Reduction of Driver Stress Using AmI Technology while Driving in Motorway Merging Sections

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Abstract. High average intensity of traffic and problems like traffic congestions, road safety, etc. are challenging problems striking highway operators in these days. With the broad application of intelligent transport systems (ITS), particularly for the most dense street sections, some of these problems can be minimized or even solved; supplementary great potential is attributed to applications based on state-of-the art technology like car-to-x communication, for instance by extending an individuals "field of vision" by observations taken from all the vehicles in front. In this work we present a simulation based approach for improving driving experience and increasing road safety in merging sections by redirecting vehicles in advance according to a negotiation of requirements and desires of the flowing traffic on the main road and cars merging from the entrance lane. The simulation experiments performed in a cellular automaton based environment were data driven and on real scale, using traffic flow data on a minute-by-minute basis from a large urban motorway in a main city of the European Union. Our results have shown that the application of AmI technology has potential to influence driver's behavior (seamlessly invoking for a lane change well before an abrupt merging point) resulting in a reduction of panic, particularly for sections with limited range of view.

Keywords: Data driven simulation, Driver assistance, Motorway merging, Field of view extension, Vibro-tactile seat, Safety belt interface.

1 Introduction and Motivation

It has been reported for merging sections of roads to have a high influence on the overall road safety as different drivers (e. g. that driving on the entrance ramp or on the main roadway) may behave, dependent on state of traffic and their physiological state, in different ways [8] and/or have opposed desires. A driver's purpose entering a main road is to do so without any delays, thus merging into immediately – which could demand traffic on the main road to apply the brake to avoid rear-end collision accidents. On the other hand, traffic moving on the

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main road also want to keep on moving with desired individual speed and without consideration of cars entering the road and causing changes in their driving habit. This, in turn, may affect fluidity of entering traffic as they would have to wait until a large enough free gap between two cars to merge into. For roads with two or more lanes (which is the focus of this paper), drivers would also have to change lanes in order to (*i*) reach the lane merging into the desired road (merging car) or (*ii*) make space for merging cars to do so (cars on the main road). For the latter group it has been reported, e. g. in [10], that sometimes drivers panic when they want to change a lane leave the motorway or let merging cars into. Buld *et al.* [1] have conducted driving simulator studies at entrance ramps of motorways to investigate the effect of traffic intensity on driver stress. From their results it can be derived that entrance ramps generates already high driver stress for medium volume of traffic and that the effect is increased for unknown ramps. Such situations could be avoided when, by application of ambient intelligence (AmI) technology, seamlessly requesting the driver to change into the appropriate lane early – this means 100s of meters ahead the merging in fluid driven road sections with large gaps. We hypothesize that the application of this approach using a background intelligence available to all cars and broad availability of state-of-the-art wireless communication technology (car-to-car communication) allows for information delivery to a driver from cars hundreds of meters ahead the field of view of the driver. The so increased "visual range" allows for earlier reactions on traffic conditions or infrastructure characteristics., would increase traffic fluidity at merging sections and furthermore decrease driver panic.

The motivation of our approach follows from the fact that many people are afraid about late merging (exceptionally in crowded situations); however, often it is not possible to change lanes earlier (for instance when unfamiliar with a road segment) because of unseeable ramps or constrictions (merging of two lanes into one; blocked lane because of road works or accident). An early realization about road structure, merging lanes and on and off ramps, forcing them to change into the appropriate lane as early as possible would ensure an improvement. A early notification coupled with application of AmI technology would guarantee that the driver is informed inattentive. The technology of choice consists of a tactile car seat, with vibration elements stimulating a driver's skin to guide him/her about lane changes (towards left or right to be particular). According to an observation of real traffic data from a large urban motorway in a city of the EU and with a very high traffic density of about 300,000 vehicles a day we suppose that a early lane change notification could help to reduce overall panic in and around merging sections. Additionally, the seamless skin based ambient vibration system guarantees the delivery of this notification in a non obstructive way.

Outline: The rest of the paper is structured as follows. In section 2 the developed AmI technology for assisting drivers' is explained in detail, section 3 focuses on the simulation model, with emphases on data and simulation environment/methodology. In section 4 the simulation results are discussed, section 5 finally concludes the paper.

