Jurnal Kejuruteraan 32(2) 2020: 289-296
https://doi.org/10.17576/jkukm-2020-32(2)-13

Rumble Strips: A Human Factors Perspective towards a Sustainable Road System

Shahren Ahmad Zaidi Adruce & Donald Stephen

Universiti Malaysia Sarawak, Malaysia
**Corresponding author: azshahren@unimas.my*

Received 14 August 2019, Received in revised form 20 November 2019
Accepted 4 January 2020, Available online 30 May 2020

ABSTRACT

Prior research substantiates the belief that human factors contribute to up to 90% of all traffic accidents. The failure to consider cognitive ergonomics in road safety initiatives will continue to cause traffic fatality, especially on straight roads. Since drivers and road safety practitioners cannot wholly avoid driver's non-compliance, skill-based errors, and mistakes, road designs should aim to reduce the severity of repercussions resulting from human errors. For example, in the case of a momentary lapse of attention leading to lane departure, drivers should be able to correct their maneuvers. A human-centered traffic system approach of road design may reduce the severity of accidents caused by human error. An investigation of road crashes in Malaysia conducted by the Malaysian Institute of Road Safety Research revealed that 66% of road crashes in Malaysia are opposite-direction head-on crashes and run-off-road (roadway departure) crashes. Installing Lane Departure Warning System such as Centerline Rumble Strips (CLRS) and Shoulder Rumble Strips (SRS) can reduce these types of crashes and compensate human errors on the road. Rumble strips alert drivers that they are deviating from their lane by providing both tactile and auditory warnings. Although the effectiveness of rumble strips is well documented in prior researches, the practice of installing rumble strips is still scarce in Malaysia. This paper highlights how rumble strips can mitigate the consequences of the human errors, in the hope that the information can help road safety researchers, authorities, and practitioners move forward in the implementation of interventions towards sustainable road system.

Keywords: Sustainable Development Goal, Road Safety, Centerline Rumble Strips, Shoulder Rumble Strips, Human Factors

INTRODUCTION

Road Safety as a Sustainable Development Goal

Road accident is the leading cause of fatal injuries globally (Makinde & Oluwasegunfunmi, 2014) with the estimated deaths at over 1.35 million annually (World Health Organization, 2018). In 2004, the World Health Organization (WHO) recognized road traffic injuries as the ninth top causes of death. They predicted that they would become the fifth most frequent causes of death by 2030 (World Health Organization, 2009). This projection is alarming because, in a more recent WHO Global status report on road safety report, it was noted that traffic accidents had become the eighth leading cause of death worldwide. Currently, it is the leading cause of death for people from 5 years of age until 29 (World Health Organization, 2018). High traffic fatality rate due to unsustainable transportation was mentioned as one of the main challenges of sustainable development, therefore addressing road safety is not only relevant but also should be a key priority (United Nations, 2017). While sustainable transportation has no definitive definition, it was unanimously recognized that a sustainable transportation system should effectively and efficiently provide safe and equitable access to essential services, while promoting economic and environmental sustainability (Jeon, Amekudzi, & Vanegas, 2006).

The burden of traffic fatality falls disproportionately on the lower income countries (Asian Development Bank, 2019). According to the World Health Organization (2018), although low-income countries constitute only 1% of the world's vehicles, they account for 13% of the total traffic fatality. Internationally, non-fatal traffic injuries recorded 20 to 50 million casualties (Rohayu, Sharifah, Jamilah, & Wong, 2012). Locally, prior research has also confirmed that traffic accident is one of the leading causes of death and injuries in Malaysia (Kareem, 2003). Enhancing road safety is the responsibility of all citizens. Eusofe and Evdorides (2017) suggested that decreasing the reliance on government sources can improve the sustainability of the transportation system in Malaysia. This article takes heed of this suggestion and provides suggestions to enhance road safety from the perspective of Human Factors.

