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A DECISION-MAKING MODEL FOR EXPLAINING DRIVER BEHAVIOR

Ph.D. Dissertation Precis

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1 Introduction

The Global Status Report on Road Safety 2018 (WHO, 2018) reveals that in 2016, approximately 3700 people died in road traffic accidents (RTAs) per day in the world, and tens of millions of people are injured or disabled every year. Although the knowledge about RTAs is increasing, there are still many lives lost on the roads. This is evident even in the most developed countries. For example, more than 90 people die in the RTAs in the USA every day (NHTSA, 2019), or more than 70 in the European Union (EC, 2019).

To develop as efficient as possible programs in the field of traffic safety, the policymakers permanently need to analyze the causes of accidents and to understand as good as possible the concept of driver behavior. There are three general categories of causes of RTA occurrence: the vehicle, road, and human factor. It is generally accepted in the literature that the human factor is the far most common cause of RTAs. Therefore, it is a need to investigate the driver behavior with the aim to conclude what kind of human activities lead to the increased likelihood of RTA occurrence. Furthermore, the studies are confirming that the human activities that lead to the RTAs are induced by certain psychological traits of a driver.

The main goal of this dissertation is to propose a methodology for modeling driver behavior based on the investigation of current methods of explaining driver behavior. This modeling would be based on assessing the propensity for RTAs by knowing the personality traits of a driver. To achieve this, it is necessary to examine which psychological instruments should be used for assessing the personality traits of a driver and what are the adequate research methods that can be applied for this purpose.

Consequently, in this dissertation, the data are collected by four questionnaires related to psychological constructs of drivers and one general questionnaire concerning demographic issues and driving history. The survey is carried out covering a sample of 305 drivers of different age groups, including both professional and the drivers of privately owned vehicles.

To analyze the data, two general approaches are applied. The first relates to statistics and the second to fuzzy logic. On one hand, to determine the relationships between the variables of interest, the hierarchical regression analysis and binary logistic regression are implemented. On the other hand, the modeling of driver behavior is performed by testing various Fuzzy Inference Systems (FISs) and after the most convenient type is determined, its optimization is done by the proposed bee colony optimization algorithm. The final FIS which describes the empirical data in a best-found way can be used as a decision-making tool for explaining driver behavior. An implementation of the proposed decision-making tool may have significant positive implications in the field of traffic safety, saving the lives of people and bringing to significant cost savings.

2 Overview of the current knowledge

In this section, an overview of existing knowledge in the field of the dissertation is given.

2.1 A review of literature about the causes of accidents, human factor and instruments that can explain driver behavior

In the literature, it is generally accepted that human factors have the biggest and most frequent impact on the occurrence of traffic accidents. For example, based on European Union research (EU, 2019), 95 % of all traffic accidents on Europe's roads involve human error. Similarly, Sam, Velanganni, and Evangelin (2016) reports that human errors are recognized as the far most common influential factor causing more than 90 % of RTAs. This factor may be analyzed in various segments, such as fatigue, inattention, impairment from drugs or alcohol, risky maneuvers, violation of traffic rules, etc. Duan, Xu, Ru, and Li (2019) classified and quantified driving fatigue according to the driving fatigue degree. The authors determined three levels of driving fatigues: mild, moderate, and severe fatigues, by measuring the variations in a heartbeat using an electrocardiogram. Further, they concluded that drivers become fatigued within a significantly shorter time while driving in the high-altitude area. Li and Chang (2019) used the geographic information system to collect traffic accidents data and concluded that the most frequent cause of accidents were: illegal overtaking, road races, lane change, improper driving direction, drunk driving, and not maintaining a safe distance. Further, operating a vehicle while impaired by alcohol or drugs is a serious offense that can lead to the occurrence of RTAs.

It is proven that the drivers who do not respect the traffic rules in one segment, usually do not behave properly also in some other segment. For example, the drivers in Serbia are forbidden to talk on the phone while driving, except when using a hands-free device. A study by Čubranić-Dobrodolac, Čičević, Dobrodolac, and Nešić (2013) showed that the participants who violate this rule, are prone to drive under the influence alcohol as well, especially the group of drivers who experienced more than three RTAs in their driving experience. This points to the conclusion that the human factor as a cause of RTAs and general driver behavior can be explained to a large extent by the corresponding psychological traits, as confirmed by Elander, West, and French (1993), Furnham, and Saipe (1993), Ulleberg, and Rundmo (2003), Shinar, (2007), Sârbescu, and Maricuţoiu (2019) or Zheng, Ma, and Cheng (2019). Accordingly, there is a need to investigate which psychological traits can indicate an accident-prone driver, and how to identify them to prevent or reduce the number of RTAs and their consequences.

There are many instruments for the assessment of psychological traits that can explain driver behavior. By reviewing the literature, it can be concluded that there are two most common psychological traits considered as the most important indicators of drivers who are characterized by risky behavior in traffic and who are prone to participate in RTAs: aggressiveness and impulsiveness (Jonah, Thiessen, & Au-Yeung, 2001; Dahlen, Martin, Ragan, & Kuhlman, 2005).

