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New scenarios for safe mobility in urban areas

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NEW SCENARIOS FOR SAFE MOBILITY IN URBAN AREAS

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Enhancing driver visibility at night: an advanced glass-powder paint technology approach

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Abstract

Driving in low visibility regions, especially at night along a transportation facility, can be particularly dangerous. Related issues include reduced illumination leading to reducing visibility and the objects fading away into obscure darkness. In such situations, albeit some drivers suffer from deficiency (including nearsightedness and cataracts), poor visibility due to road markings becoming blur could result in several problems, including damaged night vision. This study aims at addressing these issues by providing alternative measures to improve driver visibility at night using innovative glass-powder paint technology (GPPT). An introduced driveway section located at Eastern Cape Province-South Africa is selected as reference application to compare the proposed road marking paint in the current research against the conventional one. This was conducted via a developed, grouped multinomial logistics and non-parametric, quantitative analysis model in quantum flow theory. In this study, results revealed that based on a 95% confidence level assumed equivalent to 0.05 significance level, the null hypothesis was rejected, proving that driving behaviour at night on the test section is significantly improved with the introduction of the innovative GPPT. Hence, the enhanced illumination index obtained and reduction in the blur level on the road markings indicate improved glare and night illumination.

Keywords

Night driving; Visibility; Quantum optical-flow; Glass-powder paint technology; Multinomial logistics.

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1. Introduction

The benefits of providing society with improved transportation, whether justified based on economic development, mobility or safety, cannot be overemphasised (Gillwald et al., 2012; Nunes et al., 2014). The overarching effect of safer highways is of paramount interest in recent times, especially changes regarding travel behaviour in a smart city concept. Dingus et al. (Dingus et al., 2016) discovered that results from naturalistic driving studies indicated 87.7% of crashes involved human error or impairment. Although, there are ongoing efforts towards developing new technologies that could minimise or eliminate error-prone human operators through automation of vehicle and traffic systems. This, with added improvement in automated sensor detection systems, cloud computing, advanced traveller information system and advanced public transport system amongst many others, to name a few, can result in safer highways.

It is not strange to realise that high risk associated with night driving, poor visibility and distracted driving has attracted a wide concern in traffic management systems (Hounsell et al., 2009). The use of luminaire supports, road signs, and road markings has proven over time to pave solutions to improving highway driver safety (Rea et al., 2010). It is necessary to note that safety on highways may be likened to the total number of crashes recorded yearly (Hoel et al., 2008). Hoel later proposed a comprehensive set of strategies and actions to improve highway safety in 2010. This idea was designed to reduce the number of crashes and the resulting deaths, injuries and damage to property (Hoel et al., 2008).

Lately, it has been difficult to predict driver behaviour considering changing traffic components (traffic controls-signs and symbols, operational systems, transportation systems management, facility design, to name a few) (Kinderyte - Poškiene & Sokolovskij, 2010). Furthermore, the uncertainty of scenarios regarding conflict, vehicles and roadway conditions may deter operational controls regarding right-of-way, visibility (environmental conditions: precipitation, hailstones, dust, fog and mist; glare on road markings (formation of mirage)). In summary, a German physicist Werner Heisenberg in 1927, postulated the uncertainty principle, which states that the more precise the position of an object is, the less precisely its momentum can be predicted from initial conditions and vice versa. This, in application to driving *(drivers/road users)* and roadway components (carriageway and road markings), is an aspect careful attention must be given to and analysed accordingly. The relationship between the Werner Heisenberg uncertainty and driver behaviour is similar in the sense that; since it is not possible to predict the position of an object in motion under the influence of moment of inertia and the state of equilibrium experienced within the mass of the said body at any time "t". In such similarity, it is not easy to predict the behaviour of drivers driving the exact car/vehicle under prevailing driving weather conditions and expect all the drivers to behave the same way and react in the same way. This principle postulates the uncertainty in drivers driving the same vehicle and subjected to the same driving and weather conditions (Jacob & Violette, 2012).

In brief, each driver will react differently no matter the similarity in prevailing driving and environmental conditions. Hence, the proposed study relating to; improving vision at night concerning moving objects *(vehicles)*, road components and varied driving conditions (weather, traffic and driver characteristics). Furthermore, road components safety measures such as traffic control devices to improve safety using traffic signals, traffic signs, and road markings (WHO, 2005) will be discussed in future studies. These have constraints that differ in characteristics. In this study, focusing on road markings as a control system is a sustainable approach to improving visibility and reducing crashes.

Transport modes are the elements of transportation infrastructure supporting the mobility of passengers and freight. These modes vary from; land (road, rail, and pipelines), water (shipping), and air transportation. Transport modes are designed to either carry passengers or freight, but most modes can carry both. Each transportation mode is characterised by a set of technical, operational, and commercial characteristics. Technical characteristics relate to speed, capacity, and motive technology, while operational characteristics involve the context in which modes operate, traffic and highway controls (Florida Department of

Transportation, 2007). For this study, principles applied in Intelligent Transportation System (ITS) will be considered alongside theories in quantum optical flow to justify the need for improved highways and safe mobility.