Addressing road safety is imperative to achieve the Sustainable Development Goals (SDGs) as unsafe transportation systems bring calamity to public health and development (World Health Organization, 2004). Two of the Sustainable Development Goals are related to road safety: (1) SDG target 3.6 that aims to halve the rate of traffic mortality and injuries by 2020, and (2) SDG target 11.2 that aims to improve the safety, inclusiveness, and the sustainability of the transportation system by 2030 (World Health Organization, 2017). The World Health Organization (2017) has called for all sectors to plan and execute necessary actions to reduce traffic mortality and morbidity. In November 2017, member states of the United Nations had agreed on a set of 12 voluntary global performance targets for road safety. Among the notabilia of these global targets are Target 3 and Target 4, which emphasize on creating roadways that meet technical standards by 2030 (World Health Organization, 2019). The road safety climate varies across regions (Wegman, 2017). Therefore, road safety initiatives should consider local needs and the context of use.

Human Factors Perspective on Road Safety

A possible explanation for the occurrence of traffic accidents in human factors perspective is that driving is a complex process involving eye-hand-foot coordination. A slight error or inability to coordinate can lead to traffic accidents (Masuri, Md Isa, & Mohd Tahir, 2017). Drivers must have a healthy level of situational awareness (the consciousness and knowledge about their surroundings, current situation and the projection of the future situation), workload (the physical and mental tasks), as well as attention (selectively concentrating on the driving task) (Horst, 2017b).

Human errors on the road should be given more attention because prior researches have delineated that sleepiness caused more traffic accidents than alcohol (Åkerstedt, Connor, Gray, & Kecklund, 2008). The person approach of human error views errors and procedural violations as the consequences of aberrant cognitive processes such as recklessness, negligence, forgetfulness, inattention, poor motivation, non-compliance, and carelessness (Reason, 2000). The taxonomy of human errors on the road is proposed based on psychological mechanisms such as perception, attention, memory, situational awareness, and action execution (Stanton & Salmon, 2009). Error management has two components: limiting the incidence of critical errors and creating systems that are better able to tolerate errors and mitigate their damaging effects (Reason, 2000).

Human Factors perspective on traffic accidents should be studied extensively because human error accounts for almost 80% of the occurrence of traffic accidents (Stanton & Salmon, 2009; Vashisth, 2018). Another study estimated a higher percentage (90%) (Theeuwes, 2017). These findings seem consistent with the scenario in Malaysia, as the Road Safety Department of Malaysia reported that human errors cause 80.6% of traffic accidents. Road condition and vehicle accounts for 13.2% and 6.2% of road accidents, respectively (Road Safety Department of Malaysia, 2018). About 70 to 80 percent of these human errors are the results of engineering defects (Vashisth, 2018). Therefore, the design of the road system should aim to reduce the severity of accidents caused by human error by implementing robust designs that can take cognizance of human limitations.

Darma, Karim, and Abdullah (2017) conducted an analysis of traffic fatality in Malaysia based on road segments from 2000 to 2011. The study concluded that fatal crashes on straight road constitute 3000-4500 deaths per year, which is 40-70% of the total fatality recorded. Furthermore, researchers from the Malaysian Institute of Road Safety Research have investigated road fatality profile based on 2011-2013 road crashes data in Malaysia. It was noted that most of the investigated road crashes happened at straight roads rather than bend stretches (Faudzi et al., 2017). Even if people are highly motivated to behave safely, they will make errors that may result in lane departure leading to crashes as a result of sleepiness, fatigue, inattentiveness, distraction, and so forth (Horst, 2017a; Vashisth, 2018). Accidents involving lane departure are generally “unforgiving” in a way that a slight error can cause devastating consequences (La Torre, Saleh, Cesolini, & Goyat, 2012). These findings proved that the road safety authorities in Malaysia should consider implementing road designs that can reduce the severity of human errors on straight roads, as existing straight roads in Malaysia are still unsafe for road users.

A study reiterated that finding countermeasures against human errors on the road is of great importance (Åkerstedt et al., 2008). Since human error cannot be entirely averted, road technologies should aim to mitigate the consequences of human errors and allow drivers to timely correct maneuvers in lane departure (La Torre et al., 2012). Altering human behavior ought to play a central role in improving traffic safety because accidents are caused or exacerbated by human errors (Jeon et al., 2006). World Health Organization (2018) noted that the cost of human mobility is too high, especially when there are proven measures to enhance road safety. This paper explains the effectiveness of rumble strips, namely centerline and shoulder rumble strips, and their role in mitigating human errors while driving on straight roads. Rumble strips are useful to alert sleepy and distracted drivers. Rumble strips correct behavior by giving tactile (the vibration when tires are running through them) and auditory warning (the noise when tires run over the rumble strip) to drivers that they are deviating from their lane due to human errors such as fatigue, sleepiness or inattention (Åkerstedt et al., 2008; Horst, 2017a; Vadeby & Anund, 2017). The implementation of rumble strips also entails safer, more controlled, braking behavior (Harder, Bloomfield, & Chihak, 2001). There are three types of rumble strips based on the location of its installation, which are centerline rumble strips (on or near centerline), shoulder rumble strips (road shoulders), and transverse or lane (perpendicular) rumble strips.

