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Bayesian Networks for the Driver Overtaking Assistance System on Two-lane Roads

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Abstract

Unsuccessful overtaking maneuvers on two-lane rural roads are one of the major causes of road accidents in the 21st century. The complexity of this maneuver merits the adoption of a thorough method for developing a proposed assistance system to prevent accidents and consequently reduce the high number of fatalities and the associated economic costs. This study aims to introduce an intelligent Driver Overtaking Assistance System (DOAS) to assist drivers in performing overtaking maneuvers safely. The study also will introduce a method to assess the impact of all the influential variables related to the driver, vehicle, traffic, road, and the surrounding environment. In momentary driving situations, the DOAS uses the communicated information via Hello beacon messages (HBM) and a set of input sensors to measure the possibility of overtaking the preceding vehicle(s) proactively by considering whether the distance gap to the oncoming vehicle is sufficient for overtaking. Besides, the proposed system is a vehicle-based safety system based on the collection of contextual information from the driving vicinity to acquire all relevant information regarding the ambient driving environment and the vehicles involved in the overtaking. To do this, DOAS uses a Bayesian Network (BN) to model overtaking maneuvers. The work presented shows high accuracy and promising results in aiding safe overtaking, with significant improvements to overtaking maneuvers on two-lane rural roads.

Keywords

overtaking maneuver, two-lane roads, VANET, rural roads, Bayesian networks

1 Introduction

The term "overtaking maneuver" refers to passing a vehicle that is moving forward at a slower speed when driving in the same lane, by using the lane intended for travel in the opposite direction. The overtaking maneuver is both difficult to perform and dangerous on two-lane rural roads, based on the idea that the other lane is intended for traffic traveling in the opposite direction; and also as the opposite carriageway may be occupied by oncoming vehicles.

Overtaking strategies can be classified into four categories: in the majority of countries, single-carriageway rural roads comprise approximately 90% of the road network. Furthermore, these roads account for more than 60% of highway fatalities worldwide and an annual death rate of approximately 500,000 people (Lamm et al., 2006). Crashes in the USA that occur on single carriageway rural roads constitute around 75% of all head-on collisions (i.e., two vehicles hitting each other at the front end whilst traveling in opposite directions) and these are most likely to occur where overtaking is being attempted (Hegeman, 2008).

The developments in wireless communication and mobile computing have allowed for extensive development and enhancement of the Intelligent Transportation Systems (ITS) intended to improve safety on roads (Olariu and Weigle, 2009). The Vehicular Ad hoc Network (VANET) is an essential component of ITS and uses a Dedicated Short-range Communication (DSRC) to enable communication and exchange of messages and information via two types of communication: vehicle-to-vehicle (V2V), to exchange data among vehicles, and vehicle-to-infrastructure (V2I) between vehicles and roadside units (Al-Sultan et al., 2014). On these grounds, wireless communication emerged as a perfect solution for implementing safety systems on rural roads, taking into account the

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efficiency in performance and unavailability of infrastructure on these types of roads. Thus, the proposed work is intended to use VANET for communication among vehicles on rural roads to assist in maneuvering.

In this study, however, a thorough Driver Overtaking Assistance System (DOAS) is introduced, which here is a vehicle-based safety system. This system is based on the accurate and safe proactive prediction of the potential to pass a preceding vehicle (or vehicles). All aspects of the driver, vehicle, road, and environment that have an impact on how the maneuver is performed have been taken into account when modeling the DOAS.

The paper is organized as follows. Section 2 provides an overview of the most relevant literature concerning overtaking assistance models. In Section 3, an overview of BN is presented. In Section 4, an overview of the presented DOAS is given. Section 5 describes the detailed design of the DOAS and Section 6 presents the estimation method for the total effects time. The DOAS overtaking decision details are presented in Section 7, while the validations are presented in Section 8. Finally, the conclusion is delivered in Section 9.

2 Related work

The development of an advanced DOAS remains a significant necessity for managing such a dangerous maneuver. Therefore, concerning the assistant systems utilized by many high-class vehicle manufacturers such as OAS, there is much more work presented in the literature by various researchers. For instance, Loewenau et al. (2006), described a new and substantial driver assistance system developed by the BMW Group and Navteq as a dynamic pass prediction (DPP), or overtaking assistance system, to make the overtaking maneuver safer and more comfortable for the driver. It refers the driver to a safe section of road, allows the performance of the overtaking maneuver, and specifies the distance to this section. Although the DPP system provides significant assistance for drivers on rural roadways, it does not offer any substantial assistance in terms of performing the maneuver itself, as this is ultimately the driver's responsibility. In addition, the system does not consider significant and influential aspects such as oncoming traffic, driver-related factors, variables regarding the vehicle, or the surrounding environmental factors.

Olaverri-Monreal et al. (2010) proposed a Cooperative Advanced Driver Assistant and applied a See-Through System (STS) to help drivers to overtake long and vision-obstructing vehicles. The STS system relies on VANET technology to provide a video stream of the road from the preceding vehicle, which allows the driver of the overtaking vehicle to visually perceive any vehicles traveling in the opposite lane. However, this system is not free of drawbacks. The STS performs properly only in the instance of normal roadway scenarios. In other words, it would not have the same, or possibly even adequate, performance at night, or in severe weather conditions like heavy storms and fog. It also uses the User Datagram Protocol (UDP) for video streaming, although the provision of high-speed transition may cause packet loss, as missing or corrupted packets will not be retransmitted.

Besides, Milanés et al. (2012) developed an autonomous system to assist with overtaking maneuvers. This design was based on using stereo vision to detect the preceding vehicle and its speed, as well as the ability to detect the length and width of any preceding objects on the road, such as motorbikes, cars, or trucks, to make it as close as possible to the vehicle driver. A vision system for automating overtaking maneuvers has been applied to multilane trajectories. De Sousa Vieira et al. (2013) proposed a VANET-Driver Assistance System (VANET-DAS) that used the kinematics technique to model the overtaking maneuver. They employed communication protocols to predict the safety of proposed overtaking maneuvers and to exchange coordination within the vicinity of the VANET. The researchers used a flying overtaking scheme only. In addition, throughout the overtaking maneuver, the authors assumed that the speed of the overtaking vehicle must be fixed and faster than the lead vehicle.

