Het gebruik van C-ITS om de responstijd van ambulancezorg te verminderen in gesimuleerd stedelijk verkeer

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Samenvatting

Gedurende de eerste helft van de 21ste eeuw zal de digitalisatie golf zich over zowat alle domeinen voltrekken. De digitalisering schept eindeloze nieuwe mogelijkheden en brengt dan ook diepgaande sociale en maatschappelijke veranderingen teweeg. Ook in de verkeerssector zijn deze ontwikkelingen volop aan de gang en staan er enkele drastische transformaties voor de deur.
De ontwikkeling van nieuwe communicatietechnologieën, zoals ITS-G5 en 5G, de Europese inspanningen tot standaardisatie van communicatieprotocollen, en het sterk toenemende aantal voertuigsensoren effenen het pad om tot een zogenaamd geconnecteerd verkeerssysteem te komen. Een geconnecteerd verkeerssysteem bestaat uit C-ITS (Cooperative Intelligent Transport Systems), zoals voertuigen en infrastructuur eenheden, die hun sensordata met elkaar delen. Vervolgens kunnen C-ITS applicaties, zoals CACC (Cooperative Adaptive Cruise Control) en RHW (Road Hazard Warning), deze uitgewisselde informatie gebruiken om een efficiënter en veiliger verkeer te bekomen.
In deze paper worden twee C-ITS applicaties voorgesteld om de responstijd van hulpdiensten in stedelijk verkeer aanzienlijk in te korten.

- De Traffic Signal Priority Service voorziet hulpdiensten van absolute voorrang aan kruispunten met verkeerslichten. Naderende hulpdiensten delen tijdig hun geplande traject met verkeersregelinstallaties zodat deze veilig kunnen schakelen naar een toestand waarin enkel de inkomende richting van de hulpdiensten groen licht heeft.
- De Vehicle Rerouting Service moet hulpdiensten vlotter door druk, stedelijk verkeer laten rijden. Door middel van deze applicatie delen hulpdiensten hun route met andere weggebruikers zodat deze andere wegen kunnen kiezen en minder verkeersopstopping veroorzaken voor de hulpdiensten.

Beide C-ITS applicaties werden geïmplementeerd en getest in de microscopische verkeerssimulator SUMO (Simulation of Urban MObility). De evaluatie van de applicaties gebeurt op basis van hun invloed op de reistijden van zowel de hulpdiensten als van het andere verkeer. Individueel slagen beide C-ITS applicaties er in om de reistijd van hulpdiensten met ongeveer 20% te verminderen. Tot slot wordt de economische impact van de applicaties geschat door de waarde van het aantal bespaarde kwaliteitsvolle levensjaren af te wegen tegen de kosten van het vertraagde verkeer.

1. Introduction

The United Nations project that the worldwide urbanization process, which has been ongoing since at least 1950, will continue for the coming decades (DESA UN, 2019). This rapid population growth raises concerns regarding the deployment of emergency services in urban areas (Cabral, et al., 2018). With its concomitant elevated number of injuries and accidents, a larger population increases the demand for emergency services. Additionally, it stresses the present traffic infrastructure, leading to more traffic congestion (Chow, Santacreu, Tsapakis, Tanasaranond, & Cheng, 2014), possibly affecting the response time of emergency services.

Especially in life-threatening situations, a shorter response time, defined as the interval between the start of the emergency call and the arrival of the emergency services, can significantly improve the survival rate and the medical outcome of patients (Bürger, et al., 2018) (Pons, et al., 2005). Therefore, the Dutch emergency services have set a norm to achieve a response time of less than 15 minutes in 95% of the life-threatening emergencies (Milieu, Rijksinstituut voor Volksgezondheid (RIVM), 2011).

Different structural approaches to reduce the response time, such as reorganizing and relocating the ambulance bases, have been researched (Nogueira, Pinto, & Silva, 2016) (Peyravi, Khodakarim, Örtenwall, & Khorram-Manesh, 2015). However, in order to reduce the response time even further, this paper investigates the use of emerging digital solutions. The European Commission identifies digitalization as an essential driver for transforming the transport system into a smarter sector (European Commission, 2021). Crucial building blocks in this vision are the so-called Intelligent Transport Systems (ITS) which use information technologies and contain communication devices to exchange information with other ITS.

In the Netherlands, the Talking Traffic consortium supports this transformation by replacing traditional Traffic Light Controllers (TLC) with intelligent Traffic Light Controllers (iTLC) (Werkgroep Stappenplan iVRI, 2021). The Dutch iTLC are connected to the cellular network and can interact with other ITS through the exchange of standardized messages, as defined by the European communication standards organization ETSI (ETSI, 2020).