Furthermore, multinomial logistic regression sampling is used to model the nominal variables regarding driving conditions on the road. This is integrated with associated variables in terms of the nature of visibility of the road markings and the introduction of the GPPT to improve illumination at night times as well as improve glare during the daytime or night-time. Several applications can be identified under the umbrella of Intelligent Transportation Systems (ITS) (Abejide et al., 2018; Ezell, 2010; Hu et al., 2016). Some are designed to improve the safety and efficiency of passenger transportation, and others focus on freight transportation. ITS applications may reside within the transportation infrastructure and others within the vehicles themselves. Thus, ITS applications in road transportation can be referred to as Intelligent (or Smart) Roads. The study involves infrastructure-based technologies designed to improve the safety and mobility of passenger transportation.

Humans make up the active component of the traffic system (Kinderyte - Poškiene & Sokolovskij, 2010). Unlike other traffic system components, human beings are the variable components of the traffic and, hence, have unpredictable behaviour in characteristics and capabilities. The human component is the road user personified and hence possesses physiological measurable, and quantifiable qualities that determine the operations within the roadway (CM & EL, 2008). The physiological component is categorised into physiological speed, driver perception reaction time (Perception Interpretation Evaluation Volition) and sight distance requirements. However, two important components regarding road diversity as human components are visual acuity and PIEV *(perception, intellection, emotion and violation)*. The visual component of the driver is categorised into acute vision, fairly clear vision and peripheral vision.

Thus, it can be summarised that humans react quicker to situations they often encounter than those they do not often encounter (NHTSA, 2008). From other studies, the perception reaction time is usually taken as 0.5s faster than the unexpected situation. This means that certain factors can impact the reaction time, such as ageing drivers (visual acuity), traffic control systems (road markings) and glare on road markings.

The proposed study focuses on critical questions: what effect does poor visibility experienced during night driving have as a significant cause of road accidents? Will improvement in the luminaire effect on road markings result in improved visibility at night for drivers?

Hoel et al. (Hoel et al., 2008) ironically stated that young drivers are the group with the best driving skills and yet appear to be most vulnerable on the highway. The reason for this paradox is that driving ability, while necessary, is not a sufficient condition to assure safety—rather, effective driving performance is an absolute requirement.

This further illustrates that accident prevention and highway safety with strategic improvement in providing enhanced illumination on the road markings is essential. This is needed to guide drivers accordingly on driving lanes while traversing on their respective lane-track without swaying off track at spiral curves, bends and intersection circles. In addition, this study focuses on enhanced visibility at night using innovative glass-powder paint technology (GPPT) to improve visibility conditions on the roadway. It is necessary to note that driver awareness and visibility are key to safety on highways at any point in time, either day or night-time.

In the course of this study, certain parameters will be considered alongside improving visibility at night. These parameters include but are not limited to; human characteristics; *(acute vision, fairly clear vision, medication and drugs intake)*; vehicle characteristics; and travel way characteristics *(road markings, roadway elements and illumination index)* as they affect driving behaviour and driver response towards improving safety. Furthermore, the objective of this study is centred on enhancing visibility at night using a GPPT on the road markings. This will be analysed using a quantum optical-flow and multinomial logistics-based model to monitor the effect of improved illumination while drivers traverse the driveway.

2. Methodology

2.1 Modelling and quantum transformation using optical flow theorem

In order to achieve the aim of this study, a case study area, which was previously with road markings and wiped off, was selected. A study by Sheu (Sheu, 2013) examined driver behaviour characteristics during car following using quantum optical flow theory. In his research, he postulated that car following is the outcome of the intuitive response of a driver to instantaneous optical stimuli in the visual field driven by changes in the surrounding traffic environment. Regarding the proposed study, the optical stimuli are driven by the illumination response on the roadway produced by the vision sensor on the optic nerve. Hence, the modelling using multinomial logistics and parameter estimates *(effect of drugs and medication on driving behaviour; time of crash experienced by drivers either during the day or at night on the roadway; effect of visibility of the road markings before and after the intervention of GPPT on the road markings)* is analysed.

2.2 Review of the Study area

For this study, a roadway section was identified and studied for analysis. The roadway was an access road within the East London metropolis's CBD (Central Business District). The road was marked years ago, but seasonal changes had wiped out most of the road markings. This caused conflict to road users, especially at night times and reduced on-street parking control and visibility. As introduced, the roadway section is located in the CBD of the Buffalo City Metropolis in East London. This roadway is a one-way traffic lane having fixed traffic signal systems at the beginning and end of the roadway. The roadway section was recently rehabilitated in 2020. This access road has a length of approximately 150m and a total width of 15m, and with the road, markings improved using the innovative glass-paint technology intervention. In order to analyse improvement in visibility at night with the road users, a quantitative survey was performed to determine the response of drivers on the road section. Their experience was recorded before and after the intervention (introduction of the GPPT). The road is approximately 1500m long and was 6m wide with no defined shoulder and parking bay. The roadway had road markings that were wiped off over time; this made driving and parking along the road a difficult task posing confusion to drivers and pedestrians. Furthermore, asides from being located in the central part of the city, the roadway serves as a major route to enter the CBD from the N2 collector road (Fitzpatrick Road-East London). Compared with other road corridors within the CBD, the proposed road was dilapidated. Many drivers bypass the road due to its inconvenience to other road corridors in a better state.