Patra et al. (2015) proposed a new overtaking assistance system called EYES that integrates a smartphone into the vehicular network. The idea of the system is to assist the performance of an overtaking maneuver with a video feed from a vehicle in front to offer a better view of the opposite direction and the road ahead. One of the requirements of such a system is to have an Android device provided with GPS and a back camera in order to have video recording.

Richter et al. (2017) determined the impact of the infrastructural and traffic variables on the overtaking behavior of drivers and the consequences and occurrence of overtaking accidents. The authors found diverse correlations between overtaking accidents and driver behavior, as well as operational and infrastructural road characteristics. The main research results revealed that there is a lack of unity between road construction and road operation, as well as finding that the driver needs support from the road design in the task of driving to avoid accidents and errors.

Figueira and Larocca (2020) suggested a technique of observing passing maneuvers on two-lane roads on a driving simulator to analyze the impact of the speed of a preceding vehicle, the type of vehicle being overtaken, and the overtaking sight distance on the following gap distance as an indicator of driver behavior. There were 80 participants involved in the driving experiments performing 640 possible maneuvers. The authors found that at the beginning of overtaking, the effect of the speed of a preceding vehicle on the following gap was of greater consequence than the effect of the passing sight distance or the type of preceding vehicle.

Fadhil and Al-Bayatti (2022) employed predictive models to introduce a new driver overtaking assistance system to proactively predict the possibility of overtaking any preceding vehicle; the different factors that can have an impact on the maneuver have been taken into consideration as related to the driver, the vehicle, the road, and the environment. Based on driving experiments using a microscopic driving simulator, the system presented uses a specific dataset intended for use with the SVM and ANN machine-learning models to train and test the proposed assistance system. The driving experiments involved 100 participants of various ages, genders, and levels of mental awareness. In addition, the data collected includes 18 variables related to performing overtaking maneuvers on two-lane rural highways.

As can be seen, most of the studies for the overtaking assistance systems developed to date have therefore shown that considerable limitations are consistently encountered in these studies. It is particularly difficult to identify the possibility of performing an overtaking maneuver accurately and proactively due to the lack of comprehensive systems currently available, except for the reference (Fadhil and Al-Bayatti, 2022). This includes calculating the available distance for overtaking as well as taking into consideration context-aware factors that affect maneuvering as part of this process. In our research, all these limitations are addressed in the design of the proposed assistance system.

3 Bayesian networks

BNs are methods for reasoning under uncertainty. BNs are one of the Artificial Intelligence (AI) models, sometimes known as belief networks, casual networks, probabilistic casual networks, or knowledge maps (Charniak, 1991).

BNs, as described by Ben-Gal (2007), combine four types of principles, including probability theory, graph theory, statistics, and computer science. The joint probability distribution of BNs combines both structural (qualitative) and probabilistic (quantitative) parts; the qualitative part is a direct dependency of arcs that are captured by a directed acyclic graph; the nodes represent random variables of the network, whereas the direct dependency among nodes is represented by arcs. On the other hand, the quantitative part represents the probability information of the nodes or the strengths of direct dependencies in conditional probability distributions (Simoncic, 2004).

There are three basic steps to constructing a probabilistic network for any domain (Druzdzel and van der Gaag, 2000). The first step includes classifying the high-importance variables along with their values. Determining the relations among the distinguished variables and expressing these relations in graphical form is the second step. The tasks for identifying the important variables and their values, and representing these relations in a graphical model, require considerable effort from experts in the domain. The final step represents a quantitative part; this step is to obtain the required probability information for all nodes to construct a probabilistic network. The qualitative relationship between network variables should be combined with quantitative probabilities to form the BN structure (Korb and Nicholson, 2010).

4 DOAS overview

4.1 Hypotheses to consider in the DOAS

We present the hypotheses in the DOAS as follows:

- Speeds of preceding and oncoming vehicles are assumed to remain constant during overtaking maneuvers.
- Adding a large headway distance will lead to an increase in the time that the overtaking vehicle stays in the opposite road lane, consequently increasing the overtaking time. Therefore, the distance in DOAS is assumed to be equal to 1 s or less of the speed of the subject vehicle. Likewise, 2 s is designated as the lowest space distance for returning the subject vehicle to its own lane.
- All vehicles involved in the overtaking maneuver are provided with sensors to measure the preceding available distances from the vehicle in front.
- The driver has to take into account the fact that the speed difference should not exceed the limits set by traffic legislation.
- There must be a preceding vehicle in front to overtake.

4.2 System operation steps

As depicted in Fig. 1, the operation of the DOAS mechanism is based on the following steps:

- ***Step 1:*** In the first step, the DOAS implements all the following operations simultaneously.
  - *Step 1.1:* The DOAS continues to collect the speed, location, and direction of the oncoming vehicles and other neighboring vehicles in the vicinity using HBMs (periodic messages used by nodes (vehicles) whose main purpose is to allow each node in the network to inform other nearby nodes about its existence and provide them with its present situation such as its location, speed, and direction) and a relevant set of sensors (e.g. GPS, Lidar). The DOAS can communicate between vehicles using radio access technology; in this report, we used IEEE 802.11p DSRC. This ensures that all vehicles in the vicinity, as well as the infrastructure in the city, have a secure and efficient means of communication.
  - *Step 1.2:* The DOAS continues updating all sensed values through vehicle input sensors.