The introduction of iTLC facilitates the provision of basic C-ITS (Cooperative Intelligent Transport Systems) services such as Traffic Signal Priority Service (TSPS) and Green Light Optimal Advisory (GLOSA). Two pilot studies, part of the Urban Nodes project of C-Roads Germany, are testing these services to improve public transport flow in urban areas (Klöppel-Gersdorf, Zimmermann, Purschwitz, Otto, & Partzsch, 2021). In contrast to the Dutch iTLC, the presented pilots have implemented the ITS-G5 communication technology, which has a limited communication range. In the pilots, the range varied between 250 meters in bad conditions and 600 meters at line-of-sight propagation (Klöppel-Gersdorf, Zimmermann, Purschwitz, Otto, & Partzsch, 2021).

In this paper, which is set in the Dutch context, two cellular network C-ITS services are presented and evaluated using the microscopic traffic simulator SUMO (Simulation of Urban MObility) (Lopez, et al., 2018). The services will be referred to as the Traffic Signal Priority Service (TSPS) and the Vehicle Rerouting Service (VRS). Both services aim to shorten the response time of emergency services by improving their flow in urban traffic.

The first C-ITS service is an implementation of a TSPS for emergency vehicles. The implemented service provides emergency services priority when approaching signalized intersections. By informing the iTLC sufficiently in advance, potential queues in front of the intersection can be resolved by the time the emergency vehicle arrives, decreasing their incurred delays. The use of the cellular network, with a virtually unlimited communication range, is thus an important feature of the Dutch iTLC. Furthermore, this service could drastically improve the road safety of emergency services. In the Netherlands, 165 traffic accidents involved a priority vehicle in 2018 and 2019 (Instituut Fysieke Veiligheid, 2020). Nearly one-third of these accidents happened when a priority vehicle crossed a red stoplight.

A lot of research has been done regarding the prioritization of emergency services at intersections (Humagain, Sinha, Lai, & Ranjitkar, 2020). In some research, the priority of emergency vehicles is based on virtual traffic lights (Viriyasitavat & Tonguz, 2012). This paradigm shifts the functioning of TLC towards the vehicles themselves, creating so-called self-organized traffic control. The virtual traffic lights allow controlling all intersections, even those without traffic light infrastructure. However, one dysfunctional communication device could have catastrophic consequences.

Other researchers have performed simulations that are more closely related to the work presented in this paper (Suthaputchakun & Cao, 2019). In their simulations, the authors varied the traffic density and the radius at which the TSPS initiates, meanwhile evaluating the impact on the travel times of normal and emergency vehicles. However, the simulated scenarios span a limited area in which the trajectory of the emergency vehicles is predetermined and contains only one signalized intersection.

The second C-ITS service, the Vehicle Rerouting Service (VRS), is designed and implemented to decrease the traffic density along the routes of emergency vehicles. This service can thus reduce the delays emergency vehicles incur on straight roads during high traffic density conditions (Suthaputchakun & Cao, 2019). Once an emergency call is made, an interval of thirty seconds is initiated in which the emergency services are being prepared. Simultaneously, the VRS is already activated to redirect other vehicles away from the planned route of the emergency vehicle, thus resulting in fewer interruptions.

The implementations of both the TSPS and the VRS were tested in city-scale traffic simulations based on real-world traffic patterns. More specifically, the simulated scenario was set in the city center of Eindhoven, demographically the fifth-largest city in the Netherlands, with a registered population of 235,691 (Centraal Bureau voor de Statistiek (CBS), 2021). The simulations were performed for the morning rush hour and the aftermath of the evening rush hour. For both scenarios, the traffic density was based on vehicle counts obtained through the municipality of Eindhoven. While both services achieved a significant reduction in the travel time of emergency services, the most promising results were obtained through the TSPS.

The specifics of the simulated scenarios will be further elaborated in section 2. Section 3 provides a more detailed description of the two C-ITS services, while section 4 presents and discusses the results of the performed simulations. Finally, in section 5 the conclusions of this work are drawn.

2. Simulation Scenarios

This section details the design of the two traffic scenarios used to evaluate the travel time of emergency vehicles in urban traffic. In general, a simulated traffic scenario can be decomposed into two components. The first component is the static data, consisting of the road network and associated infrastructure, e.g., traffic lights. The second component is the dynamic data, which entails the entities entering and leaving the simulation during the scenario, e.g., vehicles.

