Analysing Cooperative Awareness Message generation around intersections based on macroscopic traffic parameters

G.C. Maan
University of Twente
Faculty of Electrical Engineering, Mathematics and Computer Science
Design and Analysis of Communication Systems (DACS)
P.O. Box 207, 7500AE
Enschede, The Netherlands
g.c.maan@student.utwente.nl

***Abstract*—This paper describes the analysis of event triggered Vehicle-2-Vehicle messages around intersections. The study is based on naturalistic trajectory data recorded by drone on an unsignalized intersection. The microscopic traffic data available in the dataset is used to acquire macroscopic traffic parameters and to calculate Cooperative Awareness Message generations. The macroscopic traffic behaviour is compared with the CAM generation rates to analyse the relation between them, with the aim to support the estimation of the channel load due to vehicular communication based on macroscopic parameters in the future. The study demonstrates positive linear relationships between the CAM generation rate and the traffic density and between the generation rate and traffic flow. In addition, it was found that the trigger conditions based on change in heading and change in speed both have a significant effect on CAM generations for vehicles making a turn. Besides, it is concluded that the CAM generations of vehicles going straight ahead are mainly triggered due to the displacement condition.**

***Index Terms*—V2V communication, Cooperative Awareness Message, Macroscopic traffic parameters, Unsignalized intersection**

I. Introduction

A lot has has been going on in the field of vehicular communication in the last decade. The standardization of C-ITS (Cooperative Intelligent Transportation Systems) applications in the first phase of deployment is finalized and the deployment of day-one applications has already started in 2015. With this first role-out of Cooperative Awareness (CA) applications, we are in the early stages of the movement towards a world were vehicles will drive autonomously and cooperate in so-called VANETs (Vehicular Ad hoc Networks). [1]

This first phase, also called day-one, is part of the deployment strategy of C-ITS applications established by stakeholders in Europa in the Memorandum of Understanding (MoU) [2]. Day-one is characterized by a low level of complexity and is designed to operate under low market penetration. It provides road users with warning/efficiency information without automation of tasks. In stages after day-one (day 2, 3 and 4) the complexity, market penetration and number of possible applications will gradually increase towards the ultimate goal where all vehicles cooperate autonomously and the traffic is optimized in terms of safety, efficiency and sustainability. [1]

The higher penetration of V2V equipped vehicles and strict latency requirements for after day-one applications, raises concerns regarding the load on the communication channel [1]. The assigned bandwidth is limited and the amount of transmitted messages will increase with more vehicles participating in VANETs. Therefore, it is necessary be able to estimate the load on the communication channel in different traffic situations to enable decision making about whether the current standards are adequate to deliver the intended services in the upcoming phases of vehicular communication deployments.

One of the protocols used in current-day C-ITS applications is the Cooperative Awareness Message protocol (CAM). In this protocol vehicles will broadcast basic messages containing information about the vehicle's state to the nearby road-users. Just like many other cooperative messages, CAMs are triggered based on certain events, like change in vehicle's position, speed and heading. Due to this event-based message triggering the generation rate of CAMs is variable, complicating the analysis of the load on the communication channel. Knowing the microscopic behaviour of vehicles would enable one to analyse the load on the communication channel due to generated CAMs of individual vehicles. However, it would be more meaningful to be able to estimate the channel load considering the traffic as a whole, to allow application in real life traffic situations.

Therefore, this study will aim towards finding the relation between macroscopic traffic behaviour and the CAM generation rate, focusing on traffic on intersections. The main question that will be treated in this research is: *What is the relationship between macroscopic traffic parameters and the CAM generation rate for traffic on intersections?* Besides, we will look what factors have a significant influence on CAM generations on intersections to see want is important to consider when one wants to estimate the load on the communication channel.

This research is performed by means of the analysis of a dataset with naturalistic track data of road users on an intersection. The microscopic data is used to compute the number of generated CAMs and also to calculate the macroscopic traffic parameters describing the traffic on the intersection. These results are compared and analysed in order to get an idea of a possible relationship between them. Additionally, in this work it is analysed what events have a major influence on the CAM generation rate.

The remainder of this paper is organised as follows: Section II will discuss relevant research related to the current work. In section III the needed background knowledge will be given. Section IV will discuss the methodology of the research. This will be followed by the presentation and discussion of the results in section V. To conclude in the end with a summary of the findings and recommendations for future work in section VI.

II. Related work

This section discusses previous work done about channel load in vehicular communication and the traffic density estimation.

Jaarsveld has conducted a research similar to the current work for a highway environment [3]. This study is also based on videos recorded by drone and uses the traditional formulation of macroscopic variables. Jaarseveld demonstrated existing relations for the traffic flow and traffic density with the CAM generations, and concluded an absence of relation between average speed and the CAM generation rate.

Bastani et al. propose an analytical density model for urban traffic systems in [4]. They use their model to investigate radio overlapping and channel load caused by safety message communication in VANETs around signalised intersections. In their study they conclude that a single data rate and/or transmission power cannot be applied in the urban area they consider. In [5] the reliability of V2V applications is evaluated by a simulation of different urban intersection topologies. The authors concluded that a message generation rate of 10Hz is the best trade-off between information freshness and network load.

Several studies, like [6], introduce macroscopic traffic flow models to predict average delay and maximum queue length for unsignalized intersections. However, these models do not describe the intersections in terms of density, traffic flow or average speed which is used in the current research. Other studies do actually target to traffic density estimation around urban intersections. In [7] Yeschwnath et al. estimate traffic density on intersections based on real-time processing of videos from cameras. They use deep learning techniques to determine the density. Another study [8] has also used road monitoring systems to estimate the traffic density in a highway situation. In this research two density estimation methods are assessed: one method based on extracting microscopic parameters, which includes detection and tracking of vehicles; and another by directly estimating the macroscopic behaviour based on the global movement in a video sequence. Because in both of these studies cameras along the road side are used, they do not have the complete overview of the traffic scenario. The current research makes use of video data obtained with a drone, with the benefit that it includes information about mutual interaction of different traffic streams, which was not possible in the studies that have used monitoring cameras.

