The role of a driving simulator in driver training to improve fuel economy

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Abstract – The use of driving simulators in driver training has become widespread. With the global push to reduce C02 emissions and achieve greater fuel economy, driving simulators are now being used in initiatives aimed at training drivers in Eco-Driving techniques, with varying levels of success. The Institute for Automotive and Manufacturing Advanced Practice (AMAP), at the University of Sunderland, UK, has recently used a Forum 8 driving simulator to deliver and evaluate a new Eco-Driving course for safe driving. Thirty participants took part in the study in the age range 20-64 years. Half were trained in Eco driving (intervention group) and half took part in two simulated drives without training (control group). The results indicate lasting positive effects of the training intervention on fuel economy. Results also highlight a positive role for driving simulation in the evaluation and delivery of eco driving training.

Key words: *Driving Simulator, Eco-Driving, Fuel Economy, C02 Emissions, Driver Training.*

Introduction

Driving simulators have become widely used in driving research and driver training over the past two decades [Abo1; Bla1; ESR1]. In comparison, the application of driving simulators in the field of Eco-Driving research and training is relatively new, applying various methodologies with varying levels of success [CAR1; Vir1].

Research has shown that fairly simple modifications to driving style can improve drivers fuel economy and C02 emissions [Aut1; Bar1; Ber1; FIA1; Gos1; Van1] and many organisations now offer recommendations on driving style, and training in techniques to help driver's to refine their driving in order to reduce fuel consumption, wear and tear on the vehicle and cut C02 emissions [IAM1; Ene1; Gos2; Aus1;]. A variety of titles have been used for such techniques according to the extent to which safety is a consideration. Possibly the most commonly used term to describe energy efficient use of vehicles is 'Eco Driving' [ECO1].

The Institute for Automotive and Manufacturing Advanced Practice (AMAP) [AMA1], at the University of Sunderland, UK, has recently used a Forum 8 driving simulator [For1] in the delivery and evaluation of a new Eco driving course for safe driving. The course, named the DROPLET Course (Driver Optimisation for Low Emissions Transport) is based on a theoretical Model of driver training, Goals for Driver Education (GDE) by Hattaka et al, 2002 [hat1]. Hatakka [Hat2] provides a comprehensive framework for goals and content of driver education. A driving simulator, classroom-based and on-road driving techniques were used to modify driver behaviour. This paper reports on the rationale and methodological approach underpinning the course, procedures, accompanying research, and results are discussed, and the role of driving simulators in the delivery of such courses is considered.

The aim of the DROPLET course is to raise individual's awareness of how to modify their driving to achieve optimum safety and fuel economy, and to start the process of implementing it. Research has shown that it is possible to optimise fuel economy by applying a smooth and progressive driving style [FIA2]. The DROPLET course combines best practice from the research on how drivers interact [Ful1] with methodologies and advice from existing driver training initiatives [IAM2] aimed at maximising drivers attentional and observation skills, the ability to anticipate what will happen, and plan safe, timely, controlled responses through smooth application of vehicle controls. Components of best practice in Eco-Driving applications were mapped to the GDE model of driver training [Hat3] and applied within the course methodology according to the most appropriate method of delivery for each. The mapping of the various pieces of advice and techniques to the different levels of the GDE model are shown in table 1.

