

## CLIMATE CHANGE AND ROAD SAFETY: A REVIEW TO ASSESS IMPACTS IN MALAYSIA

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### Article history

Received

30<sup>th</sup> April 2015

Received in revised form

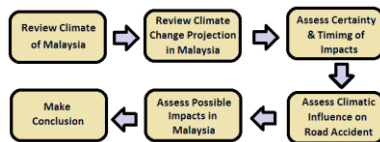
27<sup>th</sup> July 2015

Accepted

1<sup>st</sup> October 2015

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### Graphical abstract



### Abstract

Climate change is very likely to cause a sharp increase in temperature, which in turn is likely to affect atmospheric water storage, and thereby the magnitudes, frequencies and intensities of rainfall. The road environment, including the weather factors is one of the major causes of accident across the world. Therefore, it is very certain that climate change induced changes in weather factors will affect road safety, if proper adaptation measures are not taken. The major objective of this article is to review the existing literatures on the influence of climatic variables on road accident in order to assess the possible impacts of climate change on road safety in Malaysia. The analysis of exiting literatures reveals that most imminent and certain impacts of climate change on road safety will be due to increase of temperature and rainfall related extremes. However, the impacts may not be very high in Malaysia due to moderate changes of those extremes over a long time. Any potential risk would be possible to mitigate by educating the people on possible impacts of climatic extremes on road environment and motivating them to change their driving behaviour during extreme weather events.

Keywords: Climate change, road safety, extreme weather events, risk mitigation

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## 1.0 INTRODUCTION

Road accident is a great concern across the world [1]. Road traffic injuries are the eighth leading cause of death and account for 2.2% of total deaths globally [2]. Nearly 1.3 million people die and an additional 20-50 million are injured or disabled globally in road crashes each year [1]. The cost of dealing with the consequences of these road traffic crashes runs to billions of dollars [2]. Current trends suggest that by 2030 road traffic deaths will become the fifth leading cause of death unless urgent action is taken [1-2].

Various factors related to human including age, judgment, driver skill, attention, fatigue, experience; Vehicle such as, design, manufacture, and maintenance, and road environment such as, geometric alignment, cross-section, traffic control devices, surface friction, grade, signage, weather, visibility are considered to be responsible for road

accident. It has been reported that about 34% to total accident is due to road environment. Weather is considered as one of the most important factors among those related to road environment [3].

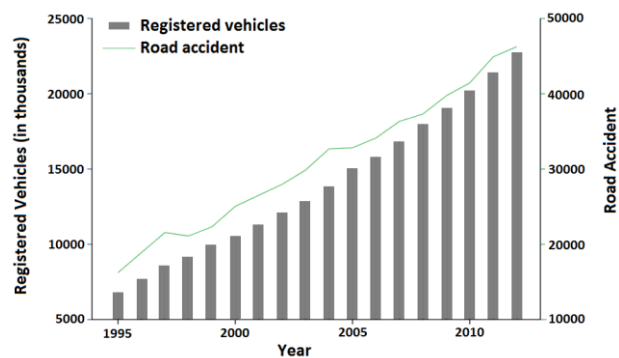
Influence of weather related variables such as, rain, snow, fog, extreme temperature, and other weather-related disasters on road accident are well established globally [3-11]. It has been reported that different weather related phenomena such as, rainfall [10], fog [12], wet or flooded pavement [7], wind speed [4], temperature [5], humidity [8], etc. affects road conditions like changes in visibility, pavement friction, lane obstruction, lane submersion, etc., which eventually increase the risk of accident [12-18].

It has been projected that climate change will alter rainfall intensity and other meteorological variables, and therefore, significantly influence road accident [7, 9, 19]. Andersson and Chapman [7] used climate change scenarios to investigate the relationship

between temperature and severe road accidents in the West Midlands, UK and demonstrated that the predicted reduction in the number of frost days reduces the number of road accidents caused due to slipperiness by approximately 50%. Jaroszweski *et al.* [9] reported the climate change impact on the road freight sector of Great Britain in order to identify potential future weather-related safety issues and reported that summer precipitation and winter ice-related accidents are likely to decrease across most of the country, whereas winter rain-related accidents to increase. Brand *et al.* [19] reported climate changes along with the changes in other factors are the causes of increase road accident fatalities in 2011 in Germany compared to last 20 years.