2.3 Theory of Quantum Flow and Design of Experiments

The principle of quantum flow is applied towards modelling drivers' visual acuity regarding improving visibility and glare on the road markings on the roadway. This phase models driver visual stimuli (i.e. driver-object nearsightedness) using quantum optical flow theory that transforms visual stimuli-glare into glare improvement (i.e. reflective glare on road markings). Quantum optical flow theory in previous studies was considered an extension of a cognitive approach (Baker, 1999; RW & HE, 1983) and is defined as an alternative method for characterising the impact of optical flow on individual decisions relative to ecological optical theories (DN, 1980; Gibson, 1966). According to Baker (Baker, 1999), the quantum mechanism approach is particularly applicable for explaining motion-related perceptual phenomena, including the visual cause-and-effect of motion and high-speed adaptation. Sheu (Sheu, 2013) applied such a quantum-mechanics based theory to illustrate how a driver is affected by lane-blocking incidents in adjacent lanes when approaching an incident site. Motivated by these studies, this work adopts quantum optical flow theory to develop a transformation function that conceptualises visual stimuli perceived by a target driver in the quantum optical field. The developmental process as provided by Sheu (Sheu, 2013) is as follows: First, target vehicle i moves in a given lane l at time t within a distance x and an optimum illumination index e. Second, according to quantum optical flow theories (Baker, 1999; Miura, 1987), one can define a quantum optical field (Q[Δx(t), Δy(t)]) associated with the target driver; this is usually a scalar quantity (Agrawal, 2008). This is used to characterise the probability-related allocation range (i.e. Δx(t) and Δy(t)) of target driver attention across the longitudinal (X) and lateral (Y) dimensions of Q[Δx(t), Δy(t)]; thus, in this study, this quantity was modified "modified quantum optical field equation" represented in Equation 1 and Equation 2:

$$Q(\Delta x(t))(\Delta y(t))e(\"{\i}) = C_x, \forall t \quad (1)$$

$$Q(\Delta y(t))(\Delta y(t))e(\"{\i}) = C_y, \forall t \quad (2)$$

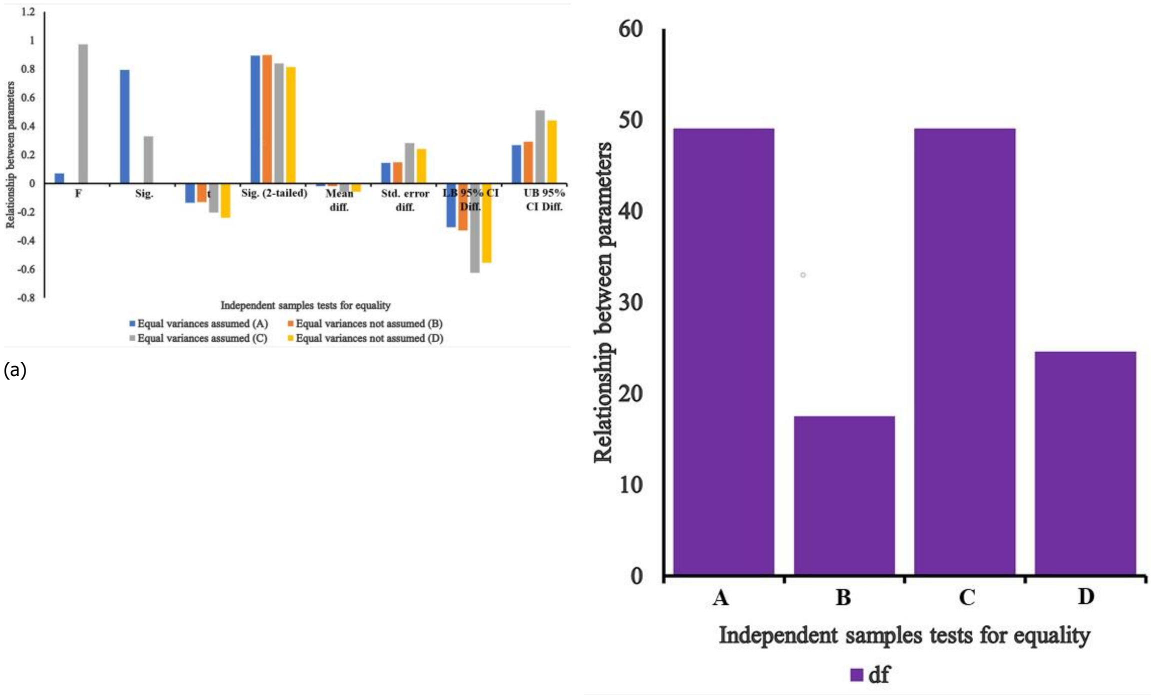
where: Δx(t) and Δy(t) are the standard deviation in the longitudinal (X) and lateral (Y) dimensions of the focal point of the target driver, respectively. e(ï) is the illumination index of the driver along the roadway of the vehicle i moving along the X-dimension at time t, and CX and CY are two constants associated with the X- and Y-dimensions, respectively (Agrawal, 2008). In reality, the original forms of Equations (1) and (2) were proposed in Baker (Baker, 1999) to characterise the relationships between the uncertainties (Δx and Δy) in the two-dimensional focal point of a driver and illumination index e(i). Experimental studies to support Equations (1) and (2) can be found in Bartmann et al. (Bartmann et al., 1991). Here, the uncertainties in a quantum optical field Q[Δx(t), Δy(t)] change as e(ï) changes. As Baker (Baker, 1999) argued, a high vehicular speed will require concentration (mind; efficient illumination; and good environmental condition) to process resources. Thus forming driver' tunnel vision', which is "a manifestation of a focus on the forward motion" along the roadway. Conversely, a low vehicular speed may result in the increases in Δx and Δy, resulting in more uncertainties in Q[Δx(t), Δy(t)] of driver response and reaction. Therefore, a trade-off relationship may be assumed to exist between Δy(t) and e(ï), as in Equation 2, and a similar trade-off also applies to the relationship between Δx(t) and e(ï), as in Equation (1). Therefore, the relationship above between the modified Q[Δx(t), Δy(t)] and e(ï) also hinges on inequality and factors such as attentional driver resources and action constant. Such uncertainty underpins a driver's mistakes in driving judgment, especially with speed and manoeuvring on the road section (Baker, 1999).