METHODOLOGY

Materials

This study compiles transportation and traffic accident data from various sources, namely the yearly traffic statistics reports by the Road Safety Department of Malaysia, Malaysian Institute of Road Safety Research, and Malaysian Royal Police. While these government and organizational reports are considered as grey literature, they serve as the most reliable source of traffic statistics in Malaysia. To establish the importance of rumble strips derived from the review of the literature (journals, conference proceedings, reports, and books) from various databases were collected. Analyses were conducted using JASP (jasp-stats.org) and Microsoft Excel.

RESULTS

Analysis of Road Accident Statistics

According to the Malaysian Ministry of Transport, a total of 28,738,194 motor vehicles were registered as of 31st December 2017 (Road Safety Department of Malaysia, 2018). The exponential increase in the number of vehicles indicates a need for more comprehensive road safety measures. Traffic accident data reported by the Road Safety Department of Malaysia (2018) was analyzed to identify patterns of traffic accidents and fatality. As in FIGURE 1, the number of road accidents in Malaysia from 1997 to 2017 has increased two-fold, from 215,632 in 1997 to 533,875 in 2017. This continual rise in the number of accidents corresponds to the rising number of vehicles registered. Up until September 2018, there are 28.7 million registered vehicles in Malaysia (Road Safety Department of Malaysia, 2018).

FIGURE 2 illustrates the number of motor vehicles involved and the number of accidents in Malaysia. FIGURE 2 shows that the increase in the number of vehicles involved in traffics accidents has not been monotonic. A possible explanation for this pattern is the increasing number of single-vehicle crashes. FIGURE *3* illustrates the number of traffic accidents in Sarawak. The accident rate in Sarawak is alarming, with a nonlinear increment of reported traffic accidents by 58.7% over 14 years from 2003 to 2017.

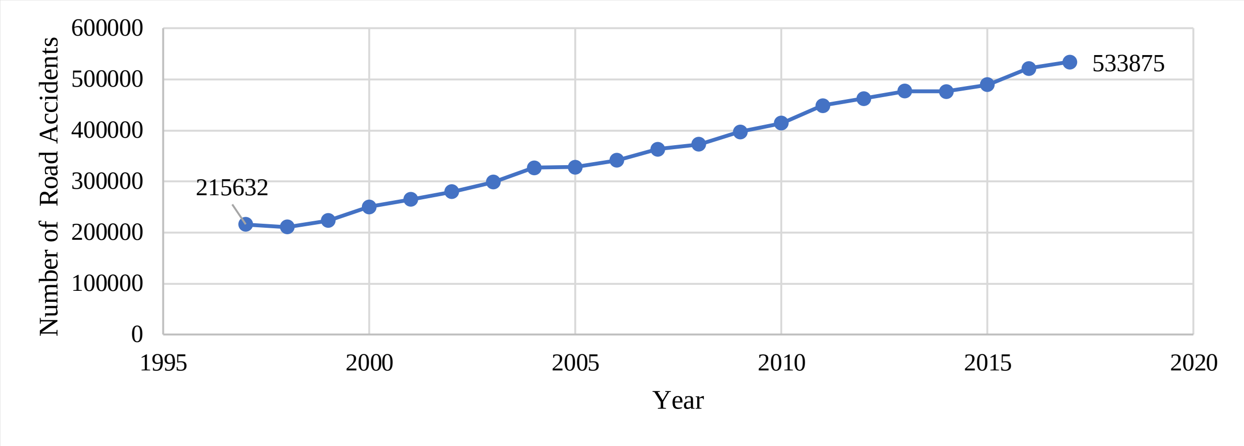

FIGURE 1. The number of road accidents in Malaysia from 1997 to 2017 (20 years)