2 AmI Technology: A Vibro-Tactile Driver Seat

Both visual and auditory channels of sense are highly saturated in vehicle operation for fulfilling driving related (primary) tasks and side activities; for a successful transmission of additional information, e. g. on lane changing or speed adaptation, it would be required to use (or even abuse) information capacity still unused. In addition it has also to be revealed that the amount of "free space" is (*i*) dynamically changing and (*ii*) dependent from the current traffic situation; thus, there is no guarantee for free capacity at all.

The sense of touch is, with about 10% of the entire information transmission capacity of humans, ranked third behind visual (70–80% [9], [5]) and auditory (10-15% [2]) senses; regardless, tactile interfaces are still used rarely in the automotive domain so that we can infer potential for this sensory channel to deliver the required information accurately and at all times. Our presumptions are supported by many recently presented applications and research studies using vibro-tactile (driver) notification, e. g. [6], [3], [7], [11]. Vibrations can be delivered precise with regard to the position (point-like) and there are many possibilities for varying the stimulation signal (frequency, intensity, pulse-pause interval, combination of vibrations using many elements, vibration patterns or tactograms [11, p. 123]). Additionally, small vibro-tactile transducer could be easily integrated or embedded into controls elements of a vehicle, such as the steering wheel, gearshift, etc. but more universally into parts the driver is in contact all the time, like safety belt or seating. Therefore, we recommend the application of a tactile user notification system integrated into either the driver seat or the safety belt, and subtle notifying the driver on merging related information collected from a background intelligence (such as shown, for instance, in [4]). The mapping of activities with the vibro-tactile notification system is proposed as follows:

***(i)* Lane changing: Move/merge to the lane on left**
  - *Seating:* All tactors on the left are activated; varying pulse-pause time corresponding to the importance for the driver to perform the action.
  - *Safety belt:* Tactors activated one after the other in a "running light" style from bottom to top; varying sequence speed corresponding to the importance for the driver to perform the action (the shorter the distance to the merging point, the faster the running light).

***(ii)* Lane changing: Move/merge to the lane on right**
  - *Seating:* All tactors on the right are activated; varying pulse-pause time as above.
  - *Safety belt:* Tactors activated one after the other in a "running light" style from top to bottom; varying sequence speed as above.

***(iii)* Speed variation: Increase driving speed**
  - *Seating:* Running light from back to front for both the left and right strip (see Fig. 1); running light speed corresponding to the deviation in speed.
  - *Safety belt:* "Outer elements" (e. g. tactors 1, 2, and 7, 8) are activated until the expected target speed is reached; vibration intensity corresponding to the speed deviation.

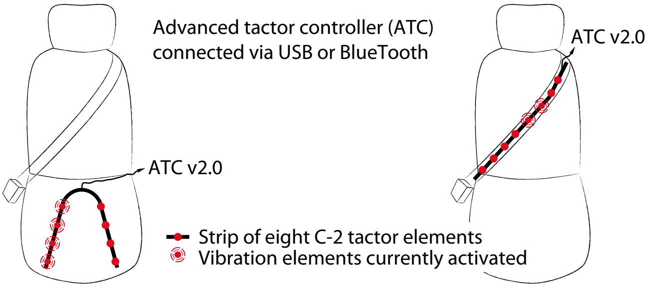

Fig. 1. Vibro-tactile stimulation in the seating, the safety belt or other control instruments in the car is projected to be used for (inattentive) notifying the driver on upcoming merging-related operations

(iv) **Speed variation: Decrease driving speed**

– *Seating:* Running light from front to back for both the left and right strip; rest as above.

– *Safety belt:* 'Inner elements" (e. g. tactors 3 to 6) are activated until the expected target speed or zero is reached; vibration intensity corresponding to the speed deviation (as above).

3 The Simulation Model

Data and Environment: The agent-based modeling method is applied as simulation paradigm using NetLogo [13] as a tool. NetLogo is a cellular automaton (CA) based simulation tool in which a grid of placeholder agents (patches) define an environment (world). The movable agents (turtles) reside on top of the patches. Each of the patch is defined by a x and y coordinate as that of a turtle residing on it (if any). For the purpose of traffic simulation, a single patch is assumed to have a width equal to $5m$. Given that a single vehicle can occupy a patch at a time, this ensures an average vehicle length of 5 meters considered to be a constant, applicable throughout the simulation. Modeling of different types of long vehicles like buses, trucks would be possible by a combination of two or more turtles, hence obtaining length of $10m$, $15m$, etc. On the other hand, the height of the patch represents the width of the lane a vehicle is moving on (this value has been devoted scant attention as it has almost no influence on the fluidity of traffic or forward moves).