Reports of aggression in the context of driving cite different forms of behavior in traffic that range from flashing lights, honking, verbal threats to other traffic participants, gestures, incapacity to maintain the proper distances from other vehicles, blocking and cutting the road to other vehicles up to more pronounced forms of aggressive behavior, such as car-ramming or even physical attacks on other drivers (Özkan, Lajunen, Parker, Sümer, & Summala, 2010). In the report of AAA Foundation for Traffic Safety (FTS, 2009), aggressive driving behavior has been identified as the basic cause of 56 % of accidents with fatalities occurred in the USA between 2003 and 2007. When it comes to the impulsiveness, there are different definitions in the literature. In the broadest sense, impulsiveness is defined as a tendency to react quickly and unexpectedly, without thinking about the negative consequences of such a response or alternative reactions (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Despite the apparent conceptual overlap and close relationship between the considered two psychological traits, in terms of poor appraisal of behavioral outcomes during decision-making, as well as insufficient self-control, they should not be equated, whereas aggressive behavior, as opposed to impulsive, includes the intent to harm the other person. The psychological instrument more related to the aggressiveness is the Aggressive Driving Behavior Questionnaire (ADBQ). On the other hand, the instrument for measuring impulsiveness is the Barratt Impulsiveness Scale (BIS-11).

The ADBQ was designed by Mouloua, Brill, and Shirkey (2007). The authors intended to create an instrument with good predictive power considering aggressive situations that are typical in driving. These vary from gestures directed toward other drivers to explicit aggressive outbursts, such as passing through a red light at an intersection. The instrument contains 20 questions. The respondents were asked to assess the likelihood of manifestation of aggressive driving using a 6-point Likert scale. Results were given in the range of 1 = never to 6 = almost always. Based on the answers, a score from the ADBQ could range from 20x1=20 to 20x6=120.

The BIS-11 instrument is used for the assessment of impulsivity while driving. In this thesis, a version of BIS-11 constructed by Patton, Stanford, and Barratt (1995) is implemented. The questionnaire consists of 30 questions, which cover a variety of situations and aspects characteristic of impulsive behavior. The respondents were required to estimate, using a 4-point Likert scale, the extent to which they agree with the statements that describe the most representative impulsive habits and practices. The scaled responses correspond to the following statements: from 1 = never/rarely to 4 = always/almost always. The score obtained from this instrument can vary from 30 to 120. When speaking about the previously explained psychological traits - aggressiveness and impulsiveness, it should be noticed that they are mostly considered as innate traits. On the other hand, in the literature, there are also psychological instruments for explaining driver behavior that measure the traits acquired during life. These relate to the attitudes of drivers and their self-assessment (Sundström, 2008; Jain, Calvert, Clayton, & Parkhust, 2017). An example of the instrument that measures attitudes is the Manchester Driver Attitude Questionnaire (DAQ). The Questionnaire for Self-Assessment of Driving Ability measures the mentioned self-assessment of drivers.

The Manchester DAQ is a questionnaire for the assessment of attitudes toward risk propensity while driving, constructed by Parker, Lajunen, and Stradling (1998). The questionnaire consists of 20 questions with a Likert scale of answers from 1 = strongly disagree to 5 = strongly agree. Most questions refer to the typical traffic situations that can be characterized as high-risk. The DAQ includes statements relating to speeding, drink-driving, close-following, and dangerous overtaking. Here the scores are arranged in such a way that higher scores correspond to higher risk propensity while driving. Scores of subjects could range from 20 to 100 points.

The Questionnaire for Self-assessment of Driving Ability was developed by Tronsmoen (2008). It consists of a set of statements about how drivers react in certain traffic situations. Based on the responses, it is possible to obtain information about participants' self-perception as a driver. There are 22 questions and answers in the form of a 4-point Likert scale. Answers ranged from 1 = never, to 4 = always/almost always. A higher score on the test corresponds to a better evaluation of one's driving abilities.

2.2 A review of literature about the use of hierarchical regression analysis and binary logistic regression to examine a relationship between the variables of interest

To assess a relationship between the variables of interest by a statistical method, the hierarchical linear regression is very popular in the literature. The implementation of this technique implies a design of several models called "blocks" by adding the variables gradually. A purpose is to examine whether adding variables significantly improves a model's ability to predict the criterion variable, in this case, the involvement in RTAs.

Swann, Lennon, and Cleary (2017) introduced the Driving Moral Disengagement Scale (DMDS) to examine if a moral disengagement can be a predictor of aggressive driving. The drivers who achieved high scores on driving moral disengagement were significantly more likely to report aggressive responses to driving situations than those with low driving moral disengagement scores. By their implementation of hierarchical regression, the results show that driving moral disengagement significantly predict driving aggression, being a more useful predictor than driving anger. The paper of Yang, Liu, Su, Cherry, Liu, and Li (2018) investigate the psychological motivation for e-bike drivers for red-light running, which represents an action characterized by a high level of risk in traffic. The results of hierarchical regression showed that attitude and perceived behavioral control, moral norm and self-identity are significant predictors for the intention of red-light running behavior. Antoniazzi, and Klein (2019) collected the data from 550 motorcyclists and by using hierarchical regression concluded that sensation seeking and aggression are strongly associated with driver behavior, such as riding errors, speeding, etc. Erkus, & Ozkan (2019) used the hierarchical regression on the sample of 38 male taxi drivers and 40 male private car users and concluded that safety skills are in opposite associations with young male drivers' speeds, overtaking behaviors, and their behaviors at traffic lights.