2.4 Null hypothesis and regression analysis using multinomial logistics

A t-test (Pincus, 2014) is used to compare the means of the groups. Taking account of *[effect of drugs and medication on driving behaviour; time of the crash – (RSA Winter Season - time zone; 5:30 pm to 6:25 am) experienced by drivers either during the day or at night on the roadway; effect of visibility of the road markings before and after the intervention of GPPT on the road markings].* This is in consideration with the proposed intervention using GPPT. The study is further analysed using parameter estimates in multinomial logistics to validate driver behaviour considering GPPT on the roadway section. Certain parameters considered are as follows: the t-test pairs = Medication with Road Markings; Medication with Drive Experience; Drive Experience with Road_Markings_visibility; Road Marking's visibility with Visible_Time_of_Crash, and Time_of_Crash with Glass_Powder_Paint_Intervention. Assuming a 5% margin of error for the study. This infers that a 95% confidence level equivalent to an acceptable significance level of 0.05 is considered.

3. Results and discussion

A quantitative analysis, as mentioned in Yin (Yin, 2014), was conducted. The sample size was estimated using the Raosoft sample size calculator (http://www.raosoft.com/samplesize.html) estimated a sample size of 3000 users and the response distribution value was 341 number of questionnaires. The questionnaires for the study were distributed and respondents identified were daily commuter drivers of the study section. A t-test was performed to compare the means of the different groups *(drugs or special treatment, driver behaviour before and after GPPT intervention, day and night visibility)*. The results indicated that the mean of the respondents under medication before the GPPT intervention who could partially see the road markings with reduced visibility was higher than the respondents' mean without medication after the GPPT intervention. This indicates that there is a significant relationship of 0.893 between the two groups. Considering Levene's test (Pincus, 2014) with equal variances, the significance level assumed for the study is set at 0.05. Considering the value of the mean difference *(0.01923, which is lower than the significance level of 0.05)* for the respondents taking drugs or on special treatment who could see clearly the road markings after the intervention. This indicates a positive impact in the implementation of the GPPT on the road markings. Furthermore, with a t-test significance value of 0.893 higher than *0.05 (mean significance assumed).* The null hypothesis is rejected. The results indicate approximately *(Zero – 0.0)* mean difference, indicating a 95 % confidence that the mean difference between drivers under medication and driving behaviour will clearly see the road markings when the innovative GPPT is introduced. Details are as indicated in Fig.1. See also Tab.1.



(b)

Fig.1 Graphical representation of the use of medication-driver behaviour relationship before GPPT intervention: (a) Levene's and t-test results and (b) df value results from t-test

		Levene's test for equality of variances		t-test for equality of means						
		F	Sig.	t	df	Sig. 2-tailed	Mean differences	Std. error differences	95% confidence interval of the differences	
									Lower	Upper
Drugs or special treatment	Equal variances assumed	0.070	0.793	−0.135	49	0.893	−0.01923	0.14283	−0.30626	0.26780
	Equal variances not assumed			−0.130	17.47	0.898	−0.01923	0.14737	−0.32950	0.29104
Driver behaviour and experience	Equal variances assumed	0.972	0.329	−0.204	49	0.839	−0.05769	0.28253	−0.62545	0.51006
	Equal variances not assumed			−0.239	24.56	0.813	−0.05769	0.24114	−0.55477	0.43938

Tab.1 Relationship between use of medication and driver behaviour prior to GPPT intervention

Furthermore, a mean value of 0.062 and 0.079 indicated that most of the drivers experienced blur vision before the intervention of the GPPT at night, as indicated in Fig.2 and Tab.2.