The processed simulation was running data driven (with regard to the traffic flow), with an underlying road network model built true to scale from a segment of a large urban motorway in a main city of the EU (the average intensity of traffic on this road is higher than $300,000$ vehicles a day). Due to the size of the network, with nodes of roads may having up to sixteen lanes distributed in different levels, it has become one of the most traveled routes within the EU and a (inter)national reference as object for traffic studies. The focused segment contains the "main road" absorbing a merging lane, an offshoot from the "lower road". The data collection agency collects the induction loop sensors data at different points of measurement (PM[1]). This data is minute-to-minute based focusing on vehicle count and average speed along with other measures. The induction loop sensors related with the road segments are shown in Fig. 2.

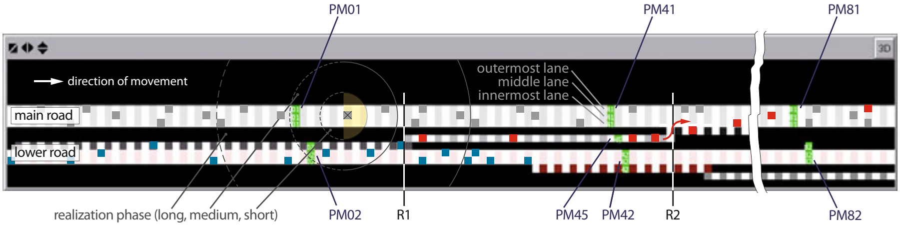

Fig. 2. "Realization" corresponds to an extended field of vision for a driver, obtained with help of AmI technology. PMxx represents the traffic counters of the road segment.

The following subset of the measurements are considered for the simulation:

- Vehicle count at PM01: Vehicles/hour counted at PM01 each minute, necessarily to generate traffic flow on "main road".
- Vehicle count at PM02: Vehicles/hour counted at PM02 each minute, necessarily to generate traffic flow on "lower road".
- Vehicle count at PM45: Vehicles/hour counted at PM45 each minute, necessarily to generate traffic flow on "merging lane"; this essentially should be a subset of vehicle count at PM02.

The purpose of the study is to ensure a smooth and less panicked merging of traffic from the merging lane to the main road following two considerations:

- For the smooth merging of the merging lanes vehicles into the main road, the innermost lane of the main road is most important. If there is a gap between incoming traffic on this lane, it would help smoothen the merging. But a totally vacant lane can also produce a lot of load on the two upper lanes, thus destroying the overall effect.
- The vehicles coming from PM02 should occupy an appropriate lane before reaching to R1 and vice versa. If drivers perform preemptive lane changes this would ensure less panic near R1 (due to the absence of congestions).

The one factor directly influencing the above two considerations is, when a driver on the main road realizes that he/she has to perform an action due to a incoming merging ramp. For example, the following actions are imaginable:

- Drivers on the main road move up in their lanes to facilitate merging traffic.
- Drivers on the main road which could not move up in the lanes (e. g. due to heavy traffic) and confront a merging car on the ramp extension may accommodate that vehicle in opposition to their right.

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[1] PM . . . measurement point ([french] point de mesure).

- Drivers on the lower road intending to merge move up in the lanes to facilitate themselves.
- Drivers on the lower road intending to keep on moving on this road move down in the lanes to facilitate themselves.
- In case of interest conflict near R1, there is no logical game theory (strictly local) which can safeguard interests of both the confronting parties.

To accommodate all of the above actions, an underpinning is the time when a driver realizes existence of a ramp at a distance. Throughout this study, we have focused on this factor named as “realization range”. With a variation in realization (assisted by AmI assistance), we have compared the average speed and appropriate lane positioning to figure out the best suitable combination.

Simulation Setup: The overall simulation process is represented with the flow shown in Fig. 3. From the dataset relating to the PMs in focus (as shown in Fig. 2), we have taken data rows representing one day of activity. Considering that the data was provided on a minute-to-minute basis this equals to $1,440$ records. In the simulation flow, we execute (read) data contents from the truncated file until the end of file marker is reached. Data preprocessing works as follows. Each iteration of the simulation represents a single second. For that it is required to firstly convert the vehicle count given on a vehicles/hour scale to a vehicles per minute scale, and then to randomize the traffic for a single minute for each of the simulation second. So, in reality, in each second (iteration step) of a minute (data row), zero to three vehicles would be registered in datasets relating to PM01 and PM02 readings. After having second to second traffic generation datasets, the simulation is run for a whole minute (60 iterations). In each second, the vehicles are generated and moved forward. In case of the first 60 seconds of the “life of a vehicle” it would be considered as a new vehicle and would not experience any lane change or speed variation activity. In fact, this information is embedded into a more complex “move forward” process flow as illustrated in Fig. 4.

