AN INVESTIGATION INTO DRIVER FATIGUE ON THE N3 BETWEEN VILLIERS AND WARDEN

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ABSTRACT

The N3 Toll Concession (Pty) Ltd (N3TC) manages the 420 km of the N3 Route between Heidelberg (Gauteng) and Cedara (KwaZulu-Natal) on behalf of SANRAL. The N3 Route is described as one of the busiest roads in South Africa linking the port of Durban with the economic hub of Johannesburg. Large volumes of vehicles (of which around a third are heavy vehicles) travel on this road daily. This paper reports on the findings of a research study into the role that driver fatigue plays in crashes occurring on specifically the 100 km (Sections N3/8x, N3/8; and N3/9) stretch between Warden and Villiers in the Free State Province. The research project entailed a literature review on fatigue and drowsy driving, human factors for engineering study as well as a study on driver fatigue as contributory factor in crashes along the respective section of freeway. All the road sections mentioned have their own unique characteristics in terms of the road environment, the type of crashes that occur as well as the level of fatigue experienced by long-haul heavy goods vehicle (HGV) drivers. This research paper provides an overview of the findings from the human factors for engineering study.

1. INTRODUCTION

Although fatigue has been researched extensively, no single definition of fatigue exists (Dobbie, 2002). The literature indicates that fatigue is associated with a decline in mental performance (Schutte and Maldondo, 2003; De Waard, Kraaij, and Bekiaris, 2003) and/or a decline in physical performance (Nilson, Nelson, and Carlson, 1997). An extensive international body of research further indicates that fatigue is the result of a combination of factors which could influence vigilance; reduce attention or awareness, and lead to drowsiness and fatigue. All of these concepts are considered to be interrelated and contributory factors in crash causation (Sagberg, Jackson, Kruger, Muzet, and Williams, 2004). Fatigue as a symptom of declining mental and physical conditions could lead to impaired driving performance (Thiffault and Bergeron, 2003). A number of causes has been cited to influence fatigue including health issues (Gill and Wijk, 2004), hours of driving and time-on-task (Sagberg et al. 2004; Nilson et al., 1997), circadian rhythm (Pack et al., 2005), time of day (Brookhuis et al., 2003;), lack of sleep or quality of sleep before starting a journey (Akcerstedt and Landstrom, 1998), substance abuse (Nelson, 1997; Fletcher, McCulloch, Baulk, Dawson, 2005; Horne and Reyner, 2001), cabin ergonomics (Schutte et al., 2003) as well as the driving environment (Thiffault et al., 2003). Although fatigue causes sleep in the long-run, Schutte et al. (2003) states that even before sleep sets in it can cause problems for heavy vehicle drivers. These problems include: slow reactions and decisions; slow control movements; decreased tolerance for other road users; poor judgement when over-taking; poor lane changing and maintenance of headways and travel speeds, and loss of situational awareness. Fatigue is considered an internal distraction for the driver (Williamson, 2007) that leads to poor decision-making (Ackerstedt et al., 1998) and cognitive impairment (Williamson, 2007). This study investigated the occurrence of heavy vehicle driver fatigue on the 100 km section between

Villiers and Warden and provides an overview of the findings from the human factors for engineering study.

2. BACKGROUND

Large numbers of heavy vehicles frequent the N3 Route on a daily basis. The vehicles travel between Johannesburg, which is the economic centre of South Africa and the busy seaport of Durban. Average daily traffic (ADT) ranges between 8 500 to 13 500 vehicles of which an estimated third, 3 500 to 5 000, are heavy vehicles. Radebe (2010) alludes to the fact that an average of 58 million tons of freight is carried on the N3 annually. N3 Route passes through a predominantly rural environment and serves as a regional connector as part of the national route network between Durban and Johannesburg. Access to it is controlled. The N3 Route is described as ranging from hilly to flat.

A key road safety concern was the 100 km stretch of road between Warden and Villiers. The N3TC appointed the CSIR in May 2011 to investigate the role that driver fatigue may play in crashes occurring on specifically this 100 km stretch between Warden and Villiers in the Free State Province.

