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# Analysis of Common Required Metrics for Vehicular Networks

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**Abstract**—The protocols for vehicular networks are mostly developed, tested and evaluated through simulations in network simulators first before implementing and experimenting them in the real-world. For simulating vehicular networks, various mobility datasets are made publicly available by SUMO that can be imported into network simulators (e.g., OMNeT++, NS-3). The development of protocols for vehicular networks requires analyzing some common metrics (such as distribution of vehicles, contact duration between vehicles and time to meet new neighbors). Therefore, researchers are high likely to implement and analyse these metrics as a first step. In this paper, we analyse the common required metrics for vehicular networks using OMNeT++ and Veins by using SUMO vehicular mobility datasets of Ireland urban and highway scenarios for rush and non-rush hours. We have provided our code publicly available as open-source that will be time-saving for researchers who start developing protocols for vehicular networks. We believe such analysis results can help in designing communication or dissemination protocols in vehicular networks and understanding vehicular traffic for further applications.

**Index Terms**—contact duration of vehicles, time to meet new neighbors, OMNeT++, SUMO, Veins, vehicular mobility datasets, vehicular metrics, vehicular networks, vehicular simulation.

## I. INTRODUCTION

In vehicular networks, while designing new protocols, it is recommended to implement them in network simulators and evaluate their performance before deploying and experimenting them on real vehicles in the real-world. There are various network simulators available (such as OMNeT++ and NS-3) which offer the simulation of vehicular networks and the development of new protocols together with SUMO (Simulation for Urban Mobility) simulator [1]. SUMO offers the simulation of vehicular scenarios and mobility. There are various vehicular mobility datasets/scenarios available for SUMO that offer realistic vehicular mobility. Such datasets are available for various cities covering rush hours and non-rush hours for urban, highway and motorway scenarios. These datasets can be imported into network simulators (OMNeT++ and NS-3) that can be used for implementing and evaluating the protocols designed for vehicular networks.

While designing protocols for vehicular networks, various metrics are required to be analyzed and they vary from protocol to protocol. However, there are some common required metrics to analyse as a first step while designing protocols for vehicular networks. Such metrics include how long vehicles stay connected with other vehicles (e.g., contact duration), how long it takes for a vehicle to meet a new neighboring vehicle (e.g., waiting time to meet new neighboring vehicle), how

many vehicles stay connected for more than certain contact duration  $\Delta t$  and how many vehicles meet new neighboring vehicles before certain time  $t$ .

Inspired from this need, in this paper, we present the analysis of these metrics by using Veins [2] framework of network simulator OMNeT++ [3] by considering vehicular mobility scenarios from SUMO [1]. We have considered five metrics that include the distribution of number of vehicles, contact duration of vehicles, waiting time to meet new vehicles, contact duration of vehicles lasting more than contact duration  $\Delta t$  and waiting time to meet new vehicles before time  $t$ . We evaluate them using SUMO mobility datasets of Ireland urban (Dublin city centre) and highway (Irish National Road) scenarios for rush and non-rush hours. However, other SUMO mobility datasets can be used in a similar manner without any change. We have made the source code as open-source at GitHub<sup>1</sup> to enable the researchers to analyse other SUMO mobility datasets in a similar manner.

To the best of our knowledge, there is no such study in the literature that provides the analysis of such common required metrics and no such open-source code available. There are three main contributions of this paper as follows:

- C.1 Selection of common metrics required to analyse during protocol design for vehicular networks.
- C.2 Evaluation of selected common metrics using SUMO vehicular mobility datasets of Ireland urban and highway scenarios for rush and non-rush hours.
- C.3 Publishing the source code as open-source that allows the researchers to analyse other SUMO vehicular mobility datasets in a similar manner.

The rest of this paper is organized as follows. Section II discusses our considered SUMO vehicular mobility datasets of Ireland urban and highway scenarios. Section III defines common required metrics for vehicular mobility analysis. Section IV evaluates the metrics and illustrate the results. Section V discusses the related works and finally, Section VI concludes the paper.