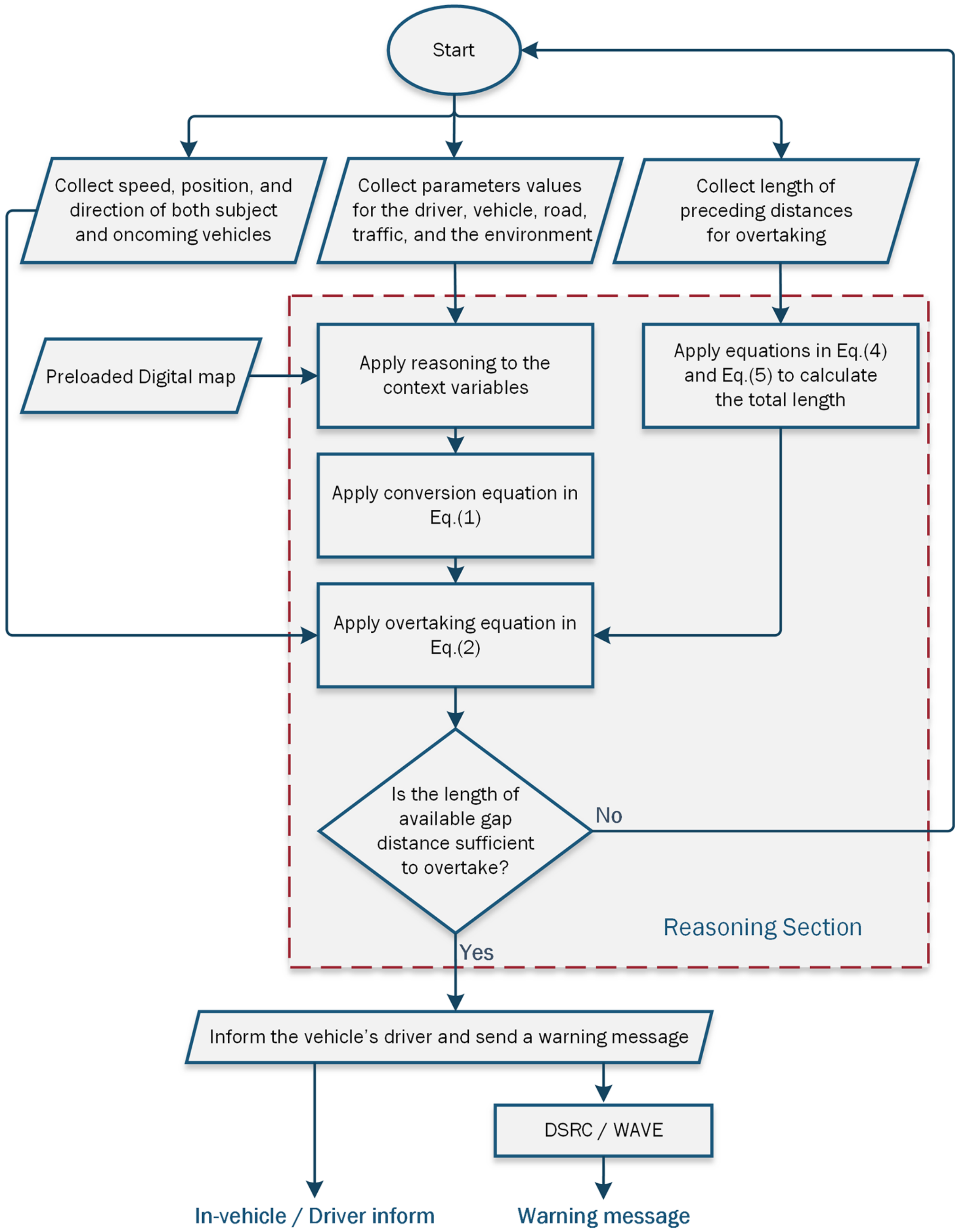

Fig. 1 The DOAS activity diagram

- *Step 1.3:* The context information to be used to assess the impact of all variables in the BN on the driver, vehicle, road, traffic, and the environment, is collected as shown in Fig. 2.
- ***Step 2:*** The resulting probabilities of the impact levels node to time are converted. This time represents the impact of different variables on driving conditions, as explained below in Section 6. It is added to the total dedicated time for overtaking to increase the overtaking time, subsequently increasing the length of the accepted distance by the DOAS.
- ***Step 3:*** The system measures the total length of the overtaking distance in front of the subject vehicle with the view so that it can be considered when calculating the accepted gap distance for overtaking; refer to Fig. 3. It includes the lengths of the preceding vehicles and the lengths of the spaces between them if there is more than one preceding vehicle. The collection of this information is via input sensors and the Hello beacon messages.
- ***Step 4:*** The proposed overtaking equation, refer to Eq. (2), is applied to decide whether to start overtaking if the available gap is sufficient to perform the maneuver or otherwise.
- ***Step 5:*** The final step includes informing the driver through an effective in-vehicle visual mechanism about the possibility of initiating an overtaking maneuver and sending a warning message to all other vehicles in the vicinity about this. Otherwise, the DOAS will continue to find another opportunity to overtake.

All the steps described above must happen in a momentary driving situation. Time is of vital importance in performing this maneuver as any delay can change the measures and calculations between vehicles in an overtaking scenario and might cause a dangerous accident. Furthermore, all the operational steps for the DOAS are discussed and implemented in detail in Sections 5–8?.

5 The DOAS Design

5.1 A Bayesian network model for the DOAS

5.1.1 Model dataset

Two datasets have been used to implement the DOAS. The police report for accidents that have taken place on two-lane roads and a simulated dataset, which was collected using a driving simulator.

