EFFECT OF ENHANCED ROAD MARKING IN ROAD SAFETY – SPEED AND LATERAL POSITION

Nor Aznirahani Mhd Yunin
Road Safety Engineering and Environment Research Centre
Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Malaysia
Email: noraznirahani@miros.gov.my

Nora Sheda Mohd Zulkiffli
Road Safety Engineering and Environment Research Centre
Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Malaysia
Email: norasheda@miros.gov.my

Akmalia Shabadin
Road Safety Engineering and Environment Research Centre
Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Malaysia
Email: akmalia@miros.gov.my

Siti Zaharah Ishak
Malaysian Institute of Road Safety Research (MIROS), 43000 Kajang, Malaysia
Faculty of Civil Engineering Universtiti Teknologi Mara, 40450 Shah Alam, Malaysia
Email: sitizaharah@miros.gov.my

ABSTRACT

Malaysia started to implement all-weather thermoplastic (AWT) road marking material in 2010 on highways and in 2012 on federal roads. However, no research was done to observe the effectiveness of the implementation in road safety. Previous research on this topic has provided mixed results and counterintuitive findings. The aim of this study is to evaluate the effectiveness of enhanced road marking in improving road safety within Malaysia. Using a before-after-after approach, the effect different types of road marking on vehicle travelling speed and lateral position of vehicles were evaluated before implementation of countermeasure (DC1), within one month after implementation (DC2) and within three months after DC2 (DC3). This study was conducted on federal road FT005 within Selangor and involved repainting of road markings (normal road marking material and also all-weather thermoplastic road marking material) along selected sites identified. Data collection was conducted during daytime and night-time. Results from this study show that there is no statistically significant interaction between the type of road marking and time of observation on vehicle travelling speed during daytime and night-time. However, findings from this study reveals that there is a statistically significant interaction between the type of road marking and time of observation on lateral positioning of vehicles during daytime and night-time. Drivers are more concentrated in driving at sections with AWT road marking as compared to sections with normal road marking. Nevertheless, it should be mentioned that findings from this study is only applicable along federal roads with a two-lane single carriageway geometry.

Keywords: road marking, speed, lateral position.

INTRODUCTION

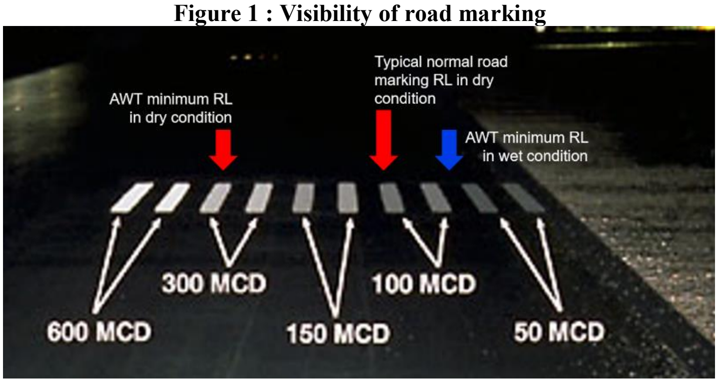
Roads are essential in our daily life. Everyone uses the road to get from point A to point B in some way. Unfortunately, this comes at a price. People are being killed or injured due to road traffic accidents. As road traffic accidents cannot be avoided, effective and comprehensive road safety strategies to reduce the number of people killed or injured due to road traffic accidents were introduced.

Road markings control traffic and encourage safe and efficient vehicle operation in a unique way as drivers do not have to shift their attention away from the roadway in order to receive continuous information. Centre and edge delineation treatments help drivers judge their position on the road, and provide advice on the road condition ahead. It is used where other improvements would be too costly or ineffective, as an interim method until other improvements can be installed.

During the day, drivers discern road markings mainly by the colour contrast between the marking and pavement surface. Alternatively, night-time visibility of road marking is generally determined by the retroreflectivity luminance (R_L) of the road marking. Retroreflectivity luminance describes the amount of light returned back to a driver from a vehicle's headlight as it is reflected back from the markings and is measured in milicandela per meter square per lux (mcd/m^2/lux). The reflected light provides the driver information and enables a safer drive at night.

As shown in Figure 1, higher R_L value is associated with greater visibility of the road condition ahead. The greater the visibility of the road condition ahead, the more time a driver will have to react to the surrounding. Based on risk compensation theory, it is hypothesised that drivers will tend to drive faster and reduce their concentration while driving along sections with enhanced road marking as compared to normal road marking.