2.1 Static Data

The city center of Eindhoven was selected as a representative area to perform simulations of urban traffic. The topology of the car road network, the location of traffic lights, and the properties of individual roads, such as the allowed vehicle types and the maximal speed, were all extracted from OpenStreetMap (OpenStreetMap contributors, 2021). This extraction was performed by the *osmWebWizard.py* script, which is part of the SUMO package (Lopez, et al., 2018). Since the aggregation of OpenStreetMap data is based on the principle of crowdsourcing, the retrieved road network is not guaranteed to be infallible. Therefore, crucial locations in the network were checked and adjusted manually to correspond better with the real-world situation. The final road network is graphically represented in Fig. 1. All lanes combine for a total length of 366.89 km.

Figure 1: Road network of the Eindhoven city center, the red arrow indicates the fixed starting location of the emergency vehicles.

2.2 Dynamic Data

Another vital part of the simulated scenario is, of course, the traffic itself. In the macroscopic view of the simulation, both the traffic density and the global traveling patterns should correspond to reality. However, traffic patterns and densities depend heavily on the time of day and the actual day. Therefore, two sufficiently different, though representative simulation periods are selected, i.e., the morning rush hour (6-9h) and the aftermath of the evening rush hour (19-23h) on a regular Monday. The simulated traffic is limited to standard passenger cars and emergency vehicles. No other modes of traffic are considered.

Standard Vehicles

The simulation of the urban traffic flow is based on real-world traffic patterns, obtained through the TomTom MOVE portal (TomTom N.V., 2022), and on real-world vehicle counts provided by the municipality of Eindhoven. First, the O/D Analysis tool of the TomTom MOVE portal was used to subdivide the road network into a grid with a unit length of 0.5 km. The API returned the origin-destination matrices of the defined grid for the requested periods, i.e., Monday 27/01/2020 between 6-9h and between 19-23h. The origin-destination matrices contain the number of vehicle trips between each square of the defined grid, as registered over these entire periods by TomTom. Next, the Traffic Stats tool, also part of the TomTom MOVE portal, was used to determine the relative traffic densities on an hourly basis, which were further refined by linear interpolation to obtain smoothly varying traffic densities. Finally, the municipality of Eindhoven provided vehicle count data at specific locations in the city center. These absolute counts were used to scale the number of trips registered by TomTom to the total number of vehicles on the roads. A profile of the traffic density during a simulation of the evening traffic is presented in Fig. 2.

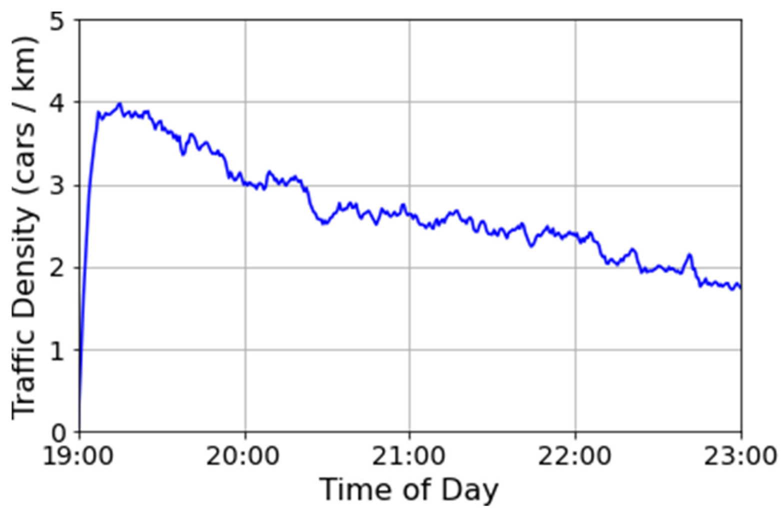

Figure 2: Evolution of the traffic density in the entire road network during the evening rush hour simulation.

Emergency Vehicles

The simulated emergency vehicles are assigned the SUMO emergency vehicle (EMV) class, allowing them to overtake on the right and on the opposite lane. Their 'impatience' attribute is set to 1, i.e., they consider all maneuvers which do not lead to a collision as safe, disregarding the fact that they might cause the need for emergency breaks. Furthermore, their 'speedFactor' is set to 1.5, which indicates that they can violate the speed limits by a factor of 1.5. Finally, the EMVs are equipped with a built-in device, called the 'blue light device' (Bieker-Walz, Behrisch, & Junghans, 2018). This device provides the EMV with special rights such as ignoring red traffic lights, and it causes the formation of a rescue lane by vehicles within a downstream distance of 25 meters.