Road transport is one of the major drivers of rapid socio-economic development in Malaysia. It has contributed a lot to the gross development in the socio-economy and people's livelihood of the country [20]. At the same time, the road accident has increased significantly in Malaysia with the expansion of road transport system and number of vehicles in the road. Malaysia is considered as the 17<sup>th</sup> most dangerous roads in the world in term of road accident. Road accident is ranked fifth among the leading cause of deaths in Malaysia. The country is burdened with more than ten billion ringgit of losses due to traffic accidents every year. According to Malaysian Road Safety Department statistics, the road accidents cost RM9.3 billion to the economy of the country in 2012, which amounted to 1.5% of the country's Gross Domestic Product (GDP). Despite implementation of various intervention measures over the years, the number of traffic accidents continues to rise. Trend in traffic accidents along with the increase in the number of vehicles in Malaysia are shown in Figure 1. The figure shows that the road accident in Malaysia has increased by more than three folds during the time period 1995-2012.

It is very certain that road transport system in Malaysia will continue to grow with population growth, economic development and urbanization. It can be anticipated that road accident will follow the increasing trend with expansion of road network and increase of road vehicles. Climate change induced changes in meteorological variables will pose another threat to road safety and increase accident susceptibility in Malaysia, if proper adaptation measures are not taken. A clear understanding of the influences of meteorological variables on road environment and safety in Malaysia is required in order to take necessary adaptation and mitigation measures. Though road accident is great concern in Malaysia and being a tropical country Malaysian road environment is supposed to be more susceptible to climate change induced rise in extreme rainfall and temperature related events, no study has been carried out so far on this issue.



**Figure 1** Increasing trends in total registered vehicles and road accident in Malaysia [67]

The objective of the present study is to review the possible changes in the climate and climate related extremes in Malaysia, review the influences of various meteorological variables on road environment, understand the impacts of climate change on road environment in Malaysian context, and finally, identify the possible adaptation measures. It is expected that the study will help different stakeholders including the planning and development organizations, policy makers, government and non-government organization working on road safety, and driving training institutes to understand the possible impacts of climate change on road safety in Malaysia, which in turn will help in adaptation and mitigation planning.

## 2.0 METHODOLOGY

A review has been carried out to understand the possible impact of climate change on road safety in Malaysia. The climate of Malaysia is characterized by year around high humidity, temperature, and rainfall. Therefore, rainfall, temperature and humidity are the only meteorological variables that affect the road environment. Therefore, present knowledge on possible change in those meteorological variables due to climate change and their impacts on road environment are analyzed in the present study. For this purpose, relevant studies in the recent years have been identified and thoroughly reviewed to understand both the direct and indirect impacts of those variables on road environment across the world. The possible changes in the climate of Malaysia are also reviewed, and the possible impacts of those changes on Malaysian road environment are assessed. Finally, possible adaptation measures are proposed to mitigate the negative impacts of climate change on road safety.

Data of vehicle registration and road accident, recent climate records, future projection of climate, etc. are collected from various open source databases and reports such as, Malaysian Institute of Road Safety Research (MIROS), National Hydraulic Research Institute of Malaysia (NAHRIM), and Malaysian Meteorological Department (MMD).

Recent journal articles related to influences of meteorological variables on road environment and road accidents are collected and systematically reviewed. Other published documents such as, annual reports, newsletters, booklets and online database of various organizations responsible for climate change projection, such as NAHRIM and MMD as well as transport management, planning and development in Malaysia such as, Road Transport Department Malaysia, Ministry of Transport Malaysia, Land Public Transport Commission of Malaysia, etc. are also analyzed.

### 3.0 CLIMATE CHANGE IN MALAYSIA

#### 3.1 Climate of Malaysia

Situated in the equatorial region, Malaysia has a tropical climate characterized by uniform high temperature, high humidity and copious rainfall. The climate of the country can be loosely divided into two monsoons namely, the north-east monsoon from December to March and the south-west monsoon from June to September, and two inter-monsoonal transitional periods, one in April and another in October [21]. Heaviest rain spells are usually observed in the east coast of peninsular Malaysia during the northeast monsoon season, while months of June and July during southwest monsoon are the driest period [22]. The country experiences almost uniform temperature throughout the year with annual variations less than 2°C around the mean temperature of 27°C. The mean monthly relative humidity in Malaysia ranges between 70% and 90% [22].

