean that the vehicles approaching the intersection of that lane has to decelerate. The image below shows the possible states of the traffic light those can be described in SUMO.

Syntax:
TraCI.trafficlights.getRedYellowGreenState("tlsID")

6. setCompleteRedYellowGreenDefinition(self, tlsID, tls)
setCompleteRedYellowGreenDefinition(string, ) -> None

7. setLinkState(self, tlsID, tlsLinkIndex, state)
setLinkState(string, string, int, string) -> None
Sets the state for the given tls and link index. The state must be one of RgGyYoOu for red, red-yellow, green, yellow, off, where lower case letters mean that the stream has to decelerate. The link index is shown the gui when setting the appropriate junctino visualization optin.

8. setPhase(self, tlsID, index)
setPhase(string, integer) -> None

9. setPhaseDuration(self, tlsID, phaseDuration)
setPhaseDuration(string, integer or float) -> None

Set the phase duration of the current phase in seconds.

10. setProgram(self, tlsID, programID)
setProgram(string, string) -> None

Sets the id of the current program.

11. setRedYellowGreenState(self, tlsID, state)
setRedYellowGreenState(string, string) -> None

Sets the named tl's state as a tuple of light definitions from rugGyYuoO, for red, red-yellow, green, yellow, off, where lower case letters mean that the stream has to decelerate.

Vehicle

1. getWaitingTime(self, vehID)

getWaitingTime() -> double
The waiting time of a vehicle is defined as the time (in seconds) spent with a speed below 0.1m/s since the last time it was faster than 0.1m/s. (basically, the waiting time of a vehicle is reset to 0 every time it moves). A vehicle that is stopping intentionally with a <stop> does not accumulate waiting time.

2. getSpeed(self, vehID)

getSpeed(string)
The speed of the vehicle in the last will be returned by this function

3. setDecel(self, vehID, decel)

setDecel(string, double) -> None

This command is used to set the maximum deceleration of the vehicle in m/s^2.

4. setMaxSpeed(self, vehID, speed)

setMaxSpeed(string, double) -> None

This instruction sets the maximum speed in m/s for the specified vehicle. The value is taken as a double.

Syntax:
TraCI.vehic.clientX.setMaxSpeed("vehID", speed)

Output of multi entry-exit detector

<table>
<thead>
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<th>#</th>
<th>vehID</th>
<th>vehID</th>
<th>vehID</th>
<th>vehID</th>
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97
Python script for SUMO
Adaptive traffic signal detecting the density of vehicles on the edge
import traci

# No.of phases can be described here
MAINGREEN = "GrGr"
MAINYELLOW="YYrY"
SIDEGREEN="GrGr"
S IDEYELLOW="rrry"

if not traci.isEmbedded():
    N = 1000
    pNE = 1./10
    pEW = 1./15
    pNS = 1./20
    pSN = 1./25
    routes = open("dy.rout.xml","r")
    log = open("log.txt", "w")
    print >> routes, "<routes>
    <vType id="Main" accel="1" decel="4.5" sigma="0.5" length="4" minGap="10" maxSpeed="13"/>
    <vType id="Side" accel="1" decel="4.5" sigma="0.5" length="4" minGap="10" maxSpeed="13"/>
    <route id="MB" edges="gneE1 -gneE2" />
    <route id="SB" edges="gneE2 gneE1" />
    <route id="EB" edges="gneE3 -gneE0" />
    <route id="WB" edges="gneE0 gneE3" />
    
    lastVeh = 0
    vehNr = 0
    for i in range(N):
        if random.uniform(0,1) < pNE:
            print >> routes, '  <vehicle id="\%d" type="Main" route="MB" depart="\%d" />' % (vehNr,
            vehNr += 1
            lastVeh += 1
        if random.uniform(0,1) < pEW:
            print >> routes, '  <vehicle id="\%d" type="Main" route="MB" depart="\%d" />' % (vehNr,
            vehNr += 1
            lastVeh += 1
        if random.uniform(0,1) < pNS:
            print >> routes, '  <vehicle id="\%d" type="Main" route="MB" depart="\%d" />' % (vehNr,
            vehNr += 1
            lastVeh += 1
        if random.uniform(0,1) < pSN:
            print >> routes, '  <vehicle id="\%d" type="Main" route="MB" depart="\%d" />' % (vehNr,
            vehNr += 1
            lastVeh += 1

    print >> routes, "</routes>
    routes.close()

