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A MODEL FOR THE CRASH OCCURRENCE IN UNEXPECTED INCIDENTS

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The objective of this paper is the investigation of the parameters that influence the crash occurrence in the case of an unexpected incident. It draws inspiration from the Safety System Approach, which is built on the position that serious injury and death in transport networks cannot be ethically acceptable. To this end, the research takes into consideration parameters regarding both the road environment and the human factor. A driving simulator experiment takes place with the participation of 56 drivers, and the employment of the appropriate equipment (driving simulator, physiological parameters sensors and software, camera, synchronization software). It investigates the effect of different road and environment parameters (road category and complexity of the environment, visibility conditions), parameters of the driver (age, gender, mental workload), physiological parameters of the driver (heart rate, skin conductance, skin temperature) and the reaction time of the driver to the unexpected incidents, as well as the way of reaction (brake, maneuver, both, none). Furthermore, parameters of the vehicle are taken into consideration (speed, acceleration, headway). A mixed logistic regression model is being developed for examining the relationship between the under study explanatory variables and the crash occurrence in unexpected incidents.

Keywords: Road safety, crash occurrence, unexpected incident, mixed logistic regression model

1. Introduction

The present paper aims to investigate the parameters regarding the road environment and the human factor that influence crash occurrence in the case of an unexpected incident while driving. Unexpected incidents include any temporary or random situation occurring on the road and which the driver does not anticipate encountering. Among the unexpected incidents commonly found in literature are: random objects on the road, the unexpected presence of a pedestrian or an animal, an unexpected maneuver of another vehicle, etc. (Schaap *et al.,* 2008; Papantoniou, 2015; Briggs *et al.,* 2018; Powelleit and Vollrath, 2019).

The present study is part of a wider research that takes place in the context of a doctoral dissertation concerning the study of out-of-the-vehicle factors that influence driving behavior. The approach focuses on Greek drivers, emphasizing driver's reactions to visual stimuli.

1.1. The worldwide landscape of road safety

Despite the 16% decrease in death rate since 2010, statistics showing a current estimate of 15 road traffic deaths per 100.000 people in 2021, still demonstrate the need for greater effort on further improving road safety. Moreover, progress is not evenly distributed, with vulnerable users, mainly from middle and low incomes, being hit hardest. Taking into account the existence of proven effective road safety measures already in place, the World Health Organization underlines that the price paid for mobility is very high, requiring action to achieve the relevant goals at national and global level (World Health Organization, 2018, 2023).

The prioritization of road safety, with the ultimate target of mitigating or even completely preventing deaths and serious injuries from road crashes, is reflected in a number of publications, from the White Paper issued by the European Union in 2011 (European Commission, 2011), to the Global Plan for the Decade of Action for Road Safety 2021 – 2030 published by the World Health Organization (World Health Organization, 2021). Nowadays, the Safety System Approach represents the forefront philosophy in road safety. It is based on the position that serious injuries and deaths in transport networks cannot be morally acceptable, dividing responsibility between authorities and citizens, and providing a set of design and operational principles for taking action towards achieving this long-term goal (International Traffic Forum, 2022; World Road Association (PIARC), 2023). Today, the Safe System Approach is at the heart of road

safety policymaking at global, regional and national level. It has been adopted by the United Nations General Assembly, the United States Department of Transportation and the European Road Safety Strategy 2021-2030 (European Parliament, 2021; U.S. Department of Transportation, 2022).

1.2. The human factor, the road and the environment in road safety

International literature reaches a consensus on the critical role of the human factor in road safety. Either as vehicle drivers or as pedestrians or other road users, people are the main decision-makers in the driver-vehicle-road and environment system (Shinar, 2007; Gregoriades *et al.*, 2010; Borsos *et al.,* 2015; Papantoniou, 2015; Zhu and Yue, 2024). Additionally, the Safe System Approach considers human error as the last failure in a chain of events leading to crash (World Health Organization, 2021).

The drivers are responsible for evaluating, assessing and processing the information received while driving, in order to make the right decisions and properly adapt their behavior. The international literature has highlighted as influencing factors of the driving behavior, among others, the driver's personality, demographic data (gender, age, etc.), experience, maturity, skills, driver stress, the state of the driver (fatigue, sleepiness, etc.), situational factors, etc (Shinar, 2007; Borowsky *et al.*, 2010). Vehicle parameters include factors related to its construction and operation, while the parameters belonging to the road and environment refer to elements of the built road environment directly connected to the driving task, but also to elements of the surrounding environment, either related or not to the driving task. The decisive influence of the environment on the driver perception highlights the importance of the appropriate design of the road and the environment to guide users towards safe decisions (Brookhuis *et al.*, 2003; Shinar, 2007; Pasetto and Barbati, 2011).