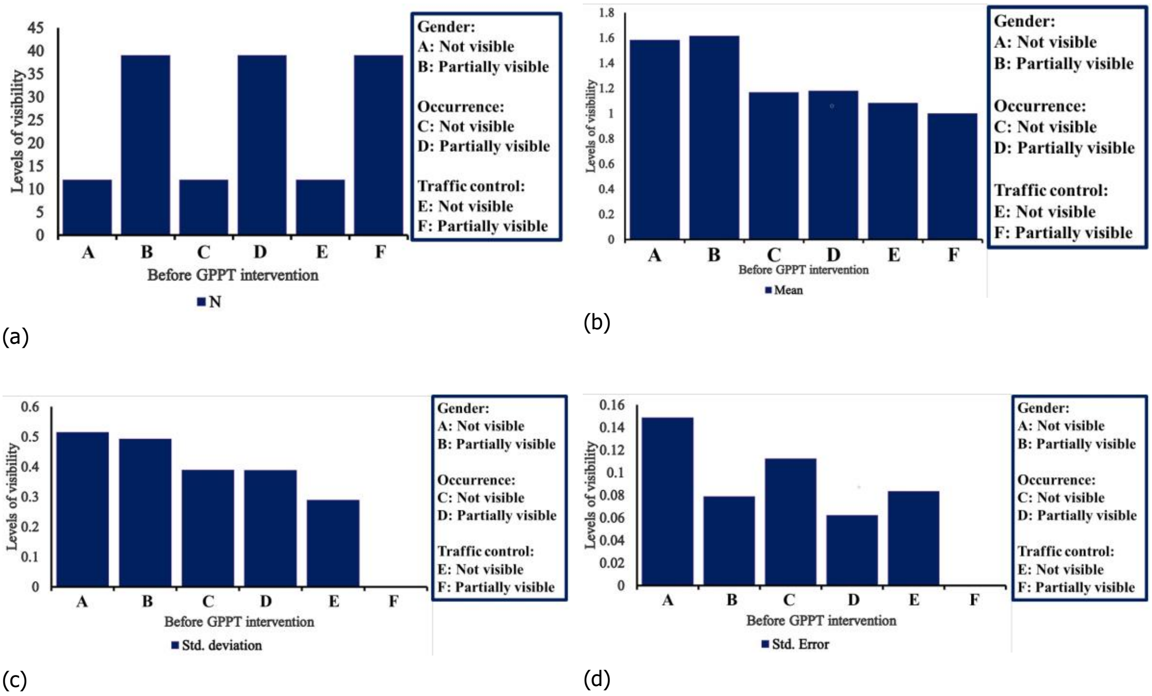


Fig.2 Graphical representation of visibility levels for road markings at night prior to GPPT intervention: (a) N value (b) Mean (c) Std. deviation and (d) Std. error

	Before glass-powder paint intervention	N	Mean	Std. deviation	Std. error
Gender	Not visible	12	1.5833	0.51493	0.14865
	Partially visible	39	1.6154	0.49286	0.07892
Occurrence	Not visible	12	1.1667	0.38925	0.11237
	Partially visible	39	1.1795	0.38878	0.06225
Traffic control	Not visible	12	1.0833	0.28868	0.08333
	Partially visible	39	1.0000	0.0000	0.0000

Tab.2 Relationship between levels of visibility of road markings at night before the GPPT intervention

Furthermore, considering the correlation between drivers under medication, driving behaviour, and experience before GPPT intervention and after GPPT intervention, it is observed that there is a significant difference of 0.815 and 0.957 with driving behaviour before and after the GPPT intervention, respectively.

In addition, a value of 0.187, 0.101 and 0.498 all indicate a significant difference higher than 0.05 (assumed significance) between the effect of drug and medication on driving behaviour before and after the GPPT intervention, respectively.

Since these values are higher than the 0.05 design hypothesis limit, the null hypothesis is rejected. This indicates a strong relationship exists between improvement in driving behaviour after the GPPT intervention. Hence there is a significant difference in the mean grouped value observed from the GPPT intervention, higher than the assumed significance level of 0.05 as indicated in Tab.3.

		Gender	**Drugs or special treatment**	**Driver behaviour**	**Before glass powder paint intervention**	**Glass powder paint intervention on road markings**
Gender	Pearson correlation	1	0.041	0.209	0.111	−0.139
	Sig. (2-tailed)		0.746	0.097	0.382	0.273
	N	64	64	64	64	64
Drugs or special treatment	Pearson correlation	0.041	1	−0.167	0.207	0.086
	Sig. (2-tailed)	0.746		0.187	0.101	0.498
	N	64	64	64	64	64
Driver behaviour and experience	Pearson correlation	0.209	−0.167	1	0.30	0.007
	Sig. (2-tailed)	0.097	0.187		0.815	0.957
	N	64	64	64	64	64
Before glass-powder paint intervention	Pearson correlation	0.111	0.207	0.030	1	0.170
	Sig. (2-tailed)	0.382	0.101	0.815		0.179
	N	64	64	64	64	64
Glass-powder paint intervention on road markings	Pearson correlation	−0.139	0.086	0.007	0.0170	1
	Sig. (2-tailed)	0.273	0.498	0.957	0.179	
	N	64	64	64	64	64

Tab.3 Multinomial logistic correlation between grouped means and GPPT intervention

It is needful to note that; in comparing grouped means between driver behaviour and time of crash rate (day or night) before and after the introduction of the GPPT intervention; a significant difference of 0.988 was observed indicating the introduction of the GPPT reduced occurrence of accidents and crashes on the road section.

This is observed in both day and night time irrespective of driving experience, see Tab.3. Thus, the null hypothesis is rejected, indicating that a strong relationship does exist between the introduction of the innovative GPPT and the level of visibility attained on the road section, as indicated in Fig.3 with a value from the non-parametric test set equating to 0 after computation.

