"A Normal Driving Based Deceleration Behaviour Study Towards Autonomous Vehicles"

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ABSTRACT

Vehicle automation has recently attracted significant interest from the research community worldwide. Notwithstanding the remarkable development in autonomous vehicles (AVs), there is still a concern about the user's comfort since most research has mainly focused on the safety aspect. To be comfortable for different users, AV should adapt its driving style to mimic the human's one. One of the most critical factors affecting the comfort level is the braking. It is however unclear which factors affect the braking behaviour and which braking profiles make the occupants feel safe and comfortable. This work therefore aims to thoroughly explore the deceleration behaviour of drivers using naturalistic driving study (NDS) data from two Field Operational Tests (FOT), the Pan-European TeleFOT (Field Operational Tests of Aftermarket and Nomadic Devices in Vehicles) project and the FOT conducted by Loughborough University and Nissan Ltd. A total of about 28 million observations were examined and almost 3,000 deceleration events from 37 different drivers and 174 different trips were identified and analysed. With the aid of a cluster analysis, a number of homogeneous scenarios based on human factors were formed. The scenarios have led to the application of multilevel mixed effect linear models to each cluster examining all influencing factors of the braking behaviour. The results indicate a dependence of the deceleration behaviour differing due to driver characteristics, initial speed and the reason for braking. Findings from this study will support vehicle manufacturers to ensure comfortable and safe braking operations of AVs.

Keywords: deceleration behaviour, normal driving, human factors, (semi)autonomous vehicles

1 INTRODUCTION

Vehicle automation offering safer, faster and cleaner transport and trying to eliminate the human error is of great interest to the society. To achieve high user acceptance and market penetration in the domain of autonomous driving, the design of automated driving functions is crucial and should offer flexibility and adaptability (Griesche et al. 2016). One design approach for those functions is the analysis of the human behaviour and a successive implementation of the results into the autonomous systems (Deligianni et al. 2017). As pointed out in several studies, occupants do not feel comfortable inside the AVs due to the unnatural driving performance of the current technology (Kuderer et al. 2015, Elbanhawi et al. 2015, Scherer et al. 2015). Therefore, AVs should resemble human driving style, taking into consideration the individual driver's preferences, who in AVs becomes a passenger (Elbanhawi et al. 2015, Scherer et al. 2015). Ride comfort is a subjective concept understood as a state achieved by the removal or absence of uneasiness and distress and may vary considerably among drivers, since human drivers adopt different driving styles based on the personality, the age, the gender, etc. (Kuderer et al. 2015). Additionally, a single subjective evaluation of ride comfort and investigation of ergonomics factors are no longer considered an acceptable and competitive way to assess the passenger experience (Elbanhawi et al. 2015). Comfort is influenced by multiple factors such as temperature, vibration, time headway, time-to-collision, longitudinal and lateral acceleration/deceleration and jerk (Le Vine et al. 2015, Elbanhawi et al. 2015). One of the most important and critical factors is the braking as a sharp deceleration is closely connected to accidents.

Elbanhawi et al. (2015) reviewed the traditional comfort measures and proposed autonomous passenger's comfort factors, e.g. naturality, apparent safety and motion sickness. Further, the gap in path planning from a passenger comfort perspective is highlighted. A study of Griesche et al. (2016) concluded that a preference among most drivers is for an AV to imitate their own driving style or a similar one. Aiming towards an increase of passenger's comfort too, Dovgan et al. (2012) developed a multi-objective algorithm to optimise the control action with three objectives, i.e. travelling time, fuel consumption and comfort. Scherer et al. (2015) examined essential driving parameters towards the increase of comfort feelings for passengers inside an autonomous car, resulting in the parameters of the longitudinal control and, more specifically, braking and acceleration.

Several studies have investigated the factors related to the braking behaviour (Haas et al. 2004, Loeb et al. 2015, Deligianni et al. 2017). To determine the differences in emergency braking performance between novice teen drivers and experienced adult drivers, Loeb et al. (2015) conducted a simulator study, resulting in poor response and quality of braking from novice drivers compared to experienced drivers. The study conducted by Deligianni et al. (2017) examined the deceleration events from different drivers and concluded that the deceleration is mostly affected by both, kinematics factors and the reason for braking. The purpose of the study conducted by Haas et al. (2004) was to evaluate driver deceleration and acceleration behaviour at stop sign–controlled intersections. The results indicate a wide variability in rates of acceleration and deceleration and a strong relationship between the initial speed and both deceleration and acceleration.

