Loughborough University

This item was submitted to Loughborough's Institutional Repository (https://dspace.lboro.ac.uk/) by the author and is made available under the following Creative Commons Licence conditions.

For the full text of this licence, please go to:
http://creativecommons.org/licenses/by-nc-nd/2.5/

Towards a driver-centred brake assist system

N. GKIKAS, J. H. RICHARDSON, J. R. HILL
Ergonomics & Safety Research Institute, Loughborough University UK

ABSTRACT

Active safety systems relevant to longitudinal control like Emergency Brake Assist (EBA) have been developed and specified based on assumptions about the differentiation of driver's input between "normal" and emergency events. The consequence of these assumptions is a system that does not accommodate for driver variability and can be engaged when it is not intended to and not engaged when it is necessary. The present paper presents data from an empirical study that examined differences in driver braking response in normal and "emergency" situations. 24 participants drove an instrumented vehicle on open roads and on a closed track. Participants were first asked to drive 10km on public roads as an indication of their "normal" braking responses. When they arrived at the closed track they were instructed to follow "at their preferred distance" another car towing a trailer at 48kmph/30mph. After 322m (0.2 mile) the trailer was released and automatically braked. Throttle pedal angle and brake pedal pressure were measured and foot/pedal movements were video-recorded. Results indicate patterns in driver responses that an intelligent brake system could "learn" from, in order to accommodate driver variability and achieve effective augmented braking.

1 INTRODUCTION

Within the mayhem of road accidents, rear-end collisions emerge as the most common type of crash, accounting for 30% of all crashes **[1-3]**. Those accidents frequently represent a breakdown in driver longitudinal control and hazard detection **[4]**. As longitudinal control in a road vehicle is mainly exercised through the operation of brake and throttle pedals, active safety systems have been developed to enhance driver braking. The most notable and common of these is Emergency Brake Assist (EBA).

Emergency Brake Assist **[5]** supports the drivers who under-deploy the brakes in an emergency situation. The function of the system is presented in figure 1. Based on findings regarding the inability of most drivers to use the full potential of the vehicle brakes **[6]** the system applies full brakes when a quick brake reaction by the driver is detected. The system uses pedal application speed (or Force) as an indicator of emergency situations. If an unusually high pedal speed (or Force) is detected, the system infers an emergency situation and applies full brakes, rather than the typically limited braking force applied via the brake pedal. Wheel lock is prevented through ABS and the system function is terminated as soon as the driver lifts their foot off the brake pedal.

The working proposal for the standardisation of "Brake Assist System (BAS)" defines three categories of systems **[7]**:

1. "Category A Brake Assist System" is a system which detects an emergency braking condition based on the brake pedal force applied by the driver.
2. "Category B Brake Assist System" is a system which detects an emergency braking condition based on the brake pedal speed applied by the driver.
3. Category C Brake Assist System" is a system which detects an emergency braking condition based on multiple criteria, one of which must be the rate at which the brake pedal is applied.
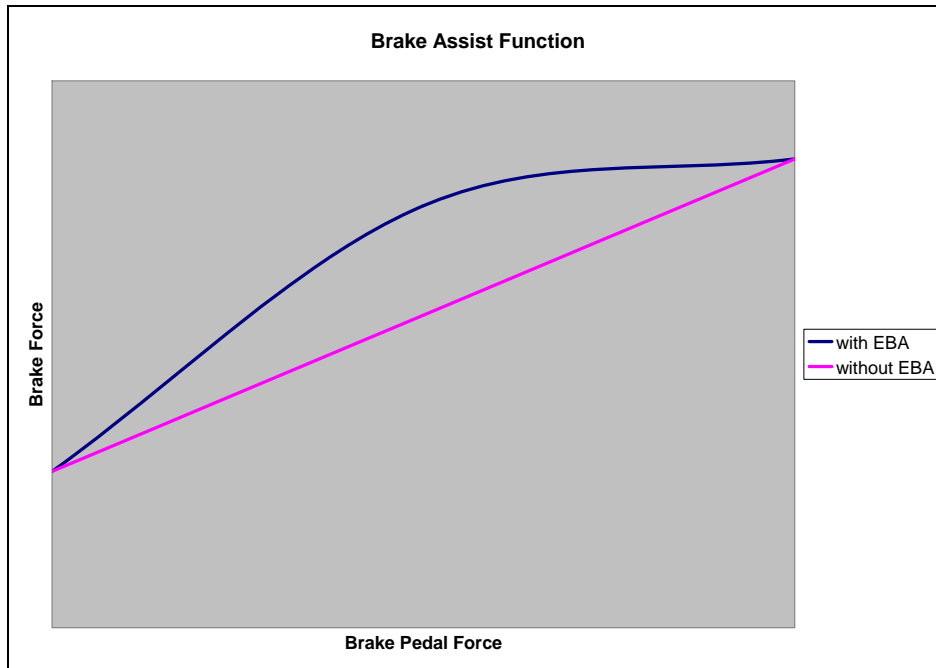
Figure 1: The EBA function

