NATURALISTIC DRIVING STUDIES IN SUPPORT OF ROAD SAFETY RESEARCH IN SOUTH AFRICA

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ABSTRACT

Internationally, evidence-based research informs the actions and interventions that are successfully implemented in developed countries, aiming for a zero fatality rate. South African progress to reduce the number of fatal road crashes remains slow and traditional approaches to address road safety seems to be ineffective. There is a need for targeted road safety research that informs the design and implementation of road safety interventions.

To promote a better understanding of the value that evidence-based road safety research plays in supporting the implementation of initiatives within the Road Traffic Safety Management System (RTSMS), CSIR Built Environment has for the past five years invested a portion of the parliamentary grant into the development of the naturalistic driving studies (NDS) methodology. NDS is a research approach that facilitates a better understanding of the contributory factors and interactions between the environment, human and vehicle. This research paper contributes baseline information regarding the development, application and value of NDS as a road safety research tool.

1. INTRODUCTION

South Africa continues to have one of the highest road traffic fatality rates in the world. 2016 estimates showed that 25.2 people per 100,000 lost their lives on the country's roads compared to world and middle-income country averages which vary between 17.4 and 18.4 (Road Traffic Management Corporation 2016; Department of Transport, 2015). South Africa, a signatory to the United Nations Decade of Action for Road Safety 2011-2020 (UNDoA), has pledged to halve road traffic crashes by 2030. Progress towards this goal remains slow with recent country estimates placing the cost of crashes to the economy at approximately three per cent of the Gross Domestic Product (RTMC, 2016). In a middle income, but developing country such as South Africa, this high cost of crashes threatens the vision for effective, efficient and sustainable transport in the country.

The Safe System approach forms the basis of UNDoA, underpinned by five pillars or clusters of focus areas which include institutional management, safer road users, safer vehicles, and infrastructure, as well as post-crash care. These pillars are not entities that work in isolation but components of the road and traffic management system. The Safe System approach facilitates a paradigm shift in that it considers humans as prone to error

and that vehicle and infrastructure designs should absorb these errors in the road transport system, preventing humans from being killed or seriously injured (Khorasani-Zavareh 2011).

Internationally, countries implementing the Safe System approach drive optimistic visions of moving towards zero fatalities. The results that are achieved are made possible through strong institutional structures that are underpinned by the Road Traffic Safety Management System (RTSMS) framework. Wegman et al (2015) highlight that since the inception of the UNDoA, high-income and highly motorised countries such as Western Australia, The Netherlands, Sweden and Switzerland have made significant strides towards a reduction in fatal crashes. These results are made possible through strong governance structures that are underpinned by the RTSMS framework. In addition, the critical success factors for these countries included policies that are data-driven and evidence-based (Wegman et al., 2015). If road safety policies are strongly science-based, the more effective they are in reducing fatalities and the severity of road accidents (Schulze, 2010).

2. RESEARCH IN SUPPORT OF ROAD SAFETY

2.1. Background

Research and Development is one of seven institutional management functions of the RTSMS. Although, Research and Development (R&D) is considered key in the promotion of innovative transport solutions, South African investment in transport research has through the years been poor (Rust, Kisten and Ittman, 2000). It is only recently that national road safety stakeholders have embarked on the implementation of targeted multi-year research programmes in support of road safety.

To address the road safety problem, there is a need to establish a credible evidence base for road safety, guided by a road safety research framework, in support of the design and execution of high impact actions plans. This research framework should prioritise research topics and manage research processes, as well synthesise research outputs for maximum effectiveness. Research topics need to be aligned with national needs, for outcomes of the research, to inform interventions that will address the road safety targets as set out in the national road safety strategy.

2.2. Human factors in road safety research

Human factors and the role it plays in crashes is a neglected area of road safety research in South Africa, despite being a contributory factor in 80 % to 90 % of fatal crashes. The lack of insight into human behaviour that, in combination with the vehicle and environment, contributes to the high death toll on our roads is detrimental to the implementation of prevention actions. Without an understanding of specific behaviour the risk is that preventative measures will continue to address general roads safety issues, rather than specific target behaviour.

2.3. Traditional approaches to road safety research

Traditionally, behaviour has been investigated through the use of self-reported behaviour studies, controlled experiments, simulation and observation studies (Venter and Sinclair, 2014). Self-reported studies make use of interviews or questionnaires to research specific behaviour. Questionnaires comprise of validated question batteries that investigate human

characteristics in relation with aspects of safe driving and crash proneness (Van Nes, Backer-Grøndahl and Eenik, 2010). The main criticism against self-report studies revolves around human error and bias, as these studies rely on the participants own interpretation of their own behaviour. Self-report studies are therefore open to recall (memory) bias, social influences, misunderstanding of questions and respondents answering "what they think is the correct answer" (Backer-Grøndahl et al., 2009).

