Institution: BRUNEL UNIVERSITY (H0113)

Unit of Assessment: 34 – Art and Design

Title of case study: Enhancing the Driver Experience in Automobiles

1. Summary of the impact (indicative maximum 100 words)

The research addressed the problem of improving the driver experience of the sound and vibration of their automobile operating under idle conditions in city traffic. As a result of the research, Shell Global Solutions UK developed and successfully adopted a test standard protocol that changed their R&D process for making diesel fuels. The research shifted the process of making fuels from one which were oriented to the product to one that was customer focused. The new test standard protocol and the vibration acceptability metric were also adopted by Ford Motor Company Ltd., Bentley Motors, BMW, Fiat, Ferrari, Jaguar Land Rover, Peugeot-Citroen and Renault.

2. Underpinning research (indicative maximum 500 words)

The research started in response to one of the many challenges facing today's automotive car designers and fuel manufacturers: to attune the overall perception of vehicle quality to the level of satisfaction a driver has with the vehicle's engine. Brand quality, comfort and situation awareness can all depend on the nature and intensity of the perceptual experience. In city traffic automobiles spend a lot of time operating under idle conditions. During city driving automobiles typically consume 30% of their fuel while idle. Decreasing the engine idle speed (600-800 rpm) is a means of reducing fuel consumption. However, lower-speed operation degrades the idle stability and increases engine speed oscillations. Fluctuations of engine idle can cause unpleasant vibrations of the vehicle leading to lower driver satisfaction.

This research developed an understanding of the relationship between the physical characteristics of diesel engine idle and the human subjective response to the sound heard, and the vibration felt through the steering wheel (Ajovalasit and Giacomin, 2007). By understanding how a driver's feeling of engine roughness or power changes with the chemical properties of the fuel, Shell's interest in the research project was to identify a strategy to choose chemical compounds that meet and exceed customer expectations. In this case, knowledge of the human perceptual characteristics was deployed to design a fuel that considered the driver as much as it did the car.

The Perception Enhancement Research (PER) Group at Brunel undertook in-depth research for Shell Research Ltd to optimise the perceptual characteristics of Shell fuel products by developing a test method for quantifying driver response to engine idle vibration and sound (Ajovalasit and Giacomin, 2007, 2009). The PER Group conducted mathematical analysis, laboratory tests, analysed and selected useful metrics for quantifying driver-feel and developed a test standard for Shell's use.

The test standard comprised detailed sensor requirements, protocol requirements, the achievable measurement accuracy, and the reporting requirements of the diesel fuel test methodology. Interactive testing, performed with Shell personnel at Shell test facilities, validated the standard. The test standard provided a reference against which to judge the effect of fuel or automobiles' properties on the human subjective response to diesel engine idle sound and vibration. Various signal processing methods, including the time-frequency wavelet transform (continuous and discrete orthogonal), were used to analyse engine idle acceleration signals, measured at both the engine block and steering wheel of several cars. Modulation depth was taken to be the dominant metric to characterise diesel idle irregularity. Extensive laboratory tests were performed to quantify the human subjective response to this irregularity. The research produced an analytical model of the growth in the human subjective response to the steering wheel vibration as a function of the modulation depth of the idle acceleration signal at the steering wheel. This subjective response was quantified in terms of both "perceived unpleasantness" and "perceived roughness", and provided a method for quantifying the degree of these two factors as a function of the modulation depth.

The benefits of the new perceptual model based on the modulation depth of the vibration stimuli go beyond a practical method to assess the irregularity of the diesel engine idle vibration. The findings provided an opportunity to investigate the choice of the subjective response metrics for quantifying

the intensity of idle vibration at the steering wheel (Ajovalasit and Giacomin 2009, Jeon et al., 2009). The vibrational energy at the steering wheel was either quantified directly (unweighted form), and also after weighting the signal's frequency components using the ISO standard frequency weighting curve, and using the Ws frequency weighting, developed specifically by the PER Group. The three methods produced slightly different conclusions regarding the best fuels, with the most accurate being the newly-developed Ws weighting function (Ajovalasit and Giacomin, 2009, Jeon et al., 2009). The project also raised numerous questions regarding the best choice of subjective response metrics for quantifying the sound at the driver's ear. Both the literature survey and the research results performed by the PER group suggested the superiority of the Zwicker Loudness method in terms of overall accuracy (Ajovalasit and Giacomin 2007). While much psychophysical research has been performed in the past for generic environmental stimuli, few have been performed for the stimuli which characterise the automotive environment, and none have been performed for those conditions which a driver feels in the vehicle when exposed to engine idle. The findings provide opportunities for new human-centred research activities for identifying which stimuli, the sound or the vibration, requires the greater investment of resources during the vehicle development programme.

The research outcome included 7 journal papers, 2 conference papers, around a dozen invited seminars at national and international workshops, 1 PhD Thesis, and 2 chapters in PhD and MPhil dissertations.

