2019 IEEE Intelligent Vehicles Symposium (IV)
Paris, France. June 9-12, 2019

Emergency Vehicle Traversal using DSRC/WAVE based Vehicular Communication

Insaf Ismath*, Tharaka Samarasinghe*†, Dileeka Dias*, Madara Wimalarathna*, Waruna Rasanga *, Nalin Jayaweera*, and Yohan Nugera*

*Department of Electronic and Telecommunication Engineering, University of Moratuwa, Sri Lanka.
†Department of Electrical and Electronic Engineering, University of Melbourne, Australia.
Email: insaf.ismath@ieee.org, {tharakas,dileeka,130675b,130503a,130253f,130410k}@uom.lk

***Abstract*—The response time of emergency vehicles (EVs) determines the outcome of many emergencies, thus improving the traversal time of EVs is of paramount importance. Vehicular communication is a key enabler of such an improvement. This paper studies two EV traversal algorithms, focusing mainly on their communication aspects. Fast moving dense traffic is modeled, and the traversal algorithms are implemented on top of the dedicated short-range communication (DSRC) / wireless access in vehicular environments (WAVE) protocol stack, while accounting for channel impairments such as path loss and fading. Algorithms that highlight the required packet transfers for the traversal and for safe lane changes are presented, and simulated in the VEINS framework for different traffic conditions. Simulation results show that the suitability of the EV traversal algorithms defer depending on the speed distribution of the vehicles. Further insights drawn from the simulation are utilized to fine tune the EV traversal algorithms and to decrease the traversal time further.**

***Index Terms*—Emergency vehicle traversal, DSRC, WAVE, intelligent transport systems, vehicular ad-hoc networks, V2V communication.**

I. Introduction

With the advent of dedicated short-range communication (DSRC), and wireless access in vehicular environments (WAVE) [1], vehicular ad-hoc network (VANET) based applications are envisioned to dominate the future of intelligent transportation systems (ITS) [2]. Improving the response time of emergency vehicles (EVs), *e.g.*, ambulances and fire trucks, is considered to be a key deliverable of ITS. Reducing the traversal time of EVs can lead to a significant improvement in the management of emergency services and their quality. In this paper, we study two EV traversal algorithms, focusing mainly on their communication aspects, with the goal of reducing the traversal time.

In the literature, reducing EV traversal time is proposed through optimal route selection [3], [4], optimal control of traffic lights and intersection handling [5], [6] and optimized lane level dynamics [7]. Among these, [7], which is the most related to our work, presents two EV traversal algorithms, namely the fixed lane strategy (FLS), and the best lane strategy (BLS) to handle lane-level vehicle dynamics. In the FLS, the EV picks a lane and stays in this lane throughout the journey. Any vehicle blocking the EV, makes way to the EV. In the BLS, the EV makes periodic lane changes, and ensures that it travels in the lane having the highest *utility*. The authors have confined their study to slow-moving traffic in heavily populated cities such as Hong Kong, Manila, Mumbai, Dhaka, and Seoul. They have simulated the performance of FLS and BLS for several traffic scenarios, mainly providing insights from a traffic engineering viewpoint. A simple communication model of an assumed radio range and a fixed propagation delay for each vehicular node is adopted. In our work, we focus on the communication aspects of a VANET that facilitates such EV traversal algorithms. We precisely define packet transfers for the traversal, and also for safe lane changes, which is mandatory for the implementation. The insights drawn from the study is used to further fine-tune FLS and BLS presented in [7].

We model fast moving dense traffic, where the majority of vehicles travel at the speed limit, or close to the speed limit.We assume that this is the case on most highways. The ideas of FLS and BLS are implemented on top of the DSRC/WAVE protocol stack, while accounting for path loss and fading in the physical layer. The two algorithms are simulated in the VEINS [8] framework for different traffic conditions. The framework, bidirectionally couples OMNet++, the network simulator that manages the communication in the VANET, and simulation of urban mobility (SUMO) [9], the vehicle traffic simulator that manages the mobility of the nodes of the VANET. We study the EV traversal time for the two algorithms and the lane changing behavior that results. Traffic conditions studied range from a typical highway scenario where all normal vehicles (NVs) travel almost at the speed limit, having a small variance among them, to a congested city environment, where NV speeds may have a larger variance. We also introduce a safe lane-change algorithm, and a technique to avoid unnecessary lane changes, which improves EV traversal.

