Analyzing the Effects of V2V and ADAS-ACC Penetration Rates on the Level of Road Safety in Intersections: Evaluating Simulation Platforms SUMO and Scene Suite

Aso Validi[1], Thomas Ludwig[2] and Cristina Olaverri-Monreal[1*], *Member, IEEE*

***Abstract*— Integration of Advanced Driver Assistance Systems (ADAS) and Vehicle to Vehicle communication (V2V) provide a wide range of applications with the potential to enhance road safety and prevent traffic accidents. During the last few years, significant attention has been paid to developing and implementing both systems, since V2V and ADAS are considered as key technologies of future Intelligent Transportation Systems (ITS). Prior to the implementation of these systems on vehicles, comprehensive analysis through exhaustive and realistic simulations is vital. This paper presents the developed methodology to improve road safety by modelling and simulating different penetration rates of V2V and ADAS-ACC (i.e. percentage of vehicles which have been equipped with either system) on three developed simulation scenarios in SUMO and "Scene Suite" showing the impact on road safety.**

I. INTRODUCTION

One of the most crucial aspects of mobility is safety as people want to be mobile and travel safely and at the same time roads are becoming more crowded and dangerous [1]. Road traffic crashes cause an alarming number of 1.25 million fatalities each year worldwide, in addition to which close to 50 million people suffer from non-fatal injuries. In 2015 the approximate cost of road accidents for governments has been reported between 3-5% of their gross domestic product [2]. As far as technology and Intelligent Transportation Systems (ITS) is concerned, the substantial improvement of road safety during past few years stems partly from the fact that active as well as passive safety systems in vehicles have improved dramatically, and the vehicles have become more intelligent [3]. These intelligent vehicles have been ushered in electronics and different software, and these intelligent technologies are mainly focused on autonomous perception of road users. The introduction and use of cooperative vehicles is a logical further consequence of the intelligence embedded in vehicles [4]. Developing and evaluating cooperative systems are challenging and complicated tasks. A proper test environment that includes various aspects of traffic with different scales is required [5]. In this paper we analyze the changes in the level of road safety by simulating different applications of V2V (Vehicle to Vehicle) communication in combination with adaptive cruise control advanced driver assistance systems (ADAS-ACC) using Scene Suite [6] and Simulation of Urban Mobility (SUMO [7]). We aim to answer the following research questions:

- What are the main effects of low penetration rate (40%) of ADAS-ACC and V2V communication alone on the level of road safety in the developed scenarios?
- What are the main effects of different penetration rates (0%, 40%, 60%, 100%) of V2V communication combined with ADAS-ACC on the level of road safety in the developed scenarios?

In order to investigate the research questions, following hypotheses have been defined and scrutinized:

- The total number of accidents that occur when *no system is applied* is higher than using *V2V or ADAS-ACC alone with 40%, 60% and/or 100%* penetration rates.
- The total number of accidents that occur using *ADAS-ACC alone with 40%, 60% and 100%* penetration rates is higher than using *V2V and ADAS-ACC combined with 40%, 60% and/or 100%* penetration rates.
- The total number of accidents that occur using *V2V alone with 40%, 60% and 100%* penetration rates is higher than using *V2V and ADAS-ACC combined with 40%, 60% and/or 100%* penetration rates.
- The total number of accidents that occur using *ADAS-ACC alone with 40%, 60% and 100%* penetration rates is higher than using *V2V alone with 40%, 60% and/or 100%* penetration rates

The remaining parts of this paper are organized as follows: Section II introduces the state of the art related to analysis of road safety considering different V2V and ADAS penetration rates. In Section III, the developed methodology is presented. The numerical and simulation results followed by the comparative analysis of different penetration rates are showed in Section IV. In Section V, conclusions and the perspective for future work have been stated.