III. Background

This section will provide the reader with the needed knowledge about the Cooperative Awareness Message protocol and macroscopic parameters which are fundamental for the remainder of this paper.

A. Cooperative Awareness Messages

The European Telecommunications Standards Institute (ETSI) introduced in 2014 the Cooperative Awareness Message basic service to enable cooperative awareness in ITSs [9]. CAMs are messages exchanged between vehicles (V2V) or between vehicles and infrastructure (V2I) containing information about the vehicle's state like position, speed and direction. The transmission interval between CAM messages is not constant because the messages are triggered based on events. The procedure of sending CAMs is as follows. Two intervals are defined: the minimum transmission interval, which is 100ms, and the maximum transmission interval, which is 1000ms. Once the minimum interval has expired after a CAM transmission, it is checked if one of the following conditions is met:

- The absolute change in heading compared to previous generated CAM exceeds 4°.
- The absolute change in position compared to previous generated CAM exceeds 4 m.
- The absolute change in speed compared to previous generated CAM exceeds 0.5 m/s.

As soon as one of the conditions is met (between 100ms and 1000ms) a new CAM is transmitted. If none of these conditions are met within the maximum time interval, a CAM is sent as well. After a CAM is transmitted, the procedure starts again with checking the conditions after the minimum time interval. Note that this results in a generation frequency ranging between 1Hz and 10Hz. [10]

B. Macroscopic flow variables

Traffic can be described on different levels. When we focus on individual vehicles, we are talking about microscopic behaviour, which is described by microscopic traffic variables, such as time headway (time between two vehicles passing the same point), distance headway (distance between two front bumpers of vehicles), speed or heading. If one wants to describe traffic as a whole, that is done by macroscopic traffic parameters. The most common macroscopic parameters are traffic flow (veh/s), traffic density (veh/m) and average speed.

Hoogendoorn and Knoop describe both the traditional and generalised formulation of these macroscopic flow variables in their book [11]. Although both definitions are correct,

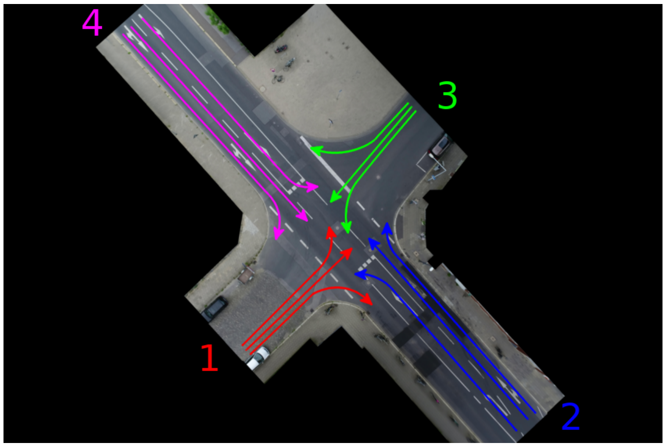

Fig. 1: Bendplatz intersection with the defined traffic flows and their direction marked. The numbering of the approaches/exits with associated coloring is also indicated.

the generalised definitions of macroscopic traffic parameters are best applicable in the intersection scenario. The similar research with the focus on highway traffic [3] used the traditional formulation, calculating the macroscopic parameters with the time headways and distance headways. However, this approach does not work for the inD dataset as 43% of the vehicles has left the image before the next vehicle arrives, making it impossible to determine headways for track data outside the image is unknown. The generalised approach is not dependant on headways and makes it possible to compute the macroscopic parameters using the known track data given in the inD.

Let us briefly summarise how the generalised macroscopic traffic parameters are defined with regard to microscopic traffic parameters. First we define the total travelled distance P, also referred to as performance, and the total travel time R as the following:

$$P = \sum_i d_i, \quad R = \sum_i r_i \tag{1}$$

We denote the distance travelled by vehicle i during period T as d_i and the total time spent by vehicle i inside region X as r_i. The generalised flow is then defined as:

$$q = \frac{P}{XT} = \frac{\sum_i d_i}{XT} = \frac{\sum_i d_i/X}{T} \tag{2}$$

In a similar way, the generalised density is given as:

$$k = \frac{R}{XT} = \frac{\sum_i r_i}{XT} = \frac{\sum_i r_i/T}{X} \tag{3}$$

Lastly, the average speed is defined as follows:

$$u = \frac{q}{k} = \frac{P}{R} \tag{4}$$

[11]

Equation (4) can be rewritten to equation (5) to clarify the fact that the speed is calculated using a weighted average, letting vehicles with a larger travel time contribute more compared to vehicles spending less time inside X.

$$u = \frac{\sum_i d_i}{R} = \frac{\sum_i u_i \cdot r_i}{R} = \sum_i \frac{r_i}{R} \cdot u_i \tag{5}$$

The same holds for the density and flow calculations, where the contribution to density is weighted based on travel time and the contribution to flow is weighted based on travel distance. (See the last notations of flow and density in eq. (2) and eq. (3))

IV. Methodology

This section describes how the data is processed to obtain the macroscopic parameters and CAM generations for the traffic on the intersection. The design decisions will be explained and we also address the validation of the computations.