Table 1. GDE/DROPLET Matrix

Goals for Driver Education (GDE) Model •	**DROPLET Course Content**
Goals for Life & Skills for Living (general) • Importance of cars in driving & driving to self development • Skills & self-control • Driver preconceptions	General awareness of social and personal benefits of eco driving and available Low Carbon Vehicle (LCV) technologies. Skill enhancement Self awareness
Goals & Context of Driving (trip related) Puropse, Environmental, Social context, Company	Plan ahead before driving. Consider using alternative modes of transport. Avoid short journeys. Plan the most direct route. Drive off peak times if possible. Check tyres (inflation,/tread depth etc.). Don't carry unnecessary lugage around. Only fill the fuel tank with the necessary amount of fuel. Consider turning the engine off if stuck in traffic. Close windows to reduce drag. Turn air conditioning off unless it is necessary.
Mastering Traffic Situations • Adapting to the demands of the situation at hand.	Use appropriate observation, anticipation and planning. Leave space and time to react, between youself and other road users. Obey speed limits Avoid stop starting in traffic. Reverse into parking bays if possible. Do not over rev the engine when conducting manoeuvres.
Vehicle Manoeuvring • Controlling speed, direction and position of the car.	Use smooth and gradual acceleration. Change gear early and keep the revs. low. Use the correct gear for the speed and control, using block changing where and when appropriate. Maintain a constant speed once the target speed is reached, when and where it is safe to do so. Use gradual and smooth braking to slow/stop, making maximum use of engine braking. Then gently apply the brakes.

Research was conducted to evaluate the effectiveness of the training course. Two groups of volunteers took part in the study. One group took part in the training course (intervention group). This group drove a short route in the driving simulator before and after taking part in the DROPLET driver training course. The other group received no training (control group) and drove the same short route in the simulator, on two occasions. It was proposed that participants in the training condition would show a greater reduction in fuel consumption and C02 emissions on their second drive in the simulator compared to the control group.

Method

Participants

From an original sample of thirty three participants, data for three of the participants was discarded due to difficulties adapting to using the driving simulator. The study therefore utilised data for thirty participants in the age range 20-64 years. Half were trained in Eco driving according to the new course criteria (intervention group) and half took part in two simulated drives with no training (control group). The intervention group consisted of fifteen participants in the age range 31 – 64 years (mean age 47.53, SD 11.154). Of these 12 were male and 3 were female. The control group consisted of fifteen participants in the age range 20-63 years (Mean age 44.07, SD 11.310) of which 11 were male and 4 were female. All participants were members of the general public or staff from the University of Sunderland who had volunteered to take part in an Eco-Driving study in response to an advertisement. All volunteers had a full and valid UK driving licence, had been driving for at least three years, and reported having normal or corrected-to-normal eyesight.

Apparatus

A Forum 8, fixed base driving simulator was used for the lab based element of the study [For2]. The hardware component of the simulator is illustrated in Figure 1. The hardware is based upon a typical vehicle cockpit comprising all the usual primary and secondary controls including steering wheel, automatic transmission selector, parking brake, accelerator and brake. Instruments include directional indicator, speedometer and engine revolution counter. The display consists of three 32 inch LCD screens, each with a resolution of 1024x768 pixels and a fourth, smaller 8.4 inch LCD TFT screen with a resolution of 800x600 pixels which can be used for display of navigational information or other data to the driver. Real time information on speed km/h and fuel consumption km/L, in bar format, is also displayed in the bottom right hand corner of the central display screen. The simulator has a plug-in based architecture and currently runs the Uc-win/Road Plug-in [Ucw1], which has an Eco-Drive module for calculating carbon footprint.

A Dell Lattitude D505 lap top computer was also used to display video clips of driving scenarios for the classroom element of the course.

Materials

Simulated road user scenarios

Three scenarios requiring the driver to interact with other road users were included in the simulated drive. The first scenario occurred at cross roads, in an urban setting, during a right turn manoeuvre and involved moving and stationary opposing traffic (cars, buses and lorries). The next scenario involved an opposing motorcycle passing through the junction. This was followed by a child on a bicycle crossing the road into which the driver was turning, as the driver turned right at the cross roads. The final scenario involved heavy traffic flow (cars and lorries) travelling in the same direction as the driver during a merge manoeuvre on a dual carriageway road.

Fig.1. Forum8 driving simulator

Video clips

A series of five video clips was developed. The video clips lasted for one minute each and were filmed from the drivers perspective during real world, on-road driving. Two of the video clips were designed specifically to help participants to contrast the effects of poor driver observation techniques with those of an effective and efficient observational technique, two were designed to enhance drivers anticipation skills and one provided a demonstration of safe, fuel efficient, cornering techniques.