The research project entailed a literature review on fatigue and drowsy driving, a high level road safety engineering study as well as a study of driver fatigue as potential contributory factor to HGV crashes. The literature review summarised international and South African research related to driver fatigue.

In summarising the driver behaviour study, by means of a questionnaire seventy nine heavy vehicle drivers participated in a self-reported fatigue survey. Participating drivers drive on the N3 Route at least once a week. The majority of the drivers were experienced drivers with between 5 - 10 years driving experience. The questionnaire was designed to include the following information: demographic information; operating/driving hours that refer to the number of hours that drivers drive for work; experience of fatigue on specific sections of the road; reasons as to why the drivers felt fatigue on specific sections of the road and strategies on how to address the fatigue felt on these sections of the road. From the survey it was evident that drivers do recognise the onset of fatigue and the survey showed that drivers indeed do experience fatigue on the section between Villiers and Warden especially when travelling from Durban (south) to Johannesburg (north). The section between Tugela Plaza (North) and Mooi River (South) was also associated with fatigue. Participating drivers indicated that the reason they felt fatigue was because the road is boring, poor quality of sleep and the long hours they spent driving. Drivers made recommendations in order to alleviate fatigue which included an additional truck stop between Warden and Villiers. This was the most prominent recommendation to alleviate fatigue on the section of road. Other engineering measures that drivers thought could contribute to alleviating fatigue included ideas regarding the separation of traffic flow (heavy vehicles and light vehicles) as well as rumble strips on the edge of the road and in the middle of the road. Driver campaigns, bill boards and placement of interesting features next to the road were the next group of considerations.

The rest of the paper provides the research results related to the human factors for engineering study.

3. OBJECTIVES OF THE STUDY

The objectives of the study were to:

- Employ a scientific method to investigate road safety problems along the 100 km section of the N3, between Villiers and Warden,
- identify HGV crash contributory factors, and
- conceptualise potential countermeasures.

4. METHODOLOGY FOR THE HUMAN FACTORS FOR ENGINEERING STUDY

The road safety engineering assessment of the respective road section consisted of three elements. Firstly, a site inspection was conducted. This site visit incorporated inspection of the 100 km stretch between Villiers and Warden. Use was made of a digital video recorder (DVR) for the site inspection. The DVR used two cameras mounted on the dashboard of a vehicle, one facing to the front and left and the other facing to the front and right of the vehicle. The recording vehicle travelled at speeds ranging between 100 km/h and 120 km/h. The site inspection included visits to the truck stops adjacent to the N3 frequented by truck drivers, as well as recording of the road environment in both directions of Sections N3/9; N3/8 and N3/8X. This image material, together with the crash data provided by N3TC, was used to plot and identify the possible problem areas identified by the CSIR team. The second element revolved around the analysis of crash data for the years 2007 to 2010. Finally a qualitative assessment was conducted using the comments which were captured by attending N3TC or law enforcement officials about each crash in the N3TC database. This qualitative assessment included comments for HGV crashes only.

5. RESULTS

N3TC crash data was provided for Sections N3/8, N3/8X and N3/9 for the years 2007 - 2010. Traffic counts were provided for the different sections correlating to the years 2007 - 2010. Use was made of the traffic counts per section to determine the exposure of risk per 100 million vehicle-kilometres travelled (per 100 mvkmt). This exposure to risk was calculated for Sections N3/8, N3/8X and N3/9. No demographic information related to gender, age, type of driver and so forth were provided in the N3TC database. It was therefore not possible to correlate crash characteristics (specifically crashes that are thought to be associated with fatigue) with age groups, gender, etc.