A. InD

Bock et al. describe how they created the intersection drone dataset in [12], which is available for non-commercial use[1]. This dataset contains naturalistic trajectory data of vehicles and vulnerable road users recorded on four different unsignalized intersections in Germany. The inD dataset is used for the analysis of CAM generations and macroscopic parameters.

The traffic situations of the four locations in the dataset differ on number of approaches, intersection shape traffic composition and priority rules. On the one hand this provides a large variety of traffic behaviour, but on the other hand it also precludes a fair comparison between the intersections. Because of the latter, only one intersection will be considered in the CAM generation analysis. The four-armed intersection Bendplatz is used because of its regular shape, low number of lanes (decreasing the complexity of the analysis) and priority regulations. The used intersection can be found in figure 1. Although this recording site contains more pedestrians due to the nearby university, the influence of pedestrians is expected to be miniature, because they do not have the right-of-way. [12]

B. Traffic flows definitions

Twelve flows are defined for the intersection: for every approach-exit combination one. This means that we distinguish three flows for every approach: one flow making a left turn, one going straight on and one for a right turn. With this way of defining the traffic streams, it is possible to investigate the influence of making a turn on the CAM generations. For the numbering and corresponding color use of the approaches and exits, the reader can refer to figure 1. Physically matching approaches and exits have the same number.

C. Preprocessing

The dataset is preprocessed to be able to extract the needed data in the next stage. MATLAB is used for the preprocessing and for the rest of computations. The following subsections will describe the steps taken.

[1]https://www.ind-dataset.com

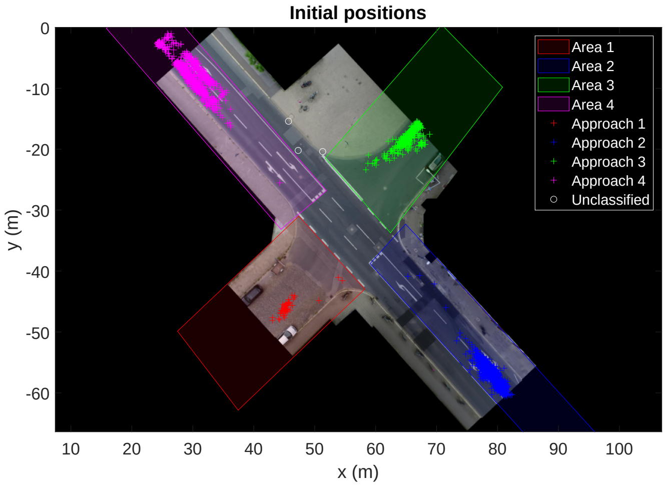

Fig. 2: Classified initial positions of vehicles in recording 7-17 after filtering.

1) Filtering: Firstly, this research is aimed at V2V communication, hence only the vehicles' data is needed. This means that the data of the vulnerable road users (VRUs), either pedestrians or bicyclists, are filtered out. Unfortunately, the detection algorithm used to generate the dataset was not able to distinguish bicycles from motorcycles [12]. The consequence is that motorcyclists are filtered out as well. However, the occupation rate of motorcyclists in traffic is low, meaning the filtering is not reckoned to be of significant influence. Secondly, the dataset also contains parked vehicles. As these will not participate in the VANET, they are filtered out as well. To do this, the average speed for all cars is calculated. Whenever this speed is almost equal to zero ($u_i < 0.001$m/s), the vehicle is not considered in the analysis. In addition, to support a correct classification in the next step, a small part of both the beginning and the ending of the recording is cut off, meaning that data in these parts is not considered in the analysis. The main reason for doing so is to solve problems with the determination of the approach of vehicles, that are in the middle of the intersection at the start of the recording. The same problem occurs in the ending of the recording.

In the end the cleaned dataset contains 2386 unique vehicles (busses, trucks and cars). The numbers of road users that were filtered out per category can be found in table I in the appendix.

2) Classification: Since the traffic flows are defined as described in section IV-B, the approach and exit of every vehicle needs to be known. This classification of approaches and exits is done based on the first and last position of every vehicle. To detect which approach is used, four areas are drawn by hand on the intersection (fig. 2). Vehicles with an initial position inside one of the areas get the corresponding approach assigned, vehicles detected outside the areas are filtered out. The drawn areas in figure 2 are only used for the determination of the approaches. The assigning of exits is done in the same way, only using slightly larger areas also covering the oncoming lanes, as it turned out that vehicles do not necessarily keep their lane while leaving the intersection.

D. *Macroscopic parameter computation*

The flow rate, density and average speed are calculated using the generalised definitions of these traffic flow variables described in section III-B. In order to do that the performance P, total travel time R, duration T and length of road segment X are needed.

The calculation of performance P and total travel time R are straightforward, since this only requires the summation of the travel time and travel distance of all vehicles. The travel time is calculated dividing the lifetime given in the dataset, which is the total number of frames a certain vehicle is tracked, by the frame rate.

$$r_i = m_i/fps \tag{6}$$

where m_i is the lifetime of vehicle i in frames and fps is the frame rate in Hz. The travel distances are calculated using the known x-coordinates and y-coordinates of every vehicle with equation (7). For every vehicle, all small travel distances between two consecutive frames are calculated using the Pythagoras theorem and subsequently added together.

$$d_i = \sum_{j=1}^{m_i} d_{i,j} = \sum_{j=1}^{m_i} \sqrt{(x_{i,j-1} - x_{i,j})^2 + (y_{i,j-1} - y_{i,j})^2} \tag{7}$$

in which m_i is the lifetime of vehicle i in frames; $d_{i,j}$ represents the small travel distance of vehicle i between frame j and $j-1$; and $x_{i,j}, y_{i,j}$ are the coordinates of vehicle i in frame j.

For time T the new established duration of every recording is used, taking into account the time cut off at the beginning and ending of the recordings.