The research to date on autonomous vehicles tends to focus on the safety aspect rather than the comfort of the passengers. Previous studies of deceleration behaviour have examined factors related either to the driver or the vehicle, but there is a lack of studies examining situational factors or considering all the factors at once (multilevel analysis) that play an important role for the driver's decisions. As a result, the impact of these factors (driver, kinematics, situational) on the deceleration behaviour has not been fully understood yet. This study aims to fill in this knowledge gap by analysing drivers' braking behaviour obtained from normal driving, which feels comfortable, using NDS data in different scenarios (i.e. different road infrastructure and different road conditions). It will focus on discovering the relationship between the braking behaviour and its influencing factors. In addition, a library of deceleration functions will be developed, suitable for different road conditions and road users, which can be of great use in the development of comfortable and safe autonomous braking.

2 DATA DESCRIPTION

Since the comfort of drivers is the key in this work, the data that were used reflects driver's normal braking and does not include any safety critical events (emergency braking). The data was obtained from two different ethical approved projects: the TeleFOT project and a cooperation project between Nissan Motor Company Ltd and Loughborough University. Both consist of Field Operational Tests providing NDS data. The equipment comprises a GPS and an accelerometer linked and synchronised to a four-channel video system monitoring the drivers' behaviour using the Race Technology Ltd with a sampling frequency of 100 Hz. The sample was composed of 37 drivers aged 18-65 with at least 2 years driving experience and the summary of the participants' information for both projects is presented in Table 1. The participants at Nissan project were asked to drive along three specific routes (trip duration 15-25 minutes) that represented different road types, i.e. rural, motorway and urban and used three different cars (i.e. a Nissan Qashqai, a Peugeot and a Ford). The participants of the TeleFOT project were asked to drive along a specific 16.5 km long route with mixed road types in the Leicestershire area of England using one instrumented vehicle (Figure 1). All participants drove for a couple of hours to familiarize with the car. Therefore, the influence of the car type should be considered and included in the model. As a result, a total of about 28 million observations were examined from 37 different drivers, 4 different cars and 174 different trips.

Table 1 – Drivers' demographic characteristics

Gender/Age	17-30	31-40	41-50	51-60	61+	Total
Male	3	6	3	6	2	20
Female	3	3	7	4	0	17
Total	6	9	10	10	2	37

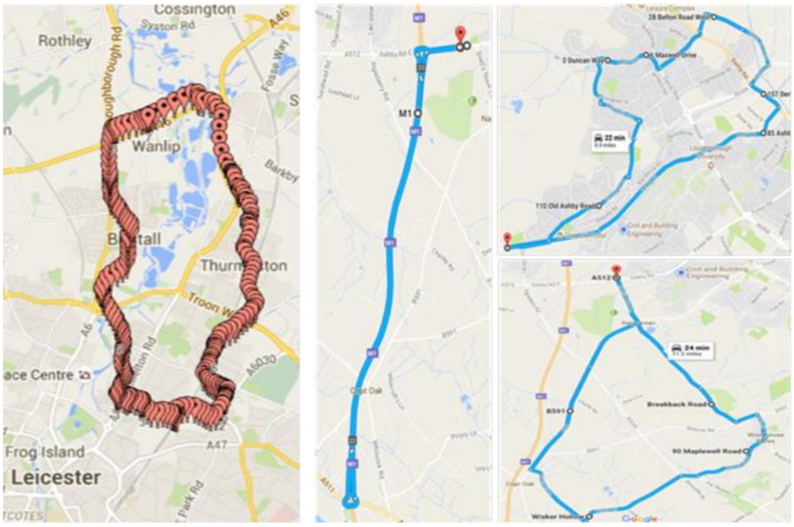

Figure 1 – The routes of the field test of the TeleFOT project (left) and of the Nissan project (two right pictures)

To extract the data of our interest from these projects, the Race Technology V8.5 software was used. The obtained variables were time, longitudinal acceleration, car speed, travelling distance, video frame and GPS coordinates for each deceleration event. The other necessary data (i.e. the trip duration, the maximum and the mean deceleration of the car during the event, the mean and the initial speed of the car during the event, the duration, the travel distance) as well as the detection of the deceleration events were calculated by an algorithm developed in MATLAB. By analysing the video at the moment of the events, two important variables were identified: traffic density and situational factors, i.e. whether there is a traffic light, a roundabout, a junction, a pedestrian crossing, an obstacle or a combination of the abovementioned which compose the reason of braking and whether the car stops in car blocks. The event starts when the acceleration is less than -0,5 m/s^2 and ends with the release of the brake. Various descriptive statistics were generated to understand these variables, the relationships between them and the effect they have on deceleration behaviour. The average maximum deceleration was found to be equal to -2.53 m/s^2, the absolute maximum value was 7.08 m/s^2 and it was observed that the car, the reason for braking, the speed and the combination of age and gender seemed to affect the deceleration value.