Emergency calls are simulated to occur at a steady interval of five minutes. This allows studying the behavior of the emergency vehicles without the added complexity of interacting EMVs. The starting location of the EMVs is predetermined and corresponds to an actual hub of ambulances, indicated by the red arrow in Fig. 1. The destination of the

EMVs is determined by sampling random coordinate pairs within the network and finding the nearest accessible street. Once the starting and ending location of the EMVs have been established, the Dijkstra algorithm (Dijkstra, 1959) is used to find the fastest route. Finally, the EMVs are inserted into the simulation thirty seconds after receiving the emergency call and calculating the fastest route. This interval represents the preparation time of the emergency services and is of importance for the Vehicle Rerouting Service.

3. Implemented Services

This section discusses the implementation of the two C-ITS services in the simulation environment. The objective of the services is to decrease the response time of emergency services by improving the flow of emergency vehicles in urban traffic. Both services are implemented using the Python version of TraCI (German Aerospace Center (DLR) and others, 2021), short for Traffic Control Interface, which allows interacting with SUMO simulations during run time.

3.1 Traffic Signal Priority Service

Densely populated areas introduce a heavy load on the main intersections of cities. Traffic lights are essential to control the flow safely and proportionally at these junctions. However, every traffic light along the emergency vehicle route is another hurdle to overcome. Though emergency vehicles are allowed to cross the stopping light in case of high emergency, often they are still delayed by the queue in front of the traffic light. Furthermore, a significant risk of causing an accident is associated with the negation of the stopping light. Therefore, the Traffic Signal Priority Service (TSPS) is designed to smoothly transition the traffic signal to a state in which approaching emergency vehicles are provided with a green wave.

The TSPS is triggered at the insertion of an emergency vehicle into the simulation, i.e., thirty seconds after receiving an emergency call. First, the Dijkstra algorithm is used to calculate the fastest route, based on the current estimated travel times of all road segments, to the emergency location. Subsequently, all the traffic lights along the route are identified. The state that will provide green signals for the approach of the emergency vehicle and stopping signals for the other approaches is determined for each traffic light. As all lanes of the approach of the EMV are provided with a green signal, all vehicles entering the intersection from that direction can pass. This results in a smoother traffic flow and, in practice, it allows emergency services to make last-minute changes to their crossing direction.

Proceeding the simulation, at every step, the distance of the emergency vehicle to its first upcoming traffic light is obtained and evaluated with respect to the predefined TSP radius, a parameter that will be varied in section 4.2. When the emergency vehicle enters this TSP radius, the actuation program of the traffic light is interrupted, and the traffic light is brought into a transition state. All signals are turned yellow (Yellow Change), indicating that the intersection should be cleared. Four seconds later, the traffic light enters the state that provides a green wave for the approach of the emergency vehicle, while all other lights are turned red (Green EMV Approach). After the emergency vehicle has safely passed the intersection, the green lights are turned yellow while the red lights remain unchanged (Yellow EMV Approach). This state lasts three seconds and is followed by an all-red clearing state (Red Clearance) which lasts two seconds. This final state ensures that the intersection is empty before the traffic light resumes its usual actuation program. Meanwhile, the emergency vehicle moves on to its destination, safely passing subsequent traffic lights in the same way.

Table 1 shows an overview of the successive state transitions defined in the TSPS. The timing of the transition states corresponds to general recommendations (National Academies of Sciences, Engineering and Medicine, 2015).

Table 1: The traffic light state transitions as defined in the TSPS.

Order	Traffic Light Controller	Transition Condition
1	Actuation Program	EMV enters TSP radius
2	Yellow Change	4 seconds
3	Green EMV Approach	EMV passes TLC
4	Yellow EMV Approach	3 seconds
5	Red Clearance	2 seconds

3.2 Vehicle Rerouting Service

High travel demands are a determining factor in the formation of urban traffic congestion (Chow, Santacreu, Tsapakis, Tanasaranond, & Cheng, 2014). The slower speeds associated with this congestion introduce another delay in the response of emergency services. The Vehicle Rerouting Service (VRS) is proposed to mitigate these delays by encouraging other vehicles to take routes that do not overlap with the predetermined route of the emergency vehicle.

The implementation of the VRS is based on the notion of edge efforts. In SUMO, every road consists of multiple connected segments, called edges. These edges can be assigned an arbitrary effort value. Then, instead of calculating the shortest or the fastest route between the origin and destination of a trip, the route which minimizes the total effort value can be determined by the Dijkstra algorithm.

