



Traffic Accident Characteristic Assessment to Enhance Sustainability in Road and Transportation Infrastructures in Indonesia

Susanti Djalante

Department of Engineering, Faculty of Civil Engineering, Haluoleo State University, Bumi Tridarma, Indonesia

Email: sdjalante@yahoo.com

How to cite this paper: Djalante, S. (2020) Traffic Accident Characteristic Assessment to Enhance Sustainability in Road and Transportation Infrastructures in Indonesia. *Open Access Library Journal*, 7: e6796. <https://doi.org/10.4236/oalib.1106796>

Received: September 7, 2020

Accepted: October 27, 2020

Published: October 30, 2020

Copyright © 2020 by author(s) and Open Access Library Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The 2030 agenda of sustainable development targets to improve road safety by creating transportation infrastructures that are more safe, accessible, and affordable for all societies. Indonesia is one of the countries committed to adapt the agenda of road safety management in its National Road Safety Master Plan. The master plan aims to minimize fatality rate by integrating the principles of sustainability, coordination, and togetherness. This research develops a framework for road safety management that effectively reduces traffic accidents. The methods used by case study, quantitative assessment and framework analysis. It reviews the general characteristics of Indonesia's roads and their relation to traffic accidents. Furthermore, the research identifies the causes of road accidents, determines their rates, and proposes a framework of road safety management. The results show that there was a significant relationship between traffic accidents, type of injuries, number of vehicles on the road, and the extent of road damages, from 2016 to 2018. Moreover, there was a relationship between the highest traffic accident rates and the severity index in 2017. In Indonesia, traffic accidents are mainly caused by factors related to humans, vehicles, equipment, and road environment. Law and regulations are the umbrellas that integrate, monitor and supervise human approaches to vehicles and the road environment.

Subject Areas

Civil Engineering

Keywords

Traffic Accident, Sustainability, Road and Transport Infrastructure, Traffic Management

1. Introduction

The 2030 agenda for sustainable development aimed to improve road safety by integrating the target 3.6%, which was focused on lowering worldwide traffic accidents and injuries by 50% by 2020. Furthermore, the government targeted 11.2%, with a focus on creating transportation systems that are safe, accessible, and affordable for all by 2030 [1]. Road traffic fatalities are expected to be the 5th cause of death in the world. As a result of this report, the UN General Assembly declared the Decade of Action (DoA) for road safety 2011-2020 [2]. This is then integrated with the Law No. 22 Year 2009 that mandated to National Master Plan on Road Safety of Indonesia to reduce fatality rate. The National Road Safety Master Plan has implemented principles of sustainability, coordination, and togetherness. Indonesia has targeted to decrease its traffic fatality from 3.93% to 1.96%, between 2016 and 2020 [3].

Indonesia has issued many regulations to decrease its traffic fatality rate. These include the law related to environmental analysis, traffic management, road safety, and engineering. However, **Figure 1** shows that the trend of traffic accident cases still rose at the end of 2018, which are followed number of vehicles and length of the road. This means traffic management and road maintenance are still lack on implementation. Therefore, this research develops a road safety management strategy that is effective in reducing Indonesia's traffic accident rates. It examines the characteristics of road accidents, analyzes the causative factors of this problem, and proposes possible solutions.

2. Materials and Methods

2.1. The Influence of Transportation Infrastructures on Road Safety

Sustainable development aims to address road safety issues as one of its goals. It should be implemented at the international, national, and local levels. However, road safety is managed by adjusting locally established regulations and human

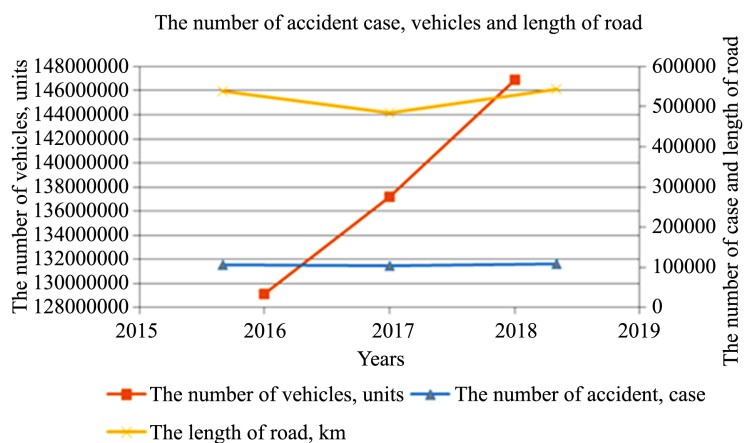


Figure 1. The relation between traffic accidents and vehicles as well as the length of road in Indonesia between 2016 and 2018.