The police reports dataset

The first dataset is the accident data (STATS19) for overtaking maneuvers on two-lane roads, which was obtained from the UK's Department for Transport (DFT) for nine years. This dataset consists of police reports of the accidents and comprises a total of 10,710 records. The original dataset has been refined to first consider only those

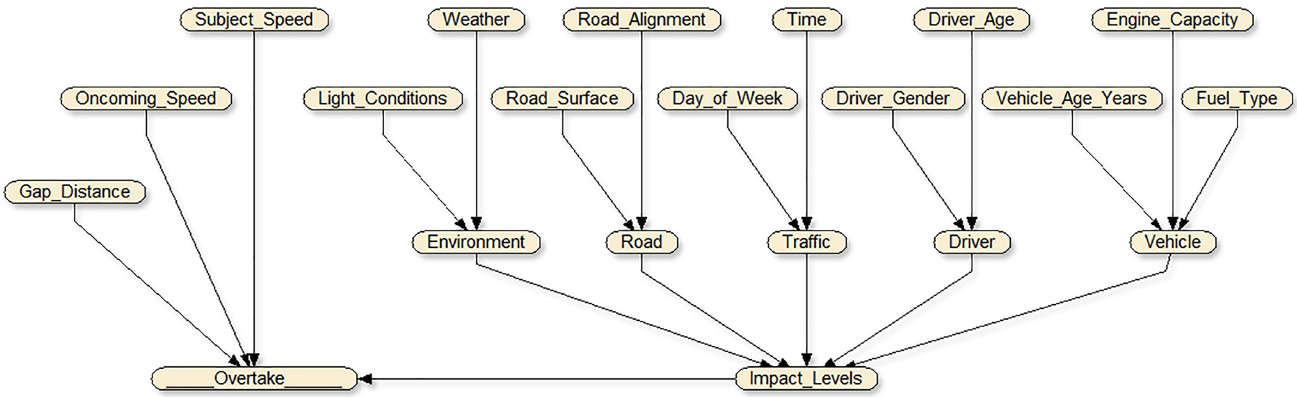

Fig. 2 The Bayesian network nodes

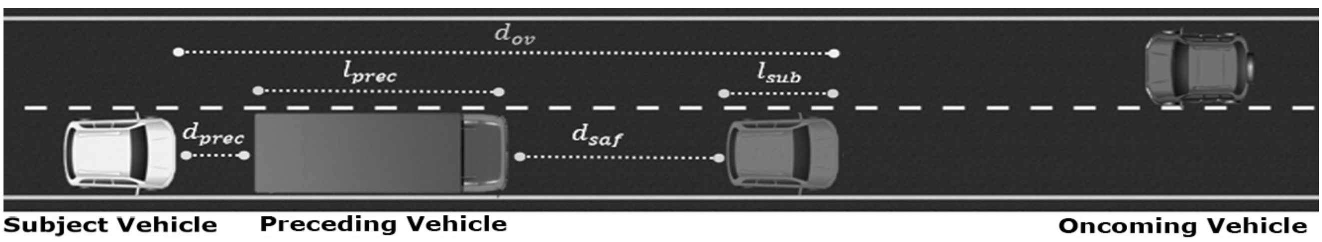

Fig. 3 Overtaking distances of d_{ov}

accidents that occurred in rural areas and secondly to consider only accidents on two-lane roads. This dataset has been used to train the DOAS Bayesian network for the reason that there are multiple advantages to using a real dataset over a simulated one.

To identify the variables that have more impact on performing overtaking maneuvers, eight variables were chosen from the dataset to construct the BN; all the variables used were significant and diverse, which helped provide a thorough consideration of all influential factors.

Data preprocessing

Data from STATS19 was processed and refined in various steps:

- The significant variables related to the proposed work from accident files were nominated by applying evaluator-search algorithms to identify the variables that have an impact on performing overtaking maneuvers on rural roads.
- The variables under investigation were combined from the STATS19 accident files.
- To increase the certainty of in-network reasoning, all missing variables were removed from the dataset.

The simulated dataset

A new dataset was collected via conducting driving experiments using a microscopic driving simulator, STISIM. The most influential variables for performing overtaking maneuvers on two-lane roads were included in the dataset. It comprises 23 variables related to the driver, vehicle, roads, and environmental conditions.

The collected dataset consists of 1,557 records in two classes: 545 records representing the incomplete maneuvers or accidents, and 1,012 records representing the completed maneuvers. In these driving experiments, 190, 355, and 0 represent the number of accidents during the acceleration, flying, and piggybacking maneuvers, respectively. This dataset is used to validate the output results of the proposed DOAS. The output results of the proposed DOAS were validated using this dataset.

5.1.2 Constructing methods

A countering algorithm in Netica_C_API (Norsys Software Corp., 2014) was used to learn the network parameters as the first step, followed by refining the prior probabilities of all the network nodes. The Netica API provides a comprehensive library of functions for working with Bayes nets and impact diagrams that can be used from within one's own programs. It includes functions for building, learning, modifying, transforming, saving, and reading nets, as well as a powerful inference engine. Table 1 shows all the unconditional probabilities of the BN.

5.1.3 BN structure

Netica_C_API (Norsys Software Corp., 2014) was used to program and implement the BN using the C programming language. Essentially, the reasoning network of DOAS consists of two groups of nodes linked together via one hypothesis node (the overtaking node), as depicted in Fig. 2. The first group represents an assessment of the impacts of a set of influencing factors on performing the overtaking maneuver. The nodes of these factors are converged together into a single named node (Impact_Levels); the probabilities of the impact levels node are ordered from lowest to highest (very low, low, medium, high, and very high). The resulting probabilities from this node represent different factors, such as the driver, vehicle, traffic, road, and ambient environment, as shown in Table 2.

The second group of nodes consisted of three nodes, as will be discussed in Section 5.1.4?, representing the speed of the subject vehicle, the speed of the oncoming vehicle, and the available gap distance between the two intended vehicles. All these nodes, in addition to the impact levels node, were converged together into one node (the overtake node).

The overtake node is a deterministic node type that represents the overtaking equation, refer to Eq. (2), for calculating the possibility of initiating an overtaking maneuver depending on the speed of the intended vehicles and the length of the available gap distance between them, in addition to considering the probabilities of the impact levels node. The overtaking decision from the overtake node is not a probable decision, based on accurate calculations in the form of 0 or 100 (either overtaking or not).