5.1. Site visit findings

The site visit was conducted on a clear winter morning in June 2011. From the site assessment it was concluded that the study section in terms of engineering standards is a good road. The respective section of the road is a four lane single carriageway road with a narrow striped centre island (a RM5 road marking consisting of a double no overtaking line with a continuous solid yellow line in between). Section N3/9 is a long straight road of approximately 76 km. Section N3/8 comprises 18 km of the study section, traversing a hilly terrain with vertical alignment considered to be good. Section N3/8x is approximately 6 km long and passes the town of Warden with a steep downhill incline from both directions. General alignment is according to standards for 120 km/h and sight distances are thus assessed as adequate. There are rest laybys alongside the road. The lane and shoulder widths of the road are respectively 3, 7 m and 2, 5 m wide and a milled rumble strip is part of the painted centre island along the entire study section.

5.2. Summary of main findings

A total number of 923 incidents were recorded for the 100 km long section between Warden and Villiers for the period 2007 to 2010. A hundred and thirty-three (133) of these incidents were related to objects on the road, dropped loads, fires, etc. These incidents were eliminated from the analysis - bringing the number of crashes analysed on the N3 Route Sections N3/8X; N3/8; N3/9 for the period 2007 to 2010 to 790. Most of the crashes occurred on the northbound section of the study area in the direction of Johannesburg.

Section	N3/9	N3/8	N3/8x
Length of study section	76 km	18 km	6 km
Fatalities per 100 mvkmt	11.7	9.6	6.9

Number of crashes		559	95	136
Number of heavy vehicle crashes		**240**	**45**	**61**
Direction of crashes	South bound	38%	51 %	40%
	North bound	62 %	49%	60%
Type of vehicles	Light vehicles	51 %	46 %	55%
	Heavy vehicles	**40 %**	**46 %**	**37%**
	PT vehicles	9%	8 %	8%
Injuries	Fatal	105	28	16
	Serious	129	33	23
	Slight/ no injury	633	105	155
	Total	867	166	194
Weather	Clear	84%	75%	82%
	Rain	9%	25%	7%
	Mist	2%	0%	6%
	Hail	0%	0%	4%
	Wind	0%	0%	1%
	Smoke	1%	0%	0%
	Overcast	4%	0%	0%
Peak times	1> heavy vehicles	3h00-5h00 and 21:00-24:00	03:00-05:00 and 21:00 - 24:00	06:00-08:00 and 18:00-20:00
	Other vehicles	a)21:00-24:00, b)15:00-17:00	15:00 and 17:00	15:00 and 17:00
Time of day	Involving 1> heavy vehicles	Night between 18:01-5:59	Night between 18:01-5:59	Night between 18:01-5:59
	Other vehicles	Day between 6:00-17:59	Day between 6:00-17:59	Day between 6:00-17:59

Table 1: N3 Study section crashes – summary of findings (year 2007 – 2010)

According to Nordengen (2009), South Africa has an inordinately high rate of HGV crash fatalities. Nordengen estimated that in 2009, there were approximately 13 fatalities per 100 mvkmt by HGVs.

Section N3/9 was the longest section (76 km) and heavy vehicle crashes constituted 40% of the crashes on this section. Most crashes (70%) occurred on this section. The fatality rate per 100 mvkmt for this section was 11.7. Sixty per cent of the crashes occurred in the direction of Johannesburg (northbound). Most heavy vehicle crashes occurred during night time and peak periods for these crashes were between 03:00 – 05:00 and 21:00 - 24:00.

Section N3/8 is approximately 18 km long. Twelve per cent of crashes occurred on Section N3/8 and the fatality rate per 100 mvkmt for this section was 9.6. More than half of the crashes occurred in the direction of Johannesburg. Slightly less than half of these crashes involved HGVs. Most HGV crashes occurred during dark hours of the day with the same peak times as Section N3/9 (03:00 - 05:00 and 21:00 - 24:00).

Section N3/8x is approximately 6 km in length. Seventeen per cent of crashes occurred on Section N3/8X and the fatality rate per 100 mvkmt for this section was 9.6. Peak times for crashes were between 06:00 - 08:00 and 18:00 - 20:00.