To explain the determining of the length of road segment X, let us consider a simple situation where the density needs to be calculated. This simple situation would be when the traffic is moving in a straight line. This only requires defining an area with length X and measuring how long each vehicle is inside the area to know the total travel time, enabling one to calculate the density if the duration of measurement T is known as well (eq. (3)). In the situation of an intersection the definition of the area with length X is different. As part of the traffic flows in this situation makes a left or right turn, the area is defined as the (partly imaginary) lane the flow uses to get from approach A to exit B. This means that the area is not always rectangular and the length X will be defined over a curved line for the flows making a turn. Under the assumption that all the vehicles from the same flow will use the same path, i.e. staying inside the same lane, mainly three ways to determine X for every flow are possible: the minimum track length, the average track length or the maximum track length. The minimum travel distance option would include an extensive loss of data due to the differences in initial position detection of the vehicles. In addition, the average travel distance would involve a relatively complex implementation to detect when a car should contribute to the traffic parameters, namely when it is driving inside X and when it is not. Using the maximum travel distance works out best as it ensures every measured data point to belong to a vehicle driving inside the defined area with length X.

E. Validation macroscopic parameters

The macroscopic parameter calculation is validated making use of the continuity equation (eq. 8). In any circumstance this equation should hold, provided that the space-mean speed is used [11].

$$q = uk \tag{8}$$

The flow and density are calculated using the positional data from the inD. However, next to the coordinates also the speed is given for every vehicle in every frame. As a result, the flow can be calculated in two ways, namely directly as described before and also by multiplying the average speed with the density (eq (8)). Both computed values for the flow can be compared to see if the implementation of the calculation makes sense. Note that it is required to calculate the average speed based on the speed data in the dataset (eq. (5)). Otherwise the comparison would not make sense as the speed would be calculated by dividing flow by density (eq. (4)) making the comparison meaningless.

Thus the flow is calculated directly and by multiplying the density with the average speed for every recording. For every instance the relative error is calculated with respect to the direct calculated flow (left hand side of equation (8)). The average relative error is established at 0.6%, which is sufficient for the objectives of this research.

F. Normalisation of CAM generations

The CAM generations are straightforward to calculate knowing the protocol described in section III-A. For every single vehicle the number of generated CAMs are calculated and assigned to the traffic flow the vehicle belongs to in order to get the total number of CAMs for every traffic stream. Next to the number of CAM generations, the events that trigger the CAMs are saved to be analysed as well.

To ensure a fair comparison of generated CAMs between the different recordings and between the different traffic flows, the number of generated CAMs are normalised with respect to time and space. The durations of the eleven recordings range between thirteen and eighteen minutes. This results in a bias for longer recordings, as more time will lead to more CAM generations. To compensate this dependence on the duration the generation rates are divided by the duration of the recording. In addition, the length of the road segments, represented as X, is different for every defined flow. This again creates a bias, as vehicles on longer road segments will produce more CAMs. Hence, the generation rates are also normalised with respect to space to get rid of the dependency on the length of the considered road segments. Thus we end up measuring the normalised generation rates in CAMs/s/m to be able to compare the traffic flows and to compare the recordings.

V. Results

This section will present and discuss the obtained results. The analysed intersection has two minor approaches (1 and 3) and two major approaches (2 and 4). Due to the different priority rules of these approaches, the traffic behaves differently in both situations, also giving different results. Hence, these two types of approaches will be discussed separately. At the end the limitations of this research will be mentioned.

A. Major approach

The results of both major approaches are comparable. For the analysis of the major approaches, approach 2 is used. The results of approach 4 can be found in the appendix (figs. 13-15).

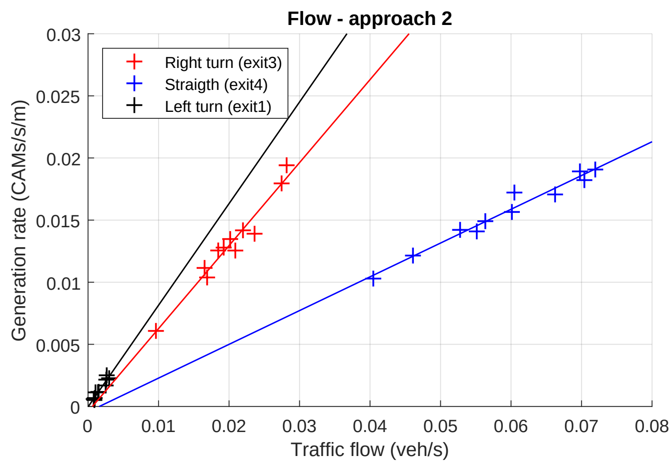

Fig. 3: The CAM generation rate plotted against the traffic flow rate for the defined flows coming from approach 2. Each point represents one traffic flow in a recording.

Figure 3 shows the CAM generation rate plotted against traffic flow for approach 2. In this figure we can observe for all the different maneuvers: higher flows result in higher CAM generation rates. Moreover, the datapoints are aligned in such a way that we can deduce positive linear relationships, which are also plotted in the current and following figures. Besides, the slope of the relationships of the vehicles making a left or right turn is higher. This can be appointed to the fact of the change in heading for the vehicles making a turn, as it should result in more CAMs generated because of the heading condition. Another cause is that vehicles making a turn will have to accelerate or decelerate quicker, as that also generates more CAMs due to the change in speed condition.