behaviors [4]. These regulations are based on the technical standards and guidelines of the road and transportation infrastructures, such as strategic, programming, and project development planning, as well as delivering, including construction, operations, and maintenance. Measuring and monitoring sustainable achievement in road and transportation infrastructures is facilitated by examining the goals, objectives, and performances discussed in previous studies (Table 1).

2.2. Factors Affecting Road Accidents

Transportation infrastructures essentially support urban development by contributing to social well-being. This is achieved through installing technical urban infrastructures, such as car parks, sidewalks, streets, and termini [7]. The urban facilities, such as roads, traffic and pavements, influence the physical conditions of transportations infrastructures. Traffic accidents are caused by various factors, such as road capacity, geometry, pedestrian access, landscaping, and drainage systems.

2.2.1. Human Factors

They are related to human behavior. With regards to drivers, cognitive behavior influences human judgement and decision making, resulting in inaccurate risk consideration [8].

2.2.2. Vehicle Factor

The maintenance of vehicles ensures that all the vital systems are in good condition, such as rear-view mirrors and brakes. Previous research stated that many accidents were caused by mechanical failures of vehicles, mainly due to defective brakes and tires. Therefore, improper mechanical inspection, including brakes, worn-out tires, as well overloading, result in unwanted road accidents [9].

2.2.3. Road Condition

Accidents are always associated with the state of roads and pavements. Road conditions and geometry contribute to many accidents. Roads in good condition, with developed pavements, as well as better surface macro texture and roughness, reduce the probability of skidding and rutting by vehicles [10].

Table 1. Table type styles (Table caption is indispensable).

No.	Authors	Aspect	Objectives	Performances
1	Zongzhi and Kumares, 2004 [5].	Highway Asset Management	to identify the risk of accident	1) Number of fatalities/populations, 2) Number of fatalities/length of roads network, 3) Number of fatalities/number of vehicles
2	Umer, <i>et al.</i> , 2016 [6].	Sustainable Transportation Infrastructure.	Ensure smooth travel and safety for people by using sidewalks	Road safety audit

2.2.4. Road Environment

This factor is associated with traffic control, road safety barriers, lighting, and marking. The installation of equipment that supports an intelligent transport system (ITS) helps in monitoring traffic flow on the roads. They serve as traffic signals for drivers, as well as directing other road users [11].

2.3. Black Spot Area

A black spot is an area with a high rate of potentially fatal accidents along a road segment. It is also referred to as a black site. A black site is the number of accidents per kilometer or vehicle that exceed a specific value [12]. Below is the equation of the road accident rates:

$$TK = JK / (T \times L) \quad (1)$$

where:

TK —Accident rate (accident per year per km road length).

JK —Number of accidents during T year.

T —The period of observation (year).

L —The Length of the road (km).

The method used for determining accident rate as [13]

$$SI = \frac{F}{A} \times 100\%$$

where:

SI —Severity Index (%).

F —The Number of deaths (person) during the period of observation.

A —number of accidents during the period of observation

2.4. Road Safety Management

Road traffic is built on based on three aspects; human, vehicles and road environment, that interrelated each other. The previous authors have categorized the relation between highway condition and traffic accident [4] [14]. They proposed factors needed considering on cycle traffic accident. Due to the factors on pre-crash are more relevant with technical aspect on sustainable road transport in aspect of planning and implementation, so those are used as a based to analyze cases on traffic accidents. **Table 2** showed Haddon's model.

3. Methods

The objectives of research are to develop a road safety management by examining the characteristics of road accidents, analyzing the causative factors of this problem, and proposing possible solutions. This study uses the methods; case study observation, quantitative assessment though analyzing secondary data from Indonesia Land Transportation Statistics, from 2016-2018, and framework analysis. And the national transport safety committee of Indonesia. The research consists of two steps: the first steps with reviewing data and documents, then

Table 2. Haddon's model.