In the case when the dependent variable is binary in nature or it is presented in this way, a simple linear regression is not useful; however, we can use binary logistic regression. The purpose of binary logistic regression implementation is to predict the relationship between predictors or independent variables and a predicted variable or dependent variable. It should be noted that in this case, the dependent variable is binary, which means that that it can take one of two values. Binary logistic regression is widely used in the literature and here are some cases where this statistical technique is implemented in the field of driver behavior.

Hussain and Shi (2019) examined the effects of driving without prior driving training and without driving licenses on traffic safety. They implemented the binary logistic regression and concluded that this type of violation is a significant factor that influences RTAs involvement. Duy, Nguyen, De Gruyter, Su, and Nguyen (2019) carried out a survey with 602 motorcycle taxi riders to examine the influencing factors on the occurrence of RTAs. The binary logistic regression showed that RTAs were associated with low education levels, high daily travel distances, regular smoking, and using a mobile phone while driving. Cheng, Zu, Lu, and Li (2019) investigating a relationship between intoxicated driving factors and involvement in RTAs. The binary logistic regression analysis was performed at the sample of 1010 drivers confirming that blood alcohol concentration affects the likelihood of being involved in RTAs. Hill, Sullman, and Stephens (2019) demonstrated by the binary logistic regression that higher scores at the Mobile

Phone Involvement Questionnaire, which covers drivers' behavioral, normative and control beliefs, is significantly associated with mobile phone use while driving.

2.3 A review of literature about the use of fuzzy logic in the field of driver behavior

Fuzzy logic is widely used in the field of road transportation. Ivanov (2015) offers a review of fuzzy methods in automotive engineering applications where the following domains are differentiated: vehicle dynamic control systems, driver and driving environment identification, ride comfort control, and energy management of electric vehicles. The field of interest for this dissertation relates to modeling driver behavior. This field is of particular relevance for fuzzy applications because psychological and emotional parameters generally imply a certain level of imprecision and fuzziness.

By reviewing the literature, it is possible to segment the implementation of fuzzy logic to model driver behavior in the following areas:

- Examination of the interaction between the driver and road infrastructure;
- Examination of the interaction between the driver and in-vehicle systems;
- Testing the psychophysical characteristics of drivers;
- Determining a driving style.

An example of modeling the interaction between the driver and road infrastructure using fuzzy logic can be found in the study by Lee and Donnell (2007), where a preference is determined for particular types of road markings most suitable during night-time driving. On the other hand, Sentouh, Nguyen, Rath, Floris, and Popieul (2019) analyzed the interaction between the driver and the in-vehicle system and proposed a steering controller for keeping in the lane, based on the integrated driver-vehicle model using the Takagi-Sugeno control technique.

With regard to the psychophysical characteristics of drivers, Boyraz, Acar, and Kerr (2008) designed a FIS to predict the drowsiness level of the driver. The selected signals for analyses included the level of eye closure, gaze vector, head motion, steering wheel angle, vehicle speed, and force applied to the steering wheel by the driver. Similar research was carried out by Wu and Chen (2008), who analyzed the facial images of drivers and proposed a fuzzy system to warn the driver of drowsiness. Riaz, Khadim, Rauf, Ahmad, Jabbar, and Chaudhry (2018) applied the fuzzy sets to compute the distraction of the drivers and proposed a corresponding road safety system.

Lin, Tsai, and Ko (2013) used fuzzy logic as a method for the early detection of motion sickness. These types of distractions while driving can endanger safety because of a decline in a person's ability to maintain self-control.

Fazio, Santamaria, De Rango, Tropea, and Serianni (2016) used fuzzy logic to identify a particular driving style and to model driving behavior. However, their conclusions about driving style were based on the car velocity and acceleration measurement using on-board diagnostics in the vehicle.

Aggressiveness in driving, although a psychological category may be assessed by explicit parameters of vehicle movement, for example by analyzing driving performance. An example of this is demonstrated in the paper by Aljaafreh, Alshabatat, and Najim Al-Din (2012). The authors measured aggressiveness based on the Euclidean norm of lateral and longitudinal acceleration, as well as considering car velocity.

The fuzzy logic was used also to form an accident prediction model based on input parameters which relate to the road infrastructure, such as road width, pavement conditions, average hourly traffic volume, speed, the number of access points to the highway and traffic signs conditions (Wahaballa, Diab, Gaber, & Othman, 2017). Selvi (2009) establishes a similar prediction model based on fuzzy logic through factors such as traffic volume, rain status, and the geometry of the roads.

2.4 A review of literature about the use of Bee Colony Optimization (BCO) metaheuristic in the field of FIS optimization

The optimization of FIS represents a tuning of the characteristics of FIS to minimize or maximize the objective function, depending on a type of the considered task. Here it is mostly the minimization task because the performance of FIS is generally measured as the level of deviation from certain empirical data. There are numerous examples where this procedure is useful. In the case of the current research, it is used to design as good as possible decision-making tool.