All the above systems are based on the assumption that there is a differential (quantitative) characteristic between normal and emergency brake application. In the first category exceeding a force threshold triggers the activation of full brakes, in the second category there is a speed threshold and in the third it is a combination of parameters. Defining these thresholds is a non-trivial task, especially if the wide variability within the driver population is considered. To date, much of the relevant research is not in the public domain as it has been undertaken in support of product development. A notable exception is the work carried out by the Laboratoire d' Accidentologie, de Biomecanique et d'etude du comportement humain (LAB).

In an attempt to answer this demanding issue, multiple studies aimed to quantify normal and emergency driver braking, using both simulators and instrumented vehicles in the test track. First, each of the main variables (throttle-off speed, brake pedal speed, brake force) were examined as for the appropriateness of using them as triggering variables **[8]** and later an attempt to create a model of driver behaviour in emergency conditions using multiple variables in artificial intelligence/neural networks **[9]**. One of the conclusions of the first study was that "due to the significant

overlap of braking parameters, distributions between normal and emergency situations" it is impossible for a universal threshold to accommodate every driver. This is because the values of the variables in normal braking for some drivers were identical to the values in emergency braking for other drivers.

To overcome this problem, it is necessary for an intelligent adaptive brake assistance to be developed. For this to happen though, the relationships between the variables in normal and emergency conditions should be understood. The present paper presents results from a study that attempted to provide an answer to the question: are there characteristics in driver braking exploitable by an adaptive brake assist system?

2 METHOD

To achieve this, an instrumented vehicle was driven on public roads and on a closed track by 24 drivers. Drivers were instructed to drive the car to the test track where they would follow another vehicle at their "preferred distance". They were unaware of the fact that the lead vehicle would release the trailer it towed. The idea was to compare quantitative characteristics of their reaction in this sudden event to the general characteristics of their braking during the public road section.

2.1 Apparatus
A Ford Fiesta ('00 model) was fitted with a camera in the footwell, an on-board camera provided view of the road environment, two Tekscan Flexiforce® sensors were fixed on the brake pedal surface (figure 2), one Flexiforce® on the clutch pedal surface, and a potentiometer was attached to the centre of the throttle-axis rotation. Sensors were calibrated according to Tekscan's guidelines [10]. A Labjack® U12 data acquisition module was connected to a Toshiba® Tecra 3 laptop using Azeotech® DAQFactory® Express software for data logging. Power was provided through the vehicle's battery when the engine was on and through the laptop's battery when it was off.
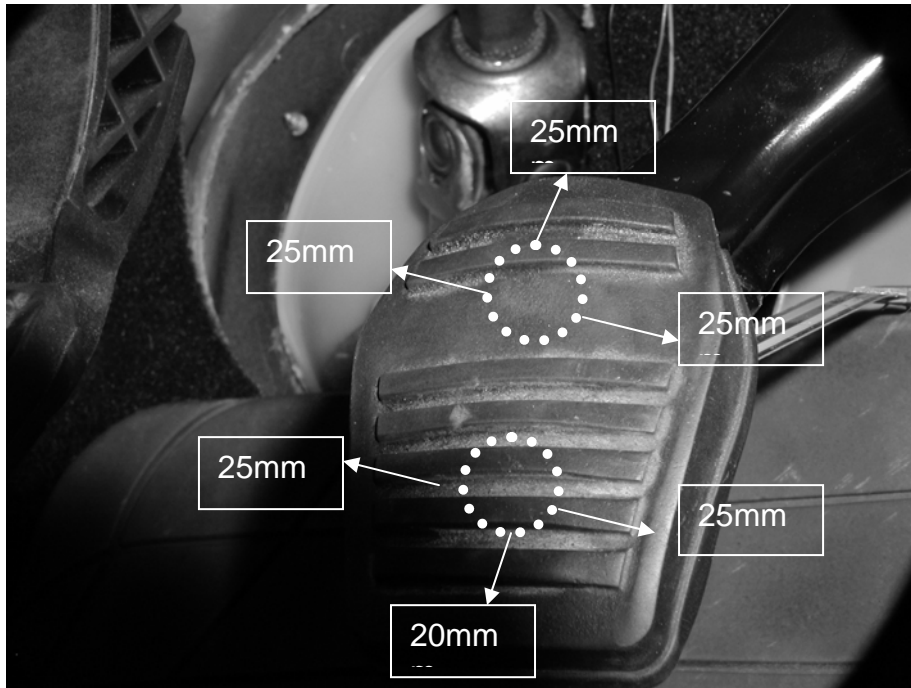
Figure 2: The layout of sensors on the brake pedal (hidden behind the rubber cover)