1.3. MWL and the driving task

The concept of Mental Workload (MWL) has been introduced to better understand driver behavior within the framework of the information processing approach. MWL encompasses both cognitive load and stress, describing the mental resources required to perform a task (Wiberg *et al.*, 2015; Young *et al.*, 2015). It is an important psychological construct influencing road crashes and driver performance, determined by task demands, external support, and past experience (De Waard, 1996; Schneegass *et al.*, 2013; Borsos, *et al.*, 2015; Young *et al.*, 2015). The multidimensional nature of MWL makes it complex to define, with a general analogy being drawn between task demands (stress) and the impact on the driver (strain) (ISO 10075, 2000). High MWL can lead to dangerous situations as it depletes the mental capacity available for concurrent activities, potentially resulting in either incorrect choices due to insufficient information or the rejection of critical information due to overload (De Waard, 1996; Fuller, 2005; Young *et al.*, 2015; Pouliou *et al.*, 2022).

Driving is inherently complex due to the constantly changing road and traffic conditions, and the intricacies of human behavior (Cantin *et al.*, 2009; Faure *et al.*, 2016; Zhu and Yue, 2024). When unexpected situations arise, they demand immediate attention and trigger a compensation process to ensure safety. Drivers must quickly adjust their behavior to maintain control of the vehicle, with their reaction depending on the nature of the incident and their individual characteristics, i.e., parameters related to the human factor (Shinar, 2007; Paxion *et al.*, 2014; Pouliou *et al.*, 2022). Higher MWL, often due to engagement in secondary tasks, can lead to longer reaction times (RT) and a reduced ability to detect unexpected incidents (Shinar, 2007, 2015). Most drivers tend to brake as an initial response to sudden incidents, even when maneuvering is possible, and maybe more efficient (Adams, 1994; Dozza, 2013; Powelleit and Vollrath, 2019). RT do not follow a linear pattern and delays in perception, decision-making, and action significantly contribute to road crashes (Macadam, 2003; Marcillo *et al.*, 2024). Improvements in road conditions and the use of Advanced Driver-Assistance Systems (ADAS) can enhance drivers' perceptual abilities and RT, although these can be adversely affected by distractions such as phone use (Ruscio *et al.*, 2015; Ruscio *et al.*, 2017; Žuraulis *et al.*, 2018). Additionally, older drivers generally exhibit longer RT, especially when tasks require higher cognitive effort (Makishita and Matsunaga, 2008). Awareness of how increased MWL impacts driving behavior can lead drivers to adopt compensatory strategies, like reducing speed, to mitigate risks (De Waard, 1996; Shinar, 2007, 2015).

The improvement of the human factor in road safety is considered particularly important, requiring the in-depth analysis of the factors that influence the driving behavior. It is considered the best - economically and socially - way of upgrading road safety, in contrast to the "harsh" and demanding measures taken to improve the vehicle, the road and the environment (e.g. new infrastructure, equipment, facilities). Still, even for the case where the improvement of vehicles, the road and its environment are being studied, the impact of these potential changes on driving behavior is a necessary element for a comprehensive approach to the issue (Pouliou *et al.*, 2022, 2023).

2. Materials and methods

For the purpose of this research, a driving simulator experiment took place in the driving simulator of the Hellenic Institute of Transport, part of the Centre for Research and Technology Hellas, with the participation of 56 drivers.

The experiment consisted of the preparation part, the driving part, and the completion of the online questionnaire in two phases (before and after the driving test). The preparation part was designed to inform and train the participating drivers on the experiment and its procedures, including the first phase of the research questionnaire, aiming to gather demographic and driving data, as well as road safety data about drivers' attitudes and habits. The driving part was designed to last less than 30 minutes, to facilitate the correct completion of the second part of the questionnaire without information loss (De Waard, 1996). This second part of the questionnaire acquired data on the drivers' experience during the experimental process and the Rating Scale of Mental Effort (RSME), without and with the secondary task employed. The driving part was designed to include a familiarization drive within the simulator vehicle and two driving routes (driving scenario A and B) (Figure 1).

Figure 1. (a) Scenario A: driving in good weather (high visibility); (b) Scenario B: driving in fog (low visibility)

In each driving route, approximately six kilometers long, six unexpected incidents were programmed to occur, requiring the driver's reaction to keep the vehicle on a safe trajectory. Different types of unexpected incidents (i.e. animal/child/pedestrian crossing the road, vehicle leaving parking slot, door opening) and in a different implementation sequence, were opt for minimizing potential learning effects that could impact research results. Furthermore, the two scenarios were presented in a different order to the drivers, approximately half of the drivers drove scenario A first, while the remaining drivers initiated the experiment with driving scenario B.