5.3. Type of crashes

The literature indicates that there are certain crashes that are more likely to occur when the driver of the vehicle is fatigued. These crashes include head-tail crashes, run-off-the-road and roll-over crashes. Head-on collisions are also highlighted in literature as a crash that could result from driver fatigue. However, the N3 data suggests that head-on collisions have successfully and systematically been addressed through the years. Some reasons for this possibly include the fact that the freeway has two lanes in both directions that provide sufficient capacity with adequate opportunity for overtaking. The other engineering measure that could have contributed to successfully limiting the risk of head-on crashes is the narrow centre island rumble strip that separates the bi-directional traffic.

For the purpose of this study, side swipe crashes were also included as a possible indicator of fatigue related crashes due to the fact that drivers need to pay extra attention to the driving environment when overtaking other vehicles. A side swipe crash could be an indication of momentary lapse of concentration/attention due to the onset of fatigue or could be an indication that the driver did indeed fell asleep while driving.

Figure 1-3 below provides an overview of the type of crashes per section. The notation "<1" refers to no heavy vehicles involved in the crash while "1>5" refers to one or more heavy vehicle involved in the crash.

- On Section N3/9 the most prominent type of heavy vehicle crash were head-tail/rear end crashes, followed by side swept, overturned vehicles and vehicles that left the road.
- On Section N3/8 the most prominent type of crashes were head-tail/rear end crashes followed by vehicles that left the road. Overturned and side swept crashes were the third and fourth most prominent types of crashes.
- On Section N3/8X, head-tail/rear end crashes were the most prominent type of crash. Vehicles that run-off-the-run as well as vehicles rolling over were the second and third most prevalent type of crashes on Section N3/8X.

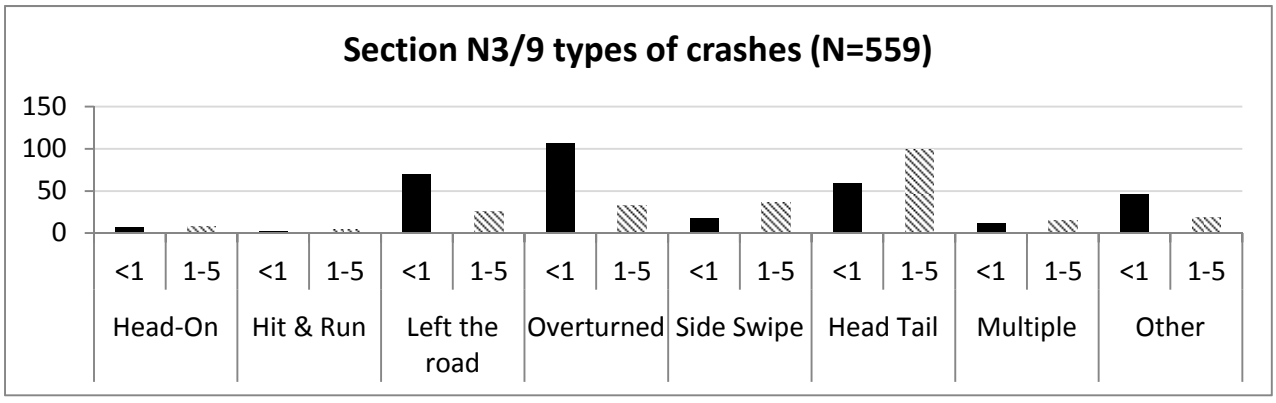

Figure 1: Section N3/9 - Type of crashes

("Other" refers to pedestrian crashes, livestock and Hazchem incidents)