The paper is organized as follows. Section II presents the system model adopted in the study. Sections III and IV introduce the EV traversal and lane change algorithms, respectively. Section V describes the simulation setup and Section VI presents the results. Section VII concludes the paper.

978-1-7281-0560-4/19/$31.00 ©2019 IEEE

II. System Model

A. Topological Model

A stretch of highway with unidirectional traffic flow in 2 lanes is considered. The width of each lane is 3.2m. The road consists of two types of vehicles, namely EVs and NVs. Each lane is assigned a legal speed limit. Each NV has a preferred speed which does not exceed the legal speed limit. In a highway, most vehicles travel at the speed limit, or close to the speed limit, and hence we model the preferred speed of each NV using a half normal distribution, where the maximum speed is the legal speed limit of the lane, *i.e.*, the probability density function (PDF) of the preferred speed is given by

$$f_S(x) = \frac{1}{\sigma}\sqrt{\frac{2}{\pi}}\exp\left\{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right\}, x < \mu,$$

where σ is the standard deviation in the corresponding normal distribution, and μ is the speed limit[1]. The preferred speed of the EV is set to the legal speed limit of the lane. An example scenario is presented in Fig. 1, where the speed limit is 100 km/h and $\sigma^2 = 10$.

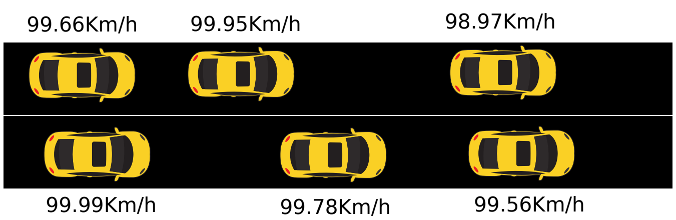

Fig. 1. Illustrative topology and preferred speed values.

Lane changes for the proposed algorithms are performed according to the *Lane Change Algorithm* (LCA) discussed in Section IV. For safety, a headway of at least two seconds is maintained by vehicles when following other vehicles using the *two-second rule* (TSR). Two-second headway is the distance traveled by a vehicle in 2 seconds.

B. Channel Model

The channel accounts for path loss using the free space propagation model, such that the received power at distance d is given by,

$$P_r(d) = P_t G_t G_r \left[\frac{\lambda}{4\pi d}\right]^2,$$

where P_t is the transmit power, λ is the wavelength, G_t and G_r are the gains of the transmitter and the receiver antennas respectively. The Nakagami-*m* fading model is used to characterize the multi-path propagation effects, such that the PDF of the received mulipath signal amplitude is given by,

$$f_Z(x) = \frac{2}{\Gamma(m)}\left(\frac{m}{\Omega}\right)^m x^{2m-1}e^{-mx^2/\Omega},$$

where m is the fading depth parameter, Ω is the average received power and $\Gamma(\cdot)$ is the Gamma function.

[1]Note that speed values drawn from this PDF can be negative, and hence, σ^2 should be chosen appropriately in the simulations.

C. Communication Model

We use DSRC/ WAVE protocols to facilitate communication between vehicles. The protocol stack for safety-critical applications is illustrated in Fig. 2. The physical (PHY) and medium access control (MAC) layers of WAVE is based on the IEEE 802.11p standard, and the WAVE Short Message Protocol (WSMP) defined by the IEEE 1609.3 standard defines the upper layers.