II. RELATED WORK

Traffic efficiency and safety are the major distinctive features of ITS. In the last 20 years, a large number of projects have been carried out to investigate V2X and ADAS with respect to safety and traffic efficiency [8]. In this section the related previously developed applications are divided into

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*Corresponding author

[1]University of Applied Sciences Technikum Wien, Dpt. of Information Engineering and Security, Vienna, Austria;
aso.validi@gmx.at, olaverri@technikum-wien.at

[2]IAV GmbH, Kauffahrtei 25, Chemnitz, Germany; t.ludwig@mail.de

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two main categories: safety and traffic efficiency improvement.

A. *Safety-Based Applications*

The authors in [9] developed an Intersection Safety (INTERSAFE) application to improve safety by detecting dangerous traffic situations. INTERSAFE combines sensor data with communication technologies to warn drivers to stop in order to avoid an accident. The results showed that INTERSAFE could effectively prevent dangerous traffic situations in intersection scenarios.

In a further project, an application known as Driving Safety Support Systems (DSSS) utilized a V2I communication system to warn the drivers of potential dangers [10]. The stated aims of the application are to prevent red light and stop sign violations as well as turning accidents, crossing path and rear-end accidents and pedestrian collisions. The research project received positive feedback from test subjects after the initial system evaluation.

Another application, the Cooperative Intersection Collision Avoidance Systems (CICAS) [11], utilizes the information about the neighboring vehicles as well as the information obtained from the infrastructure in order to enhance the approaching vehicles' understanding. It enables the drivers to avoid accidents by rerouting their trips or change their reactions on time by stopping, decelerating or accelerating. Capability of identifying the pedestrian and the cyclist in dangerous situations and informing the involved drivers, are important features of CICAS.

In further research the SUMO simulator was integrated with the In-Car Ergonomics Evaluation Platform (IC-DEEP) [12] and GeoStream framework to test ADAS relying on the Multi-Agent System (MAS) [13]. The connection of GeoStream framework with Open Street Maps provided the transmission of the Google Geolocation Application Programming Interface (API), Google Altitude API and other required data of any given location for a real-time simulation.

B. *Traffic Efficiency and Management Applications*

Among the many Traffic Efficiency and Management Applications one of the more frequently studied is the Green Light Optimized Speed Advisory (GLOSA) [14]. The authors conducted a study that considered different simulations with various penetration rates to investigate the effect of V2X communication on traffic efficiency in an urban area. The penetration rates considered for the vehicles equipped with GLOSA were 0%, 20%, 40%, 60%, 80% and 100%. The results of this study strongly suggested that fuel consumption and traffic congestion were reduced by implementing GLOSA application. Within the higher penetration rates, the stop time, trip time and fuel consumption were reduced by 80%, 9.85% and 7%, respectively. A similar study also analyzed GLOSA with V2X penetration rates of 10% to 100% in intervals of 10% [15]. According to the reported results, within a penetration rate of 100% CO2 emissions and stop time were reduced by 10% and 100% respectively. Furthermore, within a 40% penetration rate, the CO2 emissions and stop time decreased by 5% and 30% respectively.

A study carried out in [16], sought to improve traffic efficiency by developing and evaluating an approach based on V2X communication. The main purpose was to remove existing drawbacks of similar applications (i.e. data missing, delays in blocked or crowded roads). The penetration rates of V2X communication in this study varied in intervals of 5% starting from 0% to 100%. The implemented approach was capable of broadcasting and receiving the average travel speeds of vehicles and presented reliable results in terms of reducing the travel time. The results of this study show a 50% improvement in travel time at V2X penetration rates of 80% or higher. The navigation systems which relied on V2X communication performed well.

A further approach was reported in [17] to address the issue of evaluating the safety and traffic efficiency of ITS applications using a real-world dataset. The vehicle's communication system uses V2X simulation runtime infrastructure (VSimRTI) to conduct the simulation. For simulating traffic networks, the SUMO traffic simulator was implemented. The evaluation results showed that adopting Vehicle to Infrastructure (V2I) communication resulted in significant benefits, such as improvements in travel time, average speed and fuel consumption as well as improvement in safety.

