Breaking Out of the Academy: Case Studies in the Impact of Academic Design Research

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As a relatively new field of scholarship, design research now confidently defines itself through distinctive academic journals, conferences and associations/societies. However, there is a tendency for the outcomes of academic design research to focus on academic endeavour, such as ways to support teaching and theoretical approaches to designing and design knowledge. This paper explores an alternative position in which the outcomes are extended beyond the academy by making direct contributions to design practice, design innovation, design regulation, design guidelines and design technology. Whilst academic outputs inevitably result in journal publication, the most significant impact of the case studies discussed in the paper can best be described as 'non-academic' in the form of: a high visibility livery for emergency vehicles that has been adopted in the UK and beyond (design guidelines); an award-winning design tool for the Industrial Designers Society of America to standardise the language used for design representations to facilitate understanding and collaboration (design practice); an automatic braking system to reduce motorcycle traffic accidents (design technology); clothing for Great Britain's Olympic Cycling Track Team to negate the pre-race drop in muscle temperature to enhance performance (design innovation); and revisions to a United Nations regulation to increase cyclist visibility when using the rear view mirrors on large goods vehicles (design regulation).The paper concludes that the rigour, specialist in-depth knowledge and ability to view real-world problems with a fresh pair of eyes enables academic design research to have significant and far-reaching impact beyond academia.

Key words: Impact, commercialisation, case studies, industrial design, ergonomics

1. Introduction

Loughborough Design School is characterised by its distinctive approach to design research that has a focus on sustainable design, transport safety, ergonomics and design practice (http://www.lboro.ac.uk/departments/lds/research/groups/). Its five research groups and two research centres undertake research for research councils, government agencies and private companies to provide new knowledge that supports innovation, policy, well-being and design knowledge. This paper provides five case studies that demonstrate the approaches taken in the delivery of impact beyond the academy in which the key outcomes are not related to academic teaching or research. For each case study, this is achieved by providing the background to the project; the aim of the research; its methodology/methods; findings; and impact. The case studies provide an insight into research projects for the design of a National Police Livery for the UK Home Office; a design tool to support collaboration and understanding during product development for the Industrial Designers Society of America (IDSA); an investigation into automatic motorcycle braking system for the UK Highways Agency; performance enhancing muscle heating for adidas; and improvements in the capacity for drivers of large goods vehicles to see cyclists for the UK Department for Transport.

2. UK National Police Livery

2.1 Background

There are 50 police forces operating within the UK, each of whom used to have their own individual marking livery for force vehicles. An implication of this was that across the national motorway network there was a lack of consistency for the visual representation of a police vehicle and associated lack of visibility, particularly for stationary vehicles. Given the complex and dynamic nature of the driving task, it was critical that drivers were able to process and respond efficiently to visual information. Emergency vehicles need to quickly obtain the attention of other road users and improving their conspicuity is a mechanism for achieving this. The UK Home Office Police Scientific Development Branch commissioned the User Centred Design Research Group to undertake research that would help define the country’s first national police vehicle livery.

2.2 Aim of Research

The aim of the research was to determine for police traffic patrol vehicles operating in a motorway environment a suitable common standard of markings which enhances, at a distance, conspicuity and recognition as a police vehicle.

2.3 Methodology/Methods

The methods used focused on the development and evaluation of the livery through:

- Secondary data review - undertaken to identify the human factors issues relevant to improved conspicuity and the means for implementing these within a livery
- Laboratory trials - undertaken in the initial stages of the vehicle livery development to identify the performance and acceptability of the proposed markings prior to more complex road trials
- Road trials - undertaken with proposed ‘Battenburg’ vehicle livery for six months across 12 forces to obtain police driver feedback on its perceived suitability.