Questionnaires and interview materials

A driver perception questionnaire was developed for pre course, post course and follow up use. This contained five questions requiring responses on a five point Likert scale, The questions were designed specifically to tap drivers perceptions of their own ability on a series of dimensions that have been shown to be important in Eco-Driving. More specifically, the questions were designed to tap driver’s perceptions of their own ability with regards to concentration, observation, anticipation, keeping a safe distance from other vehicles, and eco-friendliness while driving. A set of 10 structured interview questions was also used in the follow up study which took place three months after the course. The questions were designed to investigate the extent to which any improvements in driving style were maintained over time.

Procedure

Lab session 1

One participant at a time took part in the study. Upon arrival at AMAP each participant was taken to the lab and provided with an explanation of what their participation in the course would involve. After a driving documentation check, they were then asked to complete a participant consent form and pre-course driver perception questionnaire before being asked to sit in the driving simulator. Once in the simulator the participant was shown how to adjust the seat and asked to make them self comfortable assuming their usual driving position. They were then given an explanation of the primary and secondary controls and instructed to turn the ignition key to start the engine. The participant took part in a short 1.23 km drive on the simulator to capture a pre-training baseline measure of Eco-Driving performance. A plan view of the route and surrounding simulated environment, with numbered feature points, is shown in Figure 3.

The simulated drive started with the drivers vehicle stationary in the left hand lane of an urban dual carriageway (start point [1]), with a 50 km/h speed restriction, on the approach to crossroads (which were situated at 0.09 km from start [2]). The driver was instructed to turn right into a triple carriageway road. The participants view from within the vehicle, at the starting point, is shown in Figure 2.

Fig.2. The drivers view at the start of the simulated drive

The driver was required to move across into the right hand lane in order to carry out the right turn junction manoeuvre. The driver then had to navigate the various road user scenarios, turning right when safe to do so. Upon turning right the driver had to get over to the far right hand lane so that they could exit the triple lane carriageway via a single lane slip road on the right of the carriageway (situated at 0.25 km from start [3]). The slip road followed a steep incline then levelled out (at 0.55 km from start [4]) onto a short dual carriageway strip of road in which the left hand lane was closed with a series of cones. The driver was then faced with two toll booths (at 0.74 km from start [5]) and instructed to go through the one on the right hand side. Upon approach the toll booth barrier opened to allow the driver to pass. Shortly after the toll booth the driver was required to merge with heavy traffic to join a dual carriageway on the left. The dual carriageway continued until reaching a fork in the road (at 1.15 km from start [6]). At the fork, the driver was required to branch left and drive for a short distance before a sign appeared on the screen signifying the end of the simulated drive (at 1.23 km from start [7].

Fig.3. Plan view of the route and surrounding environment

No feedback on performance was given to the participant at this initial stage. In instances where a participant had difficulty in adapting to driving the simulator, a minimal amount of practise drives were allowed to enable the participant to adapt.

On-road driving session

Following the first drive in the simulator each participant took part in an on- road drive. For this part of the course, the participant was first introduced to a qualified Fleet Trainer [Fle1] who explained what would be happening during the on-road training.

The trainer used a combination of recognised on-road fleet training techniques [SAF1] combined with the relevant 'Mastering Traffic Situations' level and 'Vehicle Manoeuvring' level DROPLET course content according to the GDE model [Hat4]. The on-road element of the course lasted for approximately ninety minutes, starting and ending at AMAP, and involved driving on a standardised route including a variety of dual carriageway and urban roads in the Sunderland area.

Upon completion of the on-road element the participant returned to the lab to take part in the classroom session and second simulated drive.