A review of the related literature reveals that a considerable number of reported studies focused on improving traffic efficiency, travel time and waiting time. There are only few studies that focused specifically on improving road safety by adopting different penetration rates of V2X and ADAS, a gap in the literature that this paper focuses on. Furthermore, in this paper we contribute to the state of the art considering different driver behaviors (aggressive, normal and courteous), ADAS-ACC and V2X systems (alone and combined).

III. DEVELOPED METHODOLOGY

Modelling & simulation (M&S) has proven to be of great importance in assessing the systems during initial stages of development [18]. The system architecture of the proposed simulation-based methodology is presented in Fig. 1.

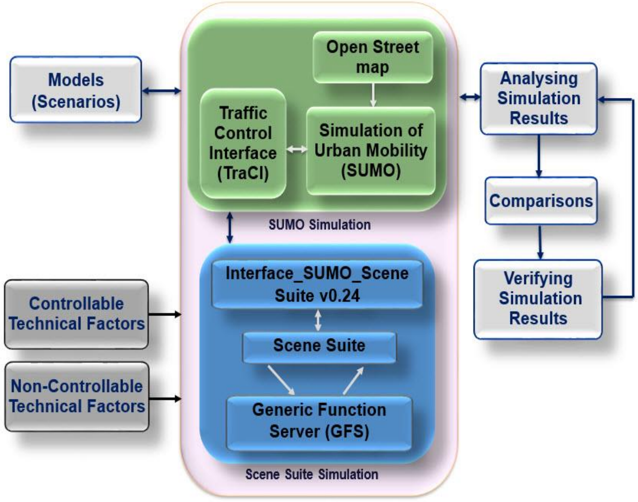


Figure 1. System architecture of the proposed methodology

The developed system architecture consists of three main phases: Specifications and Requirements, Modelling and Simulation, and Analysis and Verification. Each of the three phases consists of different steps that are briefly introduced below.

A. *Specifications and Requirements*

Models (Scenarios): We consider intersection scenarios. Three different models were developed and used to investigate the extent to which the implementation of V2V and ADAS-ACC (alone and combined) would affect the level of road safety.

Each of the generated scenarios is designed to characterize some specific aspects of a traffic scenario, although some general key specifications are applied. The different general and particular properties of the generated intersection scenarios are presented in Table 1.

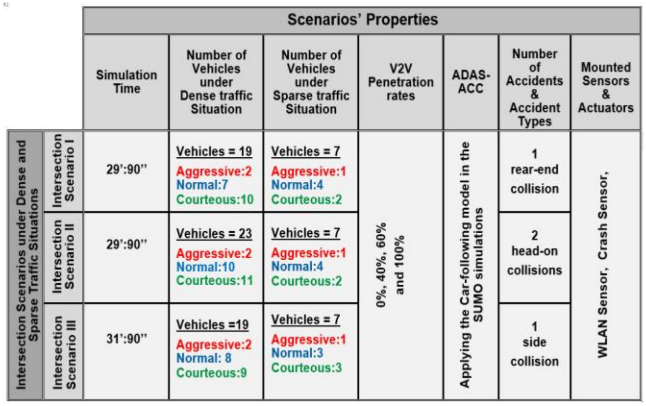
1) *Controllable Technical Factors:*

are defined in this paper as all the available capabilities of the simulation platforms that allow the generation of thentersection scenarios. The controllable factors are not restraints on the process of generating the scenarios and allow the creation of desired scenarios with different specifications.