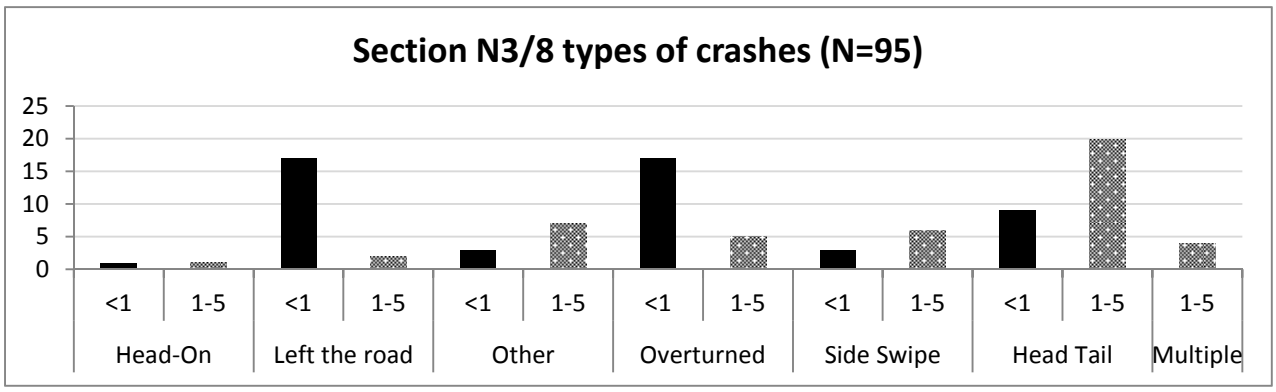

Figure 2: Section N3/8 - Type of crashes
("Other" refers to pedestrian crashes, livestock and Hazchem incidents)

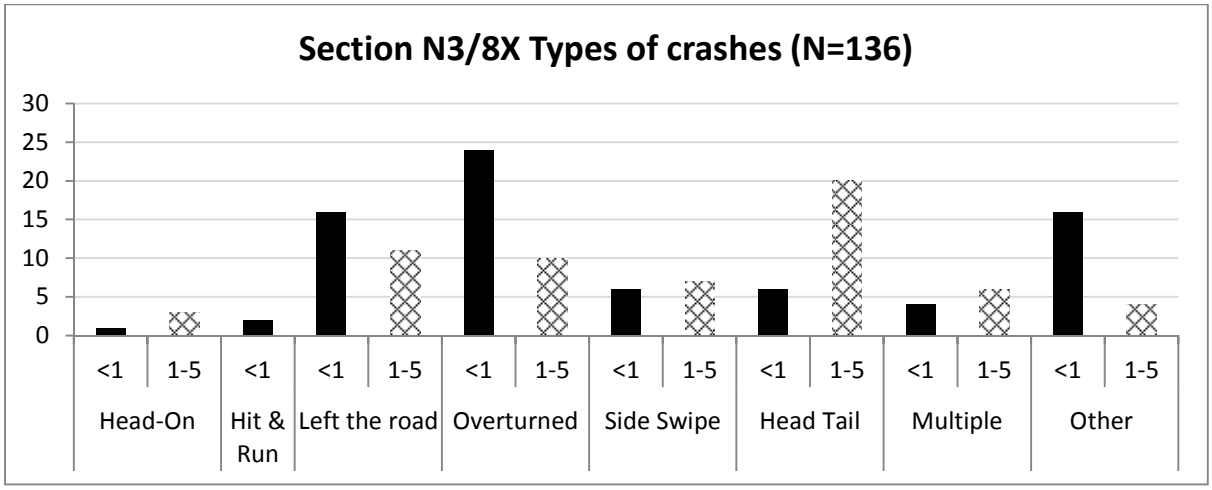

Figure 3: Section N3/8X - Type of crashes
("other" refers to pedestrian crashes, livestock and Hazchem incidents)

6. DISCUSSION

6.1. Fatigue and the type of crashes on the N3 Route

As indicated earlier, literature suggests that fatigue crashes are associated with certain times of the day. It is expected that there should be less traffic in the night time hours. According to the crash information, 53% of crashes occur on the study section of the N3 Route during night time and 47% during day time. According to traffic counts (SANRAL CTO Station 2330), 22.5% of traffic to Johannesburg is night time traffic and to Durban 24.1% of traffic is night time traffic.

Crashes on the three sections of road seem to mostly occur in clear weather conditions. Sagberg (1999) identified the following factors as contributing increasingly to the risk of feeling sleepy or less alert while driving: dry road, high speed limits, driving your own familiar vehicle, not driving daily and few years of driving experience. In instances where other weather conditions did contribute to crashes, the weather was described as misty, overcast or rainy. In terms of the site visit it was concluded that the road has a good road surface and that adequate warning signs are erected in places where drivers should be cautious when driving the road. The fact that most of the crashes occur in clear weather points to probably driver behaviour or related problems, e.g. speed too high for the circumstances or fatigue and inattention. Ackerstedt and Landstrom (1998) indicate that single vehicle crashes (over-turning, etc.) have the highest probably of occurring at night.