Phase	Factors	Mitigation
Pre-crash Crash Prevention	Human	<ul style="list-style-type: none"> • Reduction of risk exposure (reduction of the need to travel, replace of trips by modes, etc.); • Knowledge of norm and rules. • Practical training. • Raise people's awareness aiming to promote the appropriate behavior. • Police enforcement. • Use of clothing with reflective material by pedestrians, cyclists, motorcyclist and street workers at night;
	Vehicles and equipment	<ul style="list-style-type: none"> • Lighting • Proper maintenance. • Reflective devices for bicycles, motorcycles, and heavy vehicles. • Speed management. • Road worthiness.
	Road Environment	<ul style="list-style-type: none"> • Pedestrian Facilities. • Speed Limits. • Road geometry. • Drainage. • Signals.

Source: [4] [14].

describing based on trends, causative factors, and index. Whereas the second steps proposed a framework policy for solving the problems.

4. Result and Discussion

4.1. The Trend of the General Characteristics of Traffic Accidents in Indonesia

This research is divided into 4 steps, including the introduction, data collection, results, and discussion, as well as the conclusion. The secondary data used was retrieved from Indonesia Land Transportation Statistics, from 2016-2018, and The National Transport Safety Committee of Indonesia. The data were analyzed using qualitative and quantitative content descriptions. The qualitative method was used to describe the characteristics of traffic accidents. Also, it was used to describe the general conditions of causative factors of Indonesia's road accidents.

Table 3 provides an overview of general characteristics related to traffic accidents in 2016, 2017, and 2018. The number of accidents slightly decreased to 104,327 cases in 2017, and sharply increased in 2018. Accidents that caused light injuries were the most recorded, with a constant increase between 2016 and 2017, reaching 130,571 casualties in 2018. Interestingly, the number of deaths and severe injuries decreased over the years. Furthermore, the number of all of the types of vehicles rose gradually from 2016 to 2018. Also, from 2016 to 2018, the length of good and severely damaged roads showed the same trends. The trend sharply declined from 242,487 meters in 2016 to 215,398 meters in 2017

Table 3. The general characteristics concerning traffic accidents in Indonesia.

No.	The conditions related to the characteristics of traffic accidents	Year		
		2016	2017	2018
1)	Number of accidents (case)	106,644	104,327	109,215
2)	Type of accident (person)			
	a) Death	31,262	30,694	29,472
	b) Severe injury	20,075	14,559	13,315
	c) Light injury	120,532	121,575	130,571
3)	Number of vehicles (unit)			
	a) Total vehicles	129,094,823	137,211,819	146,858,759
	b) Car	14,459,388	15,423,968	16,440,987
	c) Bus	2,486,898	2,509,258	2,538,182
	d) Truck	6,998,455	7,289,910	7,778,543
	e) Motorcycle	105,150,082	111,988,683	120,101,047
4)	The length of the road by condition (km)			
	a) Total road length	537,838	484,799	543,310
	b) Good condition	242,487	215,398	237,347
	c) Damaged condition	86,605	81,083	81,869
	d) Seriously damaged	93,619	84,137	118,182
5)	The length of the road by surface type (km)			
	a) Total length	537,838	539,353	542,310
	b) Paved	326,629	321,093	329,926
	c) Non paved	179,457	184,745	212,384

Source: [15].

for roads in good condition. The length of severely damaged roads decreased from 93,619 meters in 2016 to 84,137 meters in 2017. However, there was a significant rise in the length of severely damaged roads to 118,182 meters in 2018. In contrast, the length of the damaged roads remained stable in 2017 and 2018. The length of non-paved roads underwent a gradual rise from 2016 to 2018. However, the length of paved roads decreased to 321,093 meters in 2017, then rose steadily to 329,926 meters in 2018.

4.2. Factors Affecting Accidents in Indonesia

By utilizing factors developed on Haddon's model, the frequency case of accident is analyzed based on the report from the National Transport Safety Committee of Indonesia (KNKT) related to traffic accidents and transportation of 2007-2020. The factors of Haddon's model then are developed more detail, considering the fact accident events in Indonesia. It is founded that not only the physical aspect influence on traffic accident, but also institutional management play important roles to prevent the crash events. **Table 4** and **Table 5** show detail factors on traffic accident in Indonesia.