The methods were developed with the intention of addressing the following objectives:

- Enhance officer/public safety by reducing the likelihood of road accidents where conspicuity of the police vehicle is a factor.
- Be recognisable as a police vehicle up to a distance of 500 metres in normal daylight.
- Assist in high visibility policing so as to reassure the public and enhance the potential deterrent benefits of proactive traffic patrol activity.
- Readily identifiable nationally as a police vehicle but retain the ability to associate force corporate logos.
- Capitalise on the latest materials and systems available and seek to achieve a cost-neutral option when compared with the average costs of current liveries.
- Be acceptable to at least 75% of the staff using it.

2.4 Findings

The literature review highlighted the importance of improved contrast of the vehicle against its background. In the design phase this was achieved through the use of the colour yellow since the light-adapted human eye is most sensitive to yellow-green wavelengths. Luminance (brightness) contrast was achieved through the use of passive materials i.e. fluorescent and retro-reflective for improved daytime and night-time conspicuity respectively. With respect to object definition, it was noted that large blocks of colour were preferable; that the overall size/shape of the object should be emphasised; and that object outlining can have value (Harrison, 2004). Additionally, any pre-existing visual associations with the police could potentially contribute to the livery scheme. The realisation of these factors into a vehicle livery is shown in Figure 1.

Figure 1. UK police force vehicle livery applied to Volvo estate

Key elements of the livery are:

- Block design balances camouflage against a recognisable identity, invoking a historical reference to 'Sillitoe tartan' of the police chequer band.
- Yellow material is fluorescent (aids daytime conspicuity) and is retro-reflective (aids night-time conspicuity) offering high contrasts with blue (that has a historical reference to the police service).
- Blue material is retro-reflective (aids night-time conspicuity) and contrasts with yellow.
- Outlining defines the vehicle shape.

Laboratory trials were used to investigate the extent to which the proposed livery met the research aims and outperformed existing liveries. Slides depicting the side or rear views of a range of vehicles were presented tachistoscopically for a period of 0.3 seconds (the minimum time taken by a driver to glance at a specific road scene in order to obtain information) and the sample of public drivers were asked to instantly record which vehicle stood out the most. Overall, across both day and night-time conditions, the proposed livery outperformed the civilian and police vehicles it was assessed against. Feedback indicated that the proposed livery was perceived as distinctive and readily associated with the police [1].

Road trials identified opinions/attitudes of police drivers and investigated the durability and maintainability of the livery. Trials with 170 police drivers provided feedback by means of a structured, self-administered questionnaire in which 86% considered the proposed livery to be more conspicuous than their existing force livery; 70% favoured its introduction; and 58% felt safer undertaking their duties in vehicles with the proposed livery.

2.5 Impact

Within the UK, following the successful introduction of the Battenburg livery (so called due to the similarities of the block formation with the traditional cake), the ‘Half Battenburg’ (which has a single row of blocks) was then introduced onto urban/sub-urban patrol vehicles. Further development was then undertaken to extended the Battenburg livery for police motorcycles which represents a vulnerable user group in terms of traffic accidents .

All of the Battenburg liveries are now the subject of published Home Office guidance which states the impact of the Battenburg livery as being ‘ . . . very successful in enhancing safety, in building an image that is reassuring to the public and has a deterrent effect on those who seek to break the law on our roads’[1]. Additionally, it can be observed on the UK’s roads that other emergency service organisations are adopting the Battenburg livery format. Whilst the colours differ, the block format is maintained and hence the Battenburg markings are now used to more broadly signify ‘emergency vehicle’ as opposed to police vehicle. Such services include: Ambulance, Fire and Rescue, HM Coastguard, Mountain Rescue, Rail Response, Highways Agency and National Blood Service.