In part of each route, the driver also performed a secondary task of delayed digit recall [MIT AgeLab Delayed Digit Recall Task / DDRT (1-back)], enabling the study of driving behavior in conditions of increased mental workload. The MIT AgeLab Delayed Digit Recall Task (n-back) (DDRT), originally proposed by Mehler *et al*. (2011), was adapted to the present research needs, aiming to elevate a drivers MWL by engaging their short-term memory while driving. It involved recorded auditory stimuli, in which drivers were asked to respond verbally. A sequence of 10 single digits (0-9) was played in random order, with a 2.25-second interval between each digit. During the drive, drivers were prompted to recall the 1-back digit from the sequence. The DDRT was initiated after the occurrence of the first two unexpected incidents, allowing for two incidents in each state (No additional MWL/With additional MWL).

The two driving routes presented distinct conditions. Scenario A included driving in good weather (high visibility) and scenario B included driving in fog (low visibility). Both driving routes have been developed to create the following distinct driving conditions:

- Road network: driving in interurban network / driving in urban network
- Mental workload: driving without extra mental load / driving with extra mental load (DDRT).
- Unexpected incidents: six incidents were programmed in each scenario (four in the interurban network / two in the urban network).

The experiment was realized with the employment of the appropriate equipment, including:

- the driving simulator, based on a real vehicle (Mercedes-Benz Smart) moving on a dynamic platform, enabling the recording of multiple parameters [e.g., speed, acceleration, drivers' reaction time (in sec) and drivers' way of reaction (brake, maneuver, both, none) to unexpected incidents],

- physiological parameters' sensors and software, for recording and editing the drivers' physiological data (heart activity, skin conductance and temperature),
- camera, recording the drivers' field of vision to perform quality control of the simulator data, and draw additional data regarding drivers' reaction,
- synchronization and control software, which communicated with individual systems, receiving system time for their synchronization, it initiated the driving scenario in the simulator and the camera, and produced a log.sqlite database,
- data post-processing software, used to extract produced data into new format files, more suitable for analysis and drawing conclusions.

2.1. Sample

The research was implemented with the participation of a total of 60 volunteer drivers. Among them, 4 individuals experienced significant difficulties due to simulator sickness and were unable to complete the driving task successfully. Consequently, the final sample size for the study consists of 56 drivers, with 48% being female and 52% male. Participants were categorized into four age groups: age group 1: 18–25 year; age group 2: 26–40 years; age group 3: 41–55 years; and age group 4: >56 years. The distribution of participants covered all age groups, ensuring that the sample was representative of Greek drivers in terms of age and gender. Table 1 presents the distribution of the sample size (N) to the age groups, the percentage (%) of each age group per gender, as well as the Standard Deviation (SD) for each age group in total. Specific exclusion criteria were applied to the sample:

1. the successful training in the DDRT (if less than 7/10 corrects answers in 0-back DDRT and less than 7/9 correct answers in 1-back DDRT, driver excluded),
2. health conditions or medications that could affect driving (if yes, driver excluded),
3. any form of nausea, such as simulator or travel-related nausea (if yes, driver excluded), and
4. the possession of a valid class B driver's license (if no, driver excluded).

Table 1. Gender and age distribution of sample

Age group	N	SD	Male		Female	
			N	%	N	%
1: 18 - 25	6	0,548	3	10%	3	11%
2: 26 - 40	19	0,513	10	34%	9	33%
3: 41 - 55	17	0,514	9	31%	8	30%
4: > 56	14	0,519	7	24%	7	26%
Total	56	0,504	29	100%	27	100%

2.2. Analysis methods

Current research data were edited and processed with the use of CAPTIV software, Microsoft Excel, and the custom-made data post-processing software. Next, they were analyzed by applying descriptive and inductive statistics employing the R software. Descriptive statistics were applied to the data set, aiming to understand the collected and processed data, and to draw conclusions after observing the relevant data. Next step in the research analysis was the implementation of inductive statistics, attempting to analyze the data, using statistical hypothesis testing and analyses, to identify the parameters that affect the under-study variable, i.e. crash occurrence. To investigate the effect of the studied parameters on the crash occurrence in an unexpected incident, the approach of mixed effect logistic regression was chosen as the most appropriate. This choice was made due to the binary nature of the dependent variable (crash occurrence: yes/no), as well as the existence of two subsets of measurements for each driver, one subset of data resulting from scenario A and one subset from scenario B. Different traditional models would fail as all observations were not independent to each other.