Figure 1 : Visibility of road marking

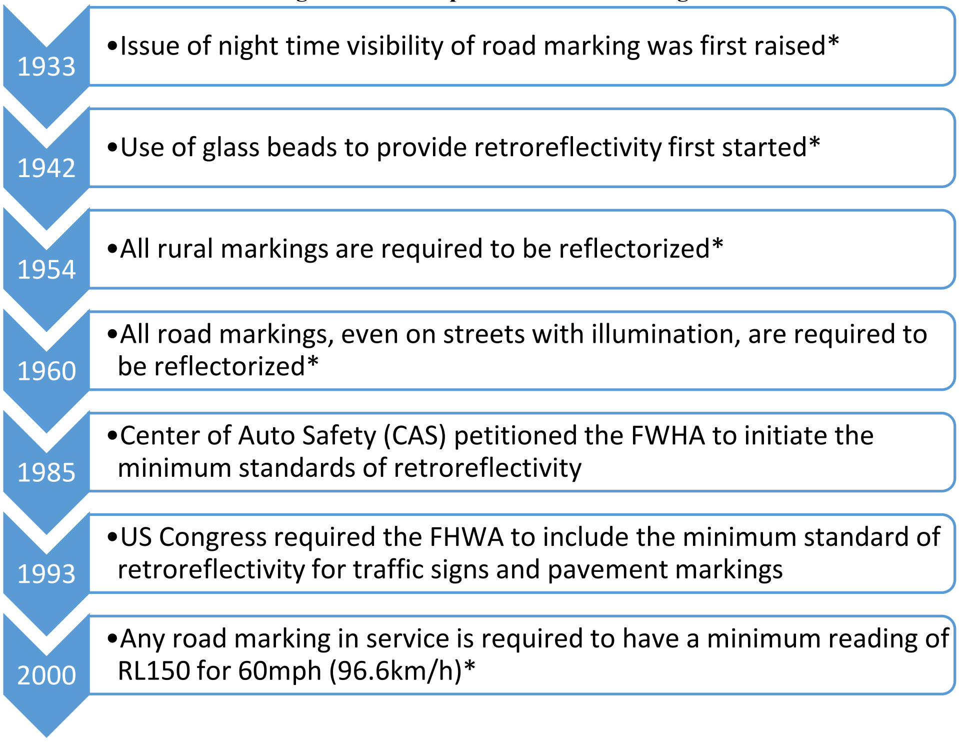


Malaysia started to implement enhanced road marking material (all-weather thermoplastic road marking material) in 2010 on highways and in 2012 on federal roads. However, no research was done to observe the effectiveness of the implementation on road safety. As previous research on this topic has provided mixed results and counterintuitive findings, it is important to study the effectiveness of enhanced road marking material in improving road safety within Malaysia.

DEVELOPMENT OF ROAD MARKING

The development of road marking started in 1933 when the issue of night-time visibility of road marking was first raised. Researchers started to study on how to make road markings visible during night-time. In 1942, the use of glass beads to provide retroreflectivity was first started. The transformation process of normal road marking material to enhanced road marking material (also known as all-weather thermoplastic, AWT) is as shown below in Figure 1.

Figure 1 : Development of road marking



* Manual on Uniform Traffic Control Devices (MUTCD), Federal Highway Administration (FHWA)

As for Malaysia, the retroreflectivity reading on road markings was not specified in the old specification for road markings. The retroreflectivity reading on road markings is only specified in the new specification on road markings (JKR/SPJ/2012/S-6 JKR 21300-0037-12). Based on this guideline, the road markings must have an initial R_L reading of 300 mcd/m^2/lux in dry condition and 75 mcd/m^2/lux in wet condition. The initial R_L reading should be taken within seven (7) days after completion of the road marking installation.

RESEARCH ON SAFETY BENEFITS OF ROAD MARKING RETROREFLECTIVITY

Over the years, several attempts to evaluate the safety benefits of road marking retroreflectivity have been done. Previous research on this topic has provided mixed results and sometimes, counterintuitive findings.

In 2006, researches in New Zealand studied the safety impacts of brighter road markings and concluded that there was no conclusive improvement in safety (Dravitzi et al., 2006). This study took advantage of a policy change in New Zealand in 1997 that required a minimum maintained retroreflectivity level of 70 mcd/m^2/lx. Using a before–after approach, the authors compared crash rates before the change in policy. They assumed that markings were brighter during the after period. It should be noted that all state roadways in New Zealand are delineated as a function of traffic volume. As volumes increase, they progressively apply the following treatments: delineators, centerlines, edge lines, and then retroreflective raised pavement markers (RRPMs). Therefore, roadways with centerlines had delineators too. This is in line with the findings from previous research conducted in the United States. According to research conducted by Molino et al. in 2003, supplemental delineation treatments, such as delineators or RRPMs, overpower the potential effect of pavement markings.