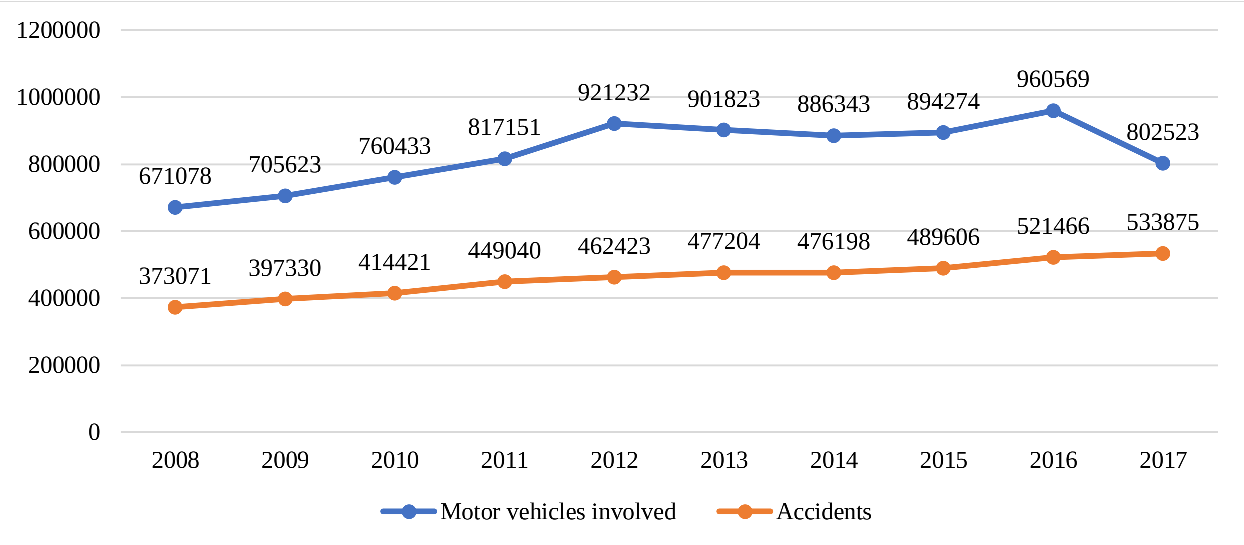

FIGURE 2. The number of motor vehicles involved & the number of accidents in Malaysia (2008-2017)

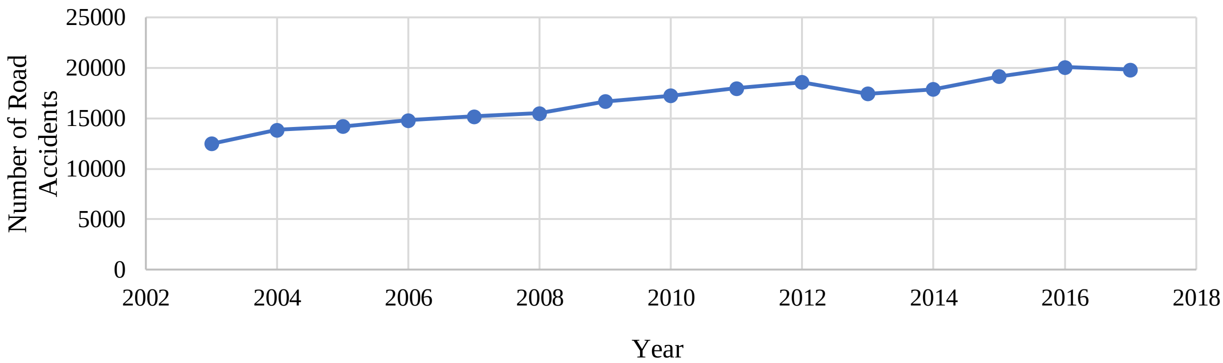

FIGURE 3. The number of traffic accidents in Sarawak (2003-2017)

Based on the traffic accidents yearly reports, the traffic fatality rate correlates positively with the number of crashes and vehicles registered. A Pearson correlational analysis was conducted to examine the correlational patterns between these three variables. Figure 4 illustrates the graphs for these relationships. Results show strong positive correlations between traffic fatality, the number of crashes, as well as the number of vehicles registered. As correlation does not imply causation, it is crucial to note that the number of vehicles does not cause an increase in traffic accidents and road deaths.