Fletcher (2005) and Horne et al. (2001) indicate that there are a few things that could potentially influence the occurrence of fatigue including long monotonous stretches of

roads. The crash database did not provide detailed information on all of the aspects below. However, it was possible to rule out certain aspects as listed in the criteria below. The criteria are listed in the first column of Table 2 below. The second column gives an indication of whether or not the information was available in the N3 Route crash database.

Criteria and characteristics of fatigue-related crashes Adapted from Fletcher (2005) and Horne et al. (2001)	**Findings from the crash database**
The driver typically runs off the road and/or collide with other vehicles or objects on the road; Drive into the back of another vehicle	For the 4 years in question (2007-2010) there was 213 head-tail crashes; 195 crashes in which single vehicles were involved in crashes or where vehicles rolled-over; 142 crashes in which vehicles left the road.
No signs of brakes that were applied; absence of skid marks or other signs of hard breaking beforehand.	No specific reference to skid marks was found in the crash descriptions
It has to be established that the driver for a few seconds (± 7 s) was able to clearly see the point where he runs off the road or hit the object.	In run-off the road crashes no specific mention was made of whether or not the driver was able to see the point where they went off the road. In some instances the description in the crash database did indicate that the driver acknowledged that he fell asleep
Other causes such as mechanical defect, weather, medical disorders and even attempted suicide needs to be ruled out.	In one instance reference was made to the driver having a heart attack. No other medical conditions were cited. In the majority of crashes the weather conditions was good. Mechanical failures mentioned included tire bursts, vehicles that caught fire, trailers that overturned.
Witnesses may have reported lane drifting prior to the incident.	No reference was made to witness statements from other motorists. Descriptions in the crash database were made based on the attending officer statements and SAPS reports.
Breathalyzer alcohol levels that are below the legal limit.	In only one description it mentioned that the driver appeared to be intoxicated. Whether or not this statement was substantiated was not clear.
Elimination of speeding and driving too close to the vehicle in front.	Speeding and reckless driving as contributory factors to the crashes was mentioned in a small number of descriptions.

Table 2: Crash criteria associated with the descriptions of crashes on the N3

6.2. Fatigue and the driving environment of the N3 Route

Although the N3 Route is considered to be a well-designed freeway, the long monotonous stretches of road between Sections N3/9 and N3/8 could potentially contribute to the experience of fatigue on the road.

Road type	Scenery	Disruptions	Road curvature	Monotony
Urban	Cluttered	Frequent	High	Low
Country road	Moderate	Few	Varying	Moderate
Minor highway	Sparse	Varying	Varying	Moderate
Major highway	**Periodic**	**Varying**	**Low**	**High**

Table 3: Criteria for different road environments and the experience of fatigue (adapted from Fletcher, Peterson and Zelinsky, 2010)

Both the psychological and physiological fluctuations can impact negatively on the driving task. Physiologically the driver might experience lower levels of activation and arousal while psychologically the feelings consist mostly of boredom and drowsiness, with a possible loss of interest in the task at hand. This could lead to habitual driving "mode" (especially for a driver frequenting the road every second day) where stimuli within the road environment are not perceived to be stimulating enough. A progressive decline in paying attention to the road is the result of the repetitive nature of monotonous conditions, no longer stimulating the driver (Thiffault et al., 2003). Dishabutation (breaking the habit) occur as the result of a sudden change in the road environment where attention to the road is restored almost immediately. Fatigue defined in terms of the road environment and the effect of the monotonous road environment can be described as a disinclination to perform the task at hand and a progressive withdrawal of attention from road and traffic demands. Thiffault et al. (2003) indicate that this disinclination or withdrawal is more likely to happen on low demanding roads where attention is more easily directed toward inner thought processes.