Many papers deal with FIS optimization issues. Therefore, here it will be offered just a review of the most frequently used techniques in the field in the last two years, from 2019 to 2020. An interesting fact to notice here is that general principles of FIS optimization set up in the past are valid also nowadays and the changes are in terms of newly applied optimizations methods, which have been proposed in the meanwhile. Guillaume (2001) systemized the procedures for fuzzy rule generations from empirical data and structured the optimization methods as “shared partitions”, “clustering”, and “hybrid methods”. The hybrid methods were based on the implementation of neuro-fuzzy modeling or heuristic algorithms, mentioning Genetic Algorithms (GA) as the most popular at that time.

A development of metaheuristic approaches based on mimicking of behavioral patterns observed in nature has been very popular in recent decades. These techniques were successfully implemented in many cases for solving complex computational tasks, such as optimization of FIS (Castillo, & Melin, 2012).

As previously mentioned, genetic algorithms (GA) are frequently used. Nagammai, Latha, & Varatharajan (2020) used GA to tune the membership functions of FIS for water level control in a conical tank process. Some authors further improved GA algorithms. El-Gendy, Saafan, Elksas, Saraya, & Areed (2020) proposed a hybrid of GA and PSO to tune the parameters of different adaptive PID controllers. The idea of PSO is inspired by the social behavior of bird flocking or fish schooling. The PSO metaheuristic is applied also by Zorić, Tomović, Obradović, Radulović, & Petrović (2019) for a self-tuning fuzzy logic controller of the piezo-fiber reinforced composite actuator.

Ajithapriyadarsini, Mary, & Iruthayarajan (2019) used differential evolution (DE) to optimize the gain of a fuzzy logic-DE algorithm-based PID controller. Ab Talib, Mat Darus, & Mohd Samin (2019) proposed an advanced firefly algorithm (AFA) for improving vehicle dynamics. Tremante, Yen, & Brea (2019) applied the Direct Search (DS) method, specifically the pattern search, for tuning of the membership functions of a FIS.

The Ant Colony Optimization (ACO) algorithm is applied by Aldair, Rashid, Rashid, & Alsaedee (2019) to tune and find the best parameters of the output membership function of the fuzzy controller for robot moves. Precup, Voisan, Petriu, Tomescu, David, Szedlak-Stinean, & Roman (2020) implemented a relatively new metaheuristic called Grey Wolf Optimizer (GWO) inspired by specific leadership styles of grey wolves. Karar, El-Garawany, & El-Brawany (2020) applied the Invasive Weed Optimization (IWO) algorithm inspired by the behavior of weed colonies. Elias & Mat Yahya (2020) applied the bats sonar algorithm (BSA) which is inspired by the echolocation process of a colony of bats to find food or prey.

Mohammadzadeh & Kayacan (2020) proposed the particle swarm optimization and artificial bee colony algorithm (PSO-ABC). The algorithms based on the bees demonstrated very competitive results in optimization procedures. For example, Yazid, Garratt, & Santoso (2019) demonstrated that the ABC outperforms the GA and PSO approach in optimizing the fuzzy logic controller for trajectory tracking of a quadcopter drone. In this dissertation, a "shared partition" and "hybrid method" as segmented by Guillaume (2001) is combined. One class of shared partition is "One rule per pair" and the principle proposed by Wang and Mendel - WM (1992) is the most popular here.

When it comes to the use of metaheuristic algorithms based on artificial bees considering a longer period in the past, there are several cases in the literature where the authors performed the optimization of FIS by this approach.

Some authors use the approach proposed by Karaboga (2005) named Artificial Bee Colony (ABC) optimization. The examples are the following. Chaiyatham, Ngamroo, Pothiya, and Vachirasricirikul (2009) optimized the load frequency control in the microgrid system. Habbi, Boudouaoui, Karaboga, and Ozturk (2015) proposed a methodology based on ABC to define Takagi–Sugeno (TS) fuzzy systems with enhanced performance from data. Konar, and Bagis (2016) applied different population-based approaches for the fuzzy modeling of the nonlinear systems and to perform the fuzzy rules optimization. They compared the performance of ABC, Particle Swarm Optimization (PSO) and Differential Evolution Algorithm (DEA).

On the other hand, some authors used the Bee Colony Optimization (BCO) approach for the optimization of FIS. BCO metaheuristic was proposed by Lučić, and Teodorović (2001, 2002, 2003a, 2003b). Caraveo, Valdez, and Castillo (2016) applied the BCO to optimize the FIS used as a water tank controller, which aims to control the water level in a tank, as well as to control the trajectory of the unicycle mobile robot. The same benchmark control problems were solved by Amador-Angulo, and Castillo (2018) who used BCO and type-2 fuzzy logic for tuning fuzzy controllers. Amador-Angulo, Mendoza, Castro, Rodríguez-Díaz, Melin, and Castillo (2016) proposed an improvement of BCO by dynamic adaptation of the algorithm's parameters. Olivas, Amador-Angulo, Perez, Caraveo, Valdez, and Castillo (2017) made a comparison among Particle swarm optimization (PSO), BCO and the Bat Algorithm (BA), while Castillo, Valdez, Soria, Amador-Angulo, Ochoa, and Peraza (2019) compared the performance of BCO, Differential Evolution (DE), and Harmony Search (HS) algorithms in the optimization of fuzzy controllers.