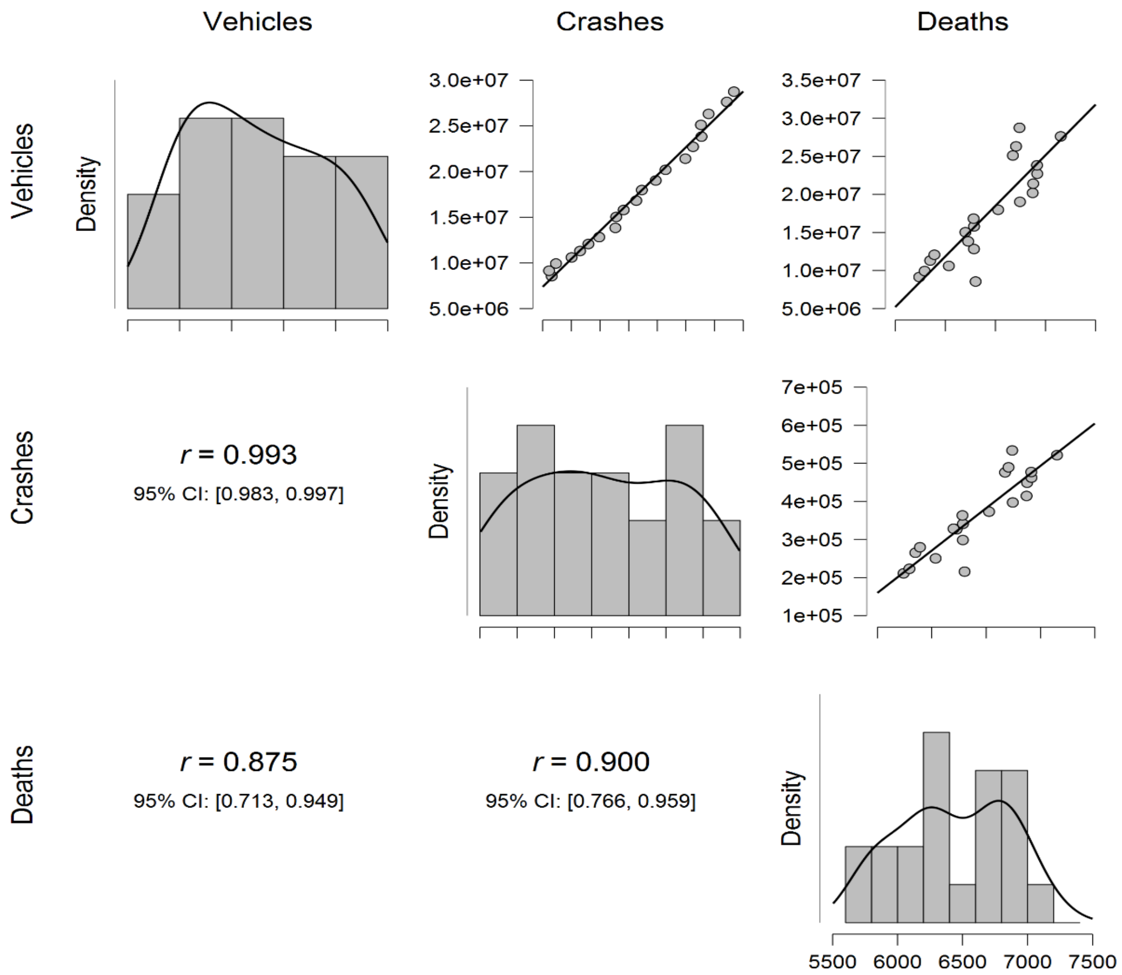

FIGURE 4. Relationship between the number of vehicles, crashes and road deaths

Rumble Strips

Each type of rumble strips has its purpose in mitigating crashes. Centerline rumble strips help to reduce opposite-direction sideswipe crashes and head-on crashes A study conducted by the Malaysian Institute of Road Safety Research found that head-on accidents recorded the highest proportion (38%) of total traffic crashes from 2011 to 2013 (Faudzi et al., 2017). The implementation of centerline rumble strips in Malaysia could ameliorate the severity and the frequency of head-on crashes. On the other hand, shoulder rumble strips help to mitigate single-vehicle roadway departure type crashes often caused by human errors. Shoulder rumble strips were most efficacious in reducing run-off-road (roadway departure) crashes for roads with relatively moderate curvature (Khan, Abdel-Rahim, & Williams, 2015). Lastly, transverse rumble strips aim to prevent intersection crashes by forcing drivers to reduce their speed (Yahya et al., 2015). In Malaysia, transverse rumble strips are more commonly applied in road designs to reduce speed on accident-prone areas, such as intersections and traffic lights. For example, the Public Works Department (JKR) has installed warning signs and rumble strips at an accident-prone area in Miri, Sarawak (Sarawak Government, 2018).

Prior researches have emphasized the safety benefit and the effectiveness of rumble strips in reducing the severity and the frequency of run-off-road collision (roadway departure) (Craig, Persaud, & Eccles, 2015; Khan et al., 2015). A case study by Khan et al. (2015) reported a 14% reduction in all lane departure crashes after installation of shoulder rumble strips. The implementation of rumble strips accounts for 20% (±13%) reduction in the overall number of severe injuries and fatalities. For single-vehicle crashes, the percentage slightly increases, at 27% (±18%) (Vadeby & Anund, 2017). Mahoney, Porter, Donnell, Lee, and Pietrucha (2003) reported that centerline rumble strips could reduce traffic accidents by approximately 15%. Meanwhile, Torbic et al. (2009) reported a higher percentage, at 44-64%, which include head-on, opposite-direction, and sideswipe fatal and injury crashes. On the other hand, shoulder rumble strips recorded an overall reduction of 40–50% of traffic accidents (Mahoney et al., 2003). For traffics accidents involving single-vehicle lane departure, shoulder rumble strips can reduce 13-51% of fatality and injuries (Torbic et al., 2009). Prior researches obtained findings on the effectiveness of rumble strips by examining accident occurrences at a targeted area, not deriving conclusions from statistical analyses (Chen, Koirala, & Pane, 2012). Figure 5 shows the installation of Shoulder Rumble Strip [left] (Washington State Department of Transportation, 2009), and Centerline rumble strips [right] (Yee, 2018).