Internationally, the US Fire Administration cited Battenburg as “the only example of international best practice” [2] whilst the Vice President of the American Ambulance Service stated that “It’s safer for our responders, safer for the community and safer for the patients, because we can get there faster without having incidents of our own” [3]. In addition, the chevron markings used to the rear of vehicles within the Battenburg livery have been incorporated within the National Fire Protection Association’s standard for automotive ambulances 2013 edition [4]. In New Zealand, the Police Executive agreed that all vehicles will carry a blue/ yellow half Battenburg livery since, as stated by Acting Assistant Commissioner for Crime Reduction and Public Safety, “this brings a consistent look to the marked vehicle fleet, with proven high-visibility and cost-savings associated with just one livery” [5]. In Hong Kong, front line staff consider the Battenburg to “…. definitely enhance the safety of police officers and road users as it is very conspicuous and can be spotted from far away” and that it is “clearly identifiable as a police vehicle” [6].

3. Design Tool to Support Collaboration during Product Development

3.1 Background

A wide range of design representations are employed by industrial designers to externalise, manipulate and communicate design intent. The complex and competitive nature of product development requires collaboration between design professionals to effectively conceptualise, develop and commercialise innovative products [7] but global variations exist in descriptive terms. Jassawalla and Sashittal [8] note that collaboration occurs when participants command equal interest, adopt transparency with high awareness, are mindful through integrated understanding, and perform with synergy. Having developed a knowledge framework on the use of design representations by industrial designers and engineering designers through PhD research by Dr Eujin Pei, key components were extracted in collaboration with the Industrial Designers Society of America (IDSA) and translated into a portable design tool called iD Cards. Through the use if literature based sources and empirical data, the iD Cards provide a name, description and image for 32 types of design representation categorized as sketches, drawings, models and prototypes. They indicate when a particular design representation is used during product development and for what type of information.

3.2 Aim of Research

The aim of the research was to provide industrial designers with a tool to support collaboration and understanding during product development

3.3 Methodology/Methods

Phase 1 involved the PhD component of the research to identify prior work, generation of taxonomy of design representations and confirm its validity with practicing designers; identify barriers to collaboration with empirical data collection using semi-structured interviews with stakeholders; identify when the key design representations identified in the taxonomy were used and for what types of information; develop a knowledge framework and its translation into a tool suitable for appraisal/validation ; appraise and validate the tool with stakeholders.

Phase 2 involved post-doctoral development and information design by generating an information design solution that would enable the most relevant elements of the PhD knowledge framework to be accessed effectively and selecting 32 images of sketches, drawings, models and prototypes that succinctly captured the nuances of representations used in the taxonomy.

Phase 3 involved stakeholder engagement and impact by making contact with key stakeholders; selecting the most appropriate stakeholder and face to face meetings to discuss details of commercialization; and developing a of strategy for dissemination.

3.4 Findings

The research resulted in a taxonomy of design representations categorised as sketches, drawings, models or prototypes. Each design representation had a name, description and image. Having been validated, the taxonomy was used as a research instrument to identify when each of the design representations was used during product development and for what types of information. The stages of product development were identified as ‘Concept’, ‘Development’, ‘Embodiment’ or ‘Detail’ and the iD Cards included a brief description of each stage. The types of information was categorised as ‘design information’ or ‘technical information’. The design information was identified as ‘Areas of Concern’, ‘Form’, ‘Design Intent’, Scenario of Use’, ‘Usability and Operation’, and ‘ Visual Character’. The types of technical information was identified as ‘Assembly’, ‘Components’, ‘Construction’, ‘Dimensions’, ‘Materials’, and ‘Performance’.

Collaboration and understanding was to be facilitated through the provision of information on design representations and a significant challenge was the translation of the knowledge framework in to a useable tool. This was achieved in consultation with the IDSA who approved the iD Cards for production in 2010 (Figure 2).