Table 4. The general characteristics concerning traffic accidents in Indonesia.

No.	Performance of road, traffic and pavement	Detail factors in traffic accidents
1	Vehicle condition	<ol style="list-style-type: none"> 1) Lack of regular mechanical maintenance 2) Brake life components exceed the limit 3) Road unworthy vehicles 4) Lack of crashworthiness of design and specification body machines
2	Traffic condition	<ol style="list-style-type: none"> 1) Freight cars enter the prohibited lanes 2) Lack of supervision of route licensing 3) Lack of route limitation to heavy vehicles 4) High operations of passenger buses
3	Vehicle speed	<ol style="list-style-type: none"> 1) Lack of speed restrictions 2) Lack of installed speed bumps 3) Lack of ribbon/rumble strips
4	Pedestrian access	<ol style="list-style-type: none"> 1) Lack of space for pedestrians 2) Poor designs of pedestrian elevation 3) Much disturbance on pedestrian access 4) Many barriers and parking on the street
5	Equipment and road lighting	<ol style="list-style-type: none"> 1) Lack of road lighting in sloping areas 2) Lack of road lighting in the black spot areas
6	Road markings and facilities	<ol style="list-style-type: none"> 1) Lack of appropriate placement of road markings, especially in sloping areas 2) Lack of clearness of road marking 3) Lack of pedestrian marking 4) Lack of road facility in stating traffic sign such as speed limit, warning, precaution and mirrors.

Source: [16].

Table 5. Regulation and supervision related to traffic accidents.

No.	Soft performances in road and traffic	Detail factors in a traffic accident
1	Regulation	<ol style="list-style-type: none"> 1) Lack of understanding traffic law 2) Lack of socialization of using seat belts
2	Human resources	<ol style="list-style-type: none"> 3) Lack of understanding of road safety and other regulations 4) Lack of staff to control black spot areas 5) Lack of driving licenses 6) Lack of supervision to the psychological conditions of road users

Based on the **Table 4** and **Table 5** indicated a leading factor of traffic accident in Indonesia is influence more physical aspects than institutional aspects. Therefore, concept of sustainability in road transport infrastructure requires to consider a proper of intergeneration equity, complete staging, and principal precaution, so accident and fatalities are able to minimize. Likewise, From **Table 4**, Lack on the pedestrian, speed, road facilities above imply failure on planning, construction and maintenance. Deficiency on physical aspect of road transport infrastructure leads so to interrelated consequences, *i.e.* congestion and lack of accessibility for road user, on achieving goals of sustainability.

On the other hand, institutional management is the biggest challenges on Indonesia management system. The national government has a national action plan, grand safety documents and technical guidance to reduce fatality in Indonesia, but the capacity of regional and local level has fewer resources. Therefore, controlling, supervising, and maintaining all aspect on safety management is lack on implementation.

The discussion above has been confirmed by the previous research by stated that barriers to implementing sustainability on road infrastructure in Indonesia are constrained insufficient human capacity resources, technical guidance, and financial resources [17].

Haddon's model has proposed mitigating factors that cause road accidents, as seen in **Figure 2**.

Figure 2 shows the frequency of traffic accidents in 3 mitigation factors. The most frequent case happens on vehicles and equipment, in relation of road worthiness. The next is followed by human case on the factors of police enforcement as well as knowledge and rules, respectively. Finally, the road environment is the smallest frequency cease in influencing accidents. This includes the unavailability of speed limit signs and inappropriate designs of road geometry.

4.3. Accident Rates and Black Spot Areas

The report from the National Transport Safety Committee of Indonesia (KNKT) related to traffic accidents and transportation of 2007-2020 analyzed and categorized the road performance. This was aimed at supporting sustainable safety in road and transport infrastructures. The factors were analyzed from 2016 to 2018, as seen in **Table 6**.

Table 6 shows that the highest accident rates in Indonesia occurred in 2017, while the lowest was recorded in 2018. However, there was a slight decrease in the rates of accidents in 2018. Therefore, road safety management needs to be more useful to reduce the rates of accidents significantly.