2) *Non-Controllable Technical Factors:*

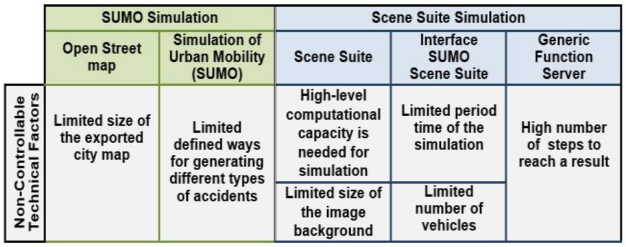
are defined as limitations on the process of generating different scenarios. For instance, the limited size of the exported data map from Open Street Map, or the limited possibility of SUMO to generate accidents (the only available possibility is to generate head-on accidents). Table 2 shows the defined non-controllable technical factors in the SUMO and Scene Suite simulation platforms.

TABLE I. PROPERTIES OF THE DEFINED INTERSECTION SCENARIOS



		Scenarios' Properties						
		Simulation Time	Number of Vehicles under Dense traffic Situation	Number of Vehicles under Sparse traffic Situation	V2V Penetration rates	ADAS-ACC	Number of Accidents & Accident Types	Mounted Sensors & Actuators
Intersection Scenarios under Dense and Sparse Traffic Situations	Intersection Scenario I	29':90"	Vehicles = 19 Aggressive:2 Normal:7 Courteous:10	Vehicles = 7 Aggressive:1 Normal:4 Courteous:2	0%, 40%, 60% and 100%	Applying the Car-following model in the SUMO simulations	1 rear-end collision	WLAN Sensor, Crash Sensor,
	Intersection Scenario II	29':90"	Vehicles = 23 Aggressive:2 Normal:10 Courteous:11	Vehicles = 7 Aggressive:1 Normal:4 Courteous:2			2 head-on collisions	
	Intersection Scenario III	31':90"	Vehicles =19 Aggressive:2 Normal: 8 Courteous:9	Vehicles = 7 Aggressive:1 Normal:3 Courteous:3			1 side collision	

TABLE II. NON-CONTROLABLE TECHNICAL FACTORS



	SUMO Simulation		Scene Suite Simulation		
	Open Street map	Simulation of Urban Mobility (SUMO)	Scene Suite	Interface SUMO Scene Suite	Generic Function Server
Non-Controllable Technical Factors	Limited size of the exported city map	Limited defined ways for generating different types of accidents	High-level computational capacity is needed for simulation	Limited period time of the simulation	High number of steps to reach a result
			Limited size of the image background	Limited number of vehicles	

B. *Modelling and Simulation*

The second defined phase of the methodology system architecture deals with two main simulation platforms that interact with some other applications and sources.

1) *SUMO Simulation:*

The main simulation tool SUMO relies on Open Street Map data and Traffic Control Interface (TraCI) which uses Python programming language to interact with the running simulation. The major steps for generating the desired SUMO simulation are presented in Fig. 2. The purpose of using the SUMO simulation is to generate different types of accidents in order to test the effects of V2V and ADAS-ACC more accurately. In order to simulate a wider range of collisions (apart from head-on), rear-end and side collision have been devised in the simulations. These are generated by creating interrelated effects in random trip generation, manipulating the "vTypeDistribution" attributes, rou.xml and net.xml generated files, as well as implementing TraCI.

2) *Scene Suite Simulation*

The main simulation tool Scene Suite interacts with SUMO-SceneSuite-Interface and Generic Function Server (GFS), two interfaces developed by IAV GmbH. Scene Suite has been used to finalize the simulation scenarios and to investigate the effects of different penetration rates of V2Vand ADAS-ACC (alone and combined) on the level of road safety.

3) *V2V Implementation*

In order to implement V2V with penetration rates of 40%, 60% and 100% in the scenarios, two different approaches have been developed and investigated.

In the first approach, the implementation of V2V in the simulations and visualization of the related consequences of the information dissemination between vehicles has been carried out by developing an innovative approach in Scene Suite. The result is a complete simulated network containing the generated accidents. Fig. 3 illustrates the steps. In order to visualize the effects of Cooperative Awareness Message (CAM) and Decentralized Environment Notification Message (DENM), the first step is to identify the times of the accidents in the related scene. This is then followed by manipulating the forward sequences of the related vehicle movements (in the generated scenes in Scene Suite) based on the time of the accident. Consequently, the involved vehicles are able to stop or decelerate by receiving the DENM messages before crashing.