A lightweight (m<30kg) trailer was built for the purpose of replicating a lead vehicle's sudden braking (a<-5m/s^2) in the test track. The trailer's stopping properties were representative of average emergency decelerations of real vehicles in experimental **[11]** and field accident studies **[12]**. The trailer (figure 3) was three wheeled for extra straight line stability; dimensions were 2.2m length, 1.25m rear width, 0.3m front width, and 0.4m height at the back. Wheels were 20inch standard road bicycle wheels. It was basically a sheet of waterproof wood reinforced with an aluminium skeleton. Two 0.75x0.5x0.5 cardboard boxes were filled in with closed empty plastic bottles and wrapped with white plastic bags before they were attached at the rear of the trailer to create a "bulkiness" illusion. Standard bicycle "V-brakes" were installed and were activated by the rotation of a lever which was activated by two springs upon release from the car. During testing average acceleration of the trailer after release was -5.81m/s^2 with an instantaneous minimum of -17.24m/s^2 achieved.

2.2 The participants

Participants were recruited through advertising in local press and local companies. Twenty-four drivers (14 male and 10 female) participated in the study. The average age was 34.4 years (min 22,

max 84), average driving experience was 15.2 years (min 1, max 48), and average mileage was 10920miles/year (min 2000, max 30000). They all held a full UK/EU driving license and had less than 6 penalty points.

Figure 3: The trailer through driver's view in the track (top left), during development (top right) and details of the auto-brake mechanism (bottom left/right)

2.3 The route

The public road section of the route driven by participants included an urban and a rural section (11km in total) that led them from the start (Loughborough University Business Park) to the test track (Wymeswold Airfield). A section of the track was isolated and marked out with cones to provide a single lane for the emergency brake test. Sessions took place between 5 and 8pm on weekdays in daylight.

2.4 The test protocol

Participants would fill in paperwork for insurance purposes before the experiment, as well as demographic data and a general health questionnaire. Just before the start of the driving session, they indicated their stress level on a 7-point scale. They were told that

the purpose of the study was to measure their preferred driving distance from other vehicles and for that purpose they would have to follow an instrumented trailer that would record this distance on the test track. Upon arrival to the test track they would stop at the entrance before they were given the OK to proceed to the track. There, they were asked to adjust their distance following another vehicle towing a trailer around the track. Post-trial questioning confirmed that they were naïve to the fact that the trailer would be released after 0.2 miles (321.86 m). In each trial the lead vehicle accelerated to 30mph (speed measured using GPS) and kept a constant speed until the release of the trailer.

2.5 Data analysis

In order to examine the appropriateness of using brake force and/or "throttle-off" rate as single triggering criteria, mean values for the public road section were compared to the peak values during the emergency response. Paired Student's T-test was utilised for that purpose. Then, in order to examine the relationship between normal and emergency braking, each variable in the public road driving condition was plotted against the same variable in the emergency braking condition. Various regression models were tested in order to find the model with the best fit to the observed data. All the analyses were carried out in the Statistics Package for Social Sciences (SPSS) ver. 15.