The results of an NCHRP study were published in 2006 with the following conclusions: "... the difference in safety between new markings and old markings during non-daylight conditions on non-intersection locations is approximately zero" (Bahar et al., 2012). Although the study incorporated large amounts of crash data and used the latest statistical techniques, there were significant limitations. For instance, the research only included crashes from California and modeled retroreflectivity (no measurements were made). The pavement marking maintenance policy of California is such that higher-volume highways are restriped up to three times a year with paint, or every 2 years with thermoplastic markings. As a result, there is only the occasional roadway with retroreflectivity levels below 100 mcd/m^2/lx.

Overlooking the concerns regarding the modeled retroreflectivity levels, the researchers also binned the retroreflectivity levels. The binning thresholds were derived linearly, which by itself is a limitation because the performance of retroreflectivity has been repeatedly shown to be best modeled logarithmically rather than linearly (Finley et al., 2002). In addition, the lowest bins for the edge lines included retroreflectivity levels from 21 to 183 mcd/m^2/lx, thus including both inadequate levels and near-desired levels in the same bin. Eight additional bins included retroreflectivity levels up to 413 mcd/m^2/lx. Therefore, all binning used in the analyses included levels deemed to be acceptable or at least above previously recommended minimum retroreflectivity levels. These concerns limit acceptability of the quoted concluding remarks shown above.

In 2007, Donnell and Sathyanarayanan reported results from an effort to develop a statistical association between measured pavement marking retroreflectivity and traffic crash frequency. For this research, data from North Carolina were used. The results suggest that increased levels of the average pavement marking retroreflectivity on multilane highways may be associated with lower expected target crash frequencies; however, the association was small in magnitude and not statistically significant. On two-lane highways, the association between pavement marking retroreflectivity and crash frequency was larger in magnitude and marginally significant. This study used measured retroreflectivity levels recorded once per year. All the retroreflectivity data were well above what might be considered minimum levels, and even near what might be considered desired levels (all data were above 100 mcd/m2/lx with an overall average of 240 mcd/m^2/lx).

In 2008, a similar effort was reported that included 3 years of measured retroreflectivity (measured once per period) in Iowa (Smadi et al., 2008). These data were analyzed along with crash records from the same year. The distributions and models of the entire database, and a subset including only two-lane highways, showed no correlation between road marking retroreflectivity and crash probability. When truncating the data to only records with retroreflectivity values less than 200 mcd/m^2/lx, a statistically significant relationship was determined. However, the correlation was small.

The four studies summarized here present the latest information regarding the relationship between pavement marking retroreflectivity and safety. Two of the studies conclude that there is no relationship, but both studies appear to have significant limitations. The remaining two studies point to some possible relationships with statistical significance but the findings are small and not consistent.

SCOPE AND LIMITATION OF THE STUDY

This study was conducted on federal road FT005 within Selangor, Jalan Morib – Banting. This study involved repainting of road markings (normal road marking material and also all-weather thermoplastic road marking material) along selected sites identified. The repainting of road marking was carried out by a contractor appointed by 3M, with the presence of MIROS personnel. Road markings was implemented according to JKR Standard Specification for Road Works; Section 6: Road Furniture; Sub- section 6.3 Road Markings (JKR/SPJ/2012/S-6 JKR 21300-0037-12).

Several criteria were outlined during the site selection. Based on the criteria set, each site selected must have similar AADT and layout, no other delineation such as Retroreflective Pavement Markers (RRPMs) and street lighting on site. However, due to difficulty in finding locations that met the outlined criteria and safety reasons, street lightings were available at the locations selected within this study.

Despite all efforts made in ensuring that the sites selected within this study had the same criteria, existence of road surface defects on the pavement within the selected study area should be noted as this factor may influence the findings of the study.

METHOD

The fundamental purpose of road marking is to enhance the safety of road users by increasing the visibility of the road ahead. The greater the visibility, the more time a driver will have to react to the surrounding before a conflict occurs. Based on this theory and Wilde's theory of risk compensation (also known as risk homoeostasis), it is hypothesised that drivers will tend to drive faster and reduce their concentration when driving along sections with better visibility as compared to sections with poor visibility.

Based on this hypothesis and taking into account the limitation in finding suitable sites with similar characteristics, the before-after with comparison group studies method was selected for this study. In order to evaluate the effect of enhanced road marking, three (3) types of data - retroreflectivity luminance level, vehicle travelling speed and lateral positioning of vehicles were measured during daytime and night-time. Data collection was conducted at three (3) different periods - before implementation of countermeasure (DC1), within one (1) month after implementation of countermeasure (DC2) and within three (3) months after DC2 (DC3).