The second approach of implementing and visualizing the related effects of V2V uses Generic Function Server (GFS). The related process of this approach is illustrated in Fig. 4. In this approach, crash sensors capabilities have been applied to the simulated vehicles in Scene Suite. Detecting the accidents in the output file of the Scene Suite simulation enables their subsequent dissemination through V2V with the purpose of preventing the potential accidents. To this end, an application in GFS was developed which obtains the XML output file of the Scene Suite simulation and provides users with the basic necessary information for preventing possible accidents. It determines the time of accident and the vehicle IDs involved in the accidents. The obtained information is fed into the

V2V application in GFS and the system visualizes the effects of the message exchanges in the final simulation by preventing the accidents.

4) *ADAS-ACC Implementation*

Adaptive Cruise Control was selected as an ADAS. To implement its functionality in the simulated scenarios, the car-following model is adopted in the SUMO road and vehicle network simulation, which determines the speed of a vehicle in relation to the vehicle ahead of it.

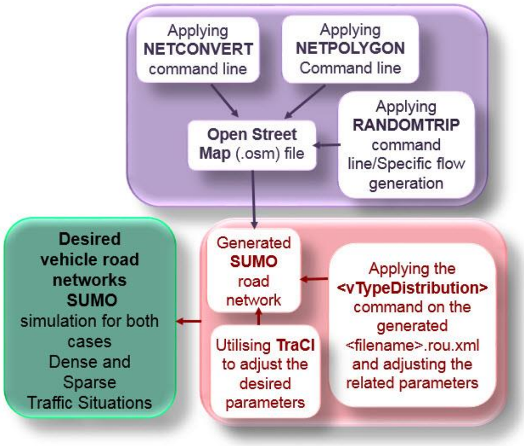


Figure 2. Sumo simulation steps

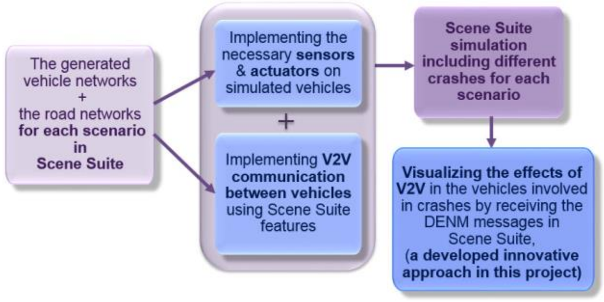


Figure 3. First approach in applying V2V & visualizing the effects

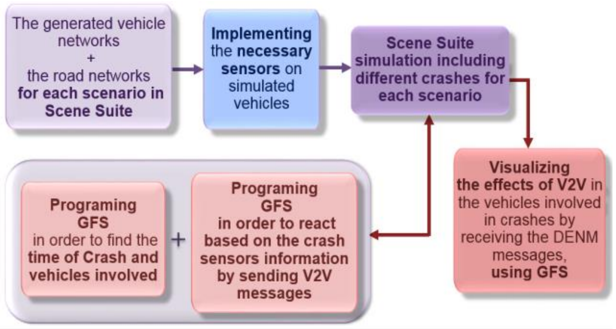


Figure 4. Second approach in applying V2V & visualizing the effects (using GFS)

IV. RESULTS

A. *Comparative Analysis*

In this section, we show the comparative analysis of three generated intersection scenarios under different penetration rates of ADAS-ACC and V2V alone and combined in terms of their capability in preventing potential accidents.

1) *Comparison 1: 0% V2V & ADAS (no system) vs 40% penetration of ADAS-ACC (alone)*

The implementation of ADAS-ACC (alone) in 40% of vehicles showed that in scenarios I and III it was not possible to avoid accidents (Fig.5 and Fig. 7). In intersection scenarios I and III (scenarios types, see Table 1) the accident types are rear-end and side collisions respectively and the ADAS-ACC implementation, with the capability of longitudinal controlling, has been proven incapable of preventing these types of accidents.