Figure 2: Both sides of the folded-out iD Cards

3.5 Impact

Judgements on the contribution, impact and benefit of the iD Cards design tool go back to the PhD during which 18 industrial design and engineering design students plus 43 industrial designers, engineering designers and academics took part in the validation process which indicated that 100% of the students and 67% of the practitioners/academics believed that it would enhance collaboration during product development. The value of the information embedded in cards was acknowledged by the IDSA and a desire to make the physical product available to members expressed. In 2010, the iD Cards, were presented to the Executive Board of the IDSA (comprising senior practitioners and academics) by their Executive Director, with a request for approval for production and distribution. Approval was given and 5000 were distributed to members in 2011 to members via 5 District Conferences in March/April (Cincinnati, St Louis, Providence, Austin, San Jose); the International Conference in September (New Orleans); by post to its 61 university chapters (59 in the USA, 2 in Canada)

In response to overwhelming demand and acknowledgement of the value of the iD Cards, a pdf version was created and made available on the Design Practice Research Group web pages of Loughborough Design School at http://www.lboro.ac.uk/departments/lds/research/groups/design-practice/

4. Automatic Motorcycle Braking System

4.1 Background

Motorcycles or Powered Two Wheelers (PTWs) are becoming increasingly popular as a form of personal transport in Europe. They use less fuel than cars because they have a more favourable power to weight ratio and are less often stationary in traffic. Additionally, they contribute to increased traffic flow because they take up less space on the road. The downside of this 'sustainable' form of transport is that the risk of serious rider injury in a crash is high [9]. Of the 40,000 road users killed each year on EU roads 16% are riders or passengers of PTWs. Taking the UK as a typical example of the European casualty situation, PTWs account for 1% of vehicle kilometres travelled but 20% of fatal and serious casualties and the rate of PTW users killed/seriously injured is 31 times higher than that for cars.

4.2 Aim of Research

The high incidence of accidents formed the backdrop to the EU Pisa project on Powered Two Wheeler Integrated Safety. The Pisa project aimed to investigate whether crash prevention technology (active safety) that now starting to be fitted to cars, could be utilised on PTWs in safety critical situations. In comparison to cars, the operation of a PTW requires more complex control actions, therefore any system that assumes autonomous control of the vehicle has the potential be to a hazard in itself. The specific research aim was to design, build and test an active safety system for PTWs. This work required multi disciplinary researchers consisting of specialists in accident analysis, biomechanics, human factors and the design of sensing systems, braking and suspension.

4.3 Methodology/Methods

European PTW accident statistics were studied to verify the most common crash configurations associated with serious injury or fatality to PTW users. In-depth cases representing those crash configurations were then studied to prioritise the functional requirements of an active safety system necessary to avoid crashes or reduce crash severity outcome. The development of autonomous braking support was chosen as the highest priority system that was within the design capabilities of the expert team. It was decided early on that an autonomous braking system capable of avoiding impact altogether would have to trigger so early in a potential crash event that it would lead to numerous false alarms in a real traffic environment. Instead, the system design needed calibrating to reduce the impact severity of a crash but not to avoid the crash altogether.

The system was required to measure the distance and time to an approaching object, make decisions concerning if and when to apply autonomous emergency braking and to apply braking without throwing the rider off. Many components were required to work together to achieve this.

A SICK AG laser scanner was mounted in the front fairing to detect objects and measure speed and distance. This was connected to a dSPACE box containing decision logic [10]. Also connected to the dSPACE box was an Xsens state estimator which measured the attitude of the PTW. The machine was fitted with a vibrating (haptic) seat and specially developed front forks whose damping was adjustable to prevent the front of the machine from diving excessively under hard braking. The damping pressure was varied by means of a stepper motor controlled by the decision logic.

When the laser scanner detects an object it sends information to the dSPACE box. If the decision logic calculates that a collision is unavoidable and the rider is not applying brakes, it vibrates the seat to warn the rider. If the brakes are still not applied, low level braking is applied automatically at 0.3g and the anti-dive forks are activated. If the rider then brakes, full emergency braking is automatically applied at 0.6g. If the rider does not brake, automatic braking is maintained at 0.3g. Laboratory tests with human subjects on a static motorcycle rig showed that 0.3g was the maximum braking tolerable by an unaware rider whilst still staying upright on the vehicle. Additionally, the system was designed not to operate at low speeds (<5km/h) and at lean angles of >10 degrees, in the interest of keeping the rider on the PTW. Much of the project time consisted of developing and testing different actuating parameters using test track trials to ensure all components worked together.