Epidemiology studies follow a public health approach and draw primarily on crash databases obtained from the police or other entities collecting data. The databases provide information related to (for example) crashes at a population level. A limitation of epidemiological and crash database studies is that is that these studies only reflect the information which was available to and captured by the police, traffic authorities and so forth (Van Nes et al., 2010).

The standard for conducting human behaviour studies has through the years been centred on controlled experiments. An advantage of controlled experiments is that observation of the behaviour is direct and immediate. The researcher controls the variables in the experiment which contributes to better interpretation and structuring of results (Van Nes et al., 2010). Studies conducted in real vehicles (on for example a test track) are considered controlled experiments as the driving environment, in which the participant operates is managed and manipulated by the researcher (Backer-Grøndahl et al., 2009).

Simulator studies (Deery, Kowadlo, Westpahl-Wedding and Fildes, 1998; Yang, Jaeger, and Mourant, 2006) and experimental studies (Harre, Forester and O'Neil, 2005; Borowsky, Shinar and Oran-Gilad, 2010; De Craen, Twisk, Hagenzieker, Elffers and Brookhuis, 2008) use still pictures or videos to assess a variety of road safety situations. These experimental studies are conducted in a controlled environment where the participant is often connected to, sensors such as eye trackers, heart monitors and so forth. A series of pictures or scenarios are shown to participants who are then required to indicate what they perceive as risky situations.

Observational studies are classified into before and after studies, as well as cross-sectional studies (Institute of Transportation Engineers, 2009). In a before and after study, the attributes of what is being measured stays constant. However, the before study entails that participants interact with what is being researched (e.g. stopping behaviour at an intersection without a traffic light) before any treatment has been applied to it. In the after study, the behaviour is again measured after the treatment has been applied (e.g. stopping behaviour at a traffic light after it has been erected at the intersection).

Cross-sectional observational studies are used to investigate the differences between groups. An example is two groups that have common features (e.g. novice drivers who use alcohol vs. novice drivers who do not use alcohol). The comparison would, therefore, focus on the safety aspects of the behaviour that is not common (Institute of Transportation Engineers, 2009). Therefore, the environment, as well as the participants are controlled and not a natural or real reflection of behaviour (Venter and Sinclair, 2014).

2.4. Instrumented vehicles – a new direction for road safety research

In order to facilitate a more proactive approach to prevent road traffic crashes and injuries, different types of technologies - such as field operation tests (FOTs) and naturalistic driving studies (NDS) are employed to collect and analyse real-world driver behaviour data

that provide insight into normal driver behaviour data, as well as the factors influencing causation of incidents and crashes.

2.4.1. Field Operation tests

FOTs refer to the methodology used by vehicle manufacturers, researchers and practitioners to test in-vehicle Information and Communication Technologies (ITC) and Intelligent Transportation Systems (ITS) or smart-vehicle solutions for better traffic management. FOT studies focus on the effect that vehicle technology has on driver behaviour and investigates the possible uses of technology in order to make vehicles as safe as possible (FOT-Net Consortium, 2010).

2.4.2. Naturalistic Driving Studies (NDS)

Internationally, NDS are used to collect large samples of driver data used to investigate driver behaviour (variety of topics, number of participants and the duration of experiments). These large experiments provide detailed insight into the occurrence of road traffic crashes and assist in the identification of factors leading to crashes and near-crash events. NDS have been successfully piloted and implemented in support of road safety research across the world.

The term "naturalistic driving studies" refers to the unobtrusive approach to study driver behaviour. This methodology enables researchers to study driver behaviour in the context of the driving task, road environment, as well as inform driver actions preceding crashes or near-crash events. The use of cameras (front camera facing the road, driver camera facing the driver and rear-facing cameras at the rear of the vehicle) allows for the collection of rich qualitative and quantitative data that provide insight into driver behaviour within specific road contexts. The image material collected provides visual information pertaining to driver behaviour while the data collected from the onboard computer enriches the image data with acceleration data (which can detect harsh braking for example), speed data, and global position system (GPS) coordinates.

The underlying assumption of this approach is that driver behaviour will not be significantly altered by being observed over the long term and that such studies would, therefore, reflect natural driver behaviour over time. The image material recorded in the vehicle, along with other in-vehicle technologies collecting data about the road environment and other vehicles provide valuable insights into driver behaviour in different driving situations.