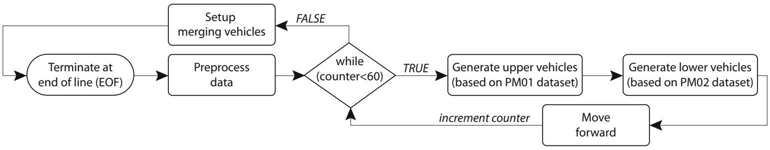

Fig. 3. Overall simulation flow (main process)

Assess vehicle states: A relatively simple task is to categorize the vehicles present in the simulation after simulation of (the first) 60 seconds. The corresponding process flow is represented by the process “Setup merging vehicles” – which is all about managing different vehicle states (or colors) as elaborately discussed subsequently. The default color of vehicles at the lower road is blue whereas the default color on the main road is gray. Both blue and gray agents represents vehicles keep on moving on their roads (without merging; note that there are no merging vehicles at the main road). Internal to the process, the flag "new-vehicle" represents a new vehicle which is not set for merging. For this reason all the vehicles in the lower road generated during the latest minute are marked "new", and as soon as the first 60 seconds are over, a comparison of all the new vehicles with the corresponding amount of merging vehicles at PM45 is made (PM values obtained from the data table). If the number of vehicles merging in the real (PM45 reading) is equal or greater then the number of new vehicles generated at PM01, all new vehicles have to be set as having the intent to merge, thus setting their color to red (a PM45 reading higher than the number of generated vehicles may appear due to data error.) If, in contrast, the number of new vehicles generated (PM01) is greater then merging vehicles (PM45), then exactly that number of vehicles equal to the PM45 values is set to merging vehicles (=red), the remaining are set to "keep on moving" (blue). At the end of this process flow, all newly generated vehicles have obtained a status/color (either red or blue) according to fractions from real vehicle movement behavior.

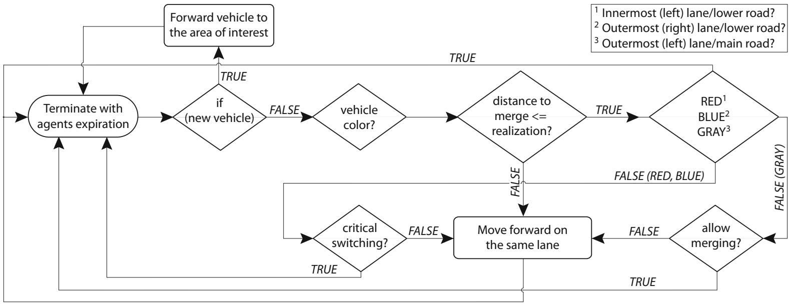

Fig. 4. Process of vehicle movement during a single second of simulation

Vehicle movement: The set of processes representing the move forward activity (see Fig. 4) is applied to all the agents (vehicles) in the system in each iteration (second). If the agent in consideration is a new vehicle, we just forward further until it reaches the area of interest (see Fig. 2). When it reaches there (influenced by the range of realization actually used for simulation), it is no longer considered as a new vehicle (applies to both lower and main roads); when moving on the lower road, additionally its merging nature (color) is set. For a vehicle which is not new, there are three possible vehicle states represented by vehicle colors, (*i*) merging (red), (*ii*) keep on moving on the lower road (blue), and keep on moving on the main road (gray). Whatever the state (color) of the vehicle is, first we need to establish its distance to the merging point (R1 for lower road traffic, R2 for main road traffic). As soon as a driver realizes that there is a merging situation ahead, he/she is within merging distance. The earlier a driver knows about an upcoming merging region, the "better" he can react on this situation based on his own desires and observations from the environment. We have experimented with different AmI technology extended "fields of vision" – this distance is represented in the simulation model by the variable *realization*

1) Lower road, vehicles intending to merge into main road (colored red)

A. Red vehicle within merging region and before R1: In this case, the vehicle would try to upgrade its lane. If successful, its execution for this iteration is complete. If it is not able to perform a up gradation (due to insufficient lane change distance or if it is already in the upper most lane), it checks its position. A „critical switching" situation occurs if the red vehicle is in the middle or lower lane and it is very close to R1. It needs to switch its lane immediately. If critical switch- ing is not required, the vehicle moves forward in the same lane ensuring a incremental speed variation (if required).