FIGURE 5. the installation of Shoulder Rumble Strip [left] and Centerline rumble strips [right]

Recommendations for future research and implementation

Authorities and practitioners should systematically plan the installation of rumble strips because traffic accidents caused by lane departure is a highly random but highly devastating event (Chen et al., 2012). Since not all roadways are suitable for the installation of rumble strips, practitioners should first establish the suitability of rumble strips on the targeted area. They should assess the feasibility of rumble strips in intersections, bridges, and roadways with different population density and poor pavement conditions. The assessment of road suitability in specific areas, while beyond the scope of this paper, remains critical for transportation sustainability. The importance of the feasibility analysis cannot be overlooked. For example, installing rumble strips on rural roads leads to a higher tendency to break early, which causes higher rates of rear-end collisions (Harder et al., 2001).

Moreover, feasibility analysis allows practitioners to judge whether existing the road meets installation requirements. For example, the roadway must be wide enough to house the rumble strips (Anund, Ahlstrom, Kecklund, & Åkerstedt, 2011). Miles and Finley (2008) outlined several variables that should be considered when deciding on rumble street designs: pavement type, vehicle type and speed passing through the area, and geometric characteristics of rumble strips (width, length, depth/height, and spacing). Researchers and practitioners should investigate suitable locations for the installation of rumble strips in Malaysia by identifying accident-prone areas and examining their road characteristics. These black spots can be identified using national traffic accident databases such as MIROS Road Accident Analysis and Database System (MROADS), and the royal police national database.

CONCLUSION

Prior researches indicated that rumble strips contribute to a significant decrease in traffic fatality and the number as well as the severity of crashes, particularly run-off-road crashes and center-line-cross crashes. Based on Malaysian traffic crashes statistics, it was found that most accidents happened on straight roads due to human errors. These findings justify the need to install centerline and shoulder rumble strips in Malaysia because rumble strips help mitigate the severity of road crashes by alerting road users in inadvertent road departure situations. In other words, rumble strips are the counteragent for human errors on the road. This paper was written in the hope that it could be helpful and informative for authorities, researchers, and practitioners.