Non-parametric hypothesis test summary				
S/No.	Null hypothesis	Test	Sig.	Decision
1	The categories of driver behaviour and experience occur with equal probabilities.	One-sample Chi-square Test	0.000	Reject the null hypothesis
2	The categories of before glass powder paint intervention occur with equal probabilities.	One-sample Chi-square Test	0.000	Reject the null hypothesis

Asymptotic significance are displayed. The significance level is 0.05.

Fig.3 Multinomial logistic correlation between grouped means and GPPT intervention

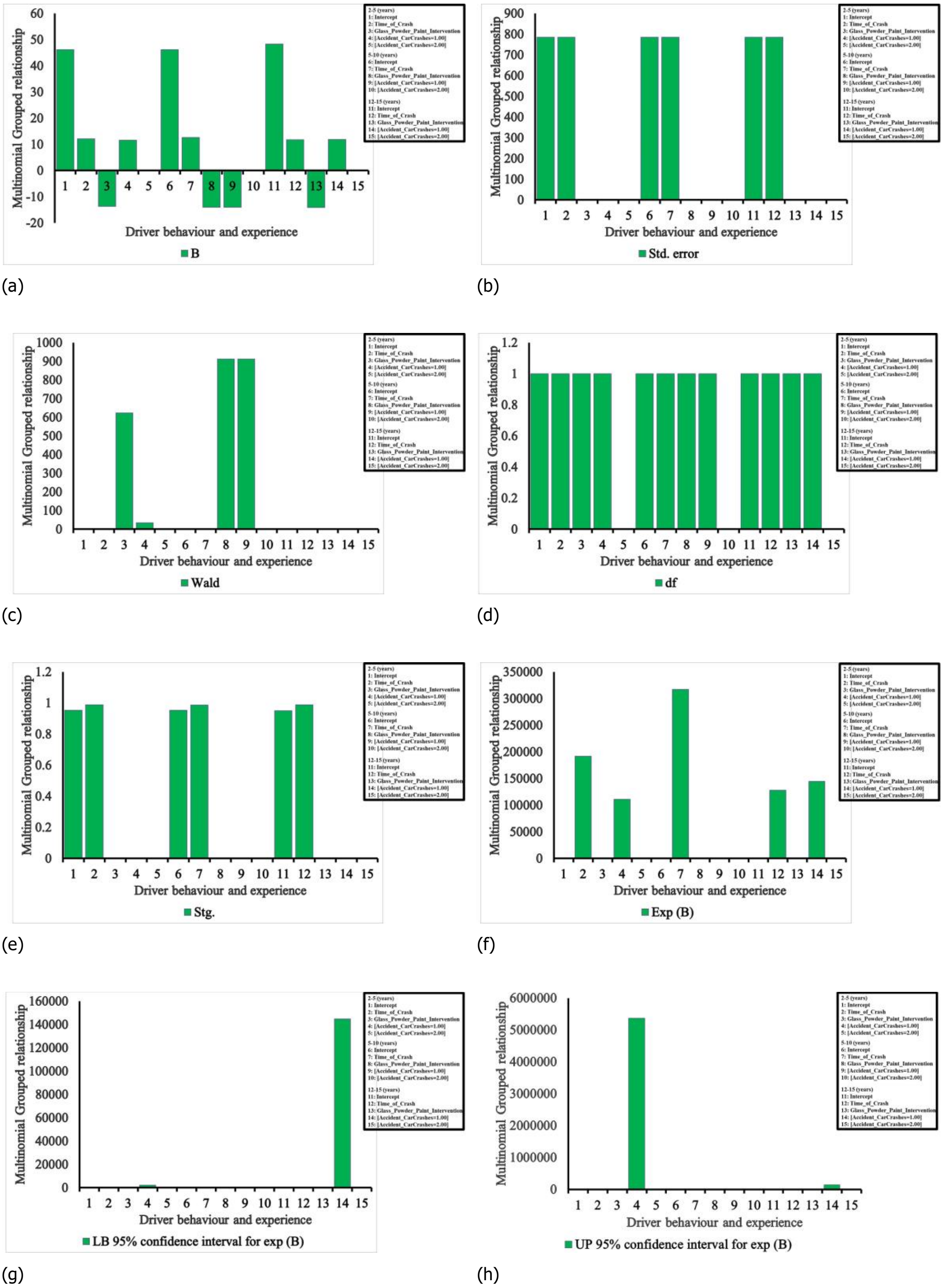


Fig.4 Graphical representation of the multinomial grouped relationship: (a) B value (b) Std. error (c) Wald (d) df (e) Stg. (f) Exp (B) (g) 95% confidence interval (CI) for exp (B) - lower bound (LB) and (h) 95% confidence interval (CI) for exp (B) - upper bound (UB)

Although females are more prone to crashes than males from the survey conducted in Tab.3; a lower bound of 0.459 and a higher bound of 1.847 indicates that it is very likely for females to be involved in crashes at night than males and with a significance level of 0.817 higher than the assumed significance level 0.05. Though, there was no clear association between the time of the crash *(Day or Night driving)* and the medical condition of drivers as there was no parameter regarding likelihood ratio testing in the occurrence of crash rates with visual ability at night or day time.