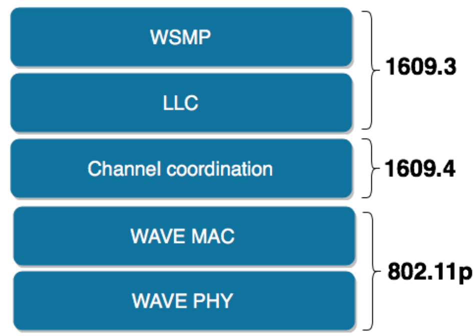

Fig. 2. The protocol stack for safety-critical applications

In VANETs, the window for communication, particularly for safety-critical applications, could be severely restricted. In such scenarios, broadcasting is preferred over uni-casting due to its simplicity and lower overheads. Every vehicle periodically broadcasts a beacon message with its telemetry data (location, lane, speed, acceleration, and whether it is an EV). All messages are created as WAVE short messages (WSMs), and broadcast in the IEEE 802.11p beacon frame over DSRC. Vehicles also broadcast emergency safety messages (ESMs) to prevent accidents. For example, if the vehicle has to slow down suddenly, it broadcasts an ESM to alert its neighbors.

III. EV Traversal Algorithms

In this section, we present the two algorithms for EV traversal, FLS and BLS. Both algorithms prioritize the EV's traversal over an NV.

A. The Fixed Lane Strategy

In the FLS, the EV chooses a lane and it stays in this lane throughout the journey. Any vehicle blocking the EV is signaled to temporarily move into the neighboring lane, and make way for the EV. After the EV has passed through, these vehicles can move back to their original lane. All lane changes are done using the LCA presented in Section IV. Intensive processing is not required at the EV as it only has to transmit beacons and obey the TSR.

The EV broadcasts beacons every T seconds. Each NV receiving this beacon has to change lanes if all the following requirements are met.

- NV is in the same lane as the EV.
- NV is ahead of the EV.
- Distance between EV and NV is less than priority distance (d_p).

Beacons from EV's are received by all NVs within its radio range. However, lane changing by NVs far ahead of the EV was observed to be unnecessary and to cause congestion. Thus, d_p prevents NVs beyond this distance from the EV from changing lanes in response to beacon messages. These ideas are formally presented in Algorithm 1. In all our algorithms, t represents current time.

Algorithm 1 Fixed Lane Strategy implemented in NVs

procedure HANDLING RECEIVED EV BEACON
  $d_p \leftarrow priorityDistance$
  $d \leftarrow distanceToEV$
  $changed \leftarrow false$
  if $EV\ behind\ \&\ in\ same\ lane\ \&\ d < d_p$ **then**
    $change\ lane\ with\ LCA$
    $changed \leftarrow true$
  else if $EV\ infront\ \&\ changed$ **then**
    $change\ lane\ with\ LCA$
    $changed \leftarrow false$

B. The Best Lane Strategy

In BLA, the EV periodically computes the *utility factor* (γ) every T_u seconds for all co-directional lanes using (1).

$$\gamma = w_a \times \frac{c_1}{V_m} + w_b \times \frac{c_2}{V_m} + w_c \times \frac{n - c_3}{n}, \tag{1}$$

where

- c_1 = minimum speed among the considered vehicles
- c_2 = average speed among the considered vehicles
- c_3 = the vehicle count on the considered lane
- μ = legal speed limit of the road
- n = maximum possible number of vehicles in front of the EV in its transmission region
- w_a, w_b, w_c are weights with values of 0.4, 0.4 and 0.2, respectively [7].

The *utility* γ characterizes the vehicle traffic flow through three factors, the normalized minimum speed (first term in (1)), the normalized average speed (second term in (1)), and the normalized free space in the considered lane (third term in (1)).

The EV tries to stay in the lane with the highest utility, and performs lane changes as necessary to locate itself in this lane. After acting on each utility calculation, the EV deletes all collected data and starts collecting new data for the next calculation. Since the EV is changing lanes to make way for itself, the NVs do not require intensive processing power. These ideas are formally presented in Algorithm 2.

IV. THE LANE CHANGE ALGORITHM

Unsafe lane changes are a major contributor to accidents. Safe lane changes are mandatory for the implementation of FLS and BLS. In this section, we present an algorithm to perform lane changes, safely.