3 METHODOLOGY

To achieve the identified objectives, the following methodology was applied. Firstly, the deceleration events were identified from the datasets using adequate thresholds. Most of the deceleration rates observed in both projects are relatively low due to the nature of the Field Operational Test (FOT) which reflects driver's normal braking with no safety-critical events. Therefore, the threshold was set at $2m/s^2$, which is the lowest value found in the literature to detect deceleration events (Deligianni et al. 2017). For this purpose, an algorithm was developed in MATLAB that recognises the deceleration events, divides them into two parts, i.e. the press and the release of the brake and estimates the best function out of three different typical braking patterns for both parts: (1) the driver brakes gradually, (2) the driver brakes smoothly and after presses the brake harder and (3) the driver brakes firmly at the beginning followed by a gradually smoother braking. Similar patterns were used for the break release.

The next step is the creation of different scenarios based on human factors, to reflect the differences among the drivers, and on the braking pattern. To accomplish that, a cluster analysis was employed. Traditional clustering methods, i.e. hierarchical clustering and K-mean clustering were eliminated as suitable solutions due to the data's nature. Specifically, hierarchical clustering cannot handle a large number of observations and K-means clustering is not appropriate for categorical variables. Therefore, the 2-step cluster analysis in SPSS was used, since this method can handle categorical variables (such as gender, age categories and braking profiles) as well as big datasets. Having the deceleration events clustered and with the aim of examining all the influencing factors of the braking behaviour, the multilevel mixed effect model was applied to each cluster using the StataMP 13 software. This model is the most appropriate as the data presents a hierarchical structure (i.e. each driver conducted several trips and each trip included many deceleration events) (Figure 2). The factors that were considered are: (1) event-level factors, such as situational factors (reason of braking, traffic density), kinematic factors at the beginning of braking, etc. (2) trip level factors, such as trip duration, trip distance, the model of the car and (3) driver level factors.

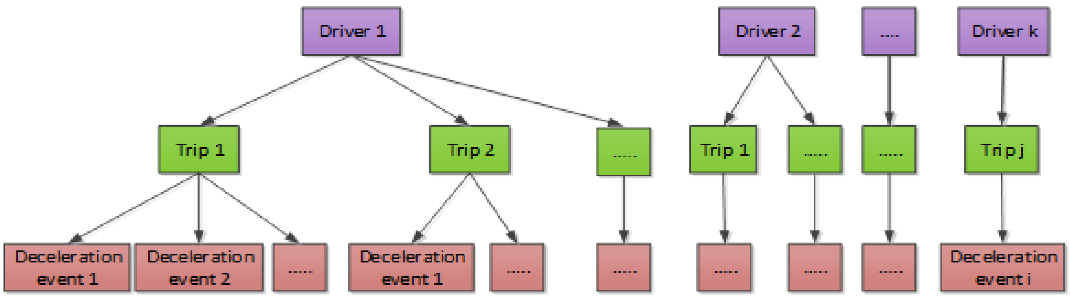

Figure 2- The hierarchical structure of the data

4 RESULTS AND DISCUSSION

The results of the estimation of the best fitted braking pattern showed that 636 out of 2715 deceleration events followed the (1) braking pattern (gradually braking), 1104 followed the (2) braking pattern (smooth followed by harder braking) and 999 followed the last one (3) (hard following by smoother braking). The influence of the driver's characteristics on the braking behaviour was analysed using the cluster analysis discussed in the previous section. Five clusters were created as an outcome and their features can be seen in Figure 3. It can be concluded that old people (cluster 1 and 3) slightly prefer the braking pattern (2) whereas young people also use the third braking pattern (3). Moreover, the different clusters present different deceleration characteristics. This can be supported by the results of the Analysis of Variance (ANOVA) test ($p=0.045<0.05$), conducted to test the differences between the means of the maximum deceleration for each cluster. Additionally, it was concluded from the Tukey's HSD test that old females brake the hardest whereas old males brake the softest.