ACKNOWLEDGEMENT

The authors would like to thank MIROS for sharing traffic accident data.

REFERENCES

Åkerstedt, T., Connor, J., Gray, A., & Kecklund, G. (2008). Predicting road crashes from a mathematical model of alertness regulation—The Sleep/Wake Predictor. *Accident Analysis & Prevention*, *40*(4), 1480–1485.

Anund, A., Ahlstrom, C., Kecklund, G., & Åkerstedt, T. (2011). Rumble Strips in Centre of the Lane and the Effect on Sleepy Drivers. *Industrial Health*, *49*(5), 549–558.

Asian Development Bank. (2019). *Road safety and social sustainability*. Retrieved from https://www.adb.org/sectors/transport/key-priorities/road-safety

Chen, C., Koirala, D., & Pane, T. (2012). Road Statistical Crash Features and Adopting Optimal Rumble Strips to Save Lives and Prevent Injuries. *Institute of Transportation Engineers Journal*, *82*(2), 28–34.

Craig, L., Persaud, B., & Eccles, K. (2015). *Safety Evaluation of Centerline Plus Shoulder Rumble Strips*. Vienna. Retrieved from http://www.ntis.gov

Darma, Y., Karim, M. R., & Abdullah, S. (2017). An analysis of Malaysia road traffic death distribution by road environment. *Sādhanā*, *42*(9), 1605–1615.

Eusofe, Z., & Evdorides, H. (2017). Assessment of road safety management at institutional level in Malaysia: A case study. *Journal of International Association of Traffic and Safety Sciences*, *41*(4), 172–181.

Faudzi, S. A. M., Abidin, A. N. S. Z., Radzi, M. A. M., Zulkipli, Z. H., D-Wing, K., Yusoff, M. A. M., … Voon, W. S. (2017). *MIROS CRASH Investigation and Reconstruction: Annual Statistical Report 2011-2013*. Kajang.

Harder, K. A., Bloomfield, J., & Chihak, B. (2001). *The Effects of In-Lane Rumble Strips on the Stopping Behavior of Attentive Drivers*. Minneapolis.

Horst, R. van der. (2017a). Resilience to Failure and Breakdown. In *Designing Safe Road Systems* (pp. 27–40). CRC Press. https://doi.org/10.1201/9781315576732-3

Horst, R. van der. (2017b). The Performance of Road Users: Hierarchical Task Levels. In *Designing Safe Road Systems* (pp. 41–56). CRC Press. https://doi.org/10.1201/9781315576732-4

Jeon, C. M., Amekudzi, A. A., & Vanegas, J. (2006). Transportation System Sustainability Issues in High-, Middle-, and Low-Income Economies: Case Studies from Georgia (U.S.), South Korea, Colombia, and Ghana. *Journal of Urban Planning and Development*, *132*(3), 172–186.

Kareem, A. (2003). *Review of global menace of road accidents with special reference to malaysia- a social perspective*. *Malaysian Journal of Medical Sciences* (Vol. 10). Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3561885/pdf/mjms-10-2-031.pdf

Khan, M., Abdel-Rahim, A., & Williams, C. J. (2015). Potential crash reduction benefits of shoulder rumble strips in two-lane rural highways. *Accident Analysis and Prevention*, *75*, 35–42.

La Torre, F., Saleh, P., Cesolini, E., & Goyat, Y. (2012). Improving Roadside Design to Forgive Human Errors. *Procedia - Social and Behavioral Sciences*, *53*, 235–244.

Mahoney, K. M., Porter, R. J., Donnell, E. T., Lee, D. W., & Pietrucha, M. T. (2003). *Evaluation of centerline rumble strips on lateral vehicle placement and speed on two-lane highways*. Washington, DC. Retrieved from https://trid.trb.org/view/661591

Makinde, O., & Oluwasegunfunmi, V. (2014). Comprehension of traffic devices amongst urban drivers- A study of Ado-Ekiti, Ekiti State, Nigeria. *European Journal of Engineering and Technology*, *2*(1), 9–19.