Fig.4a-h (see also Tab.4) indicates paired multinomial logistic regression sample correlation of GPPT while in conformity with quantum flow theory towards estimating visibility on the roadway section with the position of objects, markings, *e(i)* illumination index of the driver along the roadway as the vehicle *i* moving along the road section and driver behaviour at any time *t*.

The significant value of 0.000 indicates a clear relationship between the effect of paired means associated with driving behaviour, medical conditions, level of visibility, and GPPT intervention; therefore, the null hypothesis is rejected in Fig.5a-h and Tab.5.

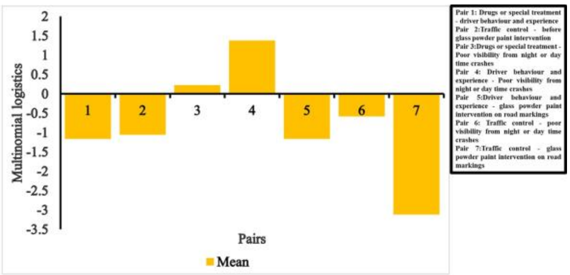
Driver behaviour and experience[a]		B	Std. error	Wald	df	Stg.	Exp (B)	95% confidence interval for exp (B)	
								Lower bound	Upper bound
2-5 (years)	Intercept	46.188	785.160	0.003	1	0.953			
	Time_of_Crash	12.164	785.149	0.000	1	0.988	191,794.774	0.000	.[b]
	Glass_Powder_Paint_Intervention	−13.671	0.547	623.809	1	0.000	$1.156E-6$	$3.953E-7$	$3.379E-6$
	[Accident_CarCrashes=1.00]	11.617	1.979	34.440	1	0.000	110,922.404	2,291.424	5,369,491.423
	[Accident_CarCrashes=2.00]	0^c	.	.		.	.	.	.
5-10 (years)	Intercept	46.194	785.157	0.003	1	0.953			
	Time_of_Crash	12.667	785.149	0.000	1	0.987	317,179.493	0.000	.[b]
	Glass_Powder_Paint_Intervention	−14.072	0.466	912.876	1	0.000	$7.739E-7$	$3.106E-7$	$1.928E-6$
	[Accident_CarCrashes=1.00]	−14.072	0.466	912.876	1	0.000	$7.739E-7$	$3.106E-7$	$1.928E-6$
	[Accident_CarCrashes=2.00]	0^c	.	.	0	.	.	.	.
10-15 (years)	Intercept	48.288	785.150	0.004	1	0.951	0	0	0
	Time_of_Crash	11.761	785.149	0.000	1	0.988	128,142.77	0.000	.[b]
	Glass_Powder_Paint_Intervention	−14.152	0.000	.	1	.	$7.146E-7$	$7.146E-7$	$7.146E-7$
	[Accident_CarCrashes=1.00]	11.884	0.000	.	1	.	144,871.787	144,871.787	144,871.787
	[Accident_CarCrashes=2.00]	0^c	.	.	0	.	.	.	.

a. The reference category is: 20 years or more.

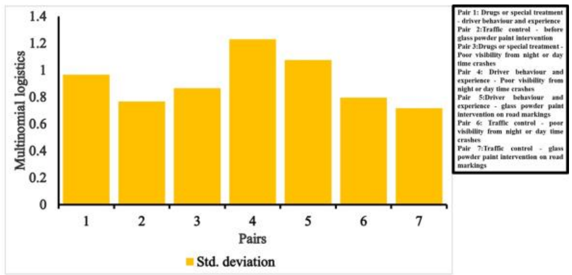
b. Floating point overflow occurred while computing this statistic. Its value is therefore set to system missing.

c. This parameter is set to zero because it is redundant.

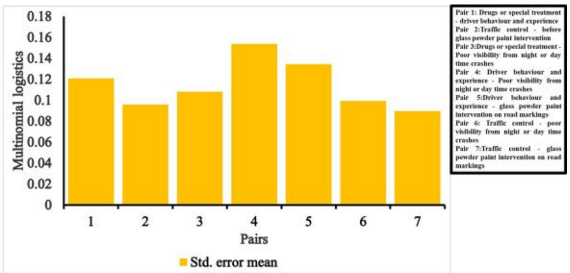
Tab.4 Multinomial grouped relationship between driving behaviour, the occurrence of accident and time of driving (Day or Night)



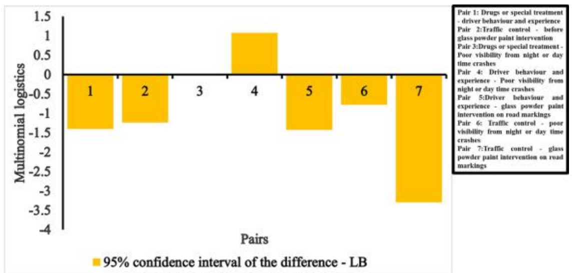
(a)