5.1.4 Network variables

The nodes of the network constructed for the DOAS were divided into three groups for clarity in describing the network structure; this network comprised 21 nodes, as depicted in Fig. 2.

Group 1: This group included all the impact level nodes. It consisted of 17 nodes, which were classified into three classes: 10 nodes representing input variables, four nodes for intermediate nodes, and one node representing the probability assessments of the impact levels node. The number of states for entire nodes ranged from two to seven.

Table 1 Unconditional probabilities of the DOAS Bayesian network

Variable	State1	State2	State3	State4	State5
Road Surface	Dry	Wet	Snow	Frost	Flood
	0.04	0.16	0.23	0.31	0.25
Weather	Fine	Raining	Snowing	Windy	Fog
	0.05	0.27	0.31	0.15	0.21
Impact Levels	Very Low	Low	Medium	High	Very High
	0.24	0.20	0.19	0.17	0.17
Time	00 to 06	06 to 12	12 to 18	18 to 24	
	0.11	0.41	0.3	0.18	
Fuel Type	Petrol	Diesel	Gas	Other Types	
	0.08	0.29	0.19	0.43	
Road Alignment	Straight	Curved	Top of Hill	Bottom of Hill	
	0.07	0.35	0.13	0.45	
Vehicle Age	1 to 5	5 to 10	≥ 10		
	0.21	0.34	0.43		
Driver Age	18 to 25	25 to 64	> 64		
	0.26	0.17	0.56		
Engine Capacity	429 to 1500	1500 to 2000	≥ 2000		
	0.46	0.35	0.19		
Light Conditions	Daylight	Darkness Light Lit	Darkness No Light		
	0.07	0.32	0.60		
	Good	Bad			
Driver	0.405	0.594			
Environment	0.632	0.367			
Road	0.418	0.581			
Traffic	0.406	0.593			
Vehicle	0.450	0.549			
Driver Gender	Male	Female			
	0.406	0.594			
Day of Week	Week Day	Week End			
	0.73	0.27			

Table 2 The Bayesian network variables

Nodes of group 1				
Driver	Vehicle	Road	Traffic	Environment
Driver Age	Fuel Type	Road Alignment	Time	Weather
Driver Gender	Engine Capacity	Road Surface	Day of Week	Light Conditions
	Vehicle Age			
Nodes of group 2				
Subject Vehicle	30	to	100 km/h	
Oncoming Vehicle	30	to	100 km/h	
Gap Distance	100	to	1000 m	
Overtake node	Pass		No Pass	

Categories of input variables were chosen based on types of influencing factors, such as driver state, vehicle specifications, road situation, traffic state, and environmental conditions. These five factors are represented in the intermediate level of the network; for simplicity, two states (Good/Bad) are used to represent these nodes as follows:

- **Driver node:** There are two parents of the driver node: driver age and driver gender. The driver age node employed three levels of ages to represent the node states (18–25/25–64/> 64) (de Oña et al., 2011). Similarly, gender nodes are used (Male/Female) to represent the node states.
- **Vehicle node:** To collect a precise estimation for vehicle specifications that have more impact on performing the overtaking maneuver, three different nodes (Fuel Type, Engine Capacity, and Vehicle Age), were chosen as parents of the vehicle node.
- **Road node:** This node assesses the road situation; the road surface condition is the first parent node (Road Surface Conditions), and the other parent node corresponds to the design of the road (Road Alignment).
- **Traffic node:** two nodes (Day of the Week and Time) represent the parents of the traffic node. The day of the week node is composed of two states – weekday and weekend – to point out the differences in overtaking on a working day or weekend. Four states were used in the time node to represent four parts of one day in hours.
- **Environment node:** This node has two parent nodes (Weather Conditions, Light Conditions). The chosen variables of the surrounding environment represent the more significant variables in performing the maneuver on two-lane roads.

CPTs are filled and regulated corresponding to values of input nodes. For instance, as shown in Table 3, the CPT for the node *Driver* has two input variables representing driver age and gender; and the corresponding input variables for all probabilities of the states (Good/Bad) are filled in for the entire table.

For example, when the driver's gender is male and age is between 25 and 64, the probability of acquiring a good driving state is 89.3%, whereas the probability of acquiring a good driver state is 32.2% when the driver is female and aged over 64 years.

Table 3 Conditional probability for *Drive* node

Driver Gender	Driver Age	Driver	
		Good	Bad
Male	18–25	81.2	18.8
Male	25–64	89.3	10.7
Male	> 64	43.6	56.4
Female	18–25	72.1	27.9
Female	25–64	78.7	21.3
Female	> 64	32.2	67.8

Group 2: This group comprises three nodes representing the speed of the subject vehicle, the speed of the oncoming vehicle, and the distance gap, as follows:

- Subject speed node: This node represents the speed of the subject vehicle at the moment of overtaking; the speed is between 30 km/h and 100 km/h. This range is adopted in the DOAS and there is flexibility to change those limits depending on traffic legislation. Each speed value represents one state in the subject speed node.
- Oncoming speed node: The considerations of the oncoming node are similar to the subject node.
- Gap distance node: The length of the available gap distance between the subject and oncoming vehicles is represented in this node, with a limit of between 100 m and 1000 m. The longest gap distance is based on the maximum potential communication range in VANET using DSRC (Fernandes and Nunes, 2007). The state of this node is represented in ranges, with a difference of 10 m in the available gap distance, for instance, 100 to 110, 110 to 120, 120 to 130, 130 to 140, and so on.

Group 3: This group includes only one node which is the query node for the entire network (Overtake node). It includes the DOAS equation, refer to Eq. (2), and all the calculations for the final overtaking decision that takes place in this node. This node has two states, *Pass* and *No Pass*, which represent the system's final decision regarding whether the driver can start overtaking or otherwise.

