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Vehicular Traffic Simulation: Real-World Traffic Scenarios from the City of Firenze

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Abstract— Computer simulation is very important analysis tool in traffic engineering especially with complexity of traffic behavior and difficulties of performing real-world traffic scenarios. Simulation of transportation can provide important opportunities to study too complicated models for analytical or even numerical use. Microscopic Simulators can track individual vehicles movements on a second or even sub-second bases. Setting up real scenarios for the use in these simulators can be time consuming even if the data is available, such efforts needed to collect, convert and adapt all the data needed for simulating these real scenarios. Usually, correctness and adaptation are needed for the available road networks to make them usable for simulation. Giving measurements and roadside structures need to be imported into the simulator architecture to allow calibration and validation of models. Thus, three real-world scenarios of traffic simulation are made of the city of Firenze.

Index Terms—

1 INTRODUCTION

Traffic congestion has many associated problems with it. Travelers can recognize the increased length of their trips when they encounter some congestions. They would probably make better decisions when they have the needed information. Low efficiency of traffic can greatly affect many travelers, especially commercial drivers since any delay in traffic can affect their performance and their work objectives. In 2008, the problem of decreasing air quality in Beijing during the Olympics has attracted the world's attention. In addition, psychological stress and traffic accidents arise as problems associated with traffic congestion increase. Sometimes, traffic accidents can be prevented if useful information is available for drivers [1]. Although, some accidents may be unavoidable, some useful actions can be performed. For example, notifying emergency personnel in a timely manner would greatly help to reduce or prevent the huge effects of the accidents. In 2011, a sport utility vehicle was carrying eight people when the driver lost control of the vehicle and drove off a bridge near Miami falling about 61 feet into the frozen Spring River. The accident was reported to the authorities by another driver, which resulted to the rescuing of five people [2]. Automatically transmitting distress signals by vehicles could increase the survivability of this scenario [3].

Road safety and traffic efficiency can be improved by enhancing Vehicle-to-Infrastructure (V2I) and Vehicle-to-Vehicle (V2V) communication, particularly around critical areas such as intersections. Unfortunately, the existing solutions, related to cellular networks and Road Side Units (RSUs), create additional costs in infrastructure deployment, which is a relatively expensive endeavor [4]. Additionally, tall buildings, forests, and other objects around the roads can inhibit satellite communication [5]. Therefore, it is a clear that great benefits can be obtained by enhancing communication methods around vehicles whether they transmitting emergency messages, traffic updates, or driver's behaviors.

Currently, vehicles come with equipped sensors and communication devices for helping them to sense the surrounded conditions. Researchers in these areas try to provide the drivers with better services by tying these devices with other transportation services. Many researches in the area of Vehicular Ad Hoc Networks (VANETs) propose different approaches to bring these together [6] [7] [8]. Wireless communications in VANETs can include vehicles, traffic lights and RSUs [9] [10] [11]. Because of unsafe functions in wireless communications, new proposed approach for privacy-preserving authentication in a VANET was presented in [12]. Their approach combined the useful features of group signature-based approaches and pseudonym-based approaches to preclude their respective drawbacks. They utilized lightweight pseudonyms for message authentication in order to provide conditional anonymity. They used computational and communication analyses to evaluate their approach and simulations for presenting a detailed network performance analysis. Thus, setting up real traffic scenarios would help in processing, analyzing and extracting data in various type of objectives.

1.1 NETWORK SIMULATION

Modelling computer network configurations is common using network simulation. Researchers can avoid potentially expensive field tests by using simulations to investigate different network setup performance. In addition, network simulations [13] can evaluate new network protocols. Large number of open source simulation tools are available such as ns-2 [14], JiST/SWANS [15], J-SIM [16], and OMNeT++ [17] [18]. The principals of these tools are similar and they may differ in the number of available models, e.g., some Internet protocols and routing.

1.2 TRAFFIC SIMULATION

Recently, many network simulators have integrated support for node mobility. However, the level of mobility model sophistication varies widely. Originally, strict geometric movement patterns were offered. With the popularity of Wireless Sensor Networks (WSNs) and Mobile Ad Hoc Networks (MANETs) applications, many movement patterns models have been developed, such as Random

Waypoint mobility model [19]. The European Telecommunications Standards Institute (ETSI) recommended the Manhattan Grid [20], moving mobile nodes along with a grid of possible ways. Nevertheless, it only covered pedestrian mobility modelling case whereas the mobility of vehicles used plain random node movement. Modelling of node mobility based on real-world mobility traces, such as [21] [22], was a major step to have real vehicle simulations compared to Random Waypoint mobility models. In many cases, vehicles in real-world trace use on-board or subsidiary devices for tracking purposes as well as recording positions in regular intervals.