## II. VEHICULAR MOBILITY SCENARIOS

In this paper, we have considered two SUMO vehicular mobility scenarios of Ireland, urban and highway roads. For each scenario, we have considered rush and non-rush hours. The rush hour (known as saturated traffic) is the hour when the traffic level is high and it starts to get congested, while

<sup>1</sup><https://github.com/yasirsaleem/vanet-required-metrics>



(a) Ireland urban scenario.



(b) Ireland highway scenario.

Fig. 1: Considered mobility scenarios.

non-rush hour (known as free flow traffic) is the hour when the traffic level is low and is in the early morning. Our preliminary tests on other datasets have shown similar results and researchers can analyse other datasets, thanks to our published open-source code.

#### A. Ireland Urban Scenario

This scenario in SUMO is a  $5\text{km} \times 3.5\text{km}$  Dublin city centre with 435 signalised intersections. A traffic light control system, called Dublin SCATS dataset<sup>2</sup>, that has SCATS sensors deployed in Dublin city was used for the generation of traffic by counting the vehicles at 480 locations, every six minutes. The traffic during 8am-9am is categorised as rush hour, while the traffic during 4am-5am is categorised as non-rush hour. This scenario is presented in Fig. 1a.

#### B. Ireland National Highway Scenario

This scenario in SUMO is a 17.1km long highway and it corresponds to N7, a 3-lane two-way highway. Each way has 11 on- and off-ramps. The traffic was generated using loop induction sensors and the data was published by Transport Infrastructure Ireland<sup>3</sup> for several months with 5-minutes aggregated data for each lane. A workday traffic of 24 hours is created by averaging the traffic, by excluding weekends and bank holidays. The traffic during 8am-9am is categorised as rush hour, while the traffic during 4am-5am is categorised as non-rush hour. This scenario is presented in Fig. 1b.

### III. COMMON REQUIRED METRICS FOR VEHICULAR MOBILITY ANALYSIS

This section presents common metrics that significantly characterise vehicular mobility from a statistical perspective.

#### A. Number of Vehicles over Time

It shows how many vehicles exist in the network at a certain time. The total number of vehicles throughout the network lifetime would be higher, because vehicles enter and leave the network, however, this metric helps to characterise the vehicular mobility with higher precision.

<sup>2</sup><https://data.gov.ie/dataset/traffic-volumes>

<sup>3</sup><https://trafficdata.tii.ie/publicmultinodemap.asp>

#### B. Contact Duration of Vehicles

It shows the duration a vehicle stays in contact with other vehicles during its lifetime. This metric helps to identify the contact duration that majority of vehicles stay connected with each other which could be used in the applications of streaming, transmitting data, and is paramount for the definition of social ties between vehicles.

#### C. Time to Meet New Neighboring Vehicles

It shows the time taken by a vehicle to meet a new neighboring vehicle. This metric helps to identify the time that majority of vehicles take to meet new vehicles which could be used for adapting the frequency of HELLO messages.

#### D. Connections Lasting More than Contact Duration $\Delta t$

It shows the percentage of connections (vehicles) that stay in contact with other neighboring vehicles for more than duration  $\Delta t$ . This metric helps to identify the connectivity time of vehicles with neighboring vehicles, which could be used in adapting the frequency of HELLO messages and designing data dissemination protocols.

#### E. Vehicles Meeting New Neighboring Vehicles Before Time $t$

It shows the percentage of vehicles that meet new neighboring vehicles before time  $t$ . This metric could be used by protocols in deciding the frequency of HELLO messages.

### IV. EVALUATION

#### A. Overview

This section evaluates the common required metrics for the analysis of vehicular simulation for Ireland urban and highway scenarios of rush and non-rush hours through simulations. The simulation is performed using network simulator OMNeT++ 5.5.1 [3] with Veins 5.0 [2] and SUMO 1.7.0 [1] frameworks. OMNeT++ and Veins simulate the vehicular communications using IEEE 802.11p standard, while SUMO constructs the scenarios and generates mobility of vehicles. The evaluation is performed using the threshold of minimum contact duration which is defined as the duration, a vehicle must stay in contact (connected) with its neighboring vehicles. Vehicles

send HELLO messages periodically after every one second. Each vehicle has the data rate of 6Mbps and transmission power of 10mW.