4.4 Findings

The prototype design exhibited some anomalies concerning the sensitivity of the laser scanner and decision logic. As objects other than the prime focus would occasionally trigger the system, attention to the calibration was required to correct this to a point where the mean triggering reliability was as high as 91% at 35 km/h. It was also shown that reliability increased when set to trigger close to impact. This demonstrated that the system was more reliable when set to severity mitigation mode rather than as an accident avoidance device.

The effectiveness of the final system design was evaluated by researchers from the Department of Mechanics and Industrial Technologies, University of Florence; the Loughborough Design School and Folksam Research [10].

The live testing of PTW impacting a stationary object can be seen in Figure 3.

Figure 3. Live testing of PTW impacting a stationary object

A PTW impacting a stationary object and an object pulling across the PTW path are two of the most common crash types represented in European crash configurations. System effectiveness was assessed using real world crashes fitting these configurations using a method previously applied to passenger car technology [11]. Where significant injury was sustained, it was shown that in 49% of cases, early braking by the rider could have avoided the crash completely. In 51% of cases, a crash was unavoidable and in 38% of cases an unavoidable crash could have been reduced in severity had the automatic braking system been present.

4.5 Impact

Unlike the case with their four wheeled counterparts, there is very little potential to protect riders of PTWs using passive safety approaches. The onus therefore rests on active safety as a means to provide some reduction in casualty numbers. ABS and Stability Control is already being adapted for use by PTWs but the transfer of car technology has been fiercely resisted by the motorcycling fraternity due to a perceived interference with the rider’s control. The riding task is much more complex than driving and it is less easy to apply technology developed for cars to powered two wheelers. This prototype PTW braking system is the first of its kind and demonstrated that a system could work in real traffic conditions and provide potential for casualty reduction.

5. Performance enhancing muscle heating for elite athletes

5.1 Background

Loughborough Design School has a long standing cooperation with several sports clothing and equipment manufacturers. In co-funded PhD projects, research is undertaken on the physiological basis for human performance in relation to climate and clothing [12, 13]. Following discussions between Loughborough Design School, adidas and British Cycling, a project was initiated to explore the impact of electric muscle heating in the period between the warm up and the actual race for sprint cyclists.

5.2 Aim of Research

The aim of the project was to develop a clothing-based intervention for use by athletes at the London Olympics that would contribute to a measurable benefit to performance.

5.3 Methodology/Methods

A raised muscle temperature is essential for optimal performance of the athlete. Unfortunately, there is often a waiting period between the warm up and the race, which can be extended due to unforeseen circumstances (crashes in other races). It was hypothesised that in this period (30 minutes) muscle temperature will drop below optimal levels and that this drop may be attenuated either by insulated trousers of electrically heated insulated trousers, worn between warm up and race.

The project employed experimental methods and the use of an environmental research chamber to determine the leg muscle temperature increase of a sprint based warm up; muscle temperature drop between warm up and a race 30 minutes later; the effect of different clothing interventions on muscle temperature; and whether any of these interventions resulted in a measurable increase in sprint performance

5.4 Findings

Muscle temperature increased by 2 to 2.4 degrees C due to the warm up. Continuous muscle temperature measurement in the leg muscle between warm up and race (30 minutes) showed that most of this increase (>1.5 ºC) is lost when a normal tracksuit or even an extra insulated tracksuit is worn. Wearing the electrically heated, insulated tracksuit trousers reduced the muscle temperature drop by around 0.5 ºC. It was only this last intervention that had a measurable effect on subsequent sprint performance. The effect observed was much larger than expected: a 10% increase in peak power output and a 4% increase in average power output over the sprint period. The adipower Hot Pants can be seen in Figure 4.