All vehicles maintain a map of its neighbors ($\mathcal{N}$), which includes the NVs in the other lane within a region spanning

Algorithm 2 Best Lane Strategy implemented in EVs

procedure BLS IN EV
  $T_u \leftarrow UtilityFactorRecalcInterval$
  $t_r \leftarrow t + T_u$
  while $true$ **do**
    if $t > t_r$ **then**
      $\gamma\ recalculation\ according\ to$ (1)
      $l_\gamma \leftarrow laneWithHighestUtilityFactor$
      $l_{now} \leftarrow currentLanes$
      if $l_\gamma \neq l_{now}$ **then**
        $change\ lane\ to\ l_\gamma\ using\ LCA$
      $t_r \leftarrow t + T_u$
      $clear\ data$

10 car-lengths centering itself. Several types of messages are exchanged between the lane change requesting party, which we call a *requester*, and its neighbors, which we call *responders*. A lane change request (LCRq) is broadcast by the requester. Depending on whether the requested lane change can be made safely or not, all neighbors send either a lane change request denied (LCRD) or a lane change request accepted (LCRA) message as the response.

The requester listens to all nodes within receiving range in the VANET, not only those within ¡script¿ N. If it receives at least one LCRD, the lane change will be aborted. The lane change will be done only if no LCRDs are received, and if all vehicles in ¡script¿ N send LCRA messages. The latter requirement ensures that collisions due to a dropped LCRD packet from one of the vehicles in the neighbor list are avoided. These ideas are formally presented in Algorithm 3.

Algorithm 3 Lane Change Algorithm implemented by the requester

procedure SENDING LCRQ AND HANDLING RESPONSE
  $\mathcal{N} \leftarrow neighborList$
  $\mathcal{N}' \leftarrow empty\ list$
  $T_i \leftarrow laneChangeCheckInterval$
  $t_L \leftarrow t + T_i$
  $isRqDenied \leftarrow false$
  $Send\ LCRq$
  while $t < t_L$ **do**
    if $response\ received$ **then**
      if $response\ is\ LCRD$ **then**
        $isRqDenied \leftarrow true$
      else if $response\ is\ LCRA$ **then**
        $add\ sender\ to\ \mathcal{N}'$
  if $isRqDenied$ **then**
    $Lane\ change\ failed$
    $Restart\ procedure$
  else if $\mathcal{N} \equiv \mathcal{N}'$ **then**
    $Perform\ lane\ change$
    $Lane\ change\ success$

The introduction of LRCD and LRCA messages enhance the safety of lane changing. This mechanism is described next. Each responder assesses the risk of collision using its position and speed relative to the requester, before transmitting an LCRD or LCRA message. We call this the *risk assessment algorithm* (RAA). For the risk assessment, three regions are defined around the requester, namely, the unsafe region (UR), the front partially unsafe region (FPUR), and the rear partially unsafe region (RPUR), as shown in Fig. 3.

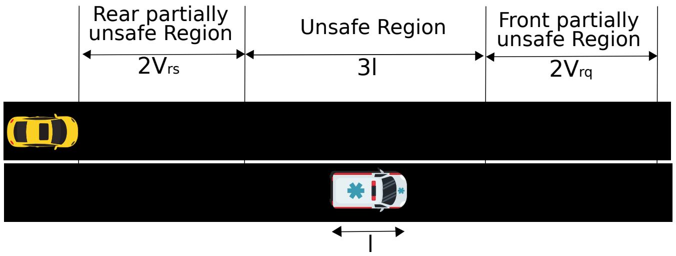

Fig. 3. Risk assessment regions around the requester

UR is the $3l$ long region centered around the requester, where l is the car-length. FPUR is defined as the region in-front of the requester starting from the forward edge of the UR, and spanning up to the two second headway distance of the requester. A similar region is defined behind the requester, which is called the RPUR. Its length is equal to the two second headway distance of the responder.

Let V_{rs} and V_{rq} denote the velocities of the responder and the requester, respectively. v_1 and v_2 denote the safety speed thresholds for the FPUR and RPUR, respectively. Note that the minimum distance that the requester can have with a vehicle in the FPUR or the RPUR is l. Hence, v_1 and v_2 are given by

$$v_1 = \sqrt{V_{rq}^2 - 2a_{rq} \times l}, \tag{2}$$

$$v_2 = \sqrt{V_{rs}^2 - 2a_{rs} \times l}, \tag{3}$$

where a_{rq} and a_{rs} denote the maximum deceleration of the requester and the responder, respectively.