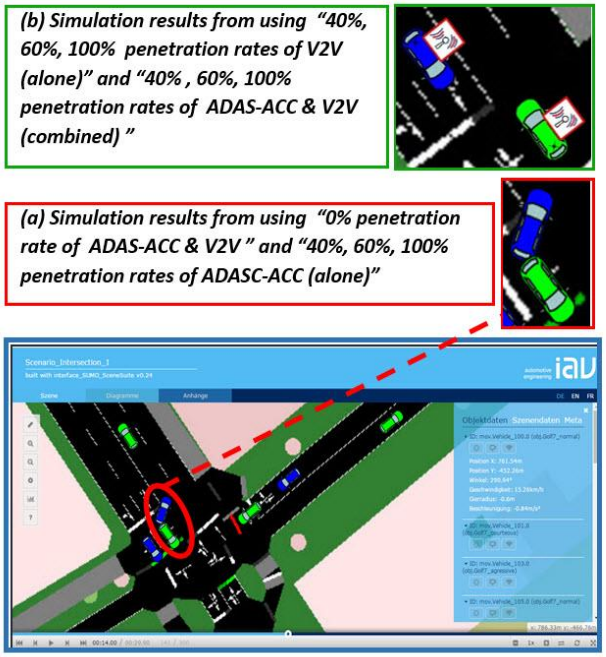
The compared simulations for intersection scenario III are presented in Fig.7, image (a) which shows a side collision that has occurred between two normal vehicles when V2V and ADAS-ACC were not implemented. The similar accident occurred also when ADAS-ACC was implemented on 40% of vehicles (Fig.7, image (a)). In contrast are the simulation results for intersection scenario II involving head-on collisions with and without a 40% penetration rate of ADAS-ACC (alone) (Fig.6). Image (c) in Fig. 6 presents a situation occurring during the 40% ADAS-ACC simulation, while image (a) in Fig.6 shows an aggressive and a courteous vehicle involved in a head-on collision in a 0% V2V & ADAS simulation. Due to its capability of longitudinally controlling and adjusting the distance between vehicles, ACC, proved to be able to prevent the head-on accident.

2) *Comparison 2: 40% penetration of ADAS (alone) vs 40% penetration of V2V (alone)*

Fig.5 presents a comparison of situations occurring in intersection scenario I when ADAS-ACC and V2V, each separate but with the same penetration rates, are implemented. Image (a) in Fig.5 is depicted a situation in which 40% ADAS-ACC is not able to cope with a rear-end crash between a normal and a courteous vehicle. In contrast, image (b) of Fig.5 shows a situation in which V2V implementation on 40% of vehicles is able to deal with the potential accident successfully.

3) *Comparison 3: 40% penetration of ADAS (alone) vs 60% penetration of ADAS (alone)*

As previously mentioned in comparison 1, 40% penetration rate of ADAS-ACC (alone) is not capable of dealing with side and rear-end collisions. An increased ADAS-ACC penetration rate of 60% in intersection scenario I (Fig.5, image (a)) shows no improvement in preventing rear-end collision accidents. Similarly, the effect of increasing the ADAS-ACC penetration rate in scenario III (Fig.7, image (a)) proved the incapability of ADAS-ACC alone to prevent side collision.