6 Estimation of total effects time

The uncertainty in most related variables needs to be considered and assessed accurately in the DOAS. This uncertainty imposes the need to find a new method to calculate the total impact of the adopted variables in BN. The time dedicated to performing the overtaking maneuver for the DOAS in optimal conditions is about 7 s, without considering any of the BN variables that are related to the driver, vehicle, traffic, roads, and the environment. Substantially, each variable has a degree of impact on performing the maneuver and might lead to serious difficulties.

There is some variation in the time adopted for overtaking and the safety margins proposed by several authors, as cited by Hegeman (2008): the mean of 7.8 s and standard deviation (SD) of 1.9 s stated by Hegeman et al. (2005), the mean of 11.2 s and SD of 2.6 s stated by Benedetto et al. (2004), the mean of 6.5 s stated by Lee et al. (2004), the mean of 8.0 s and SD of 2.6 s stated by Polus et al. (2000), the mean of 6.7 s stated by Crawford (1963), and the mean 7.5 s and SD of 1.9 s stated by Farah (2011).

Besides, the other adopted time is a safety margin time to avoid a collision between vehicles: 4 s was calculated by van der Horst and Hogema (1993), 3 s was proposed by Lee et al. (2004), and 3 s was also recommended by Farah (2011) for the minimum time to avoid a collision. Therefore, the dedicated time to conduct the maneuver in the DOAS is comprised of 7 s for overtaking, in addition to estimating the total effects time rather than adopting a fixed time in the form of a safety margin.

However, the presented notion for calculating the total effect time proposes a score for values from 1 to 5 to represent the rank of each level of the ordered impacts of the impact levels node as very low, low, medium, high, and very high, where 1 represents a very low level, 2 a low level, 3 a medium level, 4 a high level, and 5 a very high level, respectively. As represented in Eq. (1), each value of the proposed score is multiplied by the corresponding impact level and the sum of all these multiplications is to calculate the total value of the effect time.

$$t_{eff} = 1\times \text{Very Low} + 2\times \text{Low} + 3\times \text{Medium} + 4\times \text{High} + 5\times \text{Very High} \quad (1)$$

The effects time represents the amount of time (in seconds) that is added to the actual time for overtaking, which is about 7 s.

Therefore, there are differences in the added time based on a set of variables that have more impact; some variables have more impact than others. Table 4 shows the amount of added time in each instance, depending on the type of variables. For example, when the weather state is raining, the road surface is flooded, the driver's gender is female, and finally, it is a weekday, about 2.33 s is added to the actual time for the maneuver, thus changing the new total time for overtaking to 9.33 s. This will consequently impose the acceptance of a new measure for the overtaking gap distance by the DOAS following the new calculated time.

7 DOAS overtaking decision

7.1 Hypothesis in DOAS equations

We present two hypothesis in DOAS equations:

1. The minimum acceleration speed for the subject vehicle is 20 km/s and above.
2. The preceding distance in front of the subject vehicle to start an overtaking maneuver is assumed to be the equivalent of 1 s of the subject vehicle's speed. Likewise, 2 s is designated as the smallest space distance for returning the subject vehicle to its own lane.

7.2 Overtaking equations

Using VANET for telecommunication between vehicles in the vicinity, the basic information required for the DOAS to calculate the available gap distance for overtaking are the speed, location, and direction of both the subject and the oncoming vehicles. Broadcasting HBMs periodically every 0.5 s to each node in the vicinity (Al-Doori et al., 2010) enables the DOAS to provide an accurate measurement of any available gap distance for overtaking.

The range of speeds that are considered for the subject and oncoming vehicles start from 30 km/h, as the lowest speed limit to 100 km/h. It is possible to increase the higher speed limit depending on the legislation for two-lane roads, which differs between countries. Thus, the proposed DOAS applies the Eq. (2) to calculate the available gap distance for overtaking between the subject and the oncoming vehicle. The parameters of the following equations, in Eq. (2), Eq. (3) and Eq. (4), are described as follows:

Table 4 The resulting times of the impact levels node probabilities

Variables	Very low	Low	Medium	High	Very high	Effect time (s)
Weather (windy), Engine Capacity (429–1500), Fuel Type (Diesel)	0.466	0.292	0.113	0.082	0.046	1.94
Driver Age (> 64), Driver Gender (Female)	0.419	0.167	0.264	0.132	0.026	2.16
Weather (Rain), Road Surface (Wet), Light Condition (Darkness no Light)	0.641	0.133	0.101	0.050	0.073	1.78
Weather (Snow), Road Surface (Snow), Driver Age (> 64)	0.329	0.257	0.269	0.115	0.031	2.26
Fuel Type (Gas), Driver Gender (Female), Driver Age (18–25)	0.383	0.294	0.245	0.069	0.0138	2.03
Driver Gender (Female), Engine Capacity (429–1500), Weather (Fog)	0.217	0.183	0.223	0.201	0.176	2.93
Weather (Raining), Road Surface (Flood), Driver Gender (Female), Day of week (Weekday)	0.336	0.265	0.195	0.156	0.053	2.33
Road Alignment (Bottom of Hill), Road Surface (Wet)	0.765	0.088	0.060	0.099	0.077	1.81
Light Condition (Darkness Light Lit), Road Alignment (Curve)	0.563	0.146	0.116	0.094	0.080	1.98

- The assistance system considers the speed of the subject vehicle in node *A* and the speed of the oncoming vehicle in node *B*. The vehicles' speeds, locations, and directions are updated regularly using the HBMs exchanged to compute the available gap distance for overtaking, as depicted in Fig. 1.
- The next step is to find the total speed in km/h for both vehicles and to convert that total to m/s to calculate the total number of driven meters in one second, as in $(v_{sub} + v_{onc})/3.6$.
- The resulting total number of meters driven is multiplied by the summation of the actual overtaking time, t_{ov}, and the total effects time, t_{eff}, as in $(t_{ov} + t_{eff})$.
- The t_{eff}, the total effects time as discussed earlier, as shown in Eq. (1), represents the amount of time that is added to the actual time determined by the overtaking equation, refer to Eq. (2), which is 7 s. The value of the added time depends on the levels of impact, this is caused by different factors in the driving environment when performing the overtaking maneuver.
- Finally, based on the speeds and locations of the intended vehicles, if the DOAS decides to permit the driver to start an overtaking maneuver when the available distance is longer than or equal to the required distance to overtake, the driver will be warned about overtaking in an appropriate in-vehicle visible/audible manner. Besides, all other vehicles in the vicinity will be alerted proactively about the commencement of a new overtaking maneuver through the dissemination of a warning message. If this maneuver is otherwise not permitted, the system will continuously attempt to find subsequent permission to start a new overtaking maneuver.