In figure 4 the generation rate is plotted against the traffic density. The first remark to make is that we would expect zero CAMs when the density equals zero, as a density of zero implies no vehicles to send messages. Still the plotted linear relationship for the vehicles going straight (blue) is not passing through or getting near the origin. This could have a couple of reasons: The relationship is not (completely) linear; the computed results do no match reality; or the sample size is to low to establish a relationship that matches reality

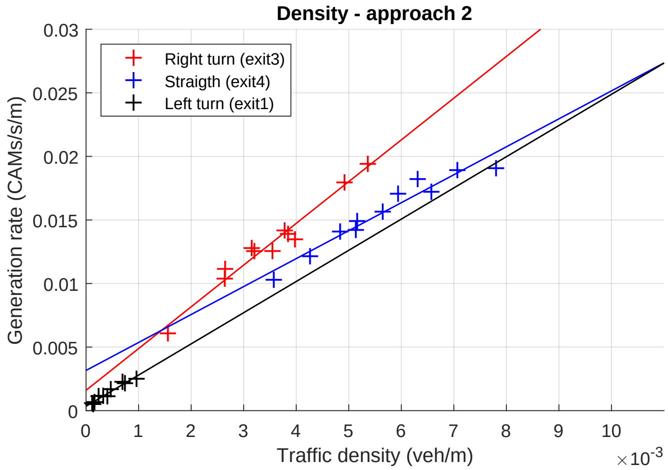

Fig. 4: The CAM generation rate plotted against the traffic density for the defined flows coming from approach 2. Each point represents one traffic flow in a recording.

sufficiently. The latter is the presumably the cause of the found relationship. Secondly, the most significant comparison in this image would be between the right turn and going straight. The generation rates for both maneuvers have a comparable range, but different corresponding density. By contrast, comparing the straight flow with the left turn, would not be of value, knowing the different domains of densities and the low sample size. Before we draw conclusions, we turn to the average speed results. See the CAM generation rate plotted against the average speed in figure 5.

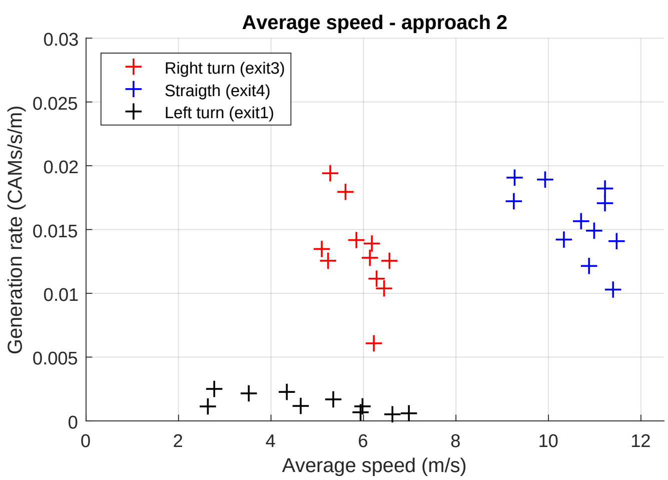

Fig. 5: The CAM generation rate plotted against the average speed of the defined flows coming from approach 2. Each point represents one traffic flow in a recording.

In this case it is not possible to establish relationships like we have seen in the generation rates plotted against the density and flow. Now, the data points are more grouped together, instead of following a single line like before. This is in accordance with the findings of the highway analysis [3]; We cannot observe a linear relationship between the average speed and the CAM generation. Nevertheless, these results are still useful when we consider the flow, density and average speed together. If we look at the average speeds of vehicles making a right turn and vehicles going straight on, we see significant higher speeds for the traffic going straight ahead. For vehicles making a left turn both flows and densities are lower than the vehicles going straight on, while the CAM generation rates are roughly the same. The higher average speed of vehicles on the straight road will results in a higher generation rate, meaning that the observed comparable generation rates for lower flows and densities are compensated by the other conditions that trigger a CAM: change in speed and change in heading. Later on we will indeed see that both of these triggering conditions have a significant influence on the CAM generation for these flows.

B. *Minor approach*

For the minor approach the results of approach 3 will be considered. The flow through of approach 1 is very low compared to the other approaches (on average 5 vehicles per recording, representing 2% of the total amount of vehicles), as a result errors in vehicle detection or parameter computations will have a significant influence on the results of this approach. Therefore, the results of approach 3 are used to draw conclusions regarding the minor approach. The interested reader can find the results of approach 1 in the appendix (figs. 10-12).

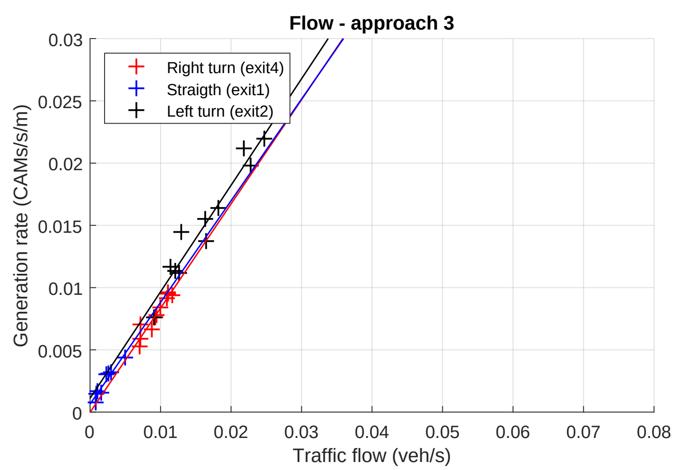

Fig. 6: The CAM generation rate plotted against the traffic flow rate for the defined flows coming from approach 3. Each point represents one traffic flow in a recording.