Lane change when a vehicle is present in UR will most likely result in a collision. Hence, the responder sends an LCRD denying the LCRq, if it is in the UR. To make a safe lane change when a vehicle is present in the FPUR, V_{rs} has to be v_1 or greater. Therefore, if this is not satisfied, an LCRD is sent by the responder, since there is a significant risk of collision. Again, we need, V_{rq} to be greater than v_2 to make a safe lane change when a vehicle is present in the RPUR. Thus, an LCRD is sent if this condition is not satisfied. Responders not falling into any of the above regions respond with an LCRA.

After sending an LCRD, the responder will slow down by a factor α, if there is an EV in the proximity. Note that this slowing down will happen only if the responder is within the radio range of the EV. The slowing down increases the possibility of making a lane change in the next attempt. This process is repeated until the lane change is successful or a timeout occurs. An ESM is broadcast each time a reduction in speed is made. The ideas are formally presented in Algorithm 4. Safety of the lane changes can be further enhanced by using sensors in the vehicle as in [10].

Algorithm 4 Risk Assessment Algorithm implemented by the responder

procedure SENDING RESPONSE FOR AN LCRQ
    $\alpha \leftarrow slowDownFactor$
    $v_s \leftarrow safety\ speed\ threshold$
    if $self\ in\ UR$ **then**
        $send\ LCRD$
        $V_{rs} \leftarrow V_{rs} \times \alpha$
        $send\ ESM$
    else if $self\ in\ FPUR$ **then**
        if $V_{rs} < v_1$ **then**
            $send\ LCRD$
            $V_{rs} \leftarrow V_{rs} \times \alpha$
            $send\ ESM$
        else
            $send\ LCRA$
    else if $self\ in\ RPUR$ **then**
        if $V_{rq} < v_2$ **then**
            $send\ LCRD$
            $V_{rs} \leftarrow V_{rs} \times \alpha$
            $send\ ESM$
        else
            $send\ LCRA$
    else
        $send\ LCRA$

V. SIMULATION SETUP

The simulation is set up using the VEINS framework, which combines OMNeT++ and SUMO, allowing bidirectional communication using the TraCi [11] command interface. Communication network and algorithms are implemented in OMNeT++, utilizing the DSRC/ WAVE protocol stack. Vehicle behavior related decisions made by the implemented algorithms are passed to SUMO, which handles macro level vehicle dynamics. Road network, vehicle characteristics and traffic are modeled using SUMO. Free space path loss model and Nakagami model with $m = 3$ [12] are implemented.

We have considered a 5km long straight stretch of road with two unidirectional lanes. Maximum acceleration and deceleration of vehicles are set to 1 ms^{-2} and 4.5 ms^{-2}, respectively. Time gap between vehicles entering a lane is modeled using an exponential distribution with $mean = 2$. Decreasing the mean beyond this value makes maintaining the TSR prohibitively hard. Vehicle traffic entering the two lanes are assumed to be independent, hence they are modeled using two independent random processes. In place of SUMO's built-in car-following models, a TSR based model is implemented to test the robustness of BLS and FLS, similar to [13]

VI. RESULTS AND DISCUSSION

In this section, we present our simulation results. All results are averaged over 100 independent runs per setting.

Firstly, we simulate the EV traversal time for two scenarios where the standard deviation σ of the NV speed is set at 0.1μ and 0.2μ, *i.e.*, 10% and 20% of the legal speed limit. This gives rise to an expressway scenario and an urban road scenario. The EV traversal times for different values of μ are illustrated in Figs. 4 and 5, respectively. We observe that FLS outperforms BLS, except at the very low-speed end for the $\sigma = 0.1\mu$ scenario. The transition point lies between the speed limits of 40 and 45 km/h. On the other hand, BLS performs better than FLS for all settings when $\sigma = 0.2\mu$. The scenario with $\sigma = 0.2\mu$ has a close resemblance to the slow moving traffic in [7]. Despite the difference in modeling the speeds, the overall conclusion of BLS being better for traffic with higher variance in speed can be drawn. This is consistent with the conclusions in [7]. In such scenarios, having slow-moving NVs cause platoons to form behind them, requiring the EV to clear them in the case of the FLS. Thus, the BLS becomes more desirable in this situation.