3. Results

An initial exploration of the under-study variables aimed to investigate possible correlations between them and was performed through the development of the correlation table (Figure 2), included Reaction Time (RT), speed, acceleration, headway [distance from the front vehicle (HWay)], Heart Rate (HR), Skin Conductance (SC), and Skin Temperature (Temp). Only low or mild correlations are noted in the correlation table, with the highest one (0.372) being observed between the speed and the headway, which is partly expected.

The mixed effect logistic regression model examined the relationship of the study explanatory variables and occurrence of a crash on unexpected incidents. To reach the chosen model, a first mixed effect logistic regression was implemented, followed by a multicollinearity check. A linear regression model of mixed effect logistic regression examined the relationship between the occurrence of a crash and the explanatory variables under study, except for the driver's no-reaction to an unexpected incident, as it was presumed that the drivers not reacting at all at an unexpected incident, are involved in crash. An Analysis of Variance (ANOVA) test was then carried out to determine that the driver's reaction was a statistically significant explanatory variable.
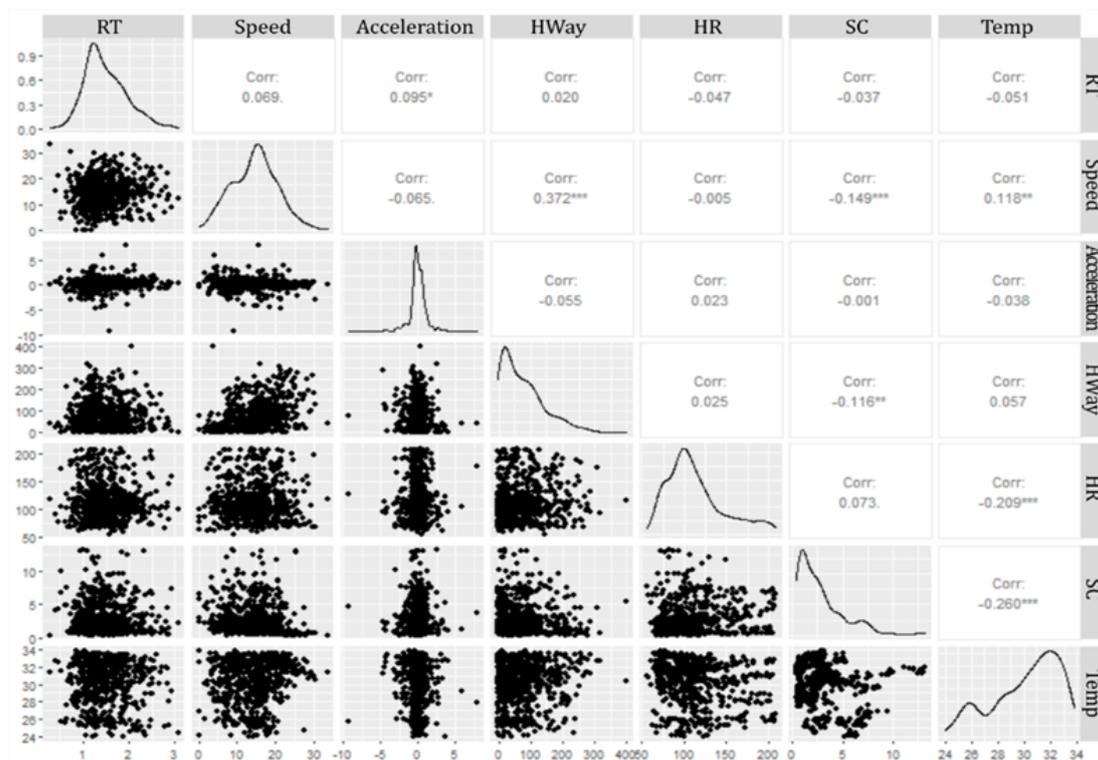

Figure 2. Correlation table

From the conducted analyses came out that the statistically significant explanatory variables are RT, speed, acceleration, age group, visibility, road network (network), and reaction (reaction to an unexpected incident with only brake/only maneuver/both reactions/none). The implemented model produced the following results, presented in Table 2. It is proved that RT (p = 1.07e-08), speed (p = 0.00019), age group 4 (p = 0.00153), visibility (p = 0.01331), and the driver's no reaction to an unexpected incident (p = 3.68e-07) are statistically significant variables for crash occurrence at significance level α = 5%. Furthermore, network (p = 0.08878) and drivers' reaction to an unexpected incident by employing the brake pedal (p = 0.06045) prove to be statistically significant variables at α = 10% significance level.