Masuri, M. G., Md Isa, K. A., & Mohd Tahir, M. P. (2017). Children, Youth and Road Environment: Road traffic accident. *Asian Journal of Environment-Behaviour Studies*, *2*(4), 13.

Miles, J. D., & Finley, M. D. (2008). Factors that Influence the Effectiveness of Rumble Strip Design. *Transportation Research Record: Journal of the Transportation Research Board*, *2030*(1), 1–9.

Reason, J. (2000). Human error: models and management. *The Western Journal of Medicine*, *172*(6), 393–396. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10854390

Road Safety Department of Malaysia. (2018). *Buku statistik keselamatan jalan raya*. Kuala Lumpur. Retrieved from http://www.kpwkm.gov.my/kpwkm/uploads/files/Penerbitan/Buku statistik/BUKU STATISTIK 2015 KPWKM.pdf

Rohayu, S., Sharifah, A., Jamilah, M. M., & Wong, S. V. (2012). *Predicting Malaysian road fatalities for year 2020* (MMR06/2012). *Malaysian Institute of Road Safety Research*.

Kuala Lumpur: Malaysian Institute of Road Safety Research.
Sarawak Government. (2018, August 10). Rumble Strips, Warning Signs Installed At Accident-Prone Spot. *The Borneo Post*. Retrieved from https://www.sarawak.gov.my/web/home/news_view/223/10993/
Stanton, N. A., & Salmon, P. M. (2009). Human error taxonomies applied to driving: A generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science*, *47*(2), 227–237.
Theeuwes, J. (2017). Self-Explaining Roads and Traffic System. In *Designing Safe Road Systems* (pp. 11–26). CRC Press. https://doi.org/10.1201/9781315576732-2
Torbic, D. J., Hutton, J. M., Bokenkroger, C. D., Bauer, K. M., Harwood, D. W., Gilmore, D. K., Lyon, C. (2009). *Guidance for the design and application of shoulder and centerline rumble strips*. Washington DC. Retrieved from www.TRB.org
United Nations. (2017). Road Safety - Considerations in Support of the 2030 Agenda for Sustainable Development. In *United Nations Conference on Trade and Development*. Gene: United Nations. Retrieved from https://unctad.org/en/PublicationsLibrary/dtltlb2017d4_en.pdf
Vadeby, A., & Anund, A. (2017). Effectiveness and acceptability of milled rumble strips on rural two-lane roads in Sweden. *European Transport Research Review*, *9*(2), 1–9.
Vashisth, A. (2018). Shoulder and Center Line Rumble Strips: Reducing Severity of Road Crashes in India. *International Journal for Traffic and Transport Engineering*, *8*(2), 241–248.
Washington State Department of Transportation. (2009). A road with centerline and shoulder rumble strips [digital image]. Retrieved from https://flic.kr/p/73WNWp
Wegman, F. (2017). The future of road safety: A worldwide perspective. *International Association of Traffic and Safety Sciences Research Journal*, *40*(2), 66–71.
World Health Organization. (2004). *World report on road traffic injury prevention*. Geneva. Retrieved from https://apps.who.int/iris/bitstream/handle/10665/42871/9241562609.pdf;jsessionid=FA345B9EFB1AF21E0F16A3DD6A7CCEDF?sequence=1
World Health Organization. (2009). *Global status report on road safety: time for action*. Gevena.
World Health Organization. (2017). *Fact sheets on sustainable development goals: health targets Road*. Copenhagen. Retrieved from www.euro.who.int/sdgs
World Health Organization. (2018). *Global status report on road safety 2018*. Geneva.
World Health Organization. (2019). *Developing global targets for road safety risk factors and service delivery mechanisms*. Retrieved June 28, 2019, from https://www.who.int/violence_injury_prevention/road_traffic/road-safety-targets/en/
Yahya, K., Sanik, M. E., Haron, Z., Yaacob, H., Othman, M. H., & Hainin, M. R. (2015). Malaysian Transverse Rumble Strips: A Review and Recommendations for Practice. *Jurnal Teknologi*, *73*(4), 117–123.
Yee, D. (2018). *Milled shoulder rumble strips* [digital image]. Retrieved from https://flic.kr/p/NcwR3y