According to the granularity with which traffic flows are examined, traffic simulation models can be classified into Microscopic, Mesoscopic, and Macroscopic models. With high level of details, system entities and their interactions are described in microscopic model, like SUMO [23], for example, lane-change with respect to its current leader –the vehicle at front. Although most entities are described at high level details in the mesoscopic model, their interactions and activities are described with low level of details, like CONTRAM [24]. While the macroscopic model describe system entities and their interactions and activities at low level of details, like METACOR [25].

1.3 SUMO Environment

SUMO [23] is an open-source software developed by German Aerospace Center Institute for Transportation Research supported by the University of Cologne Centre for Applied Computer Sciences. It allows multi-modal traffic in city scale networks. It can handle too many roads (Edges) per network and each edge can consist of one or many lanes that can be restricted only for some specific vehicle classes. In addition, traffic lights can be defined manually and computed based on demand data.

Infrastructure and traffic data are needed for modelling real-world traffic scenarios. Realistic simulation greatly relies on the quality of these data. Thus, we need input data such as road network, demand, real traffic lights, and infrastructure. Otherwise, it would be difficult to model a realistic traffic simulation. However, collecting the input data and doing the actions of processing, validating, correcting, are time and effort consuming. Getting some real data can be a challenge, especially with the real traffic light signal plans, which are rarely open to the public. Therefore, real-world scenarios from Firenze are presented in this work, to make it easier for researchers to analyze and evaluate their needs under real-world conditions.

2 Modelling Real-World Scenarios

Traffic simulation needs data that describe the infrastructure and the real–world traffic conditions to model real-world scenarios. Having these both in acceptable quality effects the simulation results validity. The following represents the traffic simulation requirements: road network, demand, traffic lights, and additional infrastructure. Figure 1 below shows the location of Firenze.

(Fig. 1: Location of Firenze [26])

3 Firenze Scenarios

The simulated areas represented the areas around "Fortezza Da Basso", "Rifredi", and "Aeroporto Amerigo Vespucci" roads. Each scenario modelled vehicles traffic in the city of Firenze with additional datasets supplied by the municipality of Firenze including average daily traffic, traffic volumes, positions of inductive loop and their measures and others. In the following, the three areas of Firenze are presented:

3.1 Fortezza Da Basso

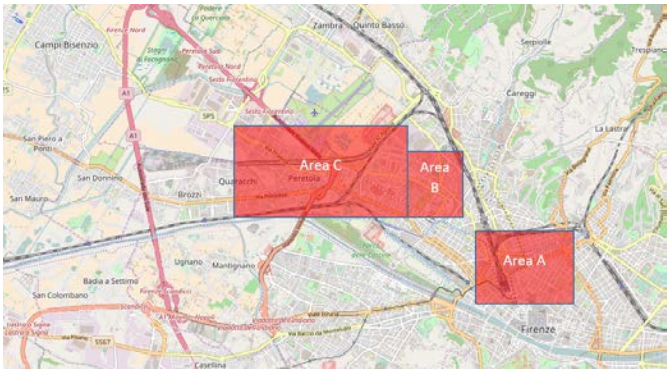
The Fortezza Da Basso scenario includes the strategic area around the historical center of the city of Firenze. It is the ideal venue for fairs, such as the historic Fiera Artigianato Firenze and major congresses, as well as for high-profile receptions and gala evenings.

3.2 Rifredi

The Rifredi scenario includes the area around the fifth district in the city of Florence and it has the largest administrative boundaries in Firenze.

3.3 Aeroporto Amerigo Vespucci

The Aeroporto Amerigo Vespucci scenario includes the area around the airport of Firenze and includes common routes and highways. Figure 2 shows the locations of simulated areas A, B and C in Firenze.