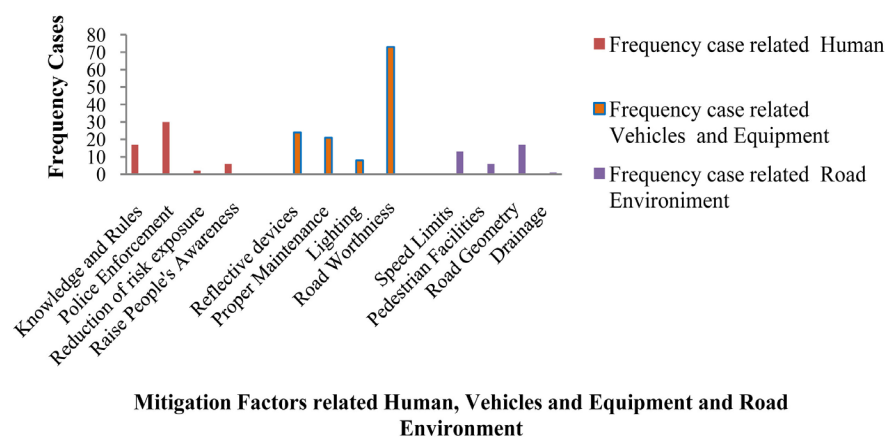


Figure 2. Utilizing Haddon's model to mitigate causative factors of traffic accidents. Source: [16].

Table 6. Regulation and supervision related to traffic accidents.

Years	Road Length (Km)	The number of accidents (Person)	The Number of Vehicles (Unit)	TK (Accident Rate per year per km)	SI Severity Index (%)
2016	537,838	1,718,869	120,094,823	0.32	18.2
2017	484,799	166,828	137,211,819	0.34	18.4
2018	543,310	173,358	146,858,759	0.31	17.0

4.4. An Integrated Road Safety Management

To achieve sustainable road safety management, an integrated solution is needed in order to develop a holistic approach. The solution should be based on:

4.4.1. Human Approach

NHTSA identified human errors that cause traffic accidents. They included recognition, decision, and performance errors [18]. In Indonesia's context, it is vital to increase drivers' knowledge and skills by developing relevant training programs. Such programs include an introduction of theories on-road recognition, provision of rules, guidance, code, psychological assessment, and enhancement of practical driving.

4.4.2. Equipment and Vehicle Approach

The use of technology is introduced through modern equipment, which helps in creating safety systems regarding road infrastructures. First, it is necessary to develop and application that is integrated in an intelligent transport system. The application of electronic systems improves safety, security, and efficiency of transportation infrastructure through application computer vision video camera [19] and speed camera [20]. Second, improving maintenance, as well as periodically controlling road equipment and facilities, ensures the systems are safe for road users. It is vital to control and maintain the vehicle's condition regularly. This involves checking vehicle functions, such as brakes, tire pressure, turn signal, body machines, and lights. Also, equipping vehicles with safety tools is essential

4.4.3. Road Environment Approach

A road safety audit is essential in comparing implementation on the field, recorded within the agreement of technical standards. It is categorized into road geometry, pavement damage performance, and harmonization of road equipment facilities. Regular monitoring and auditing, particularly in black spot areas, is essential because it helps minimize the severe impacts of accidents. The safety audit is conducted by establishing consistent geometric designs and accurate placements of road facilities.

4.4.4. Monitoring and Supervising Approach

Monitoring and supervising ensure that the traffic works according to the set rules and regulations. Also, it ensures a high level of implementation of rules and

regulations for drivers, punishment for traffic violators, guidance, and standards of road designs and facilities, as well as safety campaigns. Increasing socialization of road safety is achieved through campaigns on social media platforms, websites, or road safety applications. This requires collaborations by road authorities, police, and the society to effectively monitor and supervise the traffic system.

4.4.5. Regulation and Law Approach

The legislation is an effective way to ensure road safety management and to curb violations of rules and regulations. Many regulations and laws have been established to create legal means to achieve road safety and sustainability. Various of Indonesia's regulations and laws are in **Table 7**.

The laws and regulations above cover all aspects to increase road safety in Indonesia. However, it is vital to implement regulations and laws through technology for efficient road safety management. The framework of Road Safety Management is seen in **Figure 3**.