#### 3.2 Projected Change of Climate in Malaysia

The past records of Malaysian climate show more or less similar trend that has been encountered globally [23]. The country's temperature has increased 0.18°C per decade since 1951 [24]. A study by NAHRIM [25] showed larger increase in minimum surface temperature by 1.5°C/50-yr for Peninsular Malaysia compared to mean and maximum surface temperature. MMD [26] reported an average increase of temperature by 0.5°C to 1.5°C in Peninsular Malaysia. On the other hand, no evidence of overall increase or decrease of rainfall has been observed in Malaysia in recent years [25]. However, NAHRIM [25] reported increasing trends in number of extreme indices such as, number of days with extreme rainfall, number days with extreme wind, and number of thunderstorm days in Peninsular Malaysia. Trend analysis of averaged annual rainfall anomalies during the time period 1951-2005 over the Peninsular Malaysia showed reduction in rainfall in the recent years. Increased frequency of relatively drier years is also noticed [26].

Future projection of Malaysian climate reveals the continuation of present trends of temperature and

rainfall extremes. A number of studies have been carried out by different organization to project future climate of Malaysia [25-28]. A rise of temperature in peninsular Malaysia has been projected in the range of 1.1°C to 3.6°C at the end of this century [26]. Regional Climate Model (RCM) known as PRECIS under A1B emission scenario also projected increase of rainfall and temperature in peninsular Malaysia in the end of this century [26].

On the other hand, high variability in inter-annual and inter-seasonal rainfall is projected in peninsular Malaysia by climate models [25, 28-29]. In some parts of the peninsular Malaysia, the frequency of long dry periods will be higher with a significant increase in the mean and variability of the length of the dry spells [30]. At the same time, there will be a significant increase in the overall mean monthly rainfall in Kelantan, Pahang, Terengganu and Kedah. The increase will be more during the wet months [29]. Variability in inter-annual and inter-seasonal rainfall will cause more hydrologic extremes in the east coast of Malaysia and make the livelihood and infrastructure more vulnerable [31].

### 4.0 REVIEW OF CLIMATIC INFLUENCE ON ROAD SAFETY

The vulnerability of any sector to climate change is usually measured by considering certainty and timing of impacts. Recent trends in climate of Malaysia indicate that Malaysia is already facing an increasing daily temperature. Significant increase of extreme rainfall events like number of heavy rainfall days, rainfall intensity, etc. has also noticed. Most of the climate models also projected significant increase in rainfall along with temperature in Malaysia [24-29]. More flooding or water logging will also be experienced due to increased extreme rainfall events. Coastal or island cities will be more affected by more flooding during extreme rainfall events due to sea level rise in near future. Therefore, it can be remarked that the most imminent impacts of climate change in Malaysia will be due to increase of temperature, rainfall and rainfall related extremes.

Therefore, the impacts of climate change on road environment in Malaysia will be due to increased temperature, rainfall and related extreme. However, climate change may also alter humidity and other weather factors like wind, fogging, etc. due to increased temperature. However, changes of those factors in Malaysia are not certain and also not imminent. Therefore, in the present study only the impacts of rainfall and temperature on road accident are analyzed. A brief review of the research that has been conducted so far to assess the impacts of rainfall and temperature on road accident across the world is given below.

#### 4.1 Influence of Rainfall on Road Accident

Wet roads are largely responsible for road accidents in various periods of a year and in various parts of the world. However, rainfall influence on road accident varies widely across the world [4, 9, 32-35]. The majority of the studies reported that road accident increases during rainfall [3-5, 9, 16, 36-41]. On the other hand, few studies indicated that road accident decreases during rainfall or no influence of rainfall on road accident [33, 35, 42-44]. Therefore, review of the impacts of climate change on road accident has been divided into two sections and presented in following section.

##### 4.1.1 Reports on Increased Accident during Rainfall

It has been reported that rainfall reduces visibility which even may be only few meters during heavy rain [45]. This can be further reduced due to splashing water, particularly from heavy vehicles [39]. Reflection of headlights of oncoming vehicles from the logged water on road during heavy rainfall can cause blinding at night [38]. Increased humidity during rainfall can cloud windows and windscreens and reduce visibility [46]. Furthermore, rainfall reduces the friction of the road surface and can lead to dynamic aquaplaning [37-39]. These all together can potentially increase road accidents.