(Fig. 2: Locations of Simulated Areas A, B and C [27])

4 Development of the Scenarios

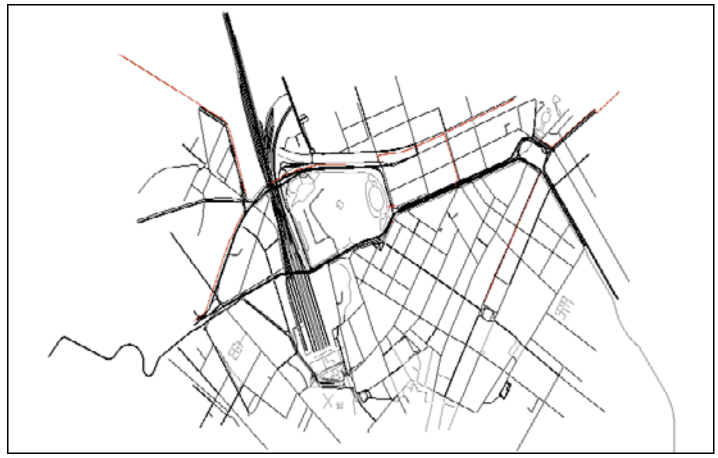
In order to make our scenarios readable and runnable in SUMO, some steps have to be taken, including importing traffic networks into readable formats, integrating traffic lights into the network and generating traffic demands. Table 1 below shows descriptions of simulated areas.

TABLE 1. Descriptions of A, B and C Areas

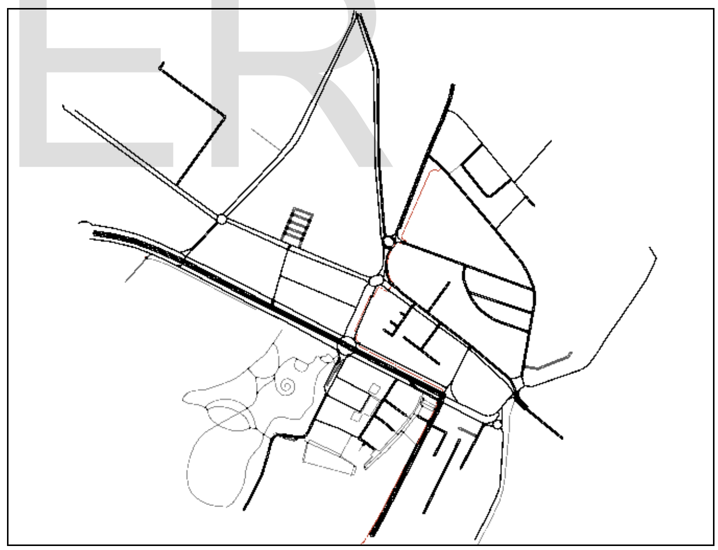
Items	Firenze Scenarios Values		
	Area A	***Area B***	***Area C***
Area size of network	3.78 km^2	1.71 km^2	11.40 km^2
Total number of nodes	1157	242	1423
Total number of edges	1791	436	2736
Traffic lights	103	10	28
Total edge length	101.58 km	26.80 km	249.50 km
Total lane length	116.81 km	30.42 km	276.93 km
Total number of edges with 1 lane	1546	378	2495
Total number of edges with 2 lanes	153	58	215
Total number of edges with 3 lanes	69	---	20
Total number of edges with 4 lanes	21	---	5
Total number of edges with 5 or more lanes	2	---	1

4.1 *Traffic Network*

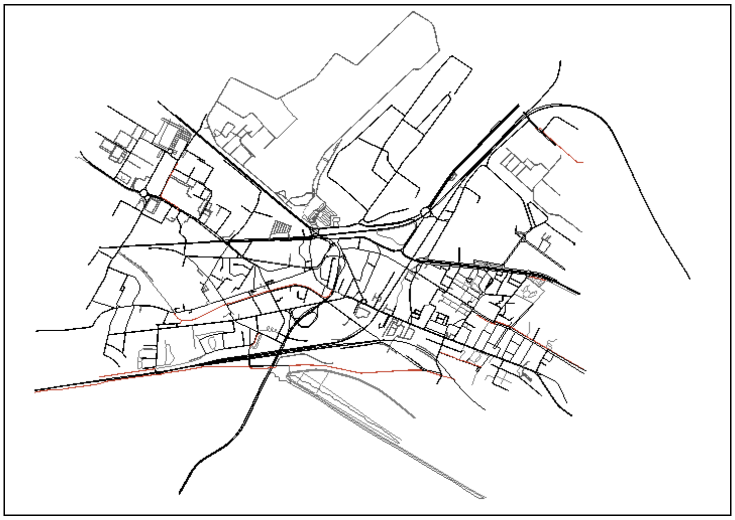
The presented three scenarios located in the city center of Firenze and around inner city ring. They describe some roads network with their directions excluding few minor ways. Traffic lights including their positions and signal plans are defined. Each network has passenger vehicles that are described in aggregated manners. Certain roads located in the network's border are given the number of vehicles to insert. Passenger vehicles follow their initial route, according to a given distribution, they pass some decision points where they get new route assigned randomly. Additionally, a description of the public bus transport are given including positions of the bus stops, routes and schedules. There are a completely different concept of modelling road network between VISSIM and SUMO although they are microscopic simulation programs. SUMO uses nodes (intersections) and edges (roads), whereas VISSIM uses only roads and connections between them which makes importing VISSIM networks very complicated and the results must often be edited by hand after an initial conversion. Figures 3, 4, and 5 show the road networks of the simulated areas.