3. PURPOSE OF THIS PAPER

The aim of this paper is to provide an overview of the use and application of the NDS methodology as an alternative to traditional road safety research methods in South Africa. The paper illustrates that it is possible to apply NDS in the South African context and that NDS is able to provide rich contextual driver behaviour information in everyday driving situations. The rich contextual data, providing information derived from the NDS approach, facilitates a comprehensive understanding of driving behaviour in a number of situations, including different weather conditions, roadways and near misses, incidents and events unique to the South African driving environment. An understanding of these relationships and the conclusions drawn from the different studies provide an evidence base for the design and implementation of interventions to move towards a safer transport system.

NDS links with the Safe Systems approach as it contributes to integrated research results pertaining to infrastructure, user behaviour (and road safety culture), mode of travel, as well as social factors. NDS is result-driven and continuously inform the development and

conceptualisation of research questions and projects that contribute to a better understanding of road user behaviour.

4. DEVELOPMENT AND APPLICATION OF NDS FOR SOUTH AFRICAN ROAD SAFETY RESEARCH

4.1. Overview of previous projects

The NDS methodology has been employed since 2012 to explore different road safety topics in the South African context. Between 2012 and 2014, three small studies utilising NDS were undertaken. The first was a pilot study where the usefulness of the methodology was explored. Two light vehicles, driven by professional drivers from a private sector firm were instrumented with data acquisition systems (DAS). The study focused on finding evidence of distracted driving (Venter, 2012). The results were favourable, and in 2013, four additional vehicles were instrumented (two pairs of parent/learner driver combinations) and the study ran for a period of six months. That study investigated and highlighted differences in scanning behaviour of novice and experienced drivers (Venter and Sinclair, 2014). A large amount of driver data was collected and one of the key elements of naturalistic driving data (NDD) is that this data could be explored in terms of different road safety topics, for years to come. The third study analysed a sample of the previously collected novice/experienced driver data to investigate the occurrence of inattentive and/or distracted driving. Secondary behaviours identified included mobile phone use, distraction by passengers and other in-vehicle behaviours (Venter, Labuschagne, Phasha, Gxowa and Khoza, 2016). Indications were that each of the four drivers showed signs of general inattention and at least one type of distracted driving behaviour. The frequency with which these behaviours occur seems to be high, leading to the question whether inattentive driving has become the norm rather than the exception for South African drivers (Venter et al., 2016).

All of the previous research studies were conducted on a very small scale and were not representative of the larger driving population. Despite the small sample sizes, the findings highlighted the potential of utilising the NDS methodology for South African human factor research. After successfully proving that this methodology has merit in the South African driving context, the research team conducted a larger study which focused on hazard perception development in young novice drivers in the process of acquiring their driver license.

4.2. Exploring hazard perception development during the learner driver phase

4.2.1. Study focus
More recently (2018), the NDS methodology was used to study hazard perception development of novice drivers during the training phase. Hazard perception is defined as the process of identifying hazards and quantifying their potential for danger, and is considered a key skill that novice drivers need to develop. It is considered a complex task that takes decades to develop. The experiment included fifty-three novice drivers, with data collected over a period of fifty weeks.

4.2.2. Description of data
The NDS methodology generated large datasets and, although it relies strongly on quantitative methods to interpret data, the large amounts of qualitative information provided detailed insights into driver behaviour in traffic. The image data consisted of three video streams that were downloaded and transcribed into .avi files for each trip. The front

and rear facing cameras provided visual information pertaining to the weather, road environment (including road markings, traffic signs and infrastructure), as well as other road users (and behaviour) in the vicinity of the novice driver. The driver facing camera, along with the audio recording, provided information about the novice driver gaze and scanning behaviour, as well as hazardous situations where the driving instructor intervened either physically (taking control of the vehicle) or verbally.

In order to analyse the NDS data, international literature was used to compile a preliminary scanning and reaction (driver behaviour) coding framework, however In-vivo coding was necessary to capture behaviour elements in relation to the environment. Elements differed from video to video and participant to participant. To provide a context for the coding, international and local literature detailing novice driver hazard perception abilities in different scenarios were used. Codes were generated for scanning behaviour, road type and intersection behaviour. Simple memorandums containing subjective information related to specific behaviours of the participants at specific points in the video were made. These texts were used to provide a context in which the video analysis could be conducted.