The VRS is triggered immediately after a simulation is initiated. The service starts by assigning all edges an effort value proportional to their length. Once an emergency call is made, the edge closest to the emergency location is identified as the destination. Starting at the hospital, the fastest route is then calculated based on the current estimated travel times. Subsequently, the efforts of the edges along the route of the EMV are multiplied by the Vehicle Rerouting Effort Multiplier (VREM), a parameter that will be varied in section 4.3. All vehicles in the simulation are immediately rerouted with respect to the updated edge efforts, i.e., such that their total route effort is minimized. As mentioned in section 2.2, the EMV is only inserted into the simulation after a preparation time of thirty seconds has passed. This provides time for the standard vehicles to clear the route of the EMV. Standard vehicles entering the simulation after the efforts have been updated and before the EMV has arrived at its destination are ensured to be rerouted according to the new efforts. Finally, as the EMV passes the edges along its route, their efforts are reset to their initial values one by one until the EMV reaches its destination.

4. Simulation Results & Discussion

This section investigates the impact of the Traffic Signal Priority Service (TSPS) and the Vehicle Rerouting Service (VRS) on the travel times of both standard and emergency vehicles. Finally, a rough estimate of the societal value of the services will be made.

4.1 Benchmark

First, simulations are performed in which the C-ITS services are not activated. The results of these simulations establish a benchmark for the remainder of this paper. The benchmark simulations are run for the morning rush (6-9h) and the evening relax (19-23h) scenarios. In the morning rush simulations, on average 17,650 standard vehicles reached their destination per hour. The traffic density in the evening relax scenario is significantly lower with an average of 12,681 standard vehicles finishing their trip per hour. A comparison of the trip statistics of the benchmark simulations is presented in the first two rows of Table 2. The errors on the last digits of the shown numbers are calculated as the standard deviations acquired after ten simulations. They are indicated between parentheses.
The average length of the trips made inside the city center is observed to be around 2.7 km. The higher traffic density during the morning rush makes standard vehicles choose for slightly longer (5%) trips than in the less busy evening scenario. Moreover, the more densely occupied road network leads to increased waiting times (68%) and lower driving speeds, both for standard vehicles (12%) and emergency vehicles (8%).
The higher speeds of EMVs compared to standard vehicles result from their specific attributes, as has been discussed in section 2.2.

Table 2: The average trip statistics of Standard Vehicles (SVs) and Emergency Vehicles (EMVs) for two traffic scenarios and different configurations of the Traffic Signal Priority Service (TSPS) and the Vehicle Rerouting Service (VRS). Indicated between parentheses are the errors on the last digits of the shown numbers, which are calculated as the standard deviations acquired after ten simulations.

Scenario	TSP Radius [m] - VREM	Trip Length [m]	Total Travel Time [h]	SV Travel Time [s]	EMV Travel Time [s]	SV Speed [km/h]	EMV Speed [km/h]	Societal Value [euro/h]
Morning Rush	/ - /	2,780(20)	4,982(40)	339(24)	220(47)	29.6(5)	44(1)	Ref.
Evening Relax		2,634(3)	3,934(6)	279.0(4)	210(12)	33.99(7)	47.7(7)	Ref.
Morning Rush	800 - /	2,784(8)	5,021(24)	341(15)	179(30)	29.4(4)	54(2)	827
Evening Relax		2,635(3)	3,964(10)	281.2(7)	175(12)	33.74(7)	57(1)	726
Evening Relax	/ - 4	2,549(3)	4,413(9)	313.1(6)	166(8)	29.31(3)	59(1)	-140
Evening Relax	800 - 4	2,550(4)	4,442(21)	315(2)	159(7)	29.1(1)	62.1(9)	-40