Talab Haghghi [36] reported that moderate and heavy rainfall have effect on accident frequencies recorded in London and Huddersfield. Sherretz and Farhar [47] reported a positive linear relationship between rainfall amount and number of road accidents. Smith [48] reported an increase of 22% of road accidents during rainfall. Brodsky and Hakkert [49] reported 6% increase of accident rates during rainfall. On the other hand, Codling [50] reported an increase of accident by about 52% during rainfall. Satterthwaite [51] reported that rainy days experienced double the accident rate of dry days. Campbell [52], and Brodsky and Hakkert [49] estimated that accident rates in wet days increased by 2.2 times and 3 times, respectively compared to dry days. Terpstra [42] reported that the risk of a crash during rain is greater than in dry weather, even though the change in the behaviors of drivers during rainfall. Eriksson [40] reported that there is a severe risk of road slipperiness when rain falls on a frozen road surface and therefore, traffic can be severely affected, with a higher frequency of road accidents in Sweden. Nokhandan et al. [4] reported that rain is one of the most important causes of accidents especially on mountainous roads in Iran. Jaroszweski et al. [9] projected an increase in winter rain-related accidents in UK. Bergel-Hayat et al. [16] mentioned that the rainfall has partly indirect effect on main roads in different European cities. Jaroszweski and McNamara [3] reported relation between weather-related accidents and rainfall in urban areas in UK cities of Manchester and Greater London.

##### 4.1.2 Reports on Decreased Accident during Rainfall

In contrary to above findings, few studies reported that drivers adjust their behaviour during rainfall and accidents reduce during rainfall. Studies suggested that motorists overtake less, drive slower, and increase their following distance [32, 35]. These changes in driving behavior can significantly reduce the risk during rainfall [42].

Edwards [33] reported that accident severity decreases significantly during rain compared with fine weather in England and Wales. Keay and Simmonds [34] reported that rainfall is the strongest correlated weather parameter with road accident in Melbourne, Australia and it had the greatest impact in winter and spring, when traffic volume is reduced on wet days. They also reported that there are statistically significant decreases of 1.35 and 2.11% in traffic volume on wet days in winter and spring. The reduction increases to 2-3% over the 2-10 mm rainfall range and these eventually decrease the number of road accidents during wet days. Mondal et al. [6] found that 12.8% of total crash took place in wet days in India. However, they reported that the value of Rain-Crash-Effect (RCEi) were negative for monsoon months (June to August). They suggested a negative rain-crash-effect during monsoon months may be the results of extra care of drivers during rainy days, low vehicle speed due to traffic congestion and runoff effect. Jaroszweski et al. [9] studied impact of increased precipitation due to climate change in Great Britain and reported that summer precipitation related accidents are likely to decrease across most of the country.

#### 4.2 Influence of Temperature on Road Accident

Compared to rainfall, temperature effect on road accident is limited. Specially, studies related to impacts of high temperature on road accident in very rare. The overall effects of temperature on road accidents have been reported to vary from no definable relationship [53] to low temperatures being associated with more accidents [8,54] and a greater level of disruption [55]. Changes in temperature can change humidity which can cloud windows and windscreens and reduce visibility [46]. High temperatures can have a psychological and/or physiological effect on a driver [56]. It has also been reported that drivers may not adapt their driving to excessive heat and therefore, the resultant fatigue and possible aggressive tendencies, uncomfortable temperatures can lead to more traffic accidents [57]. De Freitas [56] suggested that higher temperature is a root cause of accident, but it is a modifier of accident conditions. The traffic volume increases during shiny hot days, which may indirectly affect number of road accident [58].