Plotting the traffic flow versus the generation rate (fig. 6) gives different results than the same comparison for the major approach. In the case of the minor approach the lines declaring the relationship are closely together, implying that the relation between the traffic flow and CAM generation rate is independent of maneuver. Besides, the slopes of these drawn lines are comparable to the slopes of the lines that were found for the vehicles making a turn in the major approach (fig. 3). In fact, the main difference between the results of the minor and major approach is the slope of the line for vehicles going straight on. Note that we are dealing again with a significant difference in domain (between vehicles going straight for minor and major approach), which should be taken into account when we make deductions.

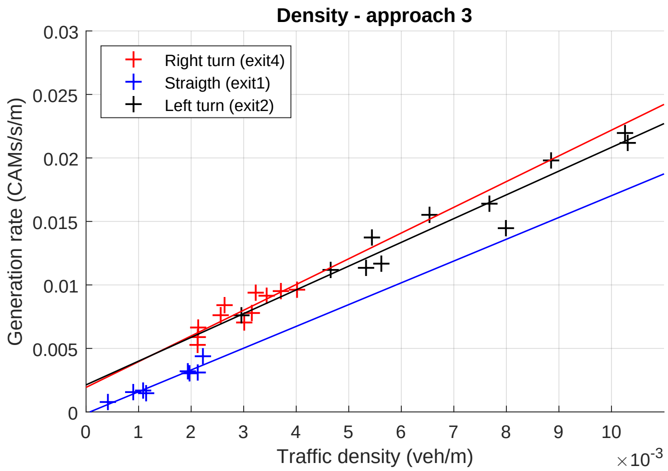

Fig. 7: The CAM generation rate plotted against the traffic density for the defined flows coming from approach 3. Each point represents one traffic flow in a recording.

The generation rates have different relations with density. In figure 7 one can observe that the generation rates for vehicles making a turn, is slightly higher than the generation rates for vehicles going straight. These different results might seem strange, because it seems obvious that higher flows are directly related with higher densities. However, if we recall the continuity equation (eq. 8) that would only be the case if the speed is constant. In the next image we will see that the average speed is not constant and therefore, these different relations are allowed.

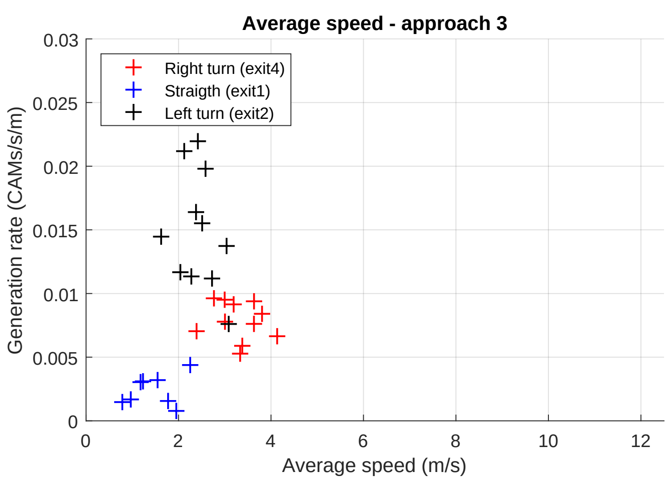

Fig. 8: The CAM generation rate plotted against the average speed of the defined flows coming from approach 3. Each point represents one traffic flow in a recording.

Just like the average speeds on the major roads, the data points in figure 8 form groups, rather than following a certain line. Hence, again we do not see a clear relationship between the generation rates and the average speed. However, figure 8 shows that all the computed average speeds are lower than 4 m/s. This means that the condition to trigger a CAM at four meters of displacement in less than one second, does not play a (significant) role for these measurements. Thus it is known that the CAMs are generated mainly due to the acceleration, the change in heading and the maximum time constraint of one second.

It is not possible to make hard conclusions about the different relations that are observed in the figures for the flows and densities on the minor approach. The drawn lines are close to each other and the limitations of the analysis become clear with lines not passing through the origin. The sample size is rather low and also the domains of the measured flow and density are very limited and different. Therefore, small deviations due to the circumstances on the intersection will have a relatively large influence the found relationships. Hence, this analysis can not be used to define the exact relationships between the macroscopic parameters and the CAM generation rates.

C. *Triggering events*

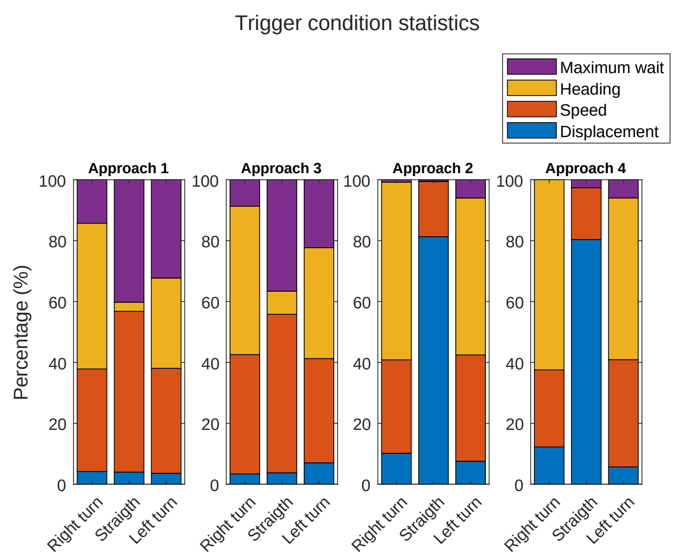

Fig. 9: For every defined flow the distribution of trigger events given as percentage of the total amount of CAMs generated on the flow. Left hand side: Minor approaches (1 and 3), right hand side: major approaches (2 and 4)

Let us take a closer look at what is triggering the CAMs on every flow. Figure 9 gives an overview of how the trigger events of the CAMs are distributed for every defined flow. This image indeed confirms what we saw before and even provides additional insight beyond that.