### B. Number of Vehicles

Fig. 2 presents the number of vehicles for urban and highway scenarios of rush and non-rush hours. During rush hour, the number of vehicles ranges from 2500 to 3000, while in non-rush hours, it ranges from 200 to 250 (almost 10 times less than rush hour). In urban scenario, the number of vehicles are almost constant (i.e., between 2000 to 2500 vehicles), while in highway scenario, the number of vehicles keeps increasing. This is because firstly, the simulation started at 17:00 for highway rush hour and at 04:00 for highway non-rush hour and hence, vehicles started to join the network at 17:00 and 04:00, respectively. However, according to longer simulations of 24 hours, there were more vehicles in the network and therefore, highway scenarios aim to reach that count, resulting in a continuous increasing stream of vehicles. Secondly, there are lesser number of exits in highway scenario as compared to urban scenario. Therefore, vehicles enter and leave the network more frequently in urban scenario, while in highway scenario, once vehicles enter the network, it takes longer for them to exit the network.

### C. Contact Duration

Fig. 3 presents the contact duration for urban and highway scenarios of rush and non-rush hours. Without considering a threshold of minimum contact duration, majority of vehicles have contact duration of less than 20s in urban scenarios and less than 10s in highway scenarios. As the threshold of minimum contact duration increases, the distribution of vehicles over contact duration reduces. Some applications (such as data offloading) have requirements of certain minimum contact duration, hence this metric gives insights about the distribution of vehicles for various minimum contact duration.

### D. Time to Meet New Neighboring Vehicles

Fig. 4 presents the time to meet new neighboring vehicles for urban and highway scenarios of rush and non-rush hours. In urban and highway rush-hour scenarios, for minimum contact duration up to 10s, the majority of vehicles meet new neighbors within 5 seconds. When the threshold increases beyond 10s, vehicles meet new neighbors after 7 seconds. In urban non-rush hour scenario, the distribution of vehicles is irregular because of lesser vehicles and higher number of junctions. In highway non-rush hour scenario, without considering the threshold, majority of vehicles meet new neighbors within 6 seconds. When considering the threshold of minimum contact duration (i.e., 3s, 10s, 25s, 40s), the distribution of percentage of vehicles is very low because of having lesser number of vehicles which gives an indication that vehicles do not stay connected longer in highway non-rush hour scenario.

### E. Connections Lasting More than Contact Duration $\Delta t$

Fig. 5 presents the distribution of connections lasting more than the contact duration  $\Delta t$  for urban and highway scenarios of rush and non-rush hours. Urban rush-hour and non-rush scenarios have similar patterns. 80% of connections last for more than 10s, 12s, 22s, 40s and 52s for no threshold and thresholds  $\geq 3s$ ,  $\geq 10s$ ,  $\geq 25s$  and  $\geq 40s$ , respectively. Highway rush-hour and non-rush scenarios also have similar patterns. 80% of connections last for more than 3s, 18s, 35s, 50s, 60s for rush-hour and 2s, 19s, 22s, 34s, 48s for non-rush hours for no threshold and thresholds  $\geq 3s$ ,  $\geq 10s$ ,  $\geq 25s$  and  $\geq 40s$ , respectively.

### F. Vehicles Meeting New Neighboring Vehicles Before Time $t$

In urban rush hour scenario, 80% of vehicles meet new vehicles within 3s, 4s, 8s, 16s and 20s for no thresholds, thresholds  $\geq 3s$ ,  $\geq 10s$ ,  $\geq 25s$  and  $\geq 40s$ , resp. Fig. 6 presents the distribution of vehicles meeting new vehicles before time  $t$  for urban and highway scenarios of rush and non-rush hours. In urban non-rush hour scenario, the time to meet new vehicles is very high and it takes more than 20s for 80% of vehicles to meet new vehicles (the maximum percentage shown in Fig. 6b is 70%). In highway rush-hour scenario, 80% of vehicles meet new vehicles within 0.5s, 2s, 3s, 6s and 9s for no thresholds, thresholds  $\geq 3s$ ,  $\geq 10s$ ,  $\geq 25s$  and  $\geq 40s$ , resp. In highway non-rush hour scenario, 80% of vehicles meet new vehicles within 4s for no thresholds. When considering the threshold of minimum contact duration, it takes very long for vehicles to meet new vehicles.