Retroreflectivity luminance level was measured by using a Retrometer. Whereas measurements on vehicle travelling speed was collected via spot speed capturing free flow speed of vehicles passing through the selected sections. Data on lateral positioning of vehicles was retrieved by video, comparing the lateral position of vehicles at two points within a section.

RESULTS

This section is divided into three (3) subsections; retroreflectivity level, vehicle travelling speed and lateral position.

RETROREFLECTIVITY LUMINANCE

The retroreflectivity luminance R_L reading throughout the study period is as shown in Table 1. The values obtained on site for normal road marking and all-weather thermoplastic road marking does not meet the minimum requirement as stated in the Standard Specification for Road Works (JKR/SPJ/2012/S-6 JKR 21300-0037-12). According to this guideline, the minimum initial reading for retroreflectivity luminance RL shall be 300mcd/m^2/lux under dry condition. The existence of road surface defects on the pavement of the selected sites may have caused the beads to sink during the repainting of road markings and hence, affecting the retroreflectivity luminance R_L readings.

Table 1: Retroreflectivity luminance R_L (mcd/m^2/lux)

	DC1	DC2	DC3
Normal	77	142	126
AWT	73	269	334

Despite the retroreflectivity luminance R_L readings not meeting the minimum requirement as stated in the guideline, it should be noted that the retroreflectivity luminance R_L for all-weather thermoplastic road marking is higher as compared to the retroreflectivity luminance R_L for normal road marking throughout the study period.

EFFECT OF ENHANCED ROAD MARKING ON VEHICLE TRAVELLING SPEED

The vehicle travelling speed measured on site is summarised in Table 2. The posted speed limit sign applicable on site is 90km/h.

In general, the 85th percentile speed within the study area does not exceed the posted speed limit and does not vary much regardless of the time of data collection. This shows that the vehicle traveling speed within the study area is not effected by the visibility of the road marking, but due to other factors such as the road environment itself. The lowest vehicle travelling speed captured within the study area was 25 km/h, whereas the highest vehicle travelling speed captured was 135 km/h.

Table 2: Vehicle travelling speed

		Daytime			Night-time		
		DC1	DC2	DC3	DC1	DC2	DC3
Normal	Min (km/h)	37	36	37	31	27	32
	Max (km/h)	127	122	128	111	103	111
	85th percentile speed (km/h)	86	85	84	76	75	77
AWT	Min (km/h)	34	30	39	29	25	35
	Max (km/h)	135	130	130	132	117	106
	85th percentile speed (km/h)	89	90	87	81	80	80

INTERACTION ON VEHICLE TRAVELLING SPEED

A two-way ANOVA was conducted to examine the effect of different types of road marking and time of observation on the vehicle travelling speed during daytime and night-time. The interaction on vehicle travelling speed is as shown in Table 3.

Table 3: Interaction on vehicle travelling speed

		SS	df	MS	F	P-value
Daytime	Normal-AWT	6157.018	1	6157.018	29.65942	0.00
	DC1-DC2-DC3	1422.727	2	711.3633	3.42676	0.03

	Interaction	981.1356	2	490.5678	2.36315	0.09
	Within	746080.7	3594	207.5906		
	Total	754641.6	3599			
Night-time	Normal-AWT	7368.98	1	7368.98	41.71106	0.00
	DC1-DC2-DC3	695.5278	2	347.7639	1.968468	0.14
	Interaction	103.4033	2	51.70167	0.29265	0.75
	Within	316941.1	1794	176.6673		
	Total	325109.1	1799			

When comparing the vehicle travelling speed at sections with normal road marking and all-weather thermoplastic road marking, a statistically significant difference in the mean speed was observed during daytime. The same pattern was observed when comparing the vehicle travelling speed at sections with normal road marking and all-weather thermoplastic road marking based on time of observation (DC1, DC2 and DC3). A statistically significant difference in the mean speed during DC1, DC2 and DC3 was observed during daytime. However, no statistically significant interaction between type of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) on vehicle travelling speed was obtained during daytime.

As for observation during night-time, a statistically significant difference in the mean speed between normal road marking and all-weather thermoplastic road marking was recorded (p=0.00), but there were no statistically significant difference in mean speed between time of observation (DC1, DC2 and DC3) (p=0.14). Same as the pattern recorded during daytime, no statistically significant interaction between different types of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) on vehicle travelling speed was obtained.

Based on these findings, it can be said that drivers do not make adjustments to their driving behaviour in terms of vehicle travelling speed when there is a change in the retroreflectivity luminance R_L in road marking.