(Fig. 3: Road Network of Area A in SUMO)



(Fig. 4: Road Network of Area B in SUMO)



(Fig. 5: Road Network of Area C in SUMO)

4.2 *TRAFFIC LIGHTS*

Positions, definitions, and signal time plans were described and written in formats SUMO can read for integrating traffic lights into existing road networks.

4.3 *TRAFFIC DEMAND*

The datasets ware supplied by the municipality of Firenze. Detectors were installed around the city of Firenze and they may cover more than one lane. Using single induction loops led to unavailability of speed information and distinction between different vehicle classes.

5 DEMAND EVALUATION

Having generated networks, researchers need a description of the vehicles moving within the city. This description is known as traffic demand and it illustrates the movement of vehicles from one area to another. Furthermore, a trip is the movement from one area to another that starts from one edge to the destination edge, and the departure time. Additionally, a route is an extended trip and it incorporates all the edges that a given vehicle passes. In SUMO, researchers need routes as the input for the movement of vehicles. However, these routes can be generated in multiple ways depending on the available data. Demand can be created using trip definitions when the available data contains the starting and ending edges as well as the departure time. In addition, flow definitions follow the same approach as the trip definitions, but multiple vehicles can be joined provided that they have the same departure and arrival edge.

In the case of Firenze, generating the actual demand would require an analysis of the three zones (A, B, and C). SUMO contains three routers namely JTRROUTER, DFROUTER, and DUAROUTER that can be used to generate traffic demand. Some researchers use the DFROUTER since it provides a way of generating traffic flow and routes based on data collected from real-time induction loops [28]. The targeted road networks should contain a network of induction loops that provide real-time traffic information that can be fed into the DFROUTER to generate traffic demand. However, this information has to be split into detector and measure files. The detector file contains a list of all detectors in the network and their locations. DFROUTER assigns a specific role to each detector during route generation. The routes start at the source detector and end at the sink detector. However, data from in-between detectors can be allowed during route creation [28]. In the three simulated zones, there are detectors distributed across the edges and the routes are assigned with equal probabilities. However, the simulation can assign routes using varying probabilities if the entire network was covered with detectors that are actively relaying data.

Traffic flows from each detector are listed in the measure file that identifies the detector, start time, and number of vehicles. The use of single induction loops makes it difficult to pinpoint the speed and type of vehicles passing through these detectors [29]. The simulation also requires a route file that contains all the routes and the corresponding number of edges in each zone. The detectors file lists all the detectors passed to the router and their specific roles. These files also contain data from traffic lights since they play an important role in generating the traffic demands.

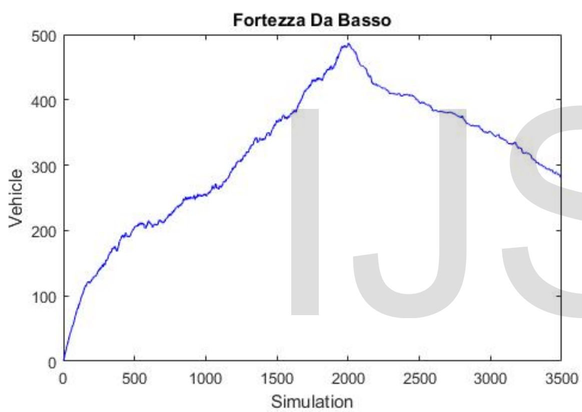
There are certain assumptions that have to be made when evaluating demand using the DFROUTER. The main assumption is that the entire network is covered by detectors. In this way, the off and on-ramps along the edges in the three zones would have induction loops. Additionally, the router requires information on the underlying network and the detector list that describes the location of each induction loop. The detectors are also color coded depending on their type. In the SUMO-GUI source detectors can be green and sink detectors can be red to denote the start and end of a route. Furthermore, in-between and discarded detectors can be indicated by blue and black colors respectively. In this way, the city of Firenze will have multiple colors to denote detectors assuming that there is enough coverage on each zone. Consequently, the JTRROUTER can be used to generate traffic routes and turning probabilities. The three zones have edges with multiple lanes and intersections. Part of the demand evaluation is to generate routes and determine the turn probabilities provided that the turning ratios at each junction and the description of the traffic flows are provided alongside the route information.