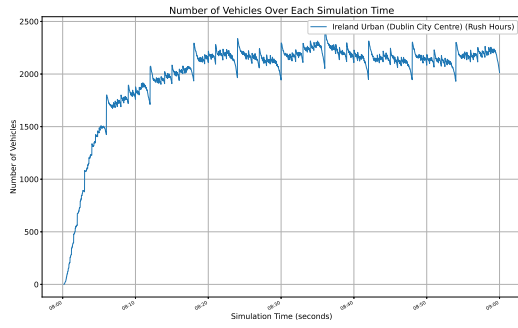
## V. RELATED WORK

The support of simulating the vehicular communications in OMNeT++ is provided by Sommer et al. [2] by developing Veins. Veins is an open-source framework for simulating vehicular networking in OMNeT++ which interacts with SUMO, a traffic mobility simulator. Although Veins provides an example and a template to develop an application, however, it does not provide any source code of common required metrics for analysing the vehicular networks.

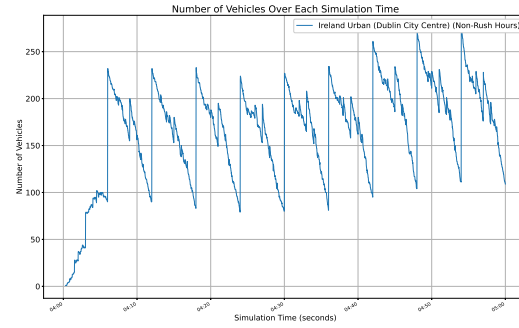
Hsieh [4] provides an open-source implementation of NS-3 and SUMO with Gym API, called V2X-Gym. It allows the researchers to apply reinforcement learning to vehicular networks. It accepts vehicular mobility files of SUMO in XML-format as input to simulate traffic mobility. Yan et al. [5] investigate automated control of vehicular networks by using deep reinforcement learning and have published their code as open-source<sup>4</sup>. Although this work uses SUMO for vehicular mobility, however it does not use any network simulator, rather uses Python for implementation. Gonzalez-Martin et al. [6] provide analytical models of the performance of cellular vehicle-to-everything (C-V2X) Mode 4 for the packet delivery ratio and publish their code as open-source<sup>5</sup>. This paper compares its results with those obtained in Veins

<sup>4</sup>[https://github.com/mit-wu-lab/automatic\\_vehicular\\_control](https://github.com/mit-wu-lab/automatic_vehicular_control)

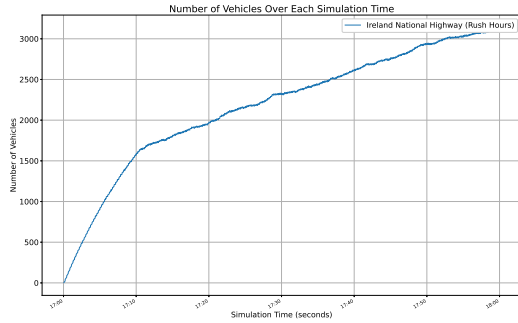
<sup>5</sup><https://github.com/msepulcre/C-V2X>



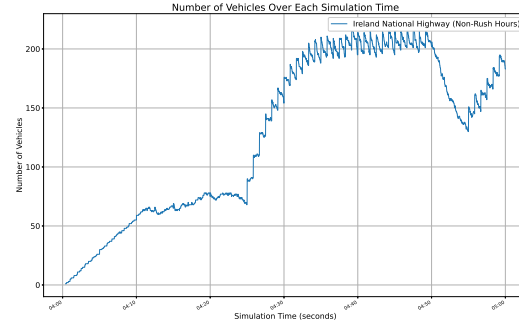
(a) Urban rush hour scenario.



(b) Urban non-rush scenario.