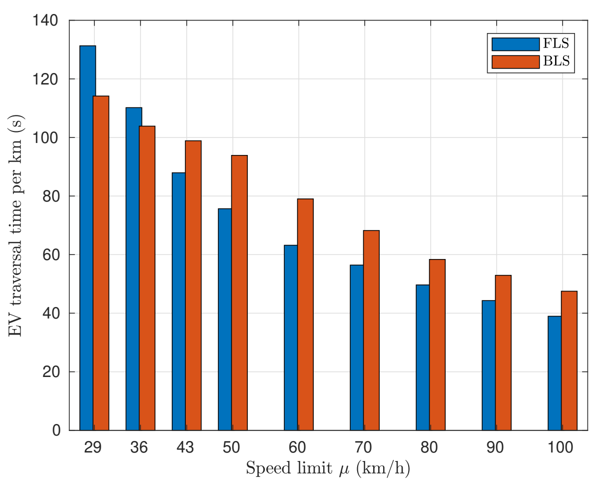

Fig. 4. EV traversal time per km, where $\sigma = 0.1\mu$.

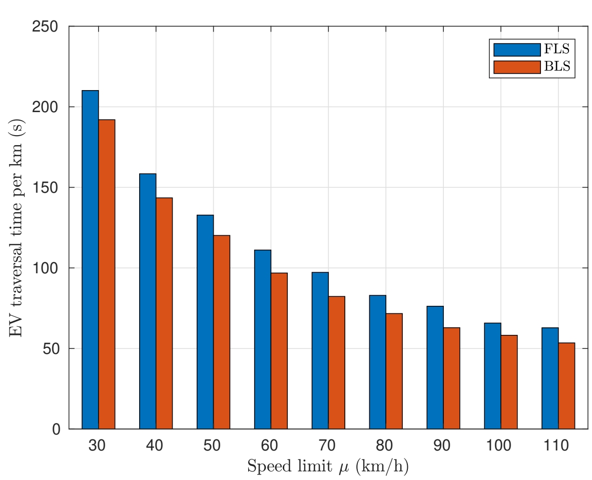

Fig. 5. EV traversal time per km, where $\sigma = 0.2\mu$.

We have also considered a scenario where the EV is granted an additional speed allowance of 10% above the legal speed limit. With $\sigma = 0.1\mu$, and results are illustrated in Fig. 6. The BLS outperforms FLS in this scenario, and this observation can be explained using the same reasoning made for Fig. 5. When the deviation between the speed of the EV and the slowest moving vehicle is high, the EV will be better off changing lanes, and hence, BLS is preferred. Therefore, intuitively, similar results can be expected for the 0.2μ scenario, where the deviation is even higher.

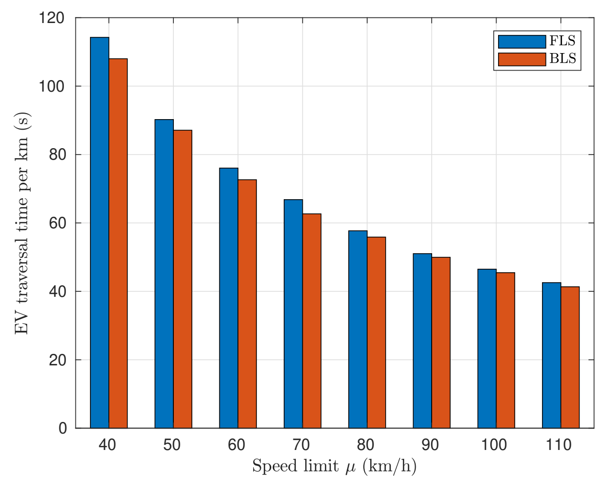

Fig. 6. EV traversal time per km, where $\sigma = 0.1\mu$ and the EV speed is 1.1μ.