When first considering the CAMs generated due to the displacement condition, one can observe a low influence for the minor approaches and a major influence on generated CAMs for the major flows continuing straight on. Even the vehicles from the major approaches making a turn have a higher rate of displacement triggers compared to the minor flows.

Next, looking at the percentages for generated CAMs due to the maximum interval constraint, one can see the influence of the priority rules on the intersection. For the major streams almost no CAMs are generated due to the exceeding of the maximum wait. On the other hand, the minor approaches have a considerable amount of CAMs generated due to this constraint. This is because they have to yield to the major road and therefore have to wait sometimes before other traffic has passed. It is remarkable that the traffic stream with the lowest priority (which has to yield every other conflicting traffic stream) does not have the largest rate of generations due to the maximum time interval. These traffic streams, the left turns on the minor approaches, do have a relatively low number of CAMs generated due to the maximum wait constraint, compared to the traffic streams going straight ahead on the minor streams. This can be appointed to not making a turn and the lower speed that is related to leaving the intersection at a minor exit.

The distributions of heading triggers and speed triggers is interesting. When we look at the flows going straight, for both major and minor flows the generation rates are not influenced or slightly influenced by the heading condition. In addition, we see comparable percentages for speed triggers for equal maneuvers on minor roads, and also comparable percentages for equal maneuvers on major roads.

In general, we can make the following conclusions. Firstly, the distributions of major approaches and minor approaches are different, while the distributions for minor flows are comparable and the distributions for the major flows are comparable as well. Hence, it is useful to make the distinction between major and minor flows, when analysing CAM generation rates related to traffic flows. Secondly, the CAM generation as a result of the maximum interval constraint plays a role for minor approaches, while it is negligible for major approaches. Thirdly, the CAMs of vehicles going straight on the major roads are mainly generated due to a change in displacement, whilst the CAMs of the same traffic flow for the minor approach are mostly generated due to change in speed and the maximum wait constraint. Lastly, the heading condition as well as the change-in-speed condition have both a significant influence on the CAM generation for vehicles making a turn on major and minor roads.

D. Limitations

The current research has its limitations. The first remark that needs to be made is that only one intersection is considered, from which only eleven recordings were available. Because every recording only gives one data point for every traffic stream the sample size is rather low. Besides, the considered intersection only contains light traffic conditions. As a result, multiple times there is not a single car showing up for a defined traffic flow, which means that several times the sample size is even lower than eleven. In addition, the domains of the measured flows and densities are highly limited and do not overlap in almost all the cases. This makes hard conclusions about the exact relationships between the macroscopic parameters and the CAM generation rate impossible.

VI. Conclusions

In this research the relation between macroscopic traffic parameters and the CAM generation rate is analysed. This study observed positive linear relationships between the flow and the generation rate as well as between the density and the generated CAMs for both major and minor roads. In addition, this analysis also shows the absence of a direct relationship between the average speed and generation rate. Besides, in this study the effects of all the different events that trigger CAM messages is demonstrated. We can conclude that both the change in heading and the change in speed have a significant effect on the generation rate of vehicles making a turn. On the other hand, vehicles going straight on generate CAMs mainly due to their displacement and to a lesser extent due to their change in speed. The limitations of this research forestall a conclusive conclusion about the exact relationships of the macroscopic parameters belonging to the defined traffic flows. Nevertheless, we obtained insight in the existing relationships and found that minor roads and major roads give different results in terms of the relationships and in terms of what is causing CAM generations. Hence, the distinction between major and minor approaches should also be taken into consideration when one wants estimate the load on the communication channel based on macroscopic traffic parameters.

Opportunities for the continuation of the current work would lie in quantitative research considering a larger domain of traffic flow rates and traffic densities to get the complete relationship between the macroscopic parameters and the CAM generations. Furthermore, similar research considering other types of intersections, with different priority rules, could serve as a valuable extension to improve the estimation of channel load in VANETs in the future.

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APPENDIX

Type	Filtered
Pedestrians	801
Bicyclists	434
Parked	62
First frame	19
Last frame	29
Approach not classified	3
Exit not classified	2
U-turn	2
Total	1352

TABLE I: The numbers of filtered units

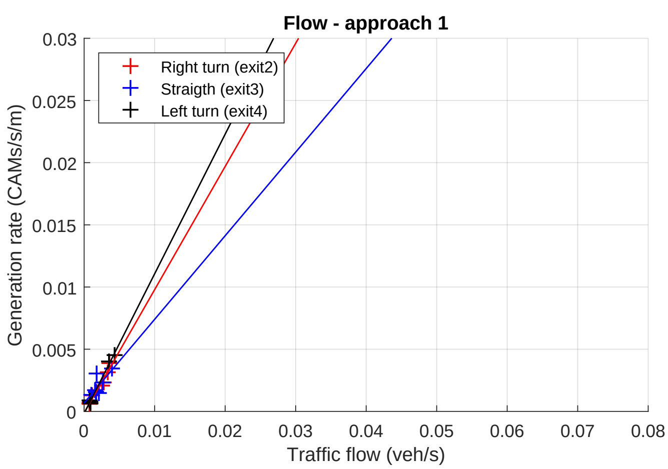

Fig. 10: The CAM generation rate plotted against the traffic flow rate for the defined flows coming from approach 1. Each point represents one traffic flow in a recording.