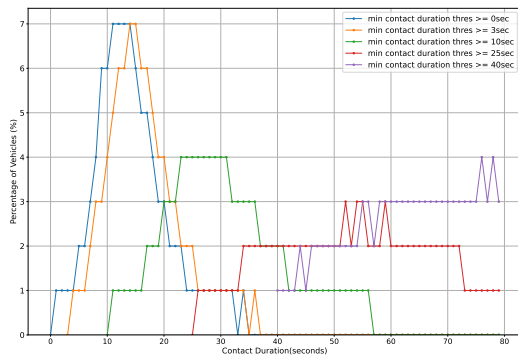


(c) Highway rush hour scenario.

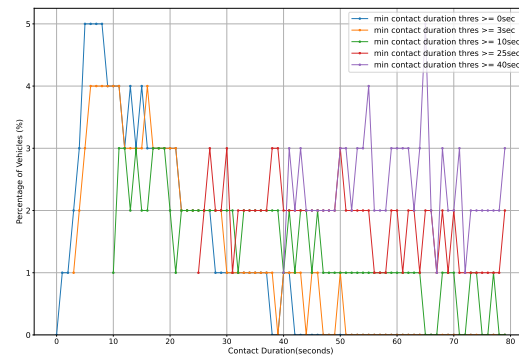


(d) Highway non-rush hour scenario.

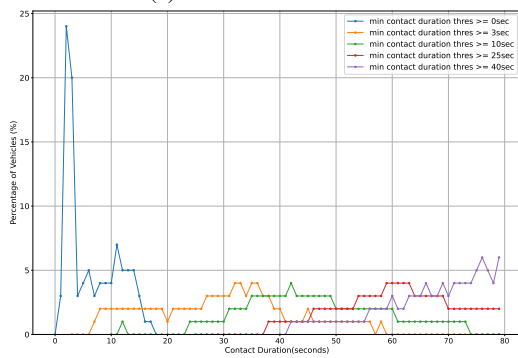
Fig. 2: Number of vehicles for each scenario.



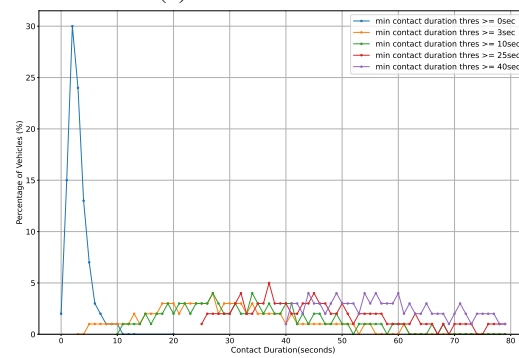
(a) Urban rush hour scenario.



(b) Urban non-rush scenario.

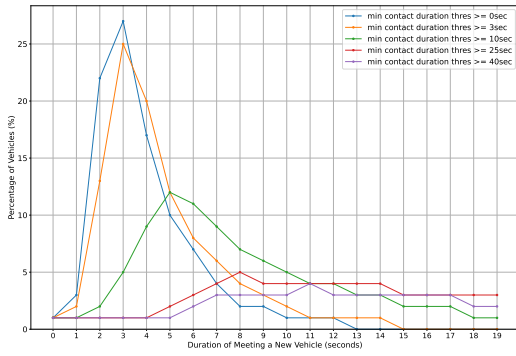


(c) Highway rush hour scenario.

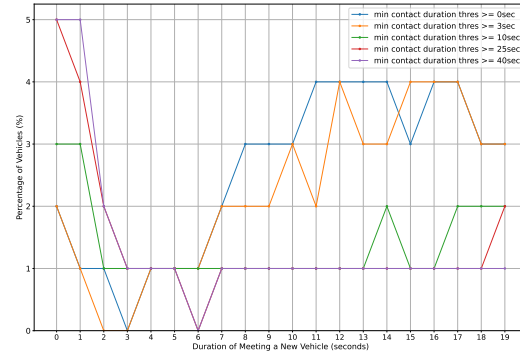


(d) Highway non-rush hour scenario.