3. References to the research (indicative maximum of six references)

The journal papers are all in public domain. They can be downloaded at the Perception Enhancement Research (PER) website: http://www.perceptionenhancement.com/documents.html

Journal paper (peer reviewed)

[1] Jeon, B., Ajovalasit, M. and Giacomin, J., 2009 Effects of gender differences on the subjective perceived intensity of steering wheel rotational vibration. International Journal of Industrial Ergonomics, Vol. 39, No.5, pp.736-743. http://dx.doi.org/10.1016/j.ergon.2009.02.010

[2] Ajovalasit, M. and Giacomin, J., 2009, Non-linear dependency of the subjective perceived intensity of steering wheel rotational vibration. International Journal of Industrial Ergonomics, Vol. 39, pp 58-67. http://dx.doi.org/10.1016/j.ergon.2008.08.002

[3] Ajovalasit, M. and Giacomin, J., 2007, Effect of automobile operating condition on the subjective equivalence of steering wheel vibration and sound. International Journal of Vehicle Noise and Vibration (IJVNV), Vol.3, No. 2, pp. 197-215. http://dx.doi.org/10.1504/IJVNV.2007.014905

4. Details of the impact (indicative maximum 750 words)

This research aimed to address the problem of improving driver's experience of the unpleasant vibration and sound produced by an automotive engine running a commercial fuel in idle condition. In recent years vehicle quality and comfort have become more important in the process of developing new vehicles.

It was estimated that the total market size of retail petrol and diesel product (including taxes) was around £47 billion in 2011.

In order to be the market leader and to compete in the long term, Shell wanted to increase its customer reach. Because the customer feedback on the quality driving experience was low in the Shell Customer Survey, Shell Global Solutions UK approached the Brunel Perception Enhancement Research Group to develop an industrial test methodology. The aim was to change Shell's process for making new diesel fuels to better respond to and incorporate the needs and wants of their customers. While assessment of fuel products in the fuel industry had often been performed, it had always been based on sustainability or product design requirements. This research shifted the approach from a product orientation to one with a consumer focus. It was

based on a human-centred approach which evaluated how the automotive fuel properties affected the customer's perception of vehicle quality. It moved away from the traditional approach of assessing the vibration of a standard test engine running a target fuel towards assessing the vibration perceived by the driver in a vehicle equipped with a target engine and a target fuel.

With this wider reach, Shell will be able to provide more people with quality branded fuels they can trust and at a competitive price. This research has allowed Shell Global Solutions UK to develop a metric which can translate the measurable mechanical (objective) quantities which define human-vehicle interaction into perceived (subjective) quantities. This metric indicates the likely response of a driver to questions about the fuel, engine or complete vehicle. The project's success was the implementation of a standard test protocol for rating the idle quality of diesel fuels as a benchmarking and product evaluation standard for use by Shell personnel at Shell test facilities. From 2009 a new Shell Research & Development Team was formed within Shell group with new members of staff recruited focussing on the "driver perception research" so as to enrich the understanding of the measures of customer interpretation and perception of fuel products which were designed using the test standard produced by this research. All new fuels went through the acceptability criteria of the test standard developed. Two or three commercial Shell diesel fuels were modified by using the industrial test standard developed and "*it proved to be valuable to Shell to develop new insights and techniques that would not have been possible using their in-house research facilities alone."* (Dr David Doyle, Project and Technology Responsible, Shell Global Solutions, UK).

Several European motor manufacturers, including Bentley Motors, BMW, Fiat, Ferrari, Ford, Jaguar Land Rover, Peugeot-Citroen and Renault have benefited from the research, and in particular are using the test standard protocol. For instance, Ford Motor Company Ltd has used the steering wheel vibration metric to assess their automobiles from the point of view of the customer experience.

The research was also presented at a meeting of the Universities Internal Combustion Engine Group (UnICEG), a leading UK-based focus group of the petroleum and motor manufacturing research sector, where it received a lot of interest from leading automotive experts from TRW, Millbrook Proving Ground and the Motor Industry Research Association (MIRA). Over the years several invited seminars were provided in the United Kingdom and overseas including Hand-Arm Perception Research Performed by the Perception Enhancement Systems Group at Brunel University (2006), Effect of Fuel Content on the Human Perception of Engine Idle Irregularity at Shell Research Centre in Thornton (2006), Effect of automobile operating condition on the subjective equivalence of steering wheel vibration and sound presented at the International Conference on Noise and Vibration Engineering ISMA (2006) in Leuven, Belgium, and Human Perception of Combined Sound and Vibration Workshop at Millbrook Technical Centre, Bedfordshire (2005).

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. A supporting letter received from Shell Projects and Technology Responsible, Shell Global Solutions, UK, confirming the impact of research on the process of making fuels.
2. Fuel Scientist, Saudi Aramco, Arabian Oil Company: Formerly, an industrial supervisor with Shell from 2000 to 2008
3. Research and Innovation Center, Ford Motor Company, USA. Evidence of using the Ws vibration metric developed by the Brunel. (SAE paper 2005-01-2473 -Equal Annoyance Contours for Steering Wheel Hand-arm Vibration.
4. Powertrain NVH Engineer, Ford Motor Company Ltd.
5. Senior Engineer, Ferrari, Italy