4.2 Traffic Signal Priority Service

Next, the performance of the TSPS is investigated using the same scenarios.
As discussed in section 3.1, the so-called TSP radius, i.e., the distance at which the traffic signal preemption is initiated, is an essential parameter of the TSPS. In order to determine a suitable radius, a parameter sweep, ranging from 100 to 900 meters, is performed using the evening scenario. The results of the sweep are presented in Fig. 3.
The graph shows that the average travel time of emergency vehicles (black dots) decreases when the TSPS is turned on. Moreover, the travel time of the EMVs decreases monotonously with increasing TSP radius, up to a length of 800 meters. This behavior can be explained as the result of vanishing queues along the oncoming lane of the EMV when the corresponding traffic signal is prematurely switched to green, thus decreasing the delay of the EMV at the intersection. When the TSP radius is set above 800 meters, the queues have dissolved, and the travel time of the EMVs starts to increase slowly. This increasing travel time is due to the growing inefficiency of the traffic signals, which causes a higher effective traffic density.
Moreover, the average travel time of standard vehicles (black crosses) grows only marginally with increasing TSP radius. However, as standard vehicles massively outnumber emergency vehicles, the total travel time (blue dots), i.e., the sum of the travel times of all vehicles in the simulation, does increase with increasing TSP radius. The determination of the optimal TSP radius does thus consist in balancing the time lost due to the inefficiency of the traffic signal control and the improved response time of emergency services.
The main objective of this paper is to prove the potential of communication devices in improving the flow of emergency vehicles in urban traffic. Therefore, the TSP radius of 800 meters is deemed optimal within the scope of this work and will be used for further simulations.
The quantitative results for both the morning rush and the evening relax scenarios using the TSPS with a TSP radius of 800 meters are shown in Table 2. The average speed of standard vehicles is observed to decrease by 0.7% compared to the benchmark results for both scenarios. Meanwhile, the speed of emergency vehicles increases by 22.7% and 19.5% for the morning rush and the evening relax scenarios, respectively.
For emergency calls within the city center of Eindhoven, the increase by approximately 20% in the speed of emergency vehicles translates to a reduction in response time of roughly thirty seconds. This time gain could be life-saving in acute emergency cases like cardiac arrests (Bürger, et al., 2018).

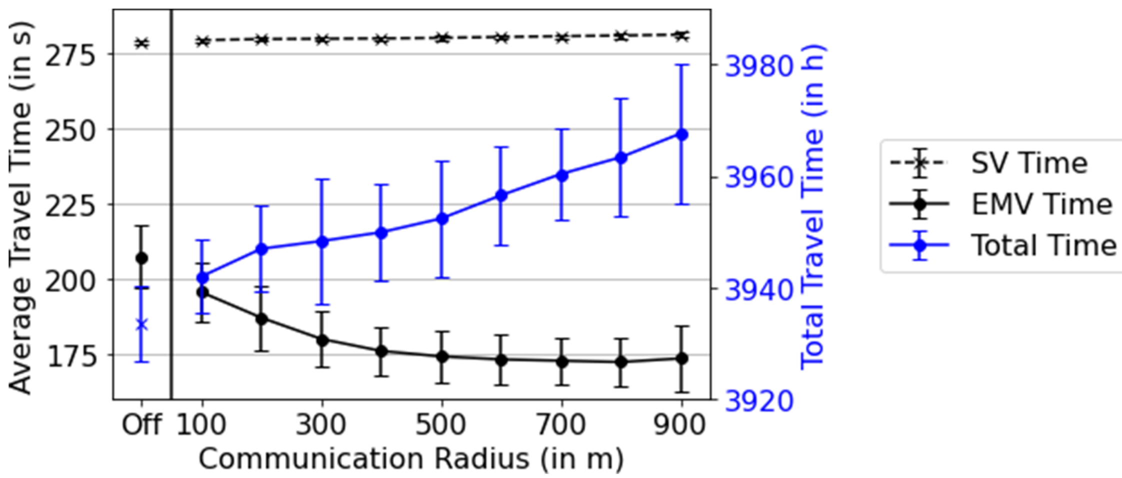

Figure 3: The total travel time of all vehicles in the simulation combined and the average individual travel times of standard vehicles (SV) and emergency vehicles (EMV) for different values of the TSP radius. The error bars mark the standard deviations obtained after ten simulation runs.

4.3 Vehicle Rerouting Service

The VRS was also tested and evaluated for both scenarios. However, the VRS, as implemented in this paper, was found to be unsuitable for the very high traffic density during the morning rush scenario. When the VRS is turned on, standard vehicles are rerouted away from the emergency vehicle routes, effectively reducing the available road network. The combination of a high traffic density and the decreased availability of roads caused severe gridlocks, rendering unrealistic traffic simulations. Further discussion of the VRS is therefore limited to the evening relax scenario.

Similar to the TSP radius in the TSPS, the Vehicle Rerouting Effort Multiplier (VREM) is an adjustable parameter in the VRS. Its influence on the simulation results is studied through another parameter sweep. The results are shown in Fig. 4.