The proposed overtaking equations (Eq. (2), Eq. (3) and Eq. (4)) for the DOAS are as follows:

$$\begin{aligned}&\text{Overtake} = \text{if}\left(A == v_{sub}\ \&\&B == v_{onc}\right)\\&\&\&\ D \geq \left(\left(\left(v_{sub} + v_{onc}\right)/3.6\right) \times \left(t_{ov} + t_{eff}\right) + d_{ov}\right),\end{aligned} \quad (2)$$

where:

- v_{sub}: speed of subject vehicle in km/h,
- v_{onc}: speed of oncoming vehicle in km/h,
- t_{eff}: total effects time in s, as described in Eq. (1),
- t_{ov}: the actual overtaking time in s;

and

$$d_{ov} = d_{prec} + l_{sub} + l_{prec} + d_{saf}\ , \quad (3)$$

where:

- d_{ov}: overtaking distance in m,
- d_{prec}: the distance between the subject and preceding vehicle before starting overtaking in m,
- l_{sub}: length of the subject vehicle in m,
- l_{prec}: length of the preceding vehicle in m,
- d_{saf}: safety distance for returning to original lane m.

When overtaking two or more vehicles, the length of the queue of vehicles in front of the subject vehicle is an important issue. Overtaking more than one vehicle is more difficult as it increases the length of time the subject vehicle stays in the overtaking lane, which might lead to a dangerous situation occurring on the road.

Therefore, once the available safety distance d_{saf} in front of the preceding vehicle is not sufficient to return the subject vehicle to its own lane, the length of the queue will be longer to consider all the vehicles in front before establishing a suitable safety distance. Equation (4) below will thus be adopted as the new overtaking distance d_{ov} in DOAS for overtaking two or more vehicles:

$$d_{ov} = d_{prec} + l_{sub} + l_{prec} + d_x + l_x + d_{saf}\ , \quad (4)$$

where:

- d_x: length of any distances between vehicles in front of the preceding vehicle,
- l_x: length of any vehicle in front of the preceding vehicle.

The DOAS presented in this research is designed to work with all overtaking strategies, which are analyzed according to various equations for overtaking proposed by different authors (Fuchs, 2009; Hegeman, 2008; Namala and Rys, 2006; van Kooten, 2011).

8 Results and validation

Proactively identifying the possibility of performing an accurate and safe overtaking maneuver will lead to enhancements in road safety and prevent accidents from taking place. Since the accuracy of the system outcome is a vital step, especially for this type of dangerous maneuver, in addition to the unavailability of similar work for comparative purposes, a new dataset was created using a driving simulator STISIM for 100 drivers to be used in the validation of the results obtained for the DOAS; see Section 5.1.1.

Therefore, all the listed effect times in Table 4 were tested in the results section and compared to the collected simulator dataset; as shown in Table 5. Thus, the simulator

Table 5 DOAS and the simulator data comparison results

DOAS							Simulator Data				
Effect time (s)	Total overtaking time (s)	Subject vehicle speed (km/h)	Oncoming vehicle speed (km/h)	Overtaker vehicle speed (km/h)	Required distance (m)	DOAS decision	Maneuver type	Simulator result	Overtaking time (s)	Overtaking distance (m)	Final results
1.38	8.38	100	90	-	482	Pass	Flying	NoAccident	6.43	205	Similar
1.05	8.05	86	71	-	381	Pass	Flying	NoAccident	6.37	165	Similar
1.94	8.94	73	77	-	403	Pass	Flying	NoAccident	5.23	116	Similar
2.16	9.16	60	65	-	353	NoPass	Flying	Accident	0.52	14.31	Similar
0	7	100	80	-	384	Pass	Accelerative	NoAccident	9.35	276	Similar
1.78	8.78	69	55	-	254	NoPass	Flying	Accident	3.23	64.52	Similar
2.26	9.26	115	110	-	598	Pass	Accelerative	NoAccident	5.22	170	Similar
2.03	9.03	75	90	-	453	NoPass	Flying	Accident	4.55	342	Similar
2.51	9.51	60	85	-	342	Pass	Flying	NoAccident	5.28	383	Similar
2.93	9.93	70	62		365	Pass	Flying	NoAccident	5.52	129	Similar
2.33	9.33	90	100	110	525	Pass	PiggyBacking	NoAccident	5.10	142	Similar
1.81	8.81	70	100	85	426	NoPass	PiggyBacking	NoAccident	6.37	503	Different
1.98	8.98	95	110	-	546	Pass	Accelerative	NoAccident	4.23	123	Similar

dataset has been analyzed carefully to determine similar variables and driving conditions as the DOAS output. This section introduces a validation for the results obtained for the proposed DOAS in reasoning about the input data.

In Table 5, the most important variables were selected for use in the comparison between the DOAS and the simulator dataset. The data adopted for the DOAS were the speed of the subject, oncoming, and approaching (the overtaker) vehicles, in addition to the required distance for overtaking and the overtaking time. It is worth noting that the column total overtaking time (s) represents the actual time, which is 7 s, as explained previously, in addition to the total effects time. Finally, the last variable is the final decision of the DOAS to recommend overtaking or otherwise. On the other hand, the selected variables in the simulator data are the same as those for the DOAS data, except for listing the maneuver type and simulator results to show how each maneuver was completed, that is, whether it resulted in an accident or otherwise.