In addition to the video data, which was collected for each participant for each lesson, the following vehicle parameters were collected: time of day, length of the lesson/training, distance driven, vehicle speed, and acceleration and deceleration data. The vehicle parameters were captured for each learner, per trip in a spreadsheet and the number of trips per lesson was computed to provide total and average information per learner per trip.

The image data and vehicle parameters were timestamped and could, therefore, be matched per millisecond. This means that in instances where learner drivers were faced with hazardous situations or near-misses, it was possible to accurately quantify the reaction of learners to these events.

4.2.3. Challenges
The challenges associated with the large databases have been documented in two previous research papers (Muronga and Venter, 2014; Muronga and Venter, 2016). Apart from being costly and human resource intensive, managing the volumes and different data formats being collected is problematic. In addition, the synthesis, coding and analysis of the data have been done manually. This requires that coders code image material (qualitative data) from two or three videos (front, back and driver facing) from beginning to end. Although this has proven to be successful, the approach is not scalable, and is thus not sustainable.

4.3. Approaches to consolidate and manage the coding and analysis of data

4.3.1. Computer vision and coding of specific road and traffic elements (front facing and back facing cameras)
In order to automate the processing of the video sets, the intent was to explore machine learning and computer vision techniques to identify and code existing, known elements in the traffic environment. This would have a drastic impact on the man-hours required to process such data in NDS studies. These elements (vehicles, pedestrians, road signs, road furniture and traffic calming devices) have specific parameters within the video feed that allow them to be identified in the roadway. This enables potential hazardous situations to be automatically detected, which can then be studied in further detail at a later stage by a human analyst, significantly reducing the time taken to process and code each trip.

Automated pedestrian detection has been demonstrated in the NDS data, and development is ongoing.

Ideally, image processing would be applied to the processing of all the video data, however, for this project, the behaviour of the drivers was coded manually making use of in-vivo coding.

4.3.2. Improving data integration and visualisation

Currently the quantitative data sets are prepared after each trip has been downloaded (and the 3 videos transcribed into .avi files). The data is cleaned and currently used to provide summary data for each trip (average and maximum speeds, duration, vehicle movements etc.). However, this data needs to be integrated with the other trip sheets to form a lesson set. This approach is acceptable if the objective of the research is to provide intelligence about individual drivers. However, there is a need to compare behaviour (speed, acceleration, deceleration and location) across lessons (in order to measure progress) per individual, as well as to compare data sets over time for different individuals, taking into consideration demographics factors such as age, gender and time under instruction. The research team therefore explored potential database structures and methodologies with which this data can be managed, organised and analysed within a particular database.

4.3.3. Addressing the efficiency of the coding process

The initial coding for the project, started with a coding scheme that was used in 2014 for coding both the road environment and driver behaviour. The rest of the image material was coded in-vivo. All videos were coded from beginning to end. MaxQDA © 2012 and 2018 were used to code the image material. Approximately 8 288 codes were generated.

The coding for each video was done from beginning to end and, therefore, includes normal driving behaviour, potential traffic conflicts, road environment (class of road, problems, and traffic control measures), as well as other road user behaviour, and novice driver overt and gaze behaviour. However, the challenges associated with the number of codes generated as well as the matching the behavioural codes with that of the environment were cumbersome.

In order to ensure that the coding is done in an optimal and efficient manner, a coding form is being developed. Simplifying the coding process will enhance the integrity of the analysis and results.

5. NDS IN SUPPORT OF A SAFE ROAD AND TRAFFIC SYSTEM

NDS is a comprehensive, but resource intensive methodology that collects detailed information from a variety of road environment and user sources. NDS supports the Safe Systems approach, as it can contribute to integrated research results pertaining to infrastructure, user behaviour, and mode of travel, as well as social factors.

This NDS study is an example of the result-driven nature of the methodology, which can potentially inform the development and conceptualisation of follow-up research projects and questions that can contribute to the knowledge base. In this experiment, information pertaining to gaze behaviour to investigated changes that might imply that novice drivers are scanning their environment more effectively over time. The result is rich, contextual information that provides comprehensive insights into driver behaviour in normal and

adverse circumstances that can be used to inform the design of evidence based and targeted interventions.

6. CONCLUSION

Current local initiatives focus on driver behaviour aspects, but naturalistic driving studies (NDS) have a much wider field of application where the knowledge gained should inform the design of different engineering and education remedial measures that are aimed to achieve ultimate safety.