Table 2. Model's results

(i) Model selection criteria				
AIC	**BIC**	**logLik**	**deviance**	**df.resid**
626,9	681,0	-301,5	602,9	659
(ii) Scaled residuals				
Min	**1Q**	**Median**	**3Q**	**Max**
-4,7290	-0,5080	-0,3517	-0,1657	5,1600
(iii) Random effects				
Groups	**Name**		**Variance**	**Std.Dev.**
Subject_ID	(Intercept)		0,1667	0,4083
Number of obs: 671, groups: Subject_ID, 56				
(iv) Fixed effects				
	Estimate	**Std. Error**	**z value**	**Pr(>|z|)**

(Intercept)	1,4544	0,5098	-2,853	0,00433 **
RT	0,6990	0,1222	5,719	1,07e-08 ***
Speed	0,4838	0,1296	3,732	0,00019 ***
Age_Group2	-0,3449	0,3935	-0,877	0,38073
Age_Group3	-0,6168	0,4042	-1,526	0,12707
Age_Group4	-1,4115	0,4454	-3,169	0,00153 **
Visibility1	0,8212	0,3318	2,475	0,01331 *
Network	-0,6378	0,3748	-1,702	0,08878 .
Reaction_none	5,6775	1,1165	5,085	3,68e-07 ***
Reaction_only brake	0,4823	0,2569	1,877	0,06045 .
Reaction_only manouvre	0,1015	0,4482	0,226	0,82083

Signif. codes: 0 '***' 0,001 '**' 0,01 '*' 0,05 '.' 0,1 ' ' 1

From the selected model, Equation 1 of the crash occurrence on an interurban road network results:

$$Y = 1,4544 + 0,6690 \cdot RT + 0,4838 \cdot Speed - 0,3449 \cdot Age_{Group2} - 0,6168 \cdot Age_{Group3} - 1,4115 \cdot Age_{Group4} + 0,812 \cdot Visibility1 - 0,6378 \cdot Network + 5,6775 \cdot Reaction_{none} + 0,4826 \cdot Reaction_{only\ brake} + 0,1015 \cdot Reaction_{only\ manouvre} \quad (1)$$

Afterwards, diagnostics regarding the validity of the model were performed with the use the DHARMa (Distributed Automatic Repeated Histogram Matching) package in R, concluded that no problems were identified and therefore the appropriateness of the model fit to the observed data was confirmed (Appendix A).

More analytically, the model demonstrates the following relationships: It is estimated that an increase in one standard deviation in RT is associated with 101% increase in the odds of crash occurrence, holding other predictors constant. Furthermore, an increase in one standard deviation in speed is associated with 62% increase in the odds of crash occurrence, holding other predictors constant. Age_Group2, Age_Group3, Age_Group4 coefficients represent the effects of different age groups (compared to a reference or baseline group that is Age_Group1) on the odds of a crash occurrence. The model states that being in the 2nd age group is associated with 29% decrease in the odds of a crash occurrence compared to the reference group (the 1st age group). Additionally, being in the 3rd age group is associated with 46% decrease in the odds of a crash occurrence compared to the reference group, while being in the 4th age group is associated with 86% decrease in the odds of a crash occurrence compared to the reference group, holding other predictors constant. The odds of crash occurrence are 127% higher under the existence of fog (low visibility) compared to the case when weather is good (high visibility), holding other predictors constant. As regards the road network, the odds of crash occurrence are 47% lower while driving in interurban network, compared to the case of urban network, holding other predictors constant. Finally, concerning the way of reaction in an unexpected incident, the odds ratio for no reaction indicates that the absence of a specific reaction (compared to the reference both-Brake & Maneuver) is associated with a substantial increase in the odds of a crash occurrence. When the Reaction is Only Brake there is 62% increase in the odds of a crash occurrence, while, when the reaction is only maneuver there is 11% increase in the odds of a crash occurrence, compared to the reference that is reacting with both brake and maneuver, holding other predictors constant.

4. Discussion

This paper attempts to contribute towards the achievement of the goal of the Safe System Approach, aiming to eliminate serious injuries and deaths in transport networks. The methodological approach developed in the context of this research significantly contributes to the field of road safety, particularly to the study of driver behavior. It comprises several individual methodological tools that collectively enable a comprehensive study of driving behavior. To this end, tools that belong to three categories of driving behavior measuring tools, found in the relevant literature, are employed:
- performance measurement tools, i.e. speed, acceleration, RT,
- tools for measuring physiological characteristics of the driver, i.e. HR, skin conductance and temperature, and
- subjective tools, i.e. questionnaire, RSME scale, video recordings' monitoring.