(b) Simulation results from using "40%, 60%, 100% penetration rates of V2V (alone)" and "40% , 60%, 100% penetration rates of ADAS-ACC & V2V (combined) "

(a) Simulation results from using "0% penetration rate of ADAS-ACC & V2V " and "40%, 60%, 100% penetration rates of ADASC-ACC (alone)"

Figure 5. Simulation comparision of different penetration rates of V2V and ADAS-ACC (combined and alone) in intersection scenario I

4) *Comparison 4: 40% penetration of ADAS (alone) vs 40% penetration of ADAS-ACC and V2V (combined)*

As presented in the previous comparisons, a 40% penetration rate of ADAS-ACC alone is not capable of tackling side and rear-end accidents. Fig.7 shows the effect of considering 40% penetration rate of ADAS-ACC and V2V combined in scenario III. Fig. 6 shows the results for scenario II. Image (b) in Fig.5, Fig.6 and Fig.7 demonstrate the capability of the combination of the two systems (ADAS-ACC and V2V) by preventing all types of accidents.

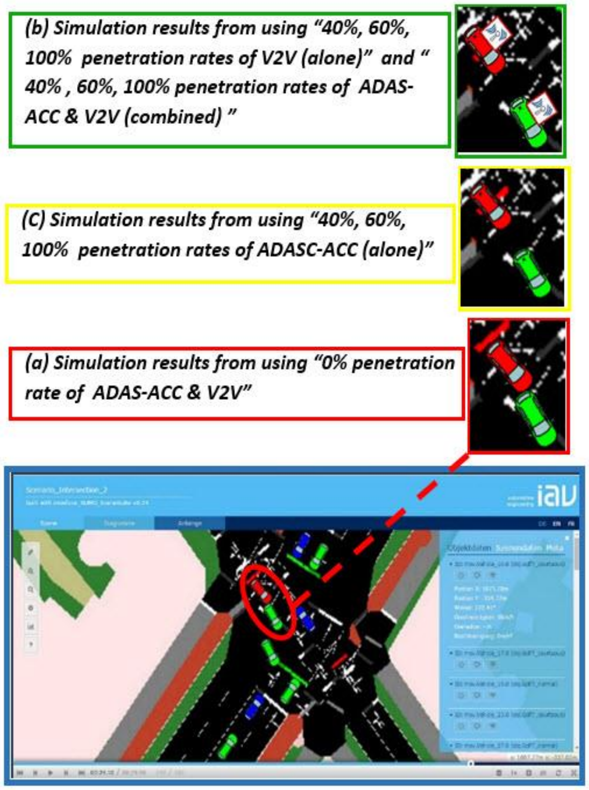
5) *Comparison 5: 60% penetration of ADAS (alone) vs 60% penetration of ADAS-ACC and V2V (combined)*

As presented in comparisons 2 and 3, 60% penetration rate of ADAS-ACC (alone) is not capable of preventing rear-end and side collisions. Whereas 60% penetration rate of ADAS-ACC and V2V (combined) proved to be capable of preventing side and rear-end collisions.

B. *Numerical Results*

The simulation results of the different systems and penetration rates in the various intersection scenarios (in terms of their effects on the number of accidents) are presented in this section (Fig. 8). As previously mentioned the adoption of ADAS-ACC alone, with either 40%, 60% or 100% penetration rates, did not prevent accidents in 2 out of 3 intersection scenarios. Only in intersection scenario II did ADAS-ACC perform as well as combined V2V and ADAS.

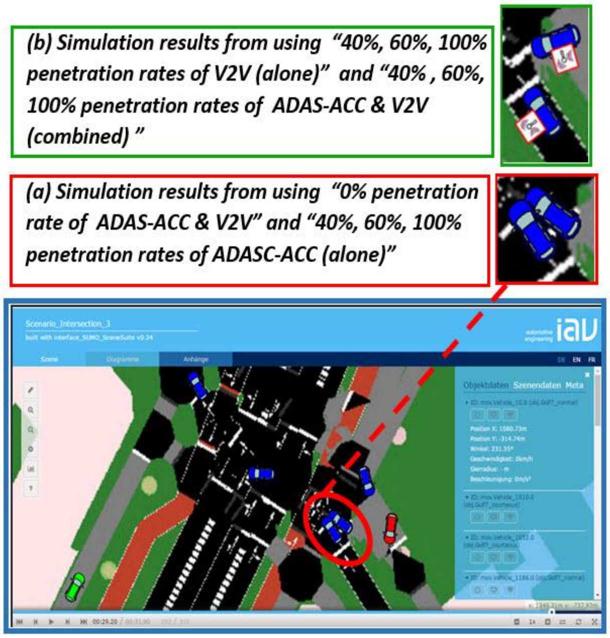
The effects of implementing different penetration rates of V2V alone have also been investigated and the results for preventing all types of accidents are favorable. The illustrated results of different penetration rates for the combined systems also demonstrate their capability of improving road safety and preventing all types of accidents.