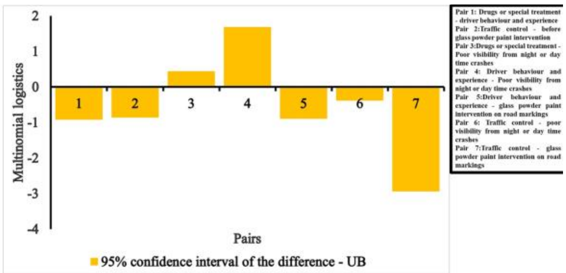
(b)



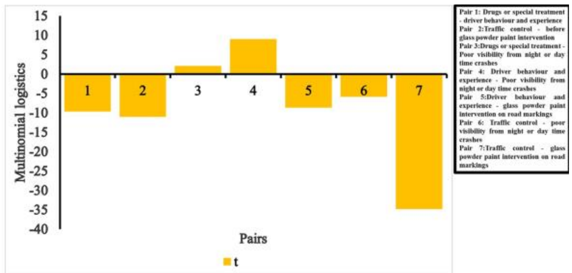
(c)



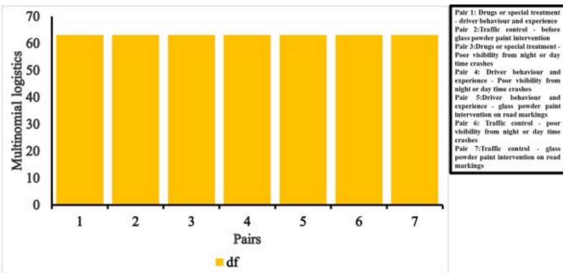
(d)



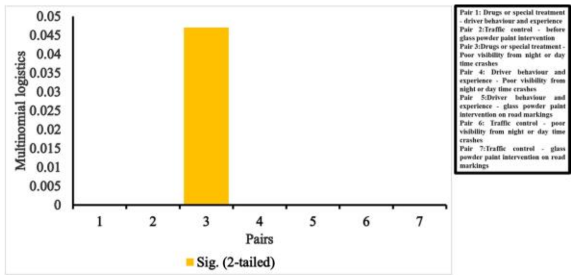
(e)



(f)



(g)



(h)

Fig.5 Graphical illustration of the multinomial logistics in optical flow theorem relationship between visibility, driving behaviour and GPPT intervention: (a) Mean (b) Standard deviation (c) Standard error mean (d) 95% confidence interval of the difference – lower bound (e) 95% confidence interval of the difference – upper bound (f) t-value (g) df and (h) Sig. (2-tailed)

		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
					Lower	Upper			
Pair 1	Drugs or special treatment – driver behaviour and experience	−1.15625	0.96311	0.12039	−1.39683	−0.91567	−9.604	63	0.000
Pair 2	Traffic control – before glass powder paint intervention	−1.04688	0.76490	0.09561	−1.23794	−0.85581	−10.949	63	0.000
Pair 3	Drugs or special treatment – poor visibility from night or day time crashes	0.21875	0.86316	0.10789	0.00314	0.43436	2.027	63	0.047
Pair 4	Driver behaviour and experience – poor visibility from night or day time crashes	1.37500	1.22798	0.15350	1.06826	1.68174	8.958	63	0.000
Pair 5	Driver behaviour and experience – glass powder paint intervention on road markings	−1.15625	1.07229	0.13404	−1.42410	−0.88840	−8.626	63	0.000
Pair 6	Traffic control – poor visibility from night or day time crashes	−0.57813	0.79292	0.09911	−0.77619	−0.38006	−5.833	63	0.000
Pair 7	Traffic control – glass powder paint intervention on road markings	−3.10938	0.71530	0.08941	−3.28805	−2.93070	−34.776	63	0.000

Tab.5 Multinomial logistics in optical flow theorem relationship between visibility, driving behaviour and GPPT intervention

4. Conclusion

Driving at night or in low visibility regions along a transportation facility can be particularly perilous. Related problems could range from reducing visibility and the objects fading away into obscure darkness with reduced illumination. In such scenarios, the road markings become a blur and eventually disappear along the driving lane. Though some drivers suffer from night vision deficiency such as nearsightedness, cataracts, retinis pigmentosa, to name a few, resulting conditions could damage their vision at night. The poor visibility due to blurred road markings could be attributed to rain and friction between tyres and road marking lines wearing these away over time. This study aims at addressing these issues by providing alternative measures to improve driver visibility at night using innovative glass-powder paint technology (GPPT). On implementation, this approach addresses other critical issues such as glass wastes on landfills and dumpsites by recycling them to improve the road markings within urban cities and highway corridors. A case study section is introduced for testing in East London CBD driveway (Eastern Cape Province-South Africa) and compared with a different marked road using conventional road marking paint. The study conducted herein develops a quantitative analysis *(grouped multinomial logistics and non-parametric test)* derived from the quantum flow theory, which proves a strong relationship between improved driver visibility on road markings with the introduction of the innovative GPPT. The results revealed that the confidence level of 95% equivalent to a 0.05 null hypothesis significance level assumed in which the *null hypothesis* was rejected indicates improvement in driving behaviour at night on the test section with the introduction of the GPPT to enhance illumination index and reduce the level of blur on the road markings and objects along the road section. This further helps to improve glare and illumination at night while enhancing driver behaviour concerning perception and positioning of objects on the roadway and increased illumination index of road markings.

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Image Sources

Fig.1, 2, 3, 4, 5: Made by the authors.

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