In our simulations, the city of Firenze is divided into three zones and each one has a different number of edges and nodes. The flow of traffic from each zone within a certain period can be computed using the origin/destin (OD) matrices [30]. They are primarily used in VISSIM to analyze and forecast traffic flows, but the NETCONVERT package in SUMO can convert the VISIM file map into a SUMO file. The OD matrices contain the amount of vehicles moving from one traffic zone to another as well as generate trip generations. In this way, the simulation can generate trip data as vehicles move within areas A, B, and C.

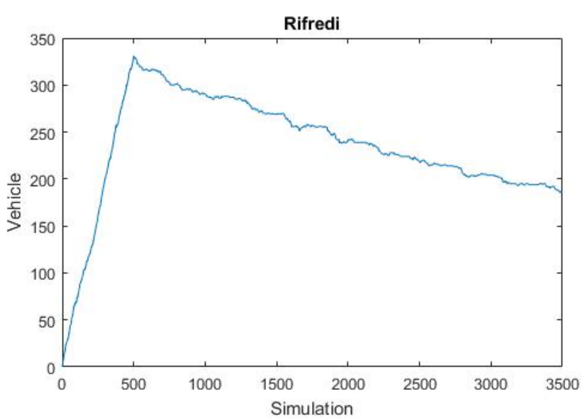
However, the datasets provided by the municipality of Firenze cannot be used to generate activity-based demand.

This information requires the total population in the city, number of inhabitants using personal cars instead of alternative travel modes, and population distribution, schools, bus lanes, and working hours [31]. Although this data can be retrieved from other departments in the city, it might not provide a clear picture of the three zones since it is not captured by detectors on the routes. Activity-based demand generates traffic depending on the preferences, population, transport modes, and activities of the residents. It also incorporates data from trips made by foot and bikes over short distances. In the city of Firenze, simulating traffic demand based on the activities of the people would be ineffective due to data shortage.

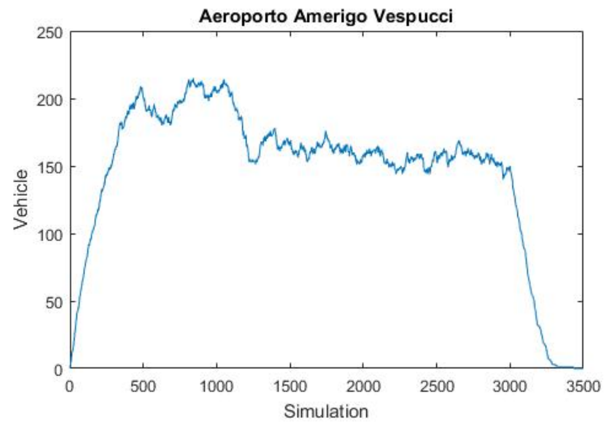
The traffic demand in the city routes can be broken down into percentages at intersections by subdividing the nodes at different areas in the zones. The JTRROUTER can generate turn percentages at intersections and compute routes within a network. This approach can be limited to a certain section or area within the vast road network in Firenze. Limiting the zone under study to ten nodes can provide a clearer image of the traffic demand in the city since it varies from one place to another.



(Fig. 6: Simulation Data in Relation to Measured Traffic Flow of Area A)



(Fig. 7: Simulation Data in Relation to Measured Traffic Flow of Area B)



(Fig. 8: Simulation Data in Relation to Measured Traffic Flow of Area C)

As a result, from the figures 6, 7 and 8 the overall numbers of vehicles which are simulated in SUMO can be seen, where vehicles in areas A and B have not totally leave the simulation, which indicate some issues related to traffic jams and other issues. However, it can be seen that the simulation in area C has more smother traffic flow. In conclusion, certain amount of time simulation is important to fill the scenarios with vehicles before reaching the stable traffic state.