2.5 A summary of the overview of current knowledge and a research plan

In the dissertation, after the implementation of the considered instruments, certain data were collected. Each participant achieve certain scores on the implemented psychological instruments, which describes the personality traits related to driver behavior of this individual. These scores can be seen as input variables. Additionally, each participant would report the number of accidents in his driving history, which can be considered as an output variable. Here, it should be noticed that the proposed models tend to exclude the impact of age and driving experience on the number of experienced RTAs and to focus exactly on the relationship between the driver's characteristics and RTAs. This is further explained in the methodological part of the dissertation. Therefore, the tasks would be to examine a relationship between the considered input and output variables (Table 1). By reviewing the literature, it is concluded that this relationship can be determined by two general approaches: statistics and fuzzy logic. Speaking about the statistical methods, a convenient statistical method is the hierarchical regression analysis when the output variable is presented as the number of experienced accidents. If the output variable is presented in a binary way (driver participated in accidents or no), then a convenient statistical method is the binary logistic regression.

Tab. 1 The structure of collected data (Source: Author)

Input data	Output data
Score from the ADBQ	
Score from the BISS - 11	The number of road
Score from the Manchester DAQ	traffic accidents
Score from the Questionnaire for Self-assessment of Driving Ability	

In this dissertation, the hierarchical linear regression is used to assess a relationship between the variables of interests, in this case, the scores from four considered psychological instruments and the number of experienced RTAs. Further, it can be very useful to compare the obtained results with another statistical method - binary logistic regression. However, in this case, the dependent variable should be arranged in a binary manner, which means that the participant should be grouped into two groups: those who participated in RTAs and those who did not.

Further, the implementation of fuzzy inference systems in the field of explaining driver behavior is very meaningful. For this aim, four achieved scores from psychological instruments are used as the input variables of the proposed FIS, and the number of RTAs as an output. A result of the FIS represents the quantification of driver propensity for RTAs.

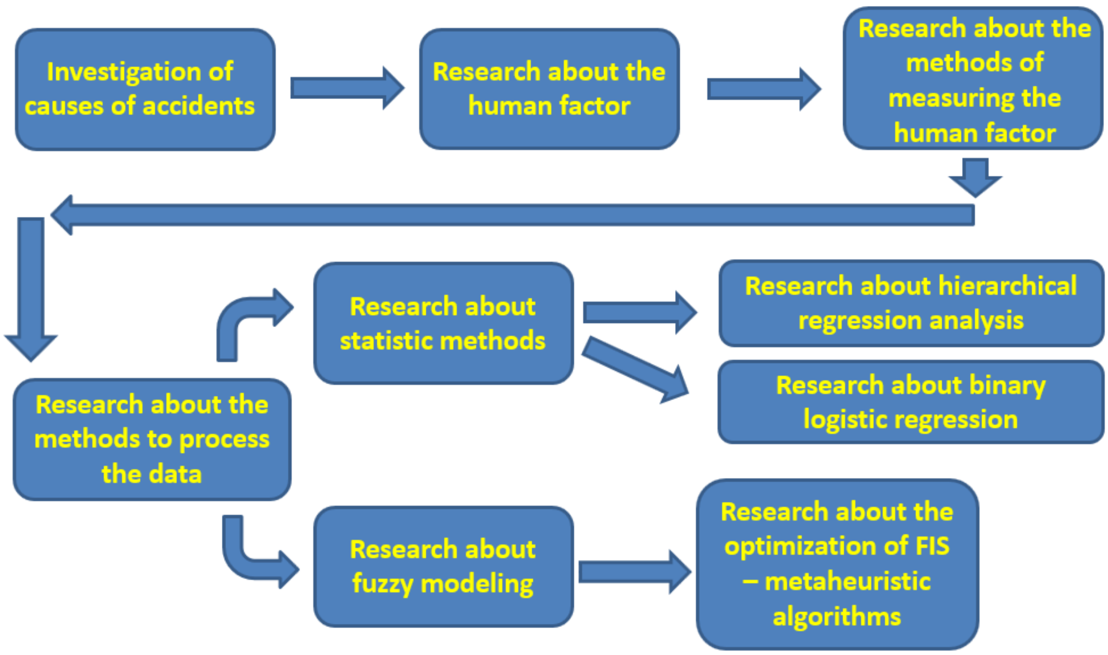

Fig. 1 The structure of the literature review and research plan (Source: Author)

Therefore, various FIS structures are designed and tested in this dissertation. The Wang and Mendel (WM) approach for generating fuzzy rules is applied combined with a metaheuristic algorithm based on Bee Colony Optimization (BCO) to perform the optimization of different FISs.