At the same time, an original methodology is developed for the combined use of the selected methodological tools, which was based on the analysis of the advantages and disadvantages of the methods

used to study driving behavior. The ultimate goal is to examine driver behavior by investigating crash occurrence in unexpected incidents across different conditions related to the road (interurban and urban networks), to the environment (visibility levels), and the driver (additional mental workload, gender, age, etc). The combined application of the above tools is a methodological innovation in Greece.

Focusing on the core of this paper, the model's findings suggest the relationship between the crash occurrence and under-study parameters. Reaction time (RT) has been shown to significantly impact drivers' involvement in crashes, with higher RT increasing the likelihood of crash. Similarly, higher speeds are also associated with a greater probability of crash occurrence. As regards the age of the driver, it is proved that being in the 1st age group (18 - 25 years) is associated with higher odds of involvement in a crash compared to the other age groups (26 – 40, 41 – 55, and > 56 years). Moreover, the presence of fog that degrades drivers' visibility leads to higher crash occurrence. Associated with increased crash occurrence is also the driving in urban areas compared to driving in interurban road network. Finally, as regards the way of reaction of the drivers to an unexpected incident, the reaction employing concurrently the brake pedal and a steering maneuver is proved to be the more effective way of reacting, following by the reaction with only a maneuver and then the reaction with only brake. As was anticipated, the absence of a specific reaction almost inevitably leads to a crash.

The limitations of this study primarily stem from the research environment of the driving simulator, which influences both the driving conditions and the drivers' reactions. Additionally, the implementation of unexpected incidents—such as the specific types of events, the way they occurred, and the potential lack of realism—further impacts driver's reaction. Moreover, the fact that participants were monitored throughout the experiment may have affected their behavior, introducing another layer of complexity to the results interpretation. It is essential for researchers to interpret the results with these limitations in mind, alongside previous studies that validate simulator outcomes under similar conditions.

5. Conclusions

The findings of the present paper, highlight the critical impact of various parameters on crash occurrence, as being studied in unexpected incidents that take place in different weather conditions (different visibility conditions), different levels of MWL, at both interurban and urban road networks. The confirmation of the significant effect of the above factors on driving behavior and performance, underlines the need for further study of their effect in different prevailing conditions and road environments (e.g. rain, snow, frost, night driving, different traffic conditions, highway).

At the same time, delving into the mechanism behind drivers' selection of way of reaction in an unexpected incident, can provide interesting insights and form improvements, either through driver training or through the development of in-vehicle Advanced Driver Assistance Systems (ADAS).
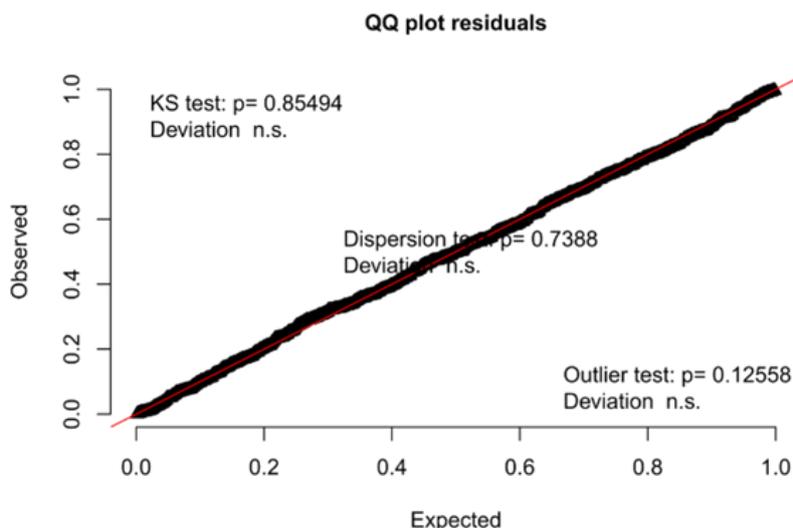
Appendix A