    sumoBinary = 'sumo-gui'
    sumoConfig = "test.sumo.cfg"
    if len(sys.argv) > 1:
        retcode = subprocess.call("%s -c %s --python-script %s" % (sumoBinary, sumoConfig, _file_),
            sys.exit(retCode)
    else:
        sumoProcess = subprocess.Popen("%s -c %s" % (sumoBinary, sumoConfig),
            shell=True, stdout=sys.stdout)

    step = 0
    max_d = 0
    i=0
    edge_density = {}
    edge_ids = traci.edge.getIDList()
    traffic_lights=traci.trafficlights.getIDList()
    traci.trafficlights.setRedYellowGreenState("gneJ1", "rrr")
    while step == 0 or traci.simulation.getNbrExpectedNumber() > 0:
        traci.simulationStep()
        for i in range(1):  
            vehicle_ids=traci.edge.getLastStepVehicleIDs(edge_ids[i])
            for vehicle in vehicle_ids:
                time=traci.simulation.getCurrentTime()
                road=traci.vehicle.getRoadID(vehicle)
                type=traci.vehicle.getTypeID(vehicle)
                speed=traci.vehicle.getSpeed(vehicle)
                accel=traci.vehicle.getAccel(vehicle)

                if(max_d == d_1 or max_d == d_2):
                    traci.trafficlights.setRedYellowGreenState("gneJ1", "gYgY")
                    if(max_d == d_3 or max_d == d_4):
                        traci.trafficlights.setRedYellowGreenState("gneJ1", "YgYg")

                step += 1
                traci.close()
                sys.stdout.flush()
Adaptive signal based on the location of the vehicle

```java
while traci.simulation.getMinExpectedNumber() > 0:
    traci.simulationStep()
    if traci.trafficlights.getPhase("gneJ12") = 0:
        traci.lane.setMaxSpeed("gneE5_0", 15)
        traci.lane.setMaxSpeed("-gneE5_0", 15)
        x = traci.simulation.getCurrentTime()
        y = x + 3000
    elif traci.trafficlights.getPhase("gneJ11") == 1:
        traci.lane.setMaxSpeed("gneE5_0", 20)
        traci.lane.setMaxSpeed("-gneE5_0", 20)
        traci.lane.setMaxSpeed("gneE6_0", 20)
        traci.lane.setMaxSpeed("-gneE6_0", 20)
        if traci.simulation.getCurrentTime() < y:
            traci.trafficlights.setPhaseDuration("gneJ12", 15)
            traci.trafficlights.setPhaseDuration("gneJ11", 10)
        elif if traci.lanearea.getLastStepVehicleNumber("e2Detector_gneE5_0_3") > 0:
            traci.trafficlights.setPhaseDuration("gneJ12", 15)
            traci.trafficlights.setPhaseDuration("gneJ11", 10)
        elif if traci.lanearea.getLastStepVehicleNumber("e2Detector_gneE5_0_2") > 0:
            traci.trafficlights.setPhaseDuration("gneJ12", 15)
            traci.trafficlights.setPhaseDuration("gneJ11", 10)
        elif if traci.lanearea.getLastStepVehicleNumber("e2Detector_gneE5_0_1") > 0:
            traci.trafficlights.setPhaseDuration("gneJ12", 15)
            traci.trafficlights.setPhaseDuration("gneJ11", 10)
```

```java
if traci.trafficlights.getPhase("gneJ12") == 2:
    traci.lane.setMaxSpeed("gneE5_0", 15)
    traci.lane.setMaxSpeed("-gneE5_0", 20)
    traci.lane.setMaxSpeed("gneE6_0", 20)
    traci.lane.setMaxSpeed("-gneE6_0", 20)
elif traci.trafficlights.getPhase("gneJ12") == 3:
    traci.lane.setMaxSpeed("gneE5_0", 15)
    traci.lane.setMaxSpeed("-gneE5_0", 15)
    traci.lane.setMaxSpeed("gneE6_0", 15)
    traci.lane.setMaxSpeed("-gneE6_0", 15)
elif traci.trafficlights.getPhase("gneJ12") == 4:
    traci.lane.setMaxSpeed("gneE5_0", 15)
    traci.lane.setMaxSpeed("-gneE5_0", 15)
    traci.lane.setMaxSpeed("gneE6_0", 15)
    traci.lane.setMaxSpeed("-gneE6_0", 15)
```