Next, we will highlight the importance of the back priority region (d_p) in FLS. We have set $\mu = 100$km/h, and $\sigma = 0.1\mu$. EV traversal times for different back priority distance values are presented in Fig. 7. We observe that the traversal time reducing with d_p first, and then increasing. When NVs in the primary lane move to the secondary lane to make way for the EV, congestion in the secondary lane increases, resulting in a reduction in the average speed of the lane due to the TSR. When d_p is high, NVs close to the EV find difficulties in making a lane change due to NVs far ahead, but still within d_p, having changed lanes, causing the secondary lane to be congested. When d_p is small, EV has to get very close to the NVs to make them change the lane. This interrupts the EV, resulting in a higher traversal time. For efficient EV traversal with FLS, d_p should neither be too long nor too short. The optimal length of the back priority region did not change significantly when we increased the deviation in speeds as well, and it remained close to 50m.

Next, we will highlight the importance of the utility recalculation interval in BLS. Again, we consider $\mu = 100$km/h and $\sigma = 0.1\mu$. EV traversal times for different T_u values are presented in Fig. 8. First, the traversal time reduces with T_u, and then it increases. . However, when T_u is further increased, the EV will be less sensitive to the dynamic traffic conditions, and hence, the traversal time will increase. From

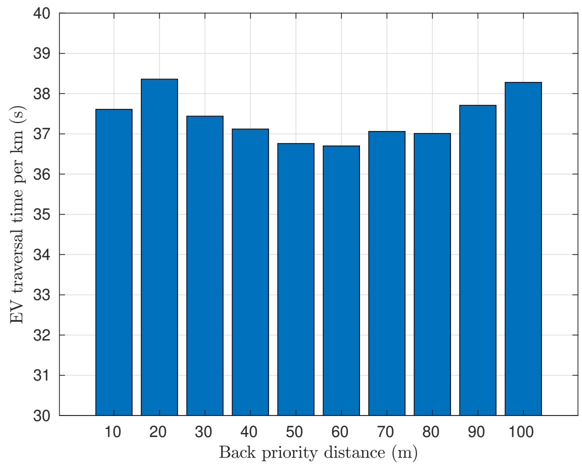

Fig. 7. EV traversal time per km, against priority distance in FLS, where μ is 100km/h and $\sigma = 0.1\mu$.

this simulation, it is clear that gains in terms traversal time can be obtained by fine tuning T_u.

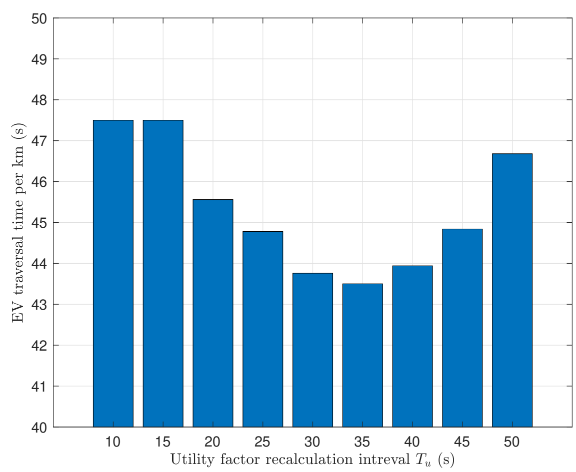

Fig. 8. EV traversal time per km, against utility recalculation interval in BLS, where μ is 100km/h and $\sigma = 0.1\mu$.