3 RESULTS

3.1 Comparison of throttle-off speed

Table 1 presents the results of the T-test of throttle-off values between normal and emergency braking. For normal braking the average value was 0.47 degrees per sampling (0.02s), while average peak value of throttle-off rate during emergency braking was 0.64 degrees per sampling. The respective standard deviations were 0.09 and 0.10 degrees respectively. The resulting t-value for the difference (-5.618) is statistically significant at $p < 0.0001$ level.

Table 1: Paired Samples Statistics and Paired Samples Test of throttle-off (in degrees) during normal and emergency braking (sampling at 50Hz)

	Mean	N	Std. Deviation	t	df	Sig.
Avg Throttle-off rate in normal conditions	.4721	24	.0956	-5.618	23	.000
Peak throttle-off in emergency conditions	.6388	24	.1011			

3.2 Comparison of braking force

Table 2 presents the results of the T-test of braking force values between normal and emergency braking. In normal braking the average value was 5.72 N and the average peak value during emergency braking was 15.61 N (**values reported are measured on 0.75 cm^2 surface sensors, not on the whole pedal surface**). The respective standard deviations were 3.58N and 20.36N. The resulting t-value for the difference (-2.385) is statistically significant at p=0.026 level.

Table 2: Paired Samples Statistics and Paired Samples Test of brake force (in Newtons) during normal and emergency braking

	Mean	N	Std. Deviation	t	df	Sig.
Average brake force in normal conditions	5.7235	24	3.58009	-2.385	23	.026
Peak brake force in emergency conditions	15.6104	24	20.35870			

3.3 Relationship models

Driver variability in car-following distances in the test-track resulted in some "safe" drivers not needing to brake significantly to avoid the obstacle in front, but instead decelerated by selecting a lower gear and swerving slightly to avoid contact. Therefore, outliers (brake force<5N) were ruled out of this part of analysis. Analysis of variance (ANOVA) of various regression models for the relationship of throttle-off between normal and emergency braking

revealed no statistically significant results. However, ANOVA of more than one regression model for the relationship of brake force between normal and emergency braking provided highly statistically significant probabilities ($p<0.01$). These are quadratic ($R= 0.910$, $p=0.002$) and cubic ($R=0.916$, $p=0.008$) regression models (figure 4).

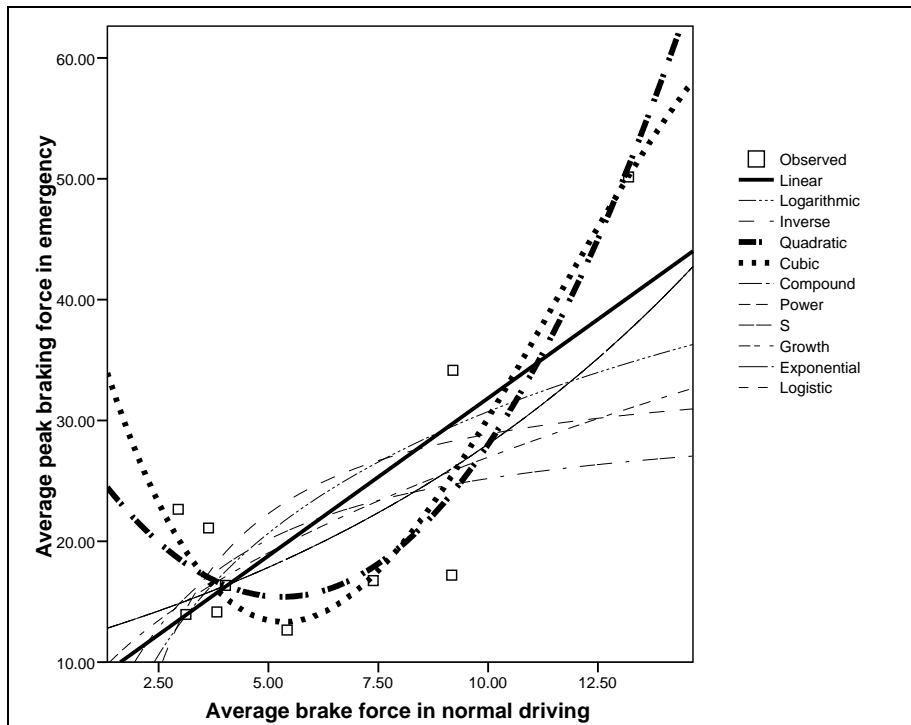**Figure 4: Plotted regression models for the relationship between normal and emergency brake force application (all values in Newtons)**