B. Red vehicle after R1 but before R3: In this case, if a critical switching situation occurs due to end of ramps R2 or R3, the vehicle needs to switch its lane immediately (moving up). If critical switching is not required, the vehicle moves forward in the same lane ensuring a incremental speed variation (if required).

C. Red vehicle after R3: In this case, there is no need for critical switching and the vehicle moves forward in the same lane ensuring a incremental speed variation (if required).

2) Lower road, vehicles intending to keep on moving on the lower road (blue cars)

A. Blue vehicle within merging region and before R1: In this case, the vehicle would try to downgrade its lane. If it is successful, its execution for this iteration is complete. If it is not able to perform a down gradation (due to insufficient lane change distance or if it is already in lower most lane), it checks it position. A critical switching situation occurs, if the blue vehicle is in the upper lane and it is very close to R1. So it needs to switch its lane immediately. If critical switching is not required, the vehicle moves forward in the same lane, ensuring a incremental speed variation (if required).

B. Blue vehicle after R1: In this case, there is no need for critical switching and the vehicle moves forward in the same lane ensuring a incremental speed variation (if required).

3) Main road, vehicles intending to keep on moving on the upper road (gray cars)

A. Gray vehicle within merging region and before R2: In this case, the vehicle would try to upgrade its lane. If it is successful, its execution for this iteration is complete. If it is not able to perform an up gradation (due to insufficient lane change distance or it is already in upper most lane), the vehicle moves forward in the same lane, ensuring a incremental speed variation (if required).

B. Gray vehicle within merging region and within R2 and R3: In this case, the vehicle would try to upgrade its lane. If it is successful, its execution for this iteration is complete. If it is not able to perform an up gradation (due to insufficient lane change distance or if it is already in upper most lane), there are two further possibilities. First, when it is very close to R3 and is in the lower lane it will check its vicinity. If a red vehicle is waiting in the merging lane just before R3 it allows the vehicle to merge by slowing down (or stopping) itself. If a „allow merging situation" is not required the vehicle moves forward in the same lane ensuring a incremental speed variation (if required). The second option is, when it is not very close to R3, that it moves forward in the same lane ensuring an incremental speed variation (if required).

C. Gray vehicle after R3: In this case, the vehicle moves forward in the same lane ensuring a incremental speed variation.

Fig. 5. Merging possibilities according to vehicles' distance to the point of merging

(explained in Fig. 2). For simulation, one important factor to cope with is the difference between a merging point already passed and a merging point located ahead. Relating to Fig. 2, in Fig. 5 all of the implemented possibilities are listed. It is important to note that successful lane changing would require a appropriate lane change distance. A second factor is that when a vehicle is moving in the same lane it performs an incremental or decremental speed variation all the time. If its speed is slower then the maximum speed allowed it would increment its speed up to the maximum but with ensuring a safe breaking distance from the vehicle in front. If it needs to apply breaks it would decrement its speed. These functionalities are, of course, part of the simulation and explained elsewhere [12].

4 Simulation Results and Discussion

The measurement points PM01, PM02 and PM81 were considered for measuring the traffic flow – it can be observed that the average speed of traffic is inversely proportional to the realization range (Fig. 6). Furthermore, the bottleneck at PM81 does not allow much variation in speed for a long simulation