6 USER GUIDELINES

SUMO consists of several packages that researchers can use to simulate traffic in Firenze. The application needs routes to illustrate vehicle movements in the city and the available data has to be converted into a format that can be imported into SUMO before running the simulations. The data collected from the municipality needs to be broken down into edge-based measurements that contains the density, speed, and travel time for each edge. In the case of Firenze, these datasets have to be broken down to reflect the flow of traffic in the three areas. In addition, users need a simulation-wide summary of the parameters that were used in the study. The number of vehicles running, loaded and waiting has ought to be captured accurately before the start of the simulation. Further, trip info for each vehicle is a necessity for the results to be conclusive. The number of induction loops in the three areas that supply data for the simulations is also needed and it should be included in the DFROUTER input.

The OpenSteetMap database holds maps that can be used when running simulations on SUMO. These maps provide a detailed view of the city and the road network under investigation. The database contains tools that allow users to download segments of the map that they wish to download and export them to files compatible with SUMO simulations. In this way, the road network in the three zones in Firenze can be studied by downloading the respective maps from the database. Acquiring these maps also makes it easy to pinpoint the exact locations of the induction loops that collect data on traffic movement. Simulations running on datasets collected from a real-life network require manual edits of the .net.xml file [32]. This file contains the routes, vehicles, properties, nodes, and edges that will be used in the simulation. In addition, the VISUM file map used to generate OD matrices needs to be converted into a .net.xml file for use in the simulator [32]. However, a package known as OD2TRIPS can be used to compute trips from the matrices according to the traffic zones specified in the matrix. When these files are ready, the .rou.xml and .net.xml files are used to turn complete simulations on SUMO. The user can see the vehicles flowing through the network and zoom certain parts for a detailed view. However, simulation statistics, route information, trip information, and node positions are not generated by default. As a result, the user has to trigger these options manually and collect the information as desired.

SUMO contains traffic management capabilities that can smoothen the flow of traffic. For instance, the simulation contains traffic lights that improve the flow of traffic in the roads [33]. In this way, road junctions in Firenze can contain traffic lights that have right-of-way rules. In addition, the model is collision-free so that the simulation can run without any interference. However, this simulation might fail in inner-city networks that have rings that are not effectively covered with induction loops. Rings on city highways introduce traffic snarl-ups that interfere with the smooth flow of vehicles.

7 Summary and Further Research

SUMO provides a platform that researchers and city planners can use to simulate the flow of traffic on the roads. The computer simulation platform contains analysis tools that engineers can use to simulate real-world traffic scenarios and anticipate the behavior and difficulties as people commute across cities. Modern vehicles have communication devices that transmit data to sensors in the road infrastructure or other vehicles. The city of Firenze contains single induction loops that collect traffic data as vehicles pass through these detectors and transmit it to the municipality network. Using SUMO, this data can be used to simulate traffic demand in the three zones that form the city's road network. The DFROUTER, a route generator in SUMO, is best suited to generate routes in the city of Firenze. This tool is effective when aggregating data collected through single induction loops. These detectors do not indicate the speed or the properties of these vehicles. In this way, the router can take data from the nodes and edges within the city and produce routes that reflect the real traffic demand. Due to the large number of nodes, the data can be represented as an origin/destin matrix that indicates the movement of a vehicle as captured by the source and destination detectors. Further, traffic lights and simple rules can be incorporated in the simulation to create a model of the flow of traffic in junctions.

Further research can simulate the flow of traffic in the city by expanding the parameters under study. The current research contains data collected by the municipality using single induction loops. This limits the parameter that can be used in to simulate traffic demand in Firenze. Subsequent studies should use detectors that can capture the speed and type of vehicle passing through these nodes. In addition, future research can simulate the demand relative to other transport modes. The city contains a railway network that commuter board after alighting from public or private vehicles. The presence of rail and waterway transport routes can be incorporated in future simulations to understand the way they influence the flow of traffic. Multi-modal simulations of rail, road, and other public transport can improve city planning. Firenze, similar to other modern cities, contains a surveillance system that plays a key role in tracking the movement of vehicles of interest. These systems provide images of vehicle positions that can be mapped to exact locations on the ground. Future research can use SUMO to simulate and test the accuracy of these systems by providing GSM data and processed images. This can provide an overview of the accuracy of the system in producing a real-time detection of the speed of vehicles in a city with multiple moving bodies. With the introduction of self-driving cars, they introduce a new dynamic in the flow of traffic in cities. These vehicles need to communicate with each other and send alerts regarding the flow of traffic and events on the roads. SUMO can be used to provide new models that leverage V2V and V2I communications when generating traffic demand.

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