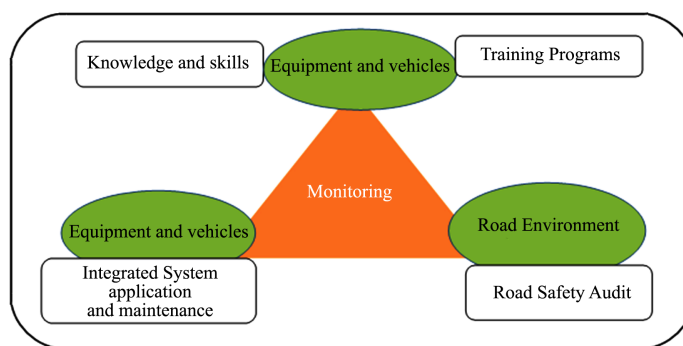


Figure 3. The framework of road safety management in Indonesia. Adapted from [4].

Table 7. Regulations and laws.

No	Type	Aspect	Rules, regulations, and guidelines in Indonesia
1	Standard and guidelines	Road geometry	Law No. 38-year 1997 concerning geometry planning for roads between cities
2	Law and standard	Road safety facility	Ministry of Transportation. Law the No. 82-year 2018 concerning control tools and safety for road users
3	Law and standard	Pedestrian planning	Ministry of Public Works, Law No. 26 of 2007, concerning procedures for pedestrian planning.
4	Standard and guidelines	Pavement design	Road Pavement Manual. No. 04/SE/Db/2017
5	Standard and guidelines	Technical guidelines for road safety	Ministry of Public Works No. 02/IN/Db/2012
6	Law and guidelines	Safety for vehicles	Government regulation No. 37-year 2017 concerning traffic safety and road transport
7	Regulation	Road infrastructure maintenance	Ministry of Public Works No. 13/PRT/M/2-11 concerning procedures of road infrastructure maintenance

5. Conclusion

There are macro and micro causative factors that influence traffic accidents in Indonesia. The macro factors include the number of vehicles, road lengths, and the increasing conditions of road damages at the regional level. The micro factors include human errors, such as lack of monitoring and supervising of vehicles, equipment and road environment, and lack of law enforcement. To deal with the macro and micro factors, 5 strategic approaches are adapted. They are listed from the human, equipment and vehicles, road environment, monitoring, and supervising, as well as regulation and law approach. Laws and regulations are an umbrella for all aspects related to human, equipment and vehicles, road environment, as well as monitoring and supervising. Supervision and monitoring must be conducted to ensure the 3 aspects of work based on law and regulation. It is useful in identifying the process of implementation by collaborating with all the stakeholders involved. The human capacity is strengthened by improving knowledge and skills through training programs. As a result, it enhances road recognition, psychological, and practical efficiency. Using technology and regular maintenance improves the performance of equipment and vehicles. Conducting road safety audits through planning, designing, and operating improves the technical aspects of road traffic performances, which reduces traffic accidents.

Acknowledgements

A short section may acknowledge special assistance and sources of research funding.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

- [1] United Nations (2017) Road Safety. Considerations in Support of the 2030 Agenda for Sustainable Development. https://unctad.org/en/PublicationsLibrary/dtltbl2017d4_en.pdf
- [2] World Health Organization (2011) Global Launch: A Decade of Action for Road Safety 2011-2020. https://www.who.int/roadsafety/decade_of_action/en
- [3] Indonesia State Secretary. Rencana Umum Nasional Keselamatan Jalan 2011-2035. <http://hubdat.dephub.go.id/spesial-konten/dokumen-publikasi/1306-rencana-umu-nasional-keselamatan-runk-jalan-2011-2035>
- [4] Bezerra, B.S. (2019) Road Safety and Sustainable Development. In: Leal Filho, W., Wall, T., Azul, A.M., Brandli, L. and Özuyar, P.G., Eds., *Good Health and Well-Being. Encyclopedia of the UN Sustainable Development Goals*, Springer, Cham, 1-13. https://www.researchgate.net/publication/329264844_Road_Safety_and_Sustainable_Development
https://doi.org/10.1007/978-3-319-95681-7_39

- [5] Li, Z. and Kumares, C.S. (2004) Multicriteria Highway Programming Incorporating Risk and Uncertainty: A Methodology for Highway Asset Management System. Purdue