4 DISCUSSION

The results suggest two important considerations for the development of any type of driver-centric brake assist system. First, throttle-off speed/rate differentiates between normal and emergency braking better than brake force. This is consistent with previous studies **[9]** and shows the way for universal triggers of EBA activation. In addition, using the throttle-off speed/rate as a trigger has the advantage of the system receiving the necessary information from the driver earlier (throttle-off takes place before brake application commences). It is therefore worrying that

stakeholders ignore the importance of this variable in defining an emergency brake instant **[7]**, although in application it is probably used by some manufacturers.

Second, it appears reasonable to propose an adaptive brake assist system that uses a driver's mean normal braking value to predict the respective emergency brake value using one of the regression models presented in figure 5. Among them, the quadratic equation seems to be the most valid option (lowest p value in ANOVA testing), while the cubic equation explains the most variance (highest R value). Both models though explain over 80% of the variance ($R^2 > 80\%$) and have very low probabilities of being the result of chance ($p < 0.01$).

The design of the study was flexible enough to allow the drivers to react in various ways at the release of the trailer in front of them. Thus it was reasonable to rule out of the second analysis drivers that did not brake or barely touched the brake pedal (F<5N). Other points of possible argument are the use of a single vehicle (Fiesta) and the sample size. However, these issues tend to be expected within strict budget and ethically challenging study designs. Further assessments with larger sample sizes and a range of braking scenarios are necessary to confirm the results obtained.

©Nikolaos Gkikas 2009

REFERENCE LIST

1   **National Safety Council.** *Accident Facts.* Itasca, IL: Author.

2   **Wang, J. A., R. R. Knipling, and L. J. Blincoe.** The dimensions of motor vehicle crash risk. *Journal of Transportation and Statistics* , 1999, **2**, 19-44.

3   **Blincoe, L. J., A. Seay, E. Zaloshnja, T. Miller, E. Romano and S. Luchter.** *The economic impact of motor vehicle crashes, 2000. Report DOTHS 809446* .National Highway Traffic Safety Administration.

4   **Lee, J. D.** Driving Safety. In R. S. Nickerson. *Reviews of Human Factors and Ergonomics,* 2006, *173-218*. Santa Monica, USA: Human Factors and Ergonomics Society.

5   **Breuer, J. J., A. Faulhaber, P. Frank, and S. Gleissner.** Real world benefits of brake assistance systems. In Proceedings of the 20th Enhanced Safety of Vehicles Conference, Lyon, June 18-21, 2007.

6   **Kiesewtter, W., W. Klinkner, W. Reichelt, and M. Steiner.** Der neue Brake-Assist von Mercedes-Benz. *Automobiltechnische Zeitschrift* , 1997, **99**, 330.

7   **The Society of Motor Manufacturers and Traders Ltd.** Brake Assist Systems (BAS)-Agenda and document for a meeting at the EC 17 April 2008. , 2008.

8   **Kassaagi, M.** *Caracterisation experimentale du comportement des conducteurs en situation d'urgence pour la specification de systemes de securite active.* These de doctorat, 2001, Ecole Centrale Paris.

9   **Bouslimi, W., M. Kassaagi, D. Lourdeaux, and P. Fuchs.** Modeling driver behavior in a straight-line emergency situation. *SAE Transactions* , 2005, **114**, 743-751.

10   **Tekscan.** Flexiforce sensors manual, 2008, **2008**.

11   **Vangi, D. and A. Virga.** Evaluation of emergency braking deceleration for accident reconstruction. *Veh. Syst. Dyn.* , 2007, **45**, 895-910.

12   **Gkikas, N., Julian Hill and John Richardson.** Getting back to basics: using road accident investigation to identify the desirable functionality of longitudinal control systems. In D. de Waard, F. O. Flemisch, B. Lorenz, H. Oberheid and K. A. Brookhuis. *Human Factors for Assistance and Automation.* 2008, *203-216*. Maastricht, the Netherlands: Shaker Publishing.