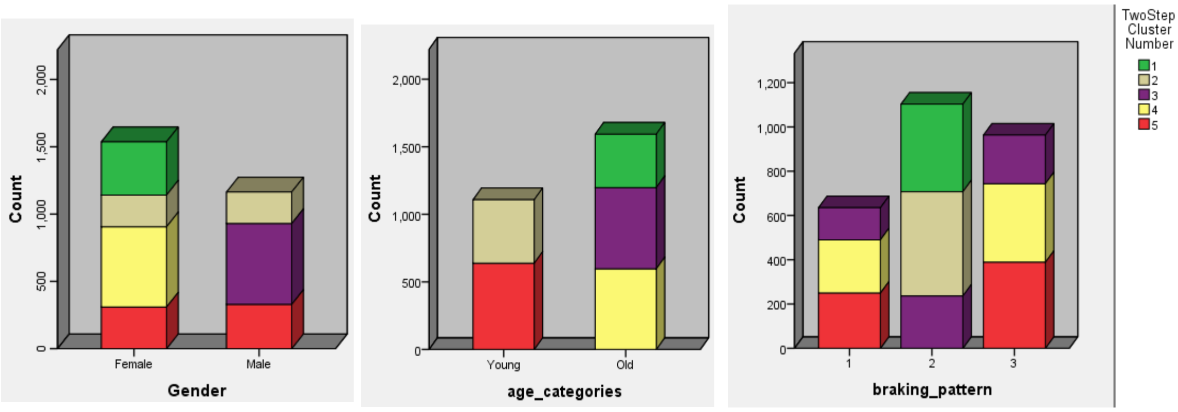

Figure 3 – Features of the five clusters

After clustering the observations into 5 groups, the maximum deceleration value was analysed using statistical analysis for each cluster. Since the driver effect has been included in the clustering, the model that was used was the 2-level linear regression model based on the trip level. The explanatory variables, which include distance, initial speed, if the car should stop, traffic density and the reason for braking, were kept the same among the clusters. The results from the analysis are presented in Table 2. The overall intra-class correlation (ICC) varies from 0.037 (cluster 1) to 0.16 (cluster 4) indicating that 3.7% and 16% of the variation in the deceleration value is explained by the trip-level hierarchical data structure. Therefore, all models show a reasonable goodness-of-fit.

Table 2 – Results from Multilevel linear regression models

	Cluster1		Cluster2		Cluster3		Cluster4		Cluster5	
Deceleration	**Coef.**	**P>z**	**Coef.**	**P>z**	**Coef.**	**P>z**	**Coef.**	**P>z**	**Coef.**	**P>z**
distance	-0.018	0.015	-0.020	0			-0.012	0.09		
initial_speed	-0.012	0.058			-0.024	0	-0.012	0.062	-0.033	0
traffic_light							0.126	0.014		
roundabout			0.164	0.008	0.106	0.031			0.164	0.019
t_junction			0.112	0.033			0.071	0.105	0.161	0.011
cross_junction			0.145	0.049	0.133	0.023			0.178	0.049
Pedestrian_crossing					-0.255	0.103			-0.553	0.001
other			0.109	0.058	0.117	0.01	0.097	0.061	0.117	0.091
stop_car	-0.198	0	-0.100	0.026	-0.217	0	-0.174	0	-0.263	0
_cons	-2.237	0	-2.482	0	-2.150	0	-2.345	0	-2.158	0
Number of observations	396		471		601		596		637	
ICC	0.037		0.055		0.07		0.16		0.11	

The most statistically significant variables affecting the deceleration value for almost all the models are the initial speed and if the car should stop. Increasing the initial speed by 1m/s leads to a harder braking (the decrease varies from 0.012 to 0.033m/s^2). Another important factor is the cause of braking. Specifically, approaching a roundabout or a junction results in softer braking compared to a dynamic obstacle, whereas approaching a pedestrian crossing leads to harder braking. Furthermore, for cluster 4 the existence of a traffic light made the braking softer. The traffic density was revealed to be insignificant for all the clusters.

Summarising this research revealed the factors that significantly affect the braking for each cluster, showing the braking preferences for each group. Also, it was concluded that drivers can accept a harder braking because of a dynamic obstacle or a pedestrian crossing. In addition, it demonstrated that driver deceleration cannot be effectively modelled by applying average rates and one braking profile, since it varies a lot depending on the driver and the situational factors, supporting more the idea of a personalised autonomous vehicle. Haas et al. (2004) have concluded in similar results, taking though into account only the gender and the speed. The limitation of this work lies in the fact that while 37 drivers are sufficient to conduct a statistical analysis, more drivers are needed to generalise the cluster analysis. Also, even if the assumption that the drivers feel comfortable when the AV mimics their own driving style is supported by different studies (Kuderer et al. 2015, Elbanhawi et al. 2015, Scherer et al. 2015, Griesche et al. 2016), it needs more investigation. This paper concentrates on studying in depth the deceleration events in normal driving in order to support vehicle manufacturers to ensure comfortable braking operations and specifically when an AV detects a hazard and calculates the distance that it should stop at, it will be able to brake in a safe and comfortable way, considering who the passenger is and different situational factors. This will lead to autonomous vehicle's wide acceptance and market penetration.

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