For the smallest VREM (equal to 1.1), the average travel time of the EMV's (black dots) decreases as expected. However, the average travel time of standard vehicles (black crosses) increases roughly by a factor of four more. This significant increase is caused by the rerouting of standard vehicles from the main roads towards local roads, which are less suited to deal with large amounts of traffic. When the VREM is further increased, the travel time of standard vehicles grows slowly, while the gain in speed for emergency vehicles is significant. For the VRS to be effective, it is thus vital to use a VREM of at least three.

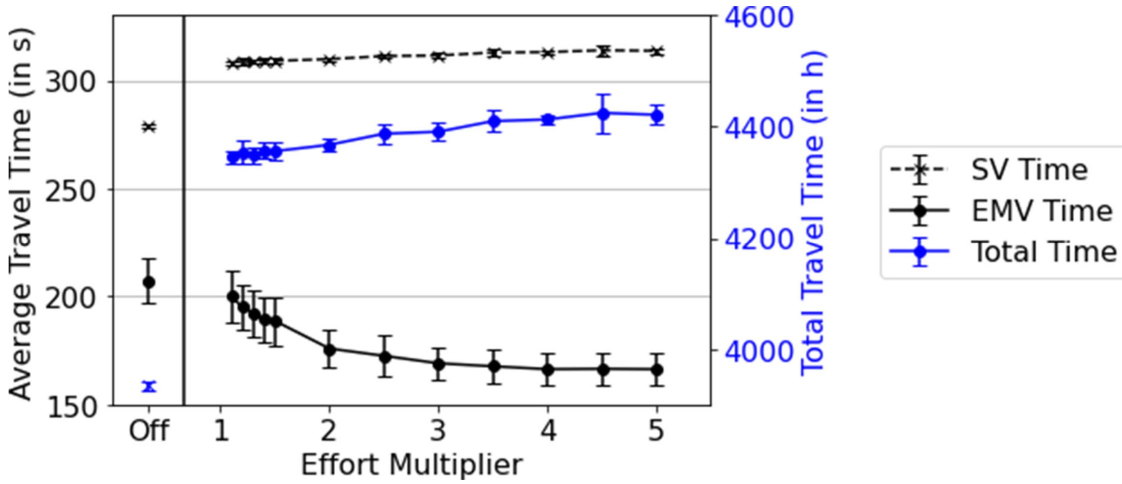

Figure 4: The total travel time of all vehicles in the simulation combined and the average individual travel times of standard vehicles (SV) and emergency vehicles (EMV) for different values of the effort multiplier (VREM). The error bars mark the standard deviations obtained after ten simulation runs.

Table 2 summarizes the quantitative simulation results for the evening relax scenario using the Vehicle Rerouting Service with a VREM of four. Compared to the benchmark simulations, the speed of emergency vehicles increases by 23.7%, while the speed of standard vehicles decreases by 13.8%.

Both the Traffic Signal Priority Service and the Vehicle Rerouting Service lead to a reduction of the travel time of emergency vehicles on the order of 20%. However, for the VRS, the time loss of all the other traffic participants is much larger, resulting in an increased economic cost due to congestion (Weisbrod, Vary, & Treyz, 2003). Furthermore, the service shifts traffic from the main roads to local roads, disturbing quiet residential areas and potentially raising safety concerns (Jacobs Engineering Group Inc, 2019).

A much less intrusive method to improve the flow of emergency vehicles is the so-called Emergency Vehicle Approaching service, which is part of the list of Day 1 C-ITS applications presented by the European Commission (European Commission, 2016).

4.4 Combined Services

In the next step, the evening relax scenario was simulated using the TSPS and the VRS in parallel. Since both services improve different aspects of the flow of emergency vehicles, combining them is expected to result in an even more considerable reduction of the response time.

For these simulations, the TSP radius and the VREM were set to 800 meters and 4, respectively. The results for this configuration are listed in Table 2. The combination of both services leads to a further increase in the speed of emergency vehicles. Compared to the benchmark situation EMVs travel 30.2% faster. This indeed shows that combining both services leads to an even further decreased travel time for emergency vehicles. However, since the VRS also decreases the queues along the lane of EMVs at signalized intersections, the services are not entirely complimentary. Furthermore, the combination of both services leads to a 14.4% reduction in the speed of standard vehicles, which seems like an exorbitant cost.

4.5 Societal Evaluation

Finally, a rough estimate of the societal value of the implemented services was obtained. The societal value is determined as the difference between the societal gain, resulting from a faster emergency response time, and the societal loss due to the delay inflicted on other traffic participants.