(b) Simulation results from using "40%, 60%, 100% penetration rates of V2V (alone)" and " 40% , 60%, 100% penetration rates of ADAS-ACC & V2V (combined) "

(C) Simulation results from using "40%, 60%, 100% penetration rates of ADASC-ACC (alone)"

(a) Simulation results from using "0% penetration rate of ADAS-ACC & V2V"

Figure 6. Simulation comparison of different penetration rates of V2V and ADAS-ACC (combined and alone) in intersection scenario II


(b) Simulation results from using "40%, 60%, 100% penetration rates of V2V (alone)" and "40% , 60%, 100% penetration rates of ADAS-ACC & V2V (combined) "

(a) Simulation results from using "0% penetration rate of ADAS-ACC & V2V" and "40%, 60%, 100% penetration rates of ADASC-ACC (alone)"

Figure 7. Simulation comparison of different penetration rates of V2V and ADAS-ACC (combined and alone) in intersection scenario III

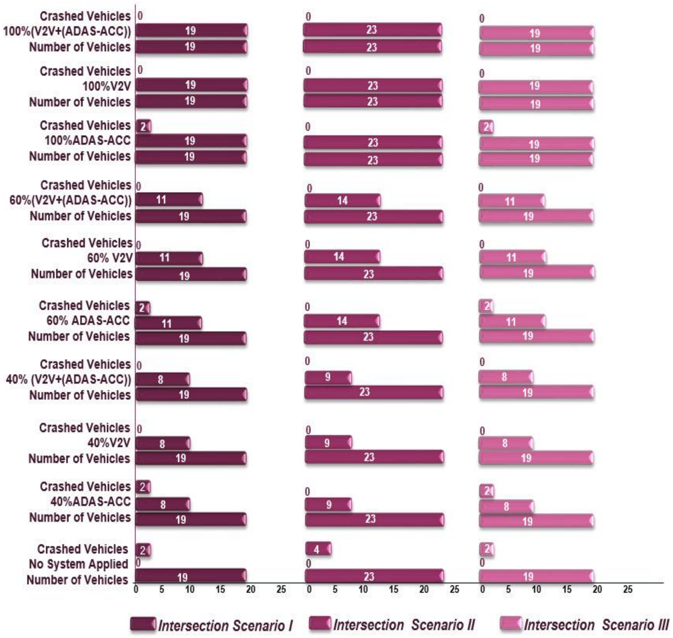


Figure 8. Simulation results of intersection scenarios with different V2V & ADAS-ACC penetration rates

V. CONCLUSION AND FUTURE WORK

Overall results show that even the lowest penetration rate (40%) of V2V resulted in a dramatic improvement in the level of road safety by preventing all types of accidents. On the other hand, ADAS-ACC requires the assistance of V2V communication in order to increase safety, especially in certain scenarios with side and rear-end collisions. The different combined V2V and ADAS-ACC penetration rates are capable of improving road safety. Finally, all different penetration rates of V2V communication, independently or combined with ADAS-ACC, are capable of reducing the number of all types of accidents in the scenarios to zero.

Future work will aim at extending this developed approach by first, providing a safe and accurate interaction between vehicle networks and infrastructure. This will require different implementations in the simulation scenarios. Secondly, by developing different Vehicle-to-Everything (V2X) communications which ultimately secure and increase the level of road safety in a large scale.

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