The overall conclusion of the literature review would be that the proposed methods would support in the best way the investigation about a relationship between the psychological traits and driver behavior. Besides, the implementation of the proposed methods would lead to the design of a decision-making tool that can be used for various purposes in the field of traffic safety. Based on the literature review, a research plan is structured as shown in Figure 1.

3 The main objective of the dissertation

One of the crucial questions in the transportation field is how to reduce the number of lost lives on the roads. A human is the most important and also the most complex factor in traffic safety. When participating in traffic, the driver is expected to possess adequate abilities, knowledge, and skills and to perform safe driving maneuvers. The lack of any of these elements can lead to making mistakes which can result in an RTA. When it comes to the analysis of the dominant personality traits of the drivers, many studies have shown a strong connection between risk perception and involvement in accidents. By understanding the factors affecting the RTAs occurrence, the ability to define adequate measures increases which should reduce the negative consequences of inappropriate behavior.

The primary objective of the research is to propose the most appropriate methodology for modeling driver behavior based on a detailed investigation of the literature and current methods of explaining driver behavior. To achieve a conclusion about the most convenient methodology, different methods are compared. The final result of modeling would be a decision-making tool for explaining driver behavior, to be used in various situations in transportation, with the main aim to improve traffic safety and save the lives of people.

To achieve the explained primary objective, it is necessary to fulfill the following partial objectives:

- To carry out a survey that implements relevant psychological instruments, as well as the demographic questionnaire;
- To perform the statistical analyses of collected data;
- To implement the hierarchical regression analysis to examine a relationship between the variables of interest;

- To implement the binary logistic regression to examine a relationship between the variables of interest;
- To implement a fuzzy logic for modeling driver behavior;
- To propose an algorithm based on BCO metaheuristic for the optimization of FIS for modeling driver behavior.

4 Overview of the research methods used to fulfill the objective of the dissertation

In this dissertation, the general, as well as specific scientific methods are used. General scientific methods are the following: analysis, synthesis, deductive and inductive reasoning, abstraction and concretization, analogy and comparison, as well as modeling. On the other hand, the applied specific methods are the following: for data collection – five types of questionnaires (a demographic one and four psychological instruments), hierarchical regression analysis, binary logistic regression, fuzzy logic, and BCO metaheuristic.

4.1.1 Hierarchical regression analysis

To analyze the relationship between experiencing traffic accidents and the observed characteristics of the driver, the hierarchical regression analysis is performed. In general, the hierarchical regression analysis is to be used if there is a need to examine whether the independent variables explain a statistically significant amount of variance in the dependent variable after accounting for all other considered variables. The procedure implies forming several regression models by adding variables to the previous model at each step. These models are often called "blocks" or "steps" in the hierarchical regression analysis. In this way, the blocks are compared and a conclusion should be reached about the impact of each independent on the dependent variable, i.e. it should be determined whether newly added variables show a significant improvement in R^2, which is the proportion of explained variance in dependent variable by the model (UVL, 2019).

4.1.2 Binary logistic regression

The binary logistic regression is the statistical technique used to predict the relationship between predictors or independent variables and a predicted variable or the dependent variable, where the dependent variable is binary, e.g. participation in RTAs (yes vs. no).

4.1.3 Implementation of fuzzy logic

In the modeling process, the input variables are the scores (results) from four implemented psychological instruments, and output is the number of RTAs. Based on this, various FIS structures are tested concerning the minimum error in the description of the data. Four types of FIS are considered, as follows: one input–one output system, two input–one output system, three input–one output system, and four input–one output system. The results of the test should lead to a conclusion as to which psychological instrument, or which combination of two, three, or all four of them, provides the best prediction results regarding driver propensity for RTAs.

4.1.4 Implementation of BCO metaheuristic

The main characteristic of BCO is that the artificial bees collectively search for the best solution and each bee is independent in the searching procedure. However, in certain moments, they compare their obtained solutions and a bee decides to continue its search following some other bee or be loyal to its own solution. The main idea behind is that certain bees should follow the bees with better solutions in order to find as good as possible solution. When a bee searches for a solution, this part of the algorithm is called *forward pass*, while the procedure of returning to the hive and comparison of achieved solutions is called a *backward pass*. All decisions are made with an adequate probability level, having in mind the quality of current achieved solutions. Instead of deciding based on the absolute values of achieved solution, the probability in the bee's decision-making to follow other bee or to stay loyal to its solution is introduced in order to avoid being trapped in local optimums.

5 Results and discussion

The results of the research and implemented methods are structured in five subsections. The first is devoted to the results of the applied questionnaires. The second subsection shows the results of hierarchical regression analysis, followed by the third where the results of binary logistic regression are. The fourth part is related to the implementation of FIS for driver behavior modeling, while in the fifth there are the results of the proposed BCO algorithm for FIS optimization.

5.1 The results of hierarchical regression analysis

By considering the β coefficients obtained in the hierarchical regression analysis and confirmed by the correlation coefficients, it can be noticed that the impact of impulsiveness on the occurrence of RTAs is the highest, followed by aggressiveness (with relatively similar values of β coefficient), while the β coefficients in the case of attitudes toward risk and driving ability self-assessment are considerably lower (with relatively similar values).