A large-scale study in the UK estimated that a reduction of the response time by one minute could improve the survival rate of out-of-hospital cardiac arrests (OHCA) by 19%, meanwhile, no evidence of an improved survival rate was found for other clinical groups (Turner, O'Keeffe, Dixon, Warren, & Nicholl, 2006). According to the study, this translates to 0.04% more survivors of life-threatening emergency calls per minute of reduced response time. For simplification purposes, this relationship between reduced response time and increased survival rate for OHCAs is assumed to be linear in the following calculations. Furthermore, a triage can categorize the emergency calls, such that the services can specifically be used for life-threatening cases only. Thus, for every minute of reduced response time in the morning rush (35 calls) and the evening relax (46 calls) scenario, 0.014 and 0.018 additional lives are saved, respectively. Moreover, the UK study estimates that on average a person surviving an OHCA will have five quality-adjusted life years (QALYs) left. In the Netherlands, the value that is assigned to an additional qualitative life year ranges between €10,000-80,000. Considering a reasonable QALY value of €60,000, saving a person with an OHCA results in a societal gain equivalent to €300,000. Finally, the societal gain of the services can be calculated by multiplying this number with the number of additionally saved people.

The societal cost of the services is approximated by multiplying the additional travel time of all vehicles with the value of travel time for cars in the Netherlands, i.e., €9 per hour (de Jong & Kouwenhoven, 2019). The cost for other traffic modes is not taken into account, since the simulated scenarios only consist of standard passenger cars.

The subtraction of the societal cost from the societal gain results in crude estimates of the societal value of the implemented services for all the presented simulations. For comparison, the results for the two scenarios were scaled by the simulation time and listed in the final column of Table 2. The positive societal value for the TSPS indicates that this service could be a valuable asset to society. On the other hand, the VRS and the combination of both services simultaneously have a negative societal value. This shows that the VRS has too large of an impact on the other traffic participants to be a viable service when a QALY is valued at €60,000. However, for a QALY value of €80,000, the VRS and the combined service also become viable.

Finally, it is important to stress that the presented societal values are very crude approximations, based on numerous assumptions. For instance, the calculation of the societal gain is only based on the improved survival rate of OHCA patients, while a faster response time of emergency vehicles could be beneficial with regards to many aspects, such as revalidation, and lowering of stress and anxiety (Turner, O'Keeffe, Dixon, Warren, & Nicholl, 2006).

5. Conclusion

In this paper, two C-ITS services were proposed to reduce the response time of emergency services in urban areas. Both services were implemented in the microscopic traffic simulator SUMO. The C-ITS services were evaluated in two traffic scenarios, set within the city center of Eindhoven.

The Traffic Signal Priority Service ensures that emergency vehicles are prioritized at signalized intersections. It was shown that initiating the service at a distance of 800 meters resulted in the optimal flow of the emergency vehicles during the aftermath of the evening rush hour. The service was observed to reduce the response time of emergency vehicles by roughly thirty seconds. Meanwhile, the average speed of the other vehicles decreased by only 0.7%.

The Vehicle Rerouting Service guides vehicles to roads that do not overlap with the routes of emergency vehicles. For the very dense traffic scenario of the morning rush hour, the rerouting of vehicles resulted in massive gridlocks. In the less busy evening scenario, the VRS could reduce the response time slightly more than the TSPS. However, the average speed of the other vehicles decreased by 13.8%.

When looking at the combination of both services, a 30.2% decrease in the emergency vehicle travel time and a 14.4% increase in the travel time of the other traffic participants is observed.

In order to evaluate the services according to their societal value, rough estimates of the societal gain corresponding to the reduced response time and the societal cost due to the additional delays for other vehicles were made. For the TSPS, the number of saved QALYs, due to the shorter response time, resulted in a net positive societal value, indicating that the implemented TSPS could be a valuable service for society. For the scenarios involving the VRS, the delays inflicted on other vehicles caused a net negative societal value. Apart from the economic cost, the VRS could also raise safety concerns due to an undesirable increase in traffic in residential areas. Implementing this service in the real world thus seems less attractive.

In the presented scenarios, urban traffic is simulated using a single standard vehicle type. In future work, a more realistic representation of urban traffic could be obtained by including other traffic modes such as cyclists, buses, and trucks. Furthermore, the presented implementation of the Traffic Signal Priority Service lacks efficiency through the use of a single Traffic Signal Priority radius for all signalized intersections. A more efficient service could be obtained by tailoring this parameter for all intersections individually or by considering real-time queue lengths.

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