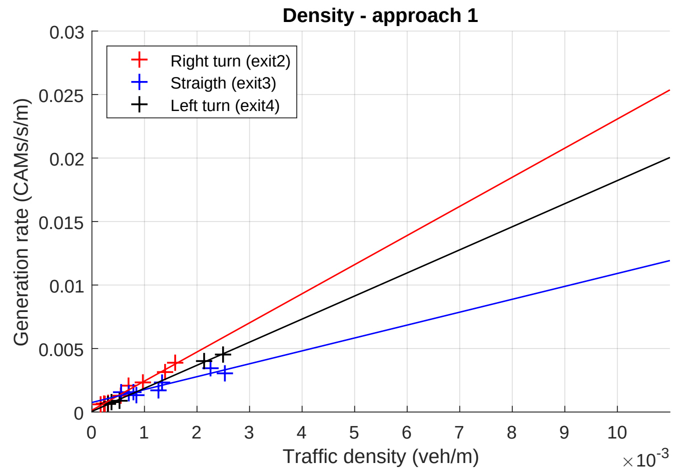

Fig. 11: The CAM generation rate plotted against the traffic density for the defined flows coming from approach 1. Each point represents one traffic flow in a recording.

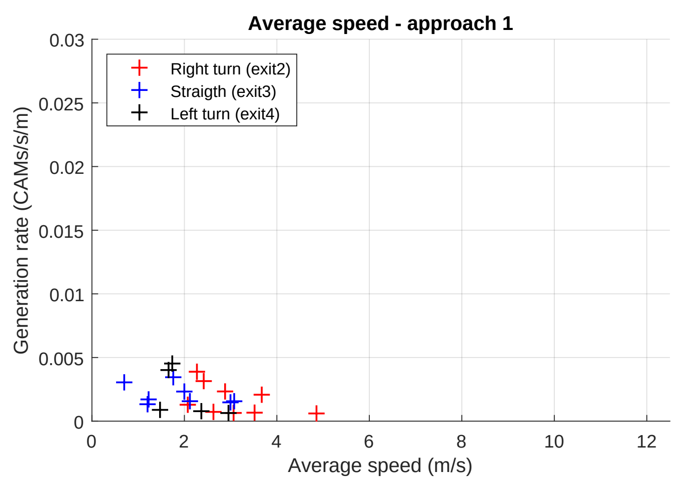

Fig. 12: The CAM generation rate plotted against the average speed of the defined flows coming from approach 1. Each point represents one traffic flow in a recording.

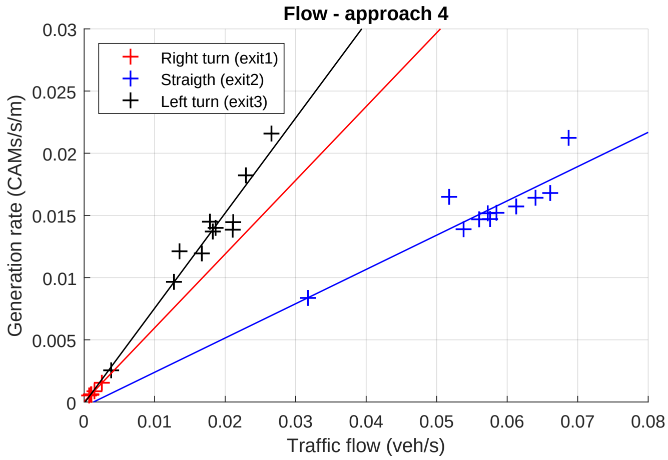

Fig. 13: The CAM generation rate plotted against the traffic flow rate for the defined flows coming from approach 4. Each point represents one traffic flow in a recording.

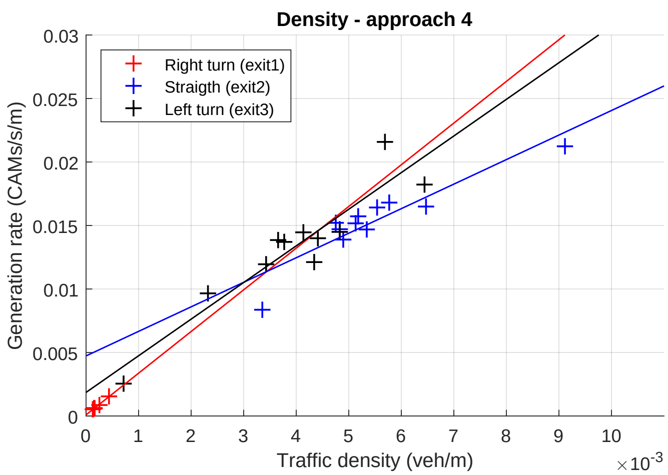

Fig. 14: The CAM generation rate plotted against the traffic density for the defined flows coming from approach 4. Each point represents one traffic flow in a recording.

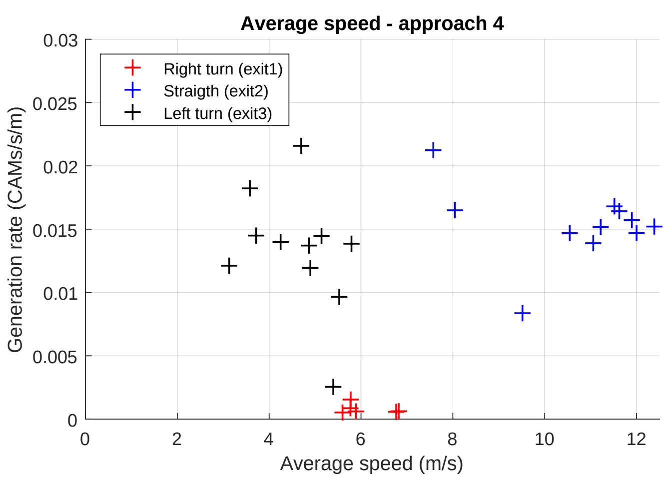

Fig. 15: The CAM generation rate plotted against the average speed of the defined flows coming from approach 4. Each point represents one traffic flow in a recording.