EFFECT OF ENHANCED ROAD MARKING ON LATERAL POSITION

The values shown in Table 4 indicate the difference in lateral positioning of vehicles between two points within the study area. From literature, it is said that drivers who are concentrated upon their driving can be assumed to continuously adjust their transverse position to avoid large deviations from a straight line. On the other hand, drivers who are less concentrated on the driving task will not notice as fast that they are moving towards the edge of the lane, and consequently, they will be slower to adjust their position. Therefore, it can be concluded that the bigger the difference in lateral positioning of vehicles, the less concentrated the driver is.

Table 4: Lateral positioning of vehicles

		Daytime			Night-time		
		DC1	DC2	DC3	DC1	DC2	DC3
Normal	Min (m)	0.00	0.01	0.00	0.00	0.00	0.00
	Max (m)	2.33	2.03	2.22	2.45	1.93	2.13
	Mean (m)	0.73	0.62	0.39	0.95	0.49	0.54
	Std Deviation (m)	0.54	0.45	0.35	0.66	0.34	0.44
AWT	Min (m)	0.01	0.00	0.00	0.01	0.00	0.00
	Max (m)	2.40	1.80	1.80	2.44	1.56	2.13
	Mean (m)	0.70	0.45	0.39	0.64	0.40	0.40
	Std Deviation (m)	0.54	0.35	0.30	0.52	0.31	0.39

Findings from this research shows that drivers are more concentrated in driving at sections with all-weather thermoplastic road marking as compared to sections with normal road marking. This finding denies the risk compensation theory.

INTERACTION ON LATERAL POSITIONING OF VEHICLES

A two-way ANOVA was conducted to examine the effect of different types of road marking and time of observation on the lateral positioning of vehicles during daytime and night-time. The interaction of lateral positioning of vehicles during daytime and night-time is as shown in Table 5.

Table 5: Interaction on vehicle travelling speed

		SS	df	MS	F	P-value
Daytime	Normal-AWT	3.646754	1	3.646754	19.53992	0.00
	DC1-DC2-DC3	64.42623	2	32.21311	172.6032	0.00
	Interaction	4.916574	2	2.458287	13.17191	0.00
	Within	670.7518	3594	0.186631		
	Total	743.7413	3599			
Ni	Normal-AWT	14.33652	1	14.33652	68.3763	0.00

DC1-DC2-DC3	46.30202	2	23.15101	110.416	0.00
Interaction	4.332145	2	2.166073	10.33082	0.00
Within	376.1495	1794	0.209671		
Total	441.1202	1799			

A statistically significant interaction between the effect of different types of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) on lateral positioning of vehicles during daytime was obtained from the study, $F(2,3594)= 13.17191$, $p=0.00$.

When comparing the difference in lateral positioning of vehicles at sections with normal road marking and all-weather thermoplastic road marking during daytime, a statistically significant difference in lateral positioning of vehicles was observed. Therefore, we reject the null hypothesis that there is no difference in the difference in lateral positioning of vehicles between sections with normal road marking and all-weather thermoplastic road marking during daytime. A statistically significant difference in the mean speed during DC1, DC2 and DC3 was also observed during daytime.

The same pattern was observed for night-time. A statistically significant interaction between the type of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) during night-time was obtained from the study, $F(2,1794)=10.33082$, $p=0.00$.

From Table 5, it can be concluded that there is a statistically significant difference in the mean lateral positioning of vehicles between sections with normal road marking and all-weather thermoplastic road marking during night-time ($p=0.00$). A statistically significant difference in the mean lateral positioning of vehicles was also observed between the time of observation (DC1, DC2 and DC3) ($p=0.00$).

DISCUSSION

Road markings are used to control traffic and encourage safe and efficient vehicle operation in a unique way. Drivers do not have to shift their attention away from the roadway in order to receive continuous information at locations where road markings are provided. Previous research and studies have confirmed that the night visibility of road markings is an essential contributor to driver comfort and road safety. However, road markings are often neglected, and in many cases, have even completely disappeared from roads.

Results from this study show that there is no statistically significant interaction between the type of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) on vehicle travelling speed during daytime and night-time. This study also reveals that there is a statistically significant interaction between the type of road marking (normal and AWT) and time of observation (DC1, DC2 and DC3) on lateral positioning of vehicles during daytime and night-time. Drivers are more concentrated in driving at sections with all-weather thermoplastic road marking as compared to sections with normal road marking.

Nevertheless, it should be mentioned that findings from this study is only applicable along federal roads with a two-lane single carriageway geometry.

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