Rooney [53] reported a non-significant influence of air temperature on road accident. Scott [59] reported that higher temperatures increase accident frequencies in UK. Frost and Andreescu [58] reported



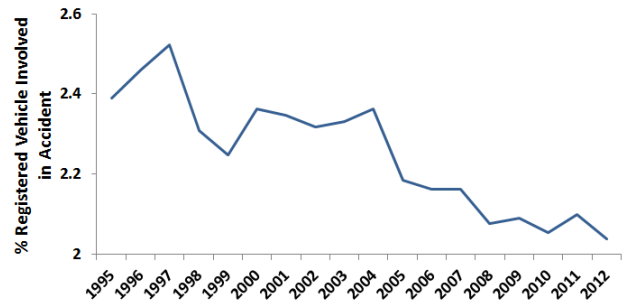
that those driving un-air conditioned vehicles may display less good judgment, and irritability. The reaction times increase during hot days, which may increase the vulnerability of accident [58]. According to a German study, emotions rise with the temperature, people become more irritable to others, they easily get tired, lose their concentration, and consequently, their reaction time increases [56]. Laaidi and Laaidi [30] reported increase in the number of crashes during heat waves, because of the high night-time temperatures and consequent sleeping disorder cause them more tired during daytime. Wyon *et al.* [60] found that drivers tended to react slower and made more mistakes during high temperature. Various forms of fatigue caused by higher temperature can also increase accidents [61]. Hermans *et al.* [62] reported that the number of hours of sunlight which indirectly affect day temperature may increase road accidents. Malyshkina [63] reported that extreme temperatures such as, high summer temperature are positively correlated with road accidents. af Wählberg [57] reported that prolonged exposure to high temperature conditions would have detrimental effects on driver performance.

Impacts of temperature on road accident in tropical region are very limited. One of the most significant studies in this regards was conducted by Al-Harbi [8] in Kuwait city. They reported that the most influential meteorological condition that causes accidents in Kuwait is temperature during the fall, spring, and winter seasons. In the summer, wind speed is identified as the most influential factor that accounts for the increased road accidents, with temperature as the second highest meteorological condition affecting accidents. The study indicates that the impact of temperature on road accident is significant in tropical region.

**5.0 POSSIBLE IMPACTS OF CLIMATE CHANGE ON ROAD SAFETY IN MALAYSIA**

From the review of influence of rainfall and temperature on road accident across the globe, it can be remarked that increased rainfall and temperature as projected in Malaysia will also influence the road safety and number of road accident in Malaysia. However, it is not possible to come to a conclusion on climate change impacts on road accident as behavioral change can offset the increased risk posed by climate change induced changes in road environment. It has been mentioned earlier (Figure 1) that number of road accidents in Malaysia is increasing with the increase of total number registered vehicles. However, this increase is due to the increase of number of registered vehicles. The percentage of registered vehicles involved in road accident in Malaysia is shown in Figure 2. The figure shows that percentage of registered vehicles involved in road accident has decreased significantly

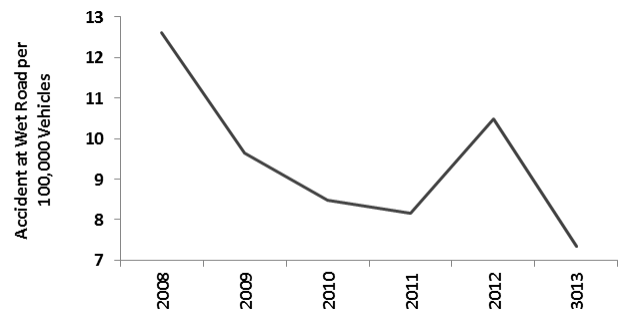
in recent year. It has also been reported that the number of road accident per ten-thousand vehicles has reduced in Malaysia. This is may be due to increased awareness of drivers in recent years. Furthermore, government measures in recent years have contributed to reduce road accident and fatalities.



**Figure 2** Percentage of registered vehicle involved in road accident over the time period 1995-2012 [67]

The impact of increase rainfall has a direct impact on road accident. However, it is very difficult to establish in many cases as it requires high resolution continuous rainfall data. In the present study, available data on road accident due to wet road condition is presented to get an idea of the impacts of recent changes in road accident due to wet road condition.

Figure 3 shows the number of road accident per 100,000 registered vehicles in wet road condition. It can be seen from the figure that there is a decreasing trend in number of road accidents per 100,000 registered vehicles due to wet road conditions.



**Figure 3** Number of road accident at wet road condition [67]

However, different trend can be observed when the ratio of number road accident due to wet road condition to the total number of road accident is considered. Figure 4 shows the changes in the percentage of the number road accident due to wet road condition to total number road accident in Malaysia over the time period 2008-2013. The figure clearly shows that the ratio of road accidents due to

wet road condition to total number of road accident has increased in Malaysia.