The term "highway hypnosis" refers to a psychological state where the driver is no longer aware that he or she is driving (Cerezuela et al. 2004). This is defined as "driving without awareness" or as "a state showing sleepiness signs, and attention slip resulting from driving a motor vehicle for a long period in a highly predictable environment with low event occurrences". Different theories as to why the reduced state of alertness occurs have been put forward. Driver related factors include: monotony, mental fatigue, conditions of disease and the road environment and the manner in which the road environment affects the operation of the oculomotor (eyes) system. The end result is that in most of these instances the driver, once attention is regained, cannot remember anything about the way that he had already travelled (; Thiffault, et al., 2003). In especially the case of monotonous road environments, the attention would shift from external (driving environment, e.g. other vehicles) to internal (intra-personal, e.g. thoughts) events and drivers become less aware of what is happening in the environment, relying on his internal schema of the familiar driving activity.

Nelson (1997) indicates that highway design play a role in the causation of fatigue related crashes, emphasising that situations of sensory restriction show that sleepiness is the primary symptom evoked by a non-stimulating environment. Fletcher et al. (2010) indicated that scenery, disruptions and physical road features such as curves coupled intrapersonal events could influence the experience of monotonous driving (table 3).

The exogenous factors stemming from the road geometry, road environment or other external factors could also influence the driving task negatively. These factors have an impact on driving as it influences arousal, alertness and essentially the driver's ability to process information. Deterioration in the driving task demands is induced by an under-load

of information from the environment that reduces the driver's alertness to the road. Thifault et al. (2003) defines a situation as monotonous when the stimuli remain unchanged or changing in a predictable manner. The driving tasks become too easy due to familiarity of the environment or low sensory input which could potentially lead to driver fatigue.
Thiffault et al. describe physiological as well as psychological reactions to monotony of the road environment. Importantly the research defined two different concepts related to monotony: monotony of the task and the monotonous state. The monotony of the task refers to simple actions taking place repetitively over long periods over time, while the monotonous state refers to a combination of physiological and psychological changes that can affect the driver when performing a monotonous task. The experience of driver fatigue should be seen as a function of environment and the relationship of the driver with a particular driving environment (Nelson, 1997). Most heavy vehicle drivers frequenting the N3 might be so used to the N3 that they simply do not pay attention to the road environment and other road users anymore.
Terrain is an important factor influencing driver workload and concentration (Smith et al., 2006) point to the fact that if the geometric layout of the road requires concentration, the driver will mentally be on high alert. On the other hand if driver demand is decreased due to less environmental and geometric pressures, the driver will be more inclined to feel fatigued. In other words crashes tend to occur when drivers start to relax after a difficult section of road when traversing to an "easier" section of the road. The familiarity of the N3 Route may therefore play an important role in the onset of fatigue on this road.

7. CONCLUSION

Based on the information from the literature review regarding the factors that contribute to the onset of fatigue, the results from the crash analysis (considering the over-representation of certain types of crashes along the study section) and the engineering inspection, it is considered likely that fatigue plays a role in the causation of crashes on the study section. This was supported by the higher levels of fatigue the drivers in the driver behaviour study reported on the study section than on other sections of the road. The fact that the road is well designed, but with long uninteresting stretches along parts of it, coupled with many HGV drivers being so familiar with the road may be regarded as contributing to feelings of monotony, boredom and eventually fatigue.

Recommendations for engineering measures to alleviate fatigue therefore included:

- Audio and tactile experiments to could potentially alert drivers when they "drift" or leave the road.
- Stimulate visual senses through the use of painted road markings and interesting road features.
- Information displays along the N3 alerting drivers of changing conditions and areas where drivers might be more prone to experience the onset of fatigue specifically through the better use of use of variable message signs.
- Rest facilities e.g. additional truck stop along the road.

However, fatigue is a contributory factor in crashes and holistic approaches that incorporate engineering, enforcement, education and driver wellness (e.g. through for example work place road safety programmes) should be considered.

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