5.2 The results of binary logistic regression

To test the cognition about the impact of psychological characteristics on the occurrence of RTAs in some other way, by a differently structured independent variable, a binary logistic regression is applied. The dichotomous dependent variable is related to the (non)participation in RTAs reported by the drivers in the questionnaire. The first category includes the respondents who had not experienced accidents in their driving history, while the second category concerns drivers who reported accidents (regardless of the number). From the results, it can be concluded that the variables which significantly contribute to the predictive power of the model are those related to DAQ, ADBQ, and BIS-11, while the instrument for self-assessment of driving ability does not show a statistically significant contribution to the model.

5.3 Modeling driver propensity for traffic accidents by a fuzzy logic approach

The result of the modeling process is the proposal of a model that can provide information about driver propensity for traffic accidents, based on the scores obtained from four psychological instruments. The modeling process consists of testing various structures of fuzzy inference systems (FISs) to select the one that produces the minimum amount of error in the description of data. Finally, the selected FIS is compared with the results of statistical analyses; in this case with multiple regression analysis. The results of the final calculation indicate that the best found FIS has four inputs and one output variable.

5.4 Proposal of a Bee Colony Optimization (BCO) based algorithm to improve a fuzzy inference system for driver behavior modeling

This Section aims to further optimize the best-found FIS in previous Subsection 5.3. The optimization here means that the considered FIS should be adjusted to the empirical data. The proposed algorithm is based on BCO metaheuristic. To illustrate the level of improvement achieved by the implementation of the proposed BCO based algorithm, the relationship between FIS structures that are not optimized by the proposed algorithm and also multiple regression analysis, and the best-found FIS are shown in Figure 2.

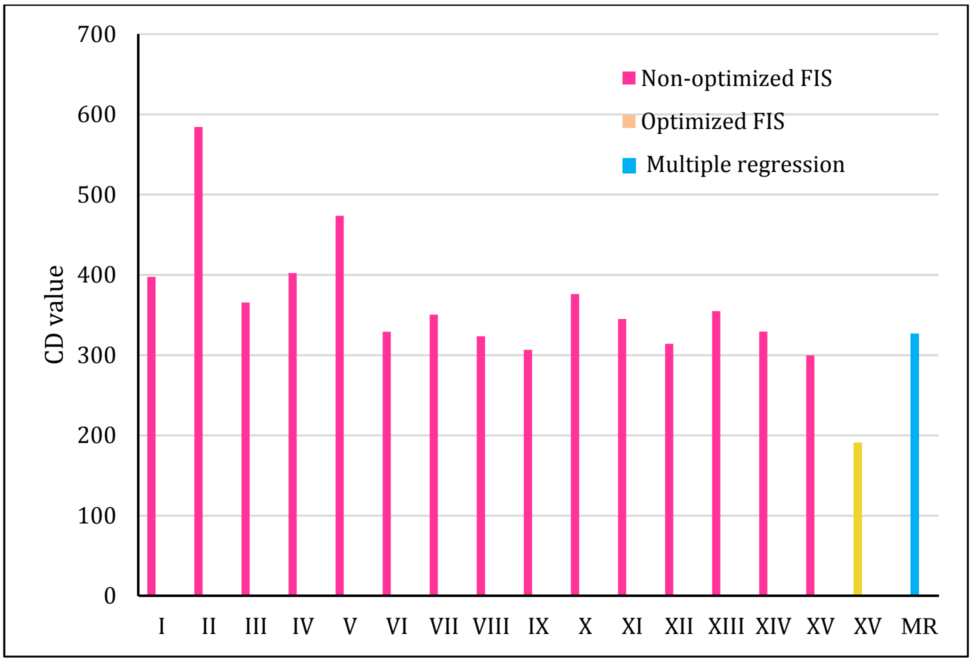

Fig. 2 A relationship between the optimized FIS, non-optimized FIS structures, and multiple regression analysis (Source: Author)