Classroom session

The classroom session began with a general discussion and opportunity to reflect upon what had been learnt during the on-road session. In particular, the participant was given further advice and reinforcement on how to implement and continue improving on the various GDE 'Mastering Traffic Situations' and 'Vehicle Manoeuvring' level eco-driving techniques. During the classroom session the participant was also given general strategic advice and advice on attitudes to driving, according to the specified course elements for the 'Goals for Life and Skills for Living' and 'Goals and Context of Driving' levels of the GDE model [Hat5]. Participants were then shown a series of videos to reinforce further what had been taught and discussed during the on-road session and earlier part of the classroom session.

Lab session 2

Following the classroom session, the participant was reminded how to implement all of the 'Mastering Traffic Situations' level and 'Vehicle Manoeuvring' level Eco-Driving techniques they had been taught during the course and asked to take a final drive in the simulator, this time putting into practise everything that they had learnt during the course. The procedure and content of the second simulated drive was the same as for the first except the participant was given feedback on their performance upon completing the drive according to on-screen feedback as shown in Figure 4. The participant's scores on fuel consumption and C02 emissions were compared for the first and second drive in order to demonstrate any improvements. Where a participant wished to work on gaining further improvement they were allowed to have further practise on the driving simulator, but in every case data from the first and second drive only were saved for use in the analysis. Finally, the participant was asked to complete a post course driver perception questionnaire.

Participants in the control group drove the simulator on two occasions but did not take part in any of the training interventions. However, feedback on individuals Eco-Driving performance was provided, following the second drive in the simulator.

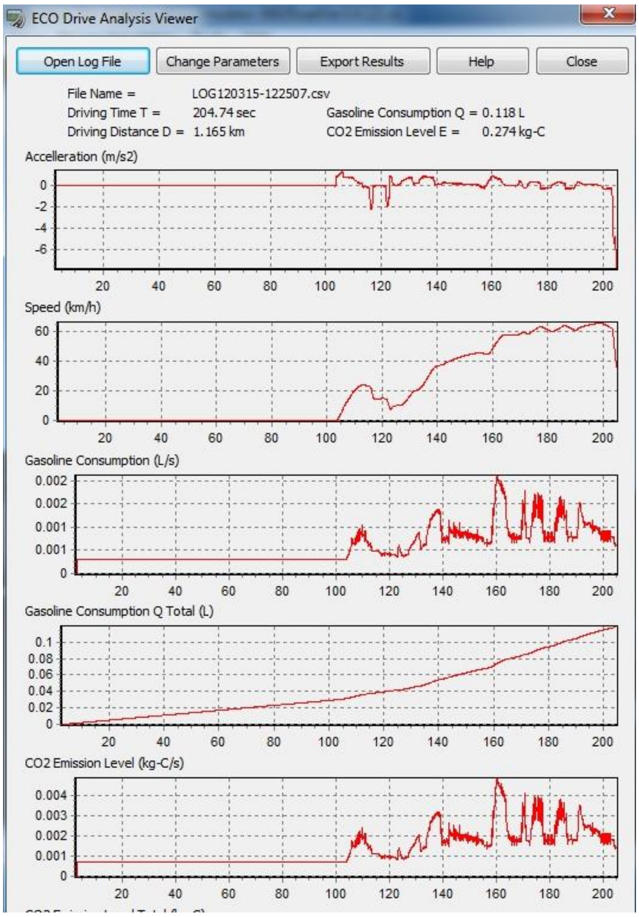

Fig.4. Eco-Drive performance feedback

Debrief

All participants were thanked for taking part in the study and given an opportunity to comment on the course. They were also asked if they would be willing to be contacted three months after taking part in the training study to take part in a follow up interview, and to complete a follow-up driver perception questionnaire.

Results

Using an Eco-Drive module located in the UC-win/Road tools menu and using the 'Calculate Carbon Footprint' function, results showing values for travel Time (T), Travel Distance (D), Fuel consumption (Q), and Carbon Footprint over time are displayed and can be output as a CSV file for use with Microsoft Excel and other statistical packages. Fuel consumption and carbon footprint across a journey, with a vehicles carbon dioxide emission is assumed to be proportional to its fuel consumption, and is estimated using the model proposed by Oguchi, Ktakura and Taniguchi (2002) as described in equation 1.

$$Q = 0.3T + 0.028D + 0.056\sum_{K}\delta_k\left(v_k^2 - v_{k-1}^2\right)$$

Equation 1. Calculation for carbon footprint

Where Q is the fuel consumption in litres, T is the travel time in seconds, D is the travel distance in meters, K is the number of measurements, $\delta_k=1$ when the current speed is greater than the previous speed or 0 otherwise, v_k is the speed at point k in ms^{-1}.