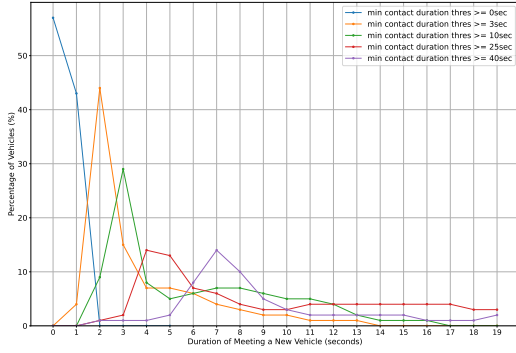
Fig. 3: Contact duration for each scenario.



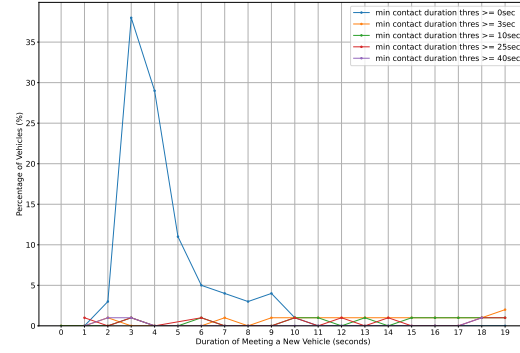
(a) Urban rush hour scenario.



(b) Urban non-rush scenario.

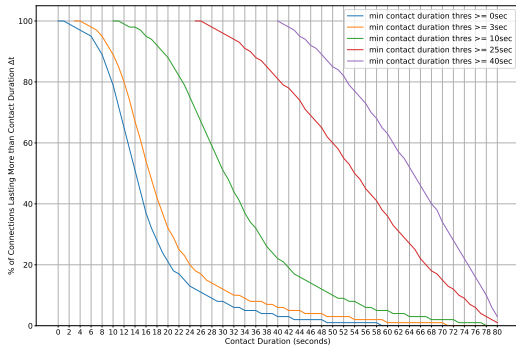


(c) Highway rush hour scenario.

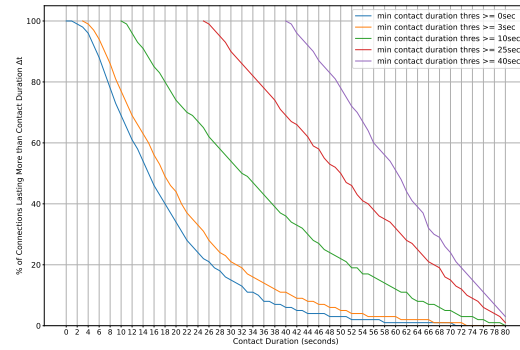


(d) Highway non-rush hour scenario.

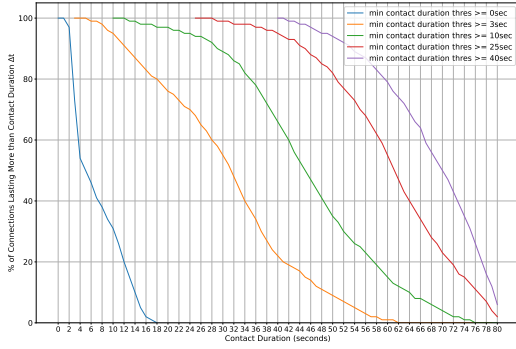
Fig. 4: Time to meet new vehicle for each scenario.



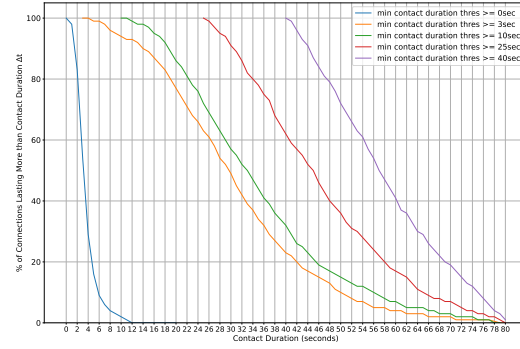
(a) Urban rush hour scenario.



(b) Urban non-rush scenario.



(c) Highway rush hour scenario.



(d) Highway non-rush hour scenario.

Fig. 5: Percentage of connections lasting more than  $\Delta t$  for each scenario.