Apart from the fact that with NDS research, South Africa will be able to contribute to a global road safety knowledge pool from a developing middle-income perspective, NDS has the potential to contribute to an in-depth understanding of road user behaviour within the South African context, that leads to near-misses, serious incidents and ultimately fatal crashes. Recent work on automating elements of the NDS data processing task has shown how the labour-costs associated with such studies can be reduced in future. This has the potential to make NDS studies more viable in future when compared with self-reported or simulator-based studies.

REFERENCES

Backer-Grondähl, A., Phillips, R., Sagberg, F., Touliou, K., & Gatscha, M., 2009, *Topics and applications of previous and current naturalistic driving studies -Deliverable D1.1. PROLOGUE project.* Brussels, European Commission, Belgium.

Borowsky, A., Shinar, D., and Oron-Gilad, T., 2010, 'Age, skill, and hazard perception in driving', *Accident Analysis and Prevention*, 42, pp. 1240-1249.

De Craen, S., Twisk, D.A.M., Hagenzieker, M.P., Elffers, H. and Brookhuis, K.A., 2007, 'Do young novice drivers over estimate their driving skills?' *Young researcher seminar*, SWOW Brno Czech Republic. .

Deery, H., Kowadlo, N., Westphal-Wedding, T and Fildes, B. *Deery, H., Kowadlo, N., Westphal-Wedding, T and Fildes, B., 1998, 'Identifying sub-types of novice drivers: Implications for matching training needs to the needs of the driver',* Monash University Accident Research Centre, Victoria, Australia.

FOT-Net Consortium, 2010, *'Field Operation Tests - Evaluating ITS applications in a real world environment', ERTICO – ITS Europe accessed on 2 February 2019 from http://www.fot-net.eu.*

Harre', N., Foster, S. and O'Neil, M., 2005, 'Self-enhancement, crash risk optimism and the impact of safety adevertisements on young drivers', *British Journal of Psychology*, 96, pp. 215-230.

Institute for Transportation and Development Policy., 2013, *TOD Standard v1.* Institute for Transportation and Development Policy, New York, USA.

Venter, K., Labuschagne, F.J.J., Phasha, S., Gxowa, M and Khoza., S, 2016, 'Indications of high levels of inattentive and distracted driving behaviour', *Southern African Transport Conference.* CSIR International Conference Centre, Pretoria, pp. 1-10.

Khorasani-Zavareh, D., 2011, 'System versus traditional approach in road traffic injury prevention: a call for action', *Journal of Injury and Violence Research*, 3(2), 61.

Meir, A., Borowsky, A., Oron-Gilad, T., Parmet, Y., & Shinar., D, 2010, 'Act and Anticipate Hazard Perception Training for Young-Inexperienced Drivers', *The 3rd International Conference on Applied Human Factors and Ergonomics (AHFE), July 17-20.*

Muronga, K and Venter, K., 2014, 'Naturalistic driving data: managing and working with large databases for road and traffic management research', *Proceedings of the 33rd*

Southern African Transport Conference 7-11 July, CSIR International Conference Centre,Pretoria, pp. 567-574.

Muronga, K. and Venter, K., 2016, 'Synthesizing naturalistic driving data: A further review', *Proceedings of the 34th South African Transport Conference,* CSIR International Conference Centre, Pretoria, pp. 1-10.

Rust, C., Itman, H and Kistan, K., 2000, 'The role of R&D in transport infrastructure in South Africa', *Southern African Transport Conference*, CSIR International Conference Centre,Pretoria, pp. 1-10.

Schulze, H and Koßmann, I., 2010, 'The role of safety research in road safety management', *Safety Science*, 48, pp. 1160-1166.

Venter K. and Sinclair, M, 2014, Exploratory study into South African novice driver behaviour', *Proceedings of the 33th South African Transport Conference*, CSIR International Conference Centre, Pretoria, pp. 1-10.

Venter, K., 2012, 'Eating, Drinking and uncontrolled steering: A South African example of distracted driving', *South African Transport Conference,* CSIR International Conference Centre, *Pretoria, pp.* 1-10.

Wegman, F., Berg, H., Cameron, I., Thompson, C., Siegrist, S., Weijermars, W. "Evidence-based and data-driven road safety management." *International Assostion of Traffic Safety Sciences* 39 (2015): 19-25.

World Health Organization, 2013, '*Pedestrian safety: a road safety manual for decision-makers and practitioner*s', World Health Organization, Italy.

Yang, G., Jaeger, B and Mourant, R.R, 2006, 'Driving performance of novice and experienced drivers in lane-change scenarios', *Proceedings of the human factors and ergonomics society 50th annual meeting, pp.* 2712-2716.