Figure 4. adipower Hot Pants

5.5 Impact

Having established the benefits, the trousers were further developed by adidas, British Cycling and Loughborough Design School for the 2012 Olympic Cycling Track Team. Trousers were individually matched to athletes using body scanning. The trousers were received enthusiastically by the athletes (e.g. Sir Chris Hoy, Victoria Pendleton and Laura Trott) and used extensively in the 2012 Olympics in which they are considered to have contributed to the British success by British Cycling who won a total of 8 gold medals. Commenting on the trousers, Sir Chris Hoy said: “I have definitely been feeling the benefits of the ‘hot pants’. As soon as you take them off immediately before you do your standing start or flying effort, your legs feel like they are ready to go. You feel like you did at the end of a warm up but not out of breath or fatigued from it. It gets you in the optimum state for training and competition.” Matt Parker, Director of Marginal Gains, GB Cycling said: "The aim of the British Cycling marginal gains strategy is to develop a performance advantage through the application of cutting edge science and technology. What adidas has delivered with the muscle warming garment is a key component of our performance preparation”. The development of the trousers was fully reported in the Journal of Medical Sports Science and Sports Exercise [14].

6. Improvements in the Capacity for Drivers of Large Goods Vehicles to see Cyclists

6.1 Background

This research concerns the development of a new volumetric vision assessment for Digital Human Modelling (DHM) and its application to transport. The research was commissioned by the UK Government who identified on-going concerns with blind spots in Large Goods Vehicles (LGVs) and their role as a contributory factor in road accidents. In particular the number of side swipe accidents, and accidents with vulnerable road users, warranted further exploration. Road accident scenarios were identified from UK accident data, modelled and then evaluated within the DHM environment SAMMIE [15].A new assessment method was developed that creates a 3D projection of the volume of space visible through an aperture (direct vision), or reflected through a mirror (indirect vision). Using these projections vision was assessed for the scenarios using three different Category N_3 vehicles (Goods vehicles > 12 tonnes). The view afforded the driver was evaluated using multiple mirror and window aperture projections simultaneously, allowing the identification of blind spots [16].

6.2 Aim of Research

The aim of the research was to identify potential blind spots for large goods vehicles (Category N_3).

6.3 Methodology/Methods

Driver's field of view assessments in vehicles have been performed using a number of tools and methods in recent years [17, 18, 19]. A common approach to identify the field of view afforded to the driver is to use a 2D mapping approach in which the field of view through an aperture such as a window, or via a mirror, is projected onto the ground plane. This approach is also employed in regulatory standards to describe the minimum field of view for vehicles of various types [20].

In reality, the field of view is a complex 3D volume, only part of which may intersect the ground plane. Figure 5 shows the 3D volumetric projection of the field of view from the driver's side mirror of a UK car. A human is stood within the visible area as projected at the ground plane but the visible volume indicates that only their feet and part of their lower leg would be visible to the driver.

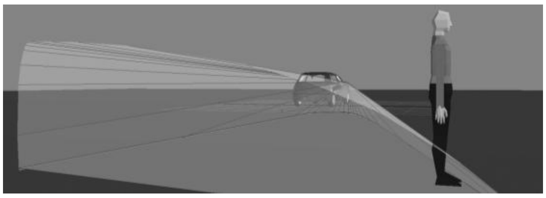

Figure 5. 3D volumetric field of view projection through a car's wing (side) mirror

To address these issues, a 3D volumetric field of view projection tool was developed and implemented within the SAMMIE DHM system. The aim of the development was to provide a tool that could be used to project the viewable volume as afforded by direct vision through an aperture such as a window, or by indirect vision through a mirror. In addition, multiple apertures / mirrors should be able to be projected simultaneously to support a full 360° evaluation of field of view around a vehicle.