**Figure 4** Percentage of road accident at wet road condition to total number of road accident [67]

It can be remarked from above analysis that number of road accident per 100,000 registered vehicles due to wet road condition has decreased in recent years in Malaysia. This can be expected as the total number of road accidents per 100,000 registered vehicles has reduced in Malaysia. On the other hand, increase in the percentage of road accident due to wet road condition to total number of road accident indicate that influence of rainfall in road accident of Malaysia is increasing. However, it is not possible to come to a concrete decision with this limited amount of available data.

Considering the short time period of data, non-parametric Mann-Kendall trend test [64, 65] was used to detect the trend in the data presented in Figures 3 and 4. The results showed that none of the trends are significant. This again indicates that it is not possible to give a concrete decision on rainfall influence on road accident in Malaysia.

The impacts of increased temperature to road accident are mostly indirect. Temporal psychological and/or physiological changes during high temperature may change driver's attention and consequently, may cause accident. However, climate change is slow phenomena, and it will cause a gradual increase of temperature and related extremes over a long time. The projected increase of temperature in Malaysia over this century is in the range of 1°C to 2°C, which is lower than projected global average increase of temperature. Therefore, the impacts of increased temperature on road accident in Malaysia can easily be adapted by growing awareness on the impacts of high temperature on human vulnerability and possible risk of road accident.

Finally, it can be remarked that climate change will certainly pose risk to road safety in Malaysia through changing road environment. However, it is not possible to come to a concrete decision on climate change impacts on road accident in Malaysia as it can also changes driver's behavior. Changes of percentage of registered vehicles involved in road accident over the time period 1995-2012 (Figure 2)

reveals that percentage of road accident has reduced in Malaysia in last two decades. Government initiative to increase public awareness on road safety is considered as one of the major causes of gradual decrease of road accident in Malaysia. The noticeable change in public awareness on road safety in recent years might help to adapt with the changing road environment due to climate change in Malaysia.

## 6.0 ADAPTATION TO CLIMATE CHANGE IMPACTS ON ROAD SAFETY IN MALAYSIA

Adaptation to climate change will not only help to reduce the loss of life and property, it will also help to achieve sustainability in road transport [68]. Malaysia has taken number of steps to increase road safety awareness. The Road Safety Education (RSE) Program has been introduced in 2007 as a long term measure to reduce the high number of road accidents and deaths. Road Safety Department of Malaysia is also actively cooperates with several private companies to conduct other various road safety programs in schools. Study also revealed that awareness of road safety, understanding of the law, and recognition of road signs have been grown among the students participated in the programs [66]. Therefore, it can be expected that more emphasis on growing awareness in road safety including those are related to possible impacts of climate change on road environment can help Malaysia in adaptation to climate change. Driving training schools can play a major role in this regards.

Furthermore, it is required to incorporate the knowledge of climate changes and their impacts in pavement and geometric design of road network. Climate information, policies and measures should be incorporated into ongoing development planning and decision-making for more sustainable transport system. Awareness and preparedness at local and community levels are necessary to adapt to the changing climate. Modern information dissemination technologies and tools should be utilized to raise public awareness of climate change and the need for adaptation. Media can play an important role in this regard. The urban infrastructure are also required to design to reduce water logging considering that the return period of major extreme events is likely to decrease considerably.

## 7.0 CONCLUSION

Climate change will cause a sharp increase in temperature and alter rainfall pattern in Malaysia like other parts of the world. Increased temperature and changing precipitation pattern will change road environment and certainly increase risk to road safety in Malaysia. The present study reviewed that influence of rainfall and temperature on road accident across

the world to assess the impacts of climate change on road safety in Malaysia. It can be concluded from the study that changing road environment due to climate change may not be very detrimental in Malaysia. This is due to increasing awareness on road safety in Malaysia as reflected from recent road accident statistics. Climate change is a slow phenomenon which will take a long time to change the climate. The change will also not be very high in Malaysia compared to other parts of the world. Therefore, it can be expected that using developed infrastructure and economic ability Malaysia will be able to mitigate the risk posed by climate change on road safety.

### Acknowledgement

Authors are grateful to Ministry of Education (MOE)-Malaysia and Universiti Teknologi Malaysia to support this research through grant no. 06H36

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