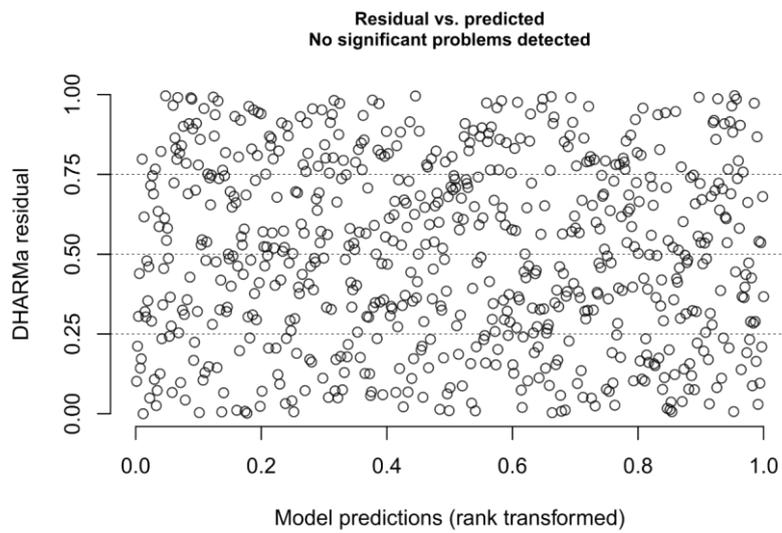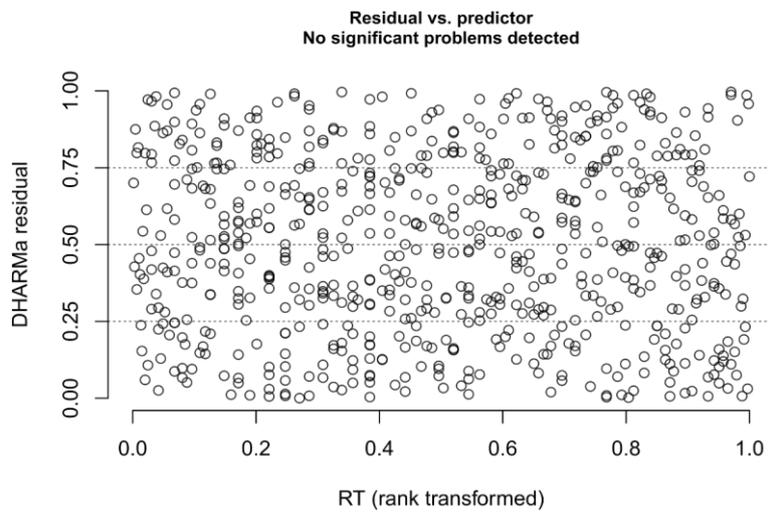*Figure A1.* QQ plot expected residuals

Residual vs. predicted
No significant problems detected

Figure A2. DHARMa residuals vs predictions

Residual vs. predictor
No significant problems detected

Figure A3. DHARMa residuals vs RT

Residual vs. predictor
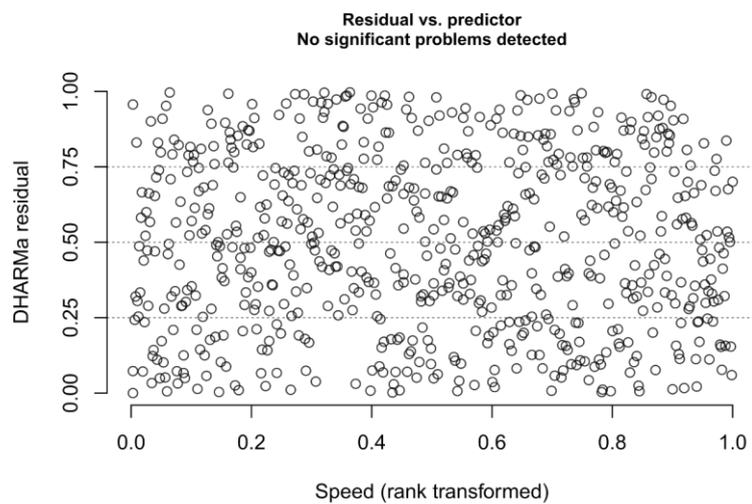**No significant problems detected**
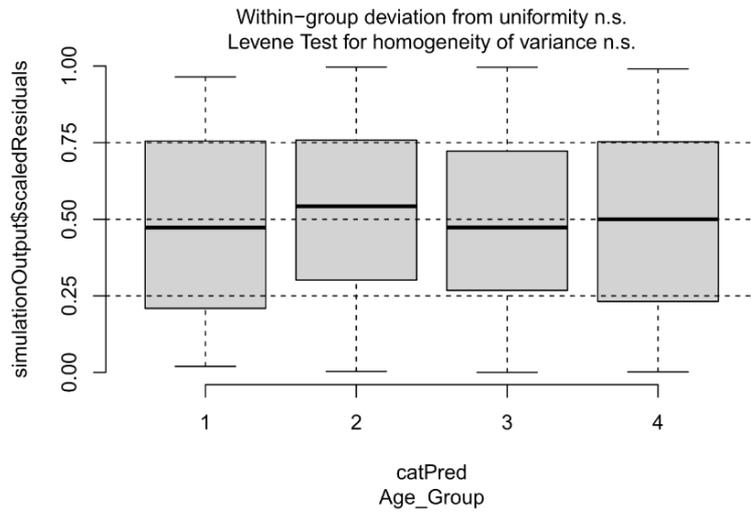