Blind spot evaluations were supported through data collection and interviews with twenty LGV drivers with a broad range of size. In addition, three Category N_3 vehicles: DAF XF 105, the Volvo 480 and SCANIA R420 were selected based on sales data. The Volvo vehicle was left hand drive to allow an analysis of the situation for vehicles driving on UK roads (right hand drive layout) that originate from mainland Europe. The DAF and SCANIA vehicles were right hand drive. Each of these vehicles was digitized in three dimensions using the FARO ARM data capture system. These data were then imported into the SAMMIE DHM system for analysis.

Each of three vehicles were setup in the SAMMIE DHM system with accurate positioning and adjustability of controls and mirrors. Digital Human Models were created using the anthropometric data gathered from the smallest and largest drivers from the previous interviews and the virtual vehicles were adjusted to allow realistic driving postures to be recreated. Blind spots were analysed by projecting the mirrors and window apertures.

The identified blind spots were then tested by modelling scenarios derived from the UK accident data, within the DHM system. The scenarios focused primarily on the analysis of 'side swipe' accidents and those involving Category N_3 vehicles turning left at junctions in the UK and colliding with cyclists.

6.4 Findings

The research highlighted the benefits of using a highly visual 3D projection technique within a virtual environment to explore the issues of driver vision. Blind spots were found to exist for all three of the vehicles evaluated and all driver sizes. Scenario testing highlighted the potential for these blind spots to be a causal factor in accidents that occur on UK roads.

The analysis of a specific accident scenario that resulted in the injury of a cyclist was based upon the premise that the driver should be aware of the cyclist being in a location that is to the left of the Category N_3 vehicle before pulling away and starting the left hand turn. It was determined that it is possible for the cyclist to be completely obscured from the drivers vision for all of the test vehicles.

As part of the research performed potential solutions were analysed. An aftermarket mirror was identified that has the potential to fill the blind spot between the volume of space visible through direct vision, and the volume of space visible through current Class V mirrors. This mirror was tested in both real world and DHM analyses and was shown to allow the identified blind spot to be eliminated. Figure 6 shows an example of the DHM analysis using the DAF XF 105 Category N_3 vehicle.

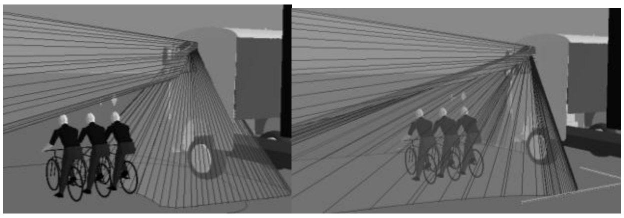

Figure 6. The virtual testing of the aftermarket mirror. The left hand image shows the standard Class V mirror fitted to the vehicle. The right hand image shows the volume of coverage of aftermarket mirror

6.5 Impact

This research identified a key blind spot that had the potential to be associated with the accidents highlighted by UK accident data. This led to the definition of a proposed change to directive UN Regulation 46 which was presented at the 100th United Nations GRSG committee, and was accepted at the 101st GRSG meeting. The change proposed was to mandate an increased area of the floor that is visible to the driver, with the aim of removing the identified blind spots. It is hoped that the fitment of these larger mirrors will improve the field of view of all drivers of these vehicles and help to reduce potential accidents. It is therefore necessary to acknowledge the interplay between the reactive and proactive nature of design research by which academics both respond to and initiate opportunities.

7. Conclusions

Through the use of case study examples, this paper demonstrates the breadth of applications for academic design research, with examples of ways in which contributions to new knowledge have been made for design guidelines, design practice, design technology, design innovation and design regulation. Methods and methodologies were selected to address the research questions posed for the specific project, with examples of strategies that employed both experimental and social science-based techniques.

The case studies have been selected on the basis of impact beyond academia and, for this to take place, a high degree of engagement with external stakeholders was required. However, whilst some of the case studies had this inplace at the outset of the project, others did not (e.g. adipants and iD Cards). The case studies demonstrate that through the use of robust research methods and credible stakeholder engagement, academic research can make a valuable contribution to wealth generation and social well-being.

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