Data on fuel consumption and C02 emissions captured using the UC-win/Road Eco-Drive module, was exported from to IBM Statistical Package for the Social Sciences (SPSS) for further analysis.

Intervention group

A paired samples T-Test was used to compare drivers fuel consumption and C02 emissions before and after training.

Fuel consumption was significantly lower after training than before training.

($t = 6.740$, $df = 14$, $p<0.0005$)

C02 emissions were also significantly lower following training than before training.

($t = 6.740$, $df = 14$, $p<0.0005$)

Control group

A paired samples T-Test was also used to compare drivers fuel consumption and C02 emissions for the first and second simulated drive, for drivers in the control group.

Fuel consumption was significantly lower for the second drive compared to the first drive.

($t = 6.037$, $df = 14$, $p<0.0005$)

C02 emissions were also significantly lower for the second drive compared to the first drive.

($t = 6.001$, $df = 14$, $p<0.0005$)

Intervention group verses control group

The difference between scores before and after training was calculated for each participant in the intervention group, and the difference between the first and second simulated drive was calculated for each participant in the control group. A paired samples T test was then carried out to compare the relevant differences between the groups and to establish whether or not there was a significant effect of training intervention.

The results show that the reduction in fuel consumption for the intervention group was significantly greater than that for the control group.

($t = 2.803$, df,= 14, $p = 0.14$)

The reduction in C02 emissions for the intervention group was also significantly greater than for the control group.

($t = 2.803$, $df = 14$, $p = 0.14$)

Analysis of data for the driver perception questionnaires and follow-up interviews is currently on-going and is not reported in-depth in the current paper. However, an initial review of content suggests general improvements in driver perceptions on elements of driving associated with Eco-Driving following participation in the DROPLET course. Furthermore these improvements appear to be reasonably well maintained over time.

Discussion and Conclusion

Participants first drove a short un-instructed route in the driving simulator to obtain a baseline measure of Eco-Driving performance. They then took part in some on-road and classroom based training. Following participation in the training course, drivers were required to take a final drive in the simulator, following the same route as for the baseline drive. This time drivers were asked to put into practise everything they had learned on the course, and Eco-Driving related scores for the first and final drive were compared to evaluate the effects of training. Participants completed pre-course, post-course and follow-up driver perception questionnaires. Follow-up interviews were also conducted three months after participants took part in the course, to investigate the extent to which any effects of the training were durable over time. Results from the control group were used to control for exposure related learning effects associated with simulated driving.

The results show a significant reduction in driver's fuel consumption and C02 emissions following participation in the DROPLET driver training course. This is also assumed to indicate a general improvement in driver's application of Eco-Driving techniques. However, the data also highlights a significant reduction in fuel consumption and C02 emissions for the control group between the first and second simulated drive, highlighting the important benefits of exposure to simulated driving practise. This is something that should be exploited in future studies. Results suggest a positive role for the use of driving simulators in Eco-Driver training. It is proposed that more driving scenarios should be developed for the driving simulator, in the future, so that a further study can be conducted, adapting modules from the GDE/DROPLET Matrix for a predominantly simulator based training course and evaluation study. The study further highlights the important role of driving simulators in the research and evaluation of Eco-Driver training. Driving simulators provide experimental control and guarantee safe driving conditions, something that can not be achieved with on-road driving.

Initial results from the driver perception questionnaires, and follow-up interviews indicate lasting benefits to participation in the DROPLET driver training course. A further in-depth analysis is being conducted and detailed results will be reported in a future paper.

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