Figure A4. DHARMa residuals vs speed

Figure A5. Scaled residuals vs age group
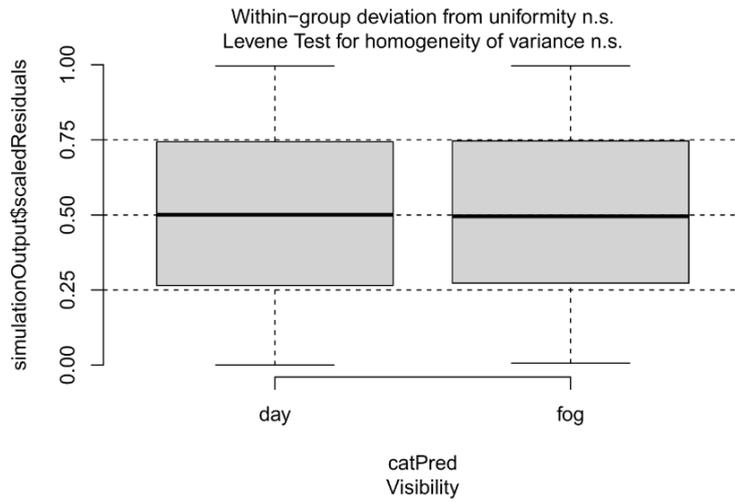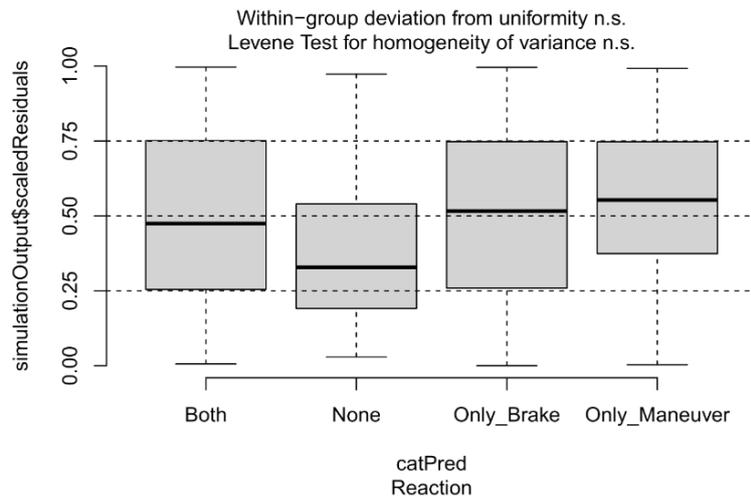

Figure A6. Scaled residuals vs visibility

Figure A7. scaled residuals vs reaction

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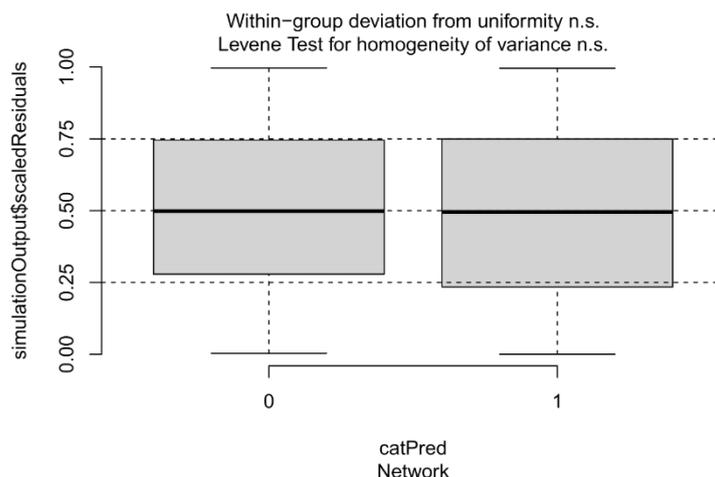*Figure A8.* Diagram of scaled residuals vs network

Acknowledgments

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