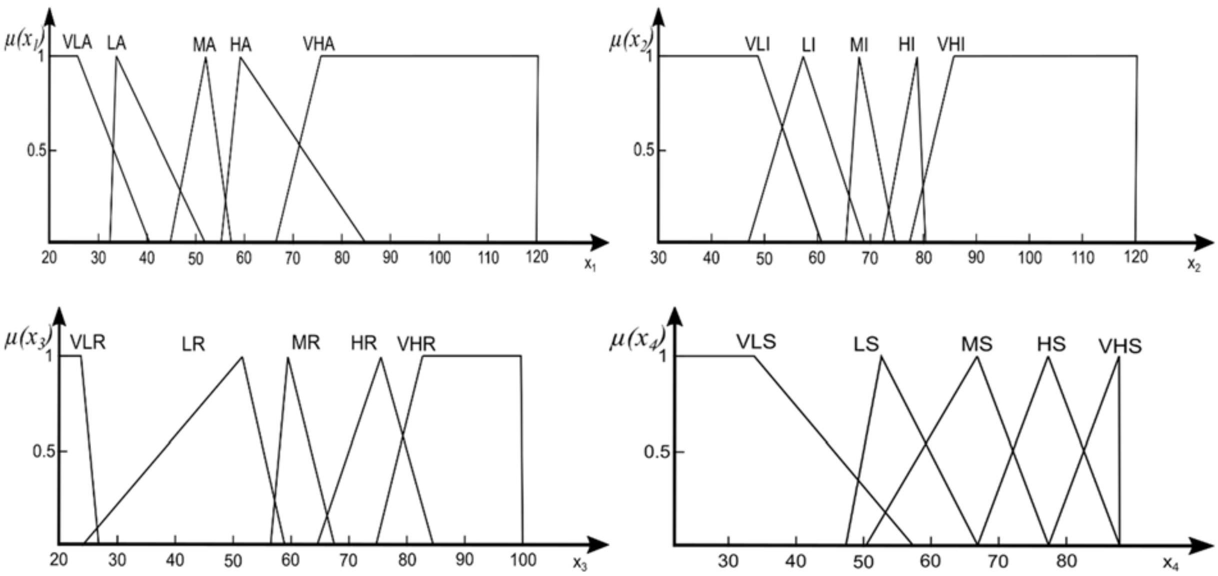

Fig. 3 MFs for input variables of the best found FIS (Source: Author)

To illustrate the characteristics of the best-found FIS, the position of MFs and fuzzy rules should be considered. The MFs of input variables of the best-found FIS are presented in Figure 3. On the other hand, fuzzy rules in the proposed BCO algorithm are designed based on the Wang-Mendel approach. This approach implies the principle of „one data pair – one rule“, however, considering the sample of 305 participants, there are 121 fuzzy rules generated from these data. The remaining 184 rules are eighter the same or conflict to these 121 rules. The list of fuzzy rules obtained by the Wang-Mendel approach is presented in Appendix C of this Ph.D. dissertation.

6 Conclusions

By reviewing the literature, it is concluded that the topic of explaining driver behavior is very important and contemporary because its better understanding can contribute to saving many lives on the roads. Further, to design a model for explaining driver behavior, it is concluded to be useful to consider two types of psychological traits of drivers – innate and acquired. Speaking about the innate, the studies confirm that the most significant psychological traits of drivers who are characterized by risky behavior in traffic and who are prone to participate in RTAs are aggressiveness and impulsiveness. Accordingly, two psychological instruments that measure these traits are chosen. When it comes to the acquired traits, which are considered as more convenient for the subsequent corrective measures of the risky drivers, they relate to the attitudes and self-assessment. Two additional psychological instruments that measure these constructs in traffic are introduced.

After a collection of data about the scores from four considered psychological instruments examining 305 participants, the adequate research methods were used to reach the appropriate conclusions.

The outcome of this dissertation is a proposal for the methodology consisting of the implementation of the hierarchical regression analysis, binary logistic regression, multiple regression analysis, fuzzy inference systems, and bee colony optimization metaheuristic, which purpose is to model driver behavior. The original models for assessing the circumstances of traffic accidents occurrence based on the driver's personality traits related to the impulsiveness, aggressiveness, attitudes, and self-assessment of personal driving abilities are proposed and tested on the real data collected for the purpose of this dissertation. As a final result, there is a decision-making model designed to assess a driver propensity for traffic accidents. The main decision-making model is based on the implementation of the FIS and BCO metaheuristic where input variables relate to the considered psychological traits of driver and output variable to the number of experienced RTAs.

Because the proposed FIS provides information about driver propensity for RTAs, the criteria used in the selection of professional drivers could be significantly improved. Certainly, the transportation companies have an interest to hire drivers who are not prone to participate in RTAs; however, this is also the interest of society as a whole. The recruitment procedure would involve the use of proposed instruments for assessing personality traits along with the psychomotor tests. When it comes to the implementation of the decision-making tool proposed in this Ph.D. dissertation, the procedure would be very simple. A human resource professional would collect the data concerning the candidate's personality traits using four determined instruments. The obtained scores should be inserted as inputs in the best-found FIS, and the result about the propensity for RTAs would be automatically calculated by using appropriate software.

In addition, the proposed decision-making tool for explaining driver behavior may have its practical implication in the design of training and education processes for candidates applying for a driving license. Furthermore, programs for the prevention of accidents and violations of laws, or for the rehabilitation of drivers who have been deprived of their driving license may be developed more effectively, according to the personality traits of the driver. Further, the results of this research could be usefully applied for some categories of vulnerable drivers to raise awareness about the consequences of risky behavior in traffic. For example, young drivers show a high rate of involvement in RTAs, especially at the beginning of their driving experience.

Finally, the main contributions of this dissertation can be structured in several fields. The first relates to a comprehensive review of the literature related to the RTAs, driver behavior, and implemented research methods. Further, the original research methodology and original decision-making tool for explaining the driver behavior is proposed. To test the proposed methodology, a survey is carried out involving 305 participants. The proposed methodology proved to be useful for explaining driver behavior and the results of this dissertation have both scientific and practical implications. From the scientific point of view, the original methods and algorithms are proposed, making a significant contribution, especially in the field of optimization algorithms. Speaking about the practical implications, the proposed decision-making tool can be used in practice, offering various benefits, from saving the lives of people in traffic to significant economic and social benefits.

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