VII. Conclusions

This paper has studied the suitability of the fixed lane strategy (FLS) and the best lane strategy (BLS) for emergency vehicle (EV) traversal from a communication perspective. While clearly presenting all required packet transfers, the two algorithms have been evaluated by simulation in the VEINS framework, utilizing the DSRC/ WAVE V2V communication protocol stack. Simulation results have shown that the suitability of the EV traversal algorithms defer depending on the speed distribution of the vehicles. When the variance among the vehicle speeds is small, *i.e.*, similar to an expressway scenario, the FLS is better in terms traversal time. However, this leads to more lane changes, which affects the safety. On the other hand, when the variance among the vehicle speeds is increased, the BLS tends to be better in terms traversal time. It has been observed that all vehicles in the radio range of an EV reacting to a lane change request causes congestion that affects the traversal adversely. Hence, a priority region has been defined, which prioritizes the vehicles close to the EV when making lane changes. Insights on setting the size of the priority region, and the performance gains due to the use of the priority region have also been demonstrated.

VIII. Acknowledgment

The authors acknowledge the support for the presentation and publication of this work by the Senate Research Committee (SRC), University of Moratuwa, Sri Lanka.

References

[1] K. Ho, P. Kang, C. Hsu, and C. Lin, "Implementation of WAVE/DSRC devices for vehicular communications," in *Proc. International Symposium on Computer, Communication, Control and Automation*, vol. 2, pp. 522–525, May 2010.

[2] G. Karagiannis, O. Altintas, E. Ekici, G. Heijenk, B. Jarupan, K. Lin, and T. Weil, "Vehicular networking: A survey and tutorial on requirements, architectures, challenges, standards and solutions," *IEEE Communications Surveys Tutorials*, vol. 13, pp. 584–616, Apr. 2011.

[3] Y. Moroi and K. Takami, "A method of securing priority-use routes for emergency vehicles using inter-vehicle and vehicle-road communication," in *Proc. International Conference on New Technologies, Mobility and Security*, pp. 1–5, Jul. 2015.

[4] M. Chen, "Improved genetic algorithm for emergency logistics distribution vehicle routing problems," in *Proc. IEEE International Conference on Security, Pattern Analysis, and Cybernetics*, pp. 385–388, Oct. 2014.

[5] A. Buchenscheit, F. Schaub, F. Kargl, and M. Weber, "A VANET-based emergency vehicle warning system," in *Proc. IEEE Vehicular Networking Conference*, pp. 1–8, Oct. 2009.

[6] A. L. C. Bazzan, "A distributed approach for coordination of traffic signal agents," *Autonomous Agents and Multi-Agent Systems*, vol. 10, pp. 131–164, 2005.

[7] A. Agarwal and P. Paruchuri, "V2V communication for analysis of lane level dynamics for better EV traversal," in *Proc. IEEE Intelligent Vehicles Symposium*, pp. 368–375, Jun. 2016.

[8] H. Noori, "Realistic urban traffic simulation as vehicular ad-hoc network (VANET) via veins framework," in *Proc. Conference of Open Innovations Association*, pp. 1–7, Nov. 2012.

[9] K. A. Hawick, "Recent development and applications of SUMO–simulation of urban mobility," *The International Journal on Advances in Systems and Measurements*, vol. 5, 2009.

[10] N. Williams, G. Wu, K. Boriboonsomsin, M. Barth, S. Rajab, and S. Bai, "Anticipatory lane change warning using vehicle-to-vehicle communications," in *Proc. International Conference on Intelligent Transportation Systems*, pp. 117–122, Nov. 2018.

[11] A. Wegener, M. Piórkowski, M. Raya, H. Hellbrück, S. Fischer, and J.-P. Hubaux, "TraCI: An interface for coupling road traffic and network simulators," in *Proc. Communications and Networking Simulation Symposium*, pp. 155–163, 2008.

[12] K. A. Hafeez, L. Zhao, B. Ma, and J. W. Mark, "Performance analysis and enhancement of the DSRC for VANET's safety applications," *IEEE Transactions on Vehicular Technology*, vol. 62, pp. 3069–3083, Sep. 2013.

[13] S. Pallewatta, P. S. Lakmali, S. Wijewardana, P. Ranathunga, T. Samarasinghe, and D. Dias, "802.11p: Insights from the MAC and physical layers for a cooperate car following application," in *Proc. EAI International Conference on Intelligent Transport Systems*, pp. 226–236, Jul. 2018.