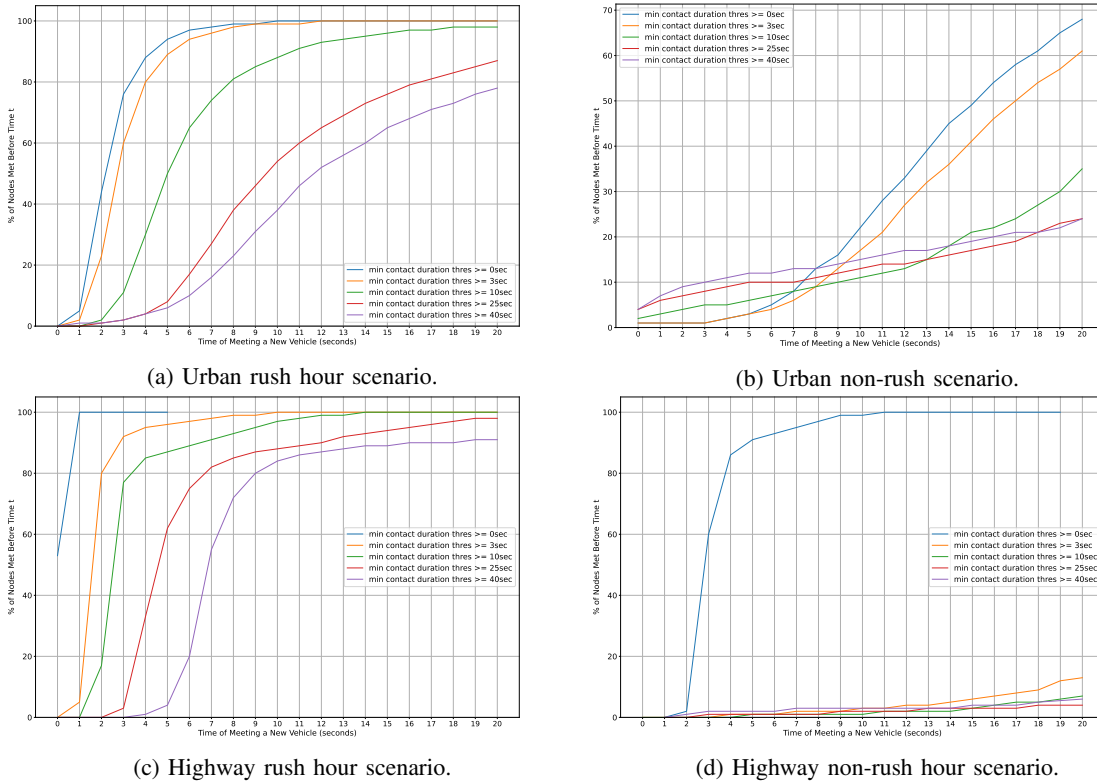


Fig. 6: Percentage of nodes met before time  $t$  for each scenario.

framework of OMNeT++ for C-V2X Mode 4. However, the authors have not used any network simulator for this study, rather used MATLAB for performance evaluation. Lian et al., [7] study resource allocation in vehicular networks based on slow fading statistics of channel state information (CSI). The purpose is to reduce signalling overhead for varying CSI. This study considers the co-existence of vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) links. This work was implemented in MATLAB<sup>6</sup>.

To the best of our knowledge, there is no work that focuses on analysing common required metrics for the simulation of vehicular networks, as well as no such open-source implementation available. The implementations of available source codes either consider MATLAB or Python which are not based on any network simulator or are not focused on common required metrics for analysis.

## VI. CONCLUSION

This paper analysed common metrics that are generally required for developing protocols for vehicular networks in network simulator. The common required metrics include the distribution of number of vehicles, contact duration, time to meet new neighboring vehicles, connections lasting more than certain duration and vehicles meeting new vehicles before certain time. We believe that such metrics are pre-requisite for all studies related to vehicular networks and therefore, researchers

working in this area have to first implement and analyse these metrics. We have evaluated these common required metrics in this paper using two realistic SUMO vehicular mobility datasets of Ireland urban and highway scenarios of rush and non-rush hours, as well as have published our code as open-source.

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<sup>6</sup><https://github.com/le-liang/ResourceAllocationV2Xgraph>