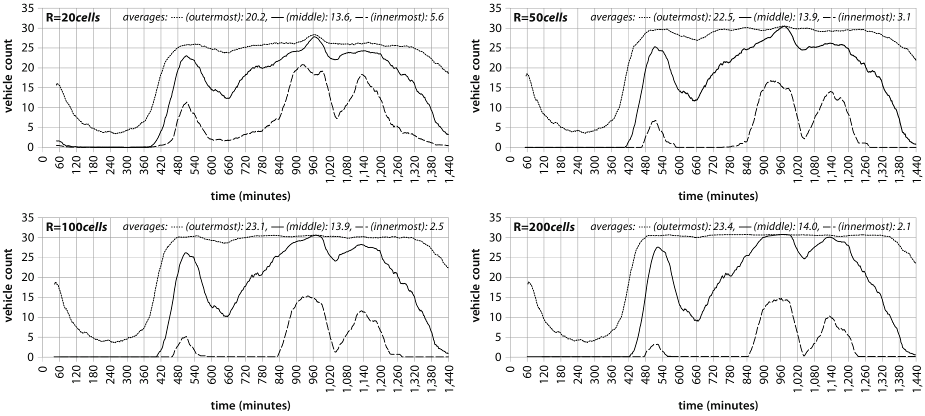

Fig. 6. Lane positioning at PM41/main road (only "gray" vehicles are counted)

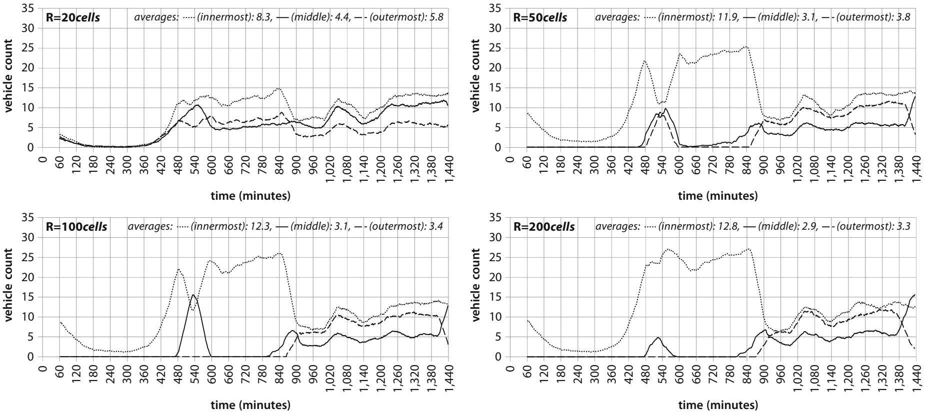

Fig. 7. Lane positioning at PM02/lower road ("red" vehicles only)

and is seen to influence the flow between PM01/PM02 and PM81 transferring the congestion in the backward direction. Having established that the overall throughput of the road section (governed by output point PM81 after merging) would not be diversely affected by realization range, we proceed to ask the question addressed by this paper, i.e. would panic be reduced with an increase in realization range? The graphs shown in Fig. 6 and Fig. 7 respond affirmatively. PM41 and PM02 are used to observe the lane occupations of vehicles where all traffic is notified about the merging just ahead. In case of main road (PM41), the innermost lane ideally should be vacant just before R2 to allow unrestricted merging. For realization range equal to $100m$, the innermost lane accommodates $5.6 vehicles/minute (v/h)$, which is progressively reduced to $2.1 v/m$ with an increase in realization range. The middle lane accommodates almost the same number of vehicles for all four cases, whereas the load from innermost lane shifts directly to outermost lane. Similarly, at PM02 the red vehicles should occupy the innermost lane just before merging. Due to too less time to perform lane changes in case of realization range equal to $100m$, less then half the red vehicles are residing in innermost lane (8.3 out of $18.5v/m$. However, with increasing the realization range this measure progressively increases to $12.8v/m$, influencing a reduction in the load of outermost and middle lanes [1]. As suggested by Buld [1], the presence of an abrupt and unknown ramp increases the driver's stress (panic). An early notification in an un-obstructive and seamless manner under the influence of an ambient setting would reduce the panic given that the driver follows the suggestion which should result in moving most of the vehicles in optimal lanes well before merging. The simulation results show the potential of panic reduction even in a high traffic road section.

5 Conclusions

Considering vibration based ambient technology providing necessary information relating to the road structure (global) and vehicles neighborhood (local) to a driver seamlessly, a data driven simulation was performed to analyze the effectiveness of two kind of notifications relating to lane and speed changes. While the speed change notifications do not generate the similar effects as that of real data values, the proposed lane changing strategy guarantees a less panicking setting near and on the merging points. As the realization range (a look ahead distance a driver is notified about an incoming merging situation) increases, the forced vibration based notification systems forces the driver to merge into appropriate lane. This would ensure an ease in highly congested merging situation, consequently decreasing the potential panic if a substantial amount of drivers find themselves into wrong lanes just before merging.

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