The results reported in Table 5 are classified into three groups depending on the overtaking decision made by the DOAS and, at the same time, how the maneuver was completed in the corresponding results in the simulator data. In group one, the DOAS decision was Pass (permitting overtaking) while the performed maneuvers were completed with No Accidents in the simulator data; whereas the DOAS decision in the second class was No Pass, and the maneuvers were completed with Accidents. Finally, the DOAS decision in the third group was No Pass but the maneuvers end with No Accidents.

Regarding the first group, in the estimated time of 1.38 s, the total time for completing the maneuver was 8.38 s, as the actual time was 7 s and the estimated effect time was 1.38 s, as explained earlier. This maneuver was completed with no accident in the simulator data; similarly, the final decision for the DOAS was to start maneuvering (Passing), as there was sufficient distance between the subject and the oncoming vehicle to complete the overtaking maneuver safely. The same results with no accidents were found for the estimated times of 1.05 s, 1.94 s, 0 s, 2.26 s, 2,51 s, 2.93 s, 2.33 s, and 1.98 s. Different conditions are considered for these times as follows:

- For the estimated time of 1.05 s, the driver was female having 10 years of driving experience and the maneuver included overtaking only one small car. Besides, there was no added time for performing the maneuver when the estimated time was zero as the driving conditions were fine and there was no impact on performing the overtaking maneuver. Therefore, the DOAS decided to permit the maneuver, while the required time for this maneuver in the simulator was 9.35 s. This high value for maneuvering time shows that the driver, who was a female having only 1 year of driving experience, took a long time to return to their own lane after passing the preceding vehicle.

- For the estimated time of 2.33 s, the speed of the overtaker (who comes from the backside for overtaking the subject and the preceding vehicle/s) was 110 km/h; the driver was a female aged 25 years old having 2 years of driving experience. The same result can be found with the estimated effect time of 2.03 s.
- Moreover, with an estimated time of 2.93 s, the driver was a female aged 27 years old having 9 years of driving experience. For this time, the maneuver required 5.52 s and 365 m for completion. This assigned distance in the DOAS was higher than that required for performing the same maneuver in the simulator, where this difference was due to the high time assigned for the maneuver, which was 9.93 s.

As shown above, the second group includes three estimated times, which are 2.16 s, 1.78 s, and 2.03 s. All the corresponding maneuvers in the simulator data were completed with accidents while the decision of the DOAS was No Pass. The results of this group are completely identical to the simulator data. In the time of 2.16 s, the maneuver was completed with an accident because the available distance for completing the maneuver safely, which was 328 m, was less than the required distance of 25 m. The age of the driver in this maneuver was 67 years with 30 years of driving experience.

For the other two estimated times, 1.78 s and 2.03 s, the results were similar to the time of 2.16 s and they ended with accidents for the same reason, namely that the available distance for completing safely was less than the required distance. As shown in Table 5, the maneuver for the time of 1.78 s ends with an accident of 3.23 s after crossing the separating road line. The same was found with the time of 2.03 s, as the required distance for overtaking is 453 m whereas the available distance is less than the required distance by 35 m.

The third group includes only one estimated time of 1.81 s. In this group, the decision from the DOAS was not to pass as the available distance was insufficient to complete the maneuver safely. On the other hand, similar records in the simulator data show that no accidents occurred. This difference in the results was because the speed of the overtaker was convenient to provide the opportunity for the subject vehicle to finish the maneuver quickly, at 85 km/h. Besides, the available distance was 552 m which was sufficient to complete the maneuver safely, which proves that all the conditions for a successful maneuver were present.

To validate the system output, a sensitivity analysis was carried out to identify parameters having a greater impact on the target node in the model, that is, the overtake node. The sensitivity analysis is an attempt to assess the sensitivity of the model output to variations of model inputs given by parameters and variations of model assumptions. To do this, there are a large number of approaches to performing a sensitivity analysis, and therefore regression analysis was used to analyze this study. The results from the model reveal that there were several parameters in the group 1 nodes that were not statistically significant, except for the road alignment, the time, and the driver gender; see Section 5.1.4. However, the results show that all the group 2 nodes are statistically significant, including the speed of the subject vehicle, the speed of the oncoming vehicle, and the size of the gap for overtaking.

Finally, the comparison between the DOAS introduced and the simulator data revealed promising results for the DOAS system. As shown in the final results column in Table 5, there is the highest percentage similarity between DOAS and the simulator data. Also, the final results show the required time for overtaking in the simulated data is less than that determined by DOAS, which is a positive point for the DOAS in terms of increasing the safety of overtaking. The difference in the overtaking time ranges from 2–5 s. Therefore, these results confirm that the accuracy of the DOAS introduced in research can exceed 95%. In addition, the method introduced to estimate the impact can be extended beyond the boundaries of the research in overtaking maneuvers on two-lane roads that can be applied in other vehicle safety systems.

9 Conclusion

Developing an overtaking assistance system in the field of transportation is of huge importance because it could make one of the most difficult and dangerous maneuvers on two-lane rural roads safer. This paper presented a fundamental approach to developing a unique intelligent system to assist drivers to perform overtaking maneuvers safely. Using a Bayesian network and information via communicated HBMs, the DOAS proactively measures the possibility of overtaking preceding vehicle(s) by considering whether the gap distance to any oncoming vehicle is sufficient for overtaking, taking into consideration different variables related to the driver, vehicle, traffic, road, and the ambient environment. The work presented reports promising results, delivering significant improvements to overtaking maneuvers. The approach will provide a foundation from which to develop a real-life application system capable of predicting safe overtaking maneuvers with minimal near-collisions or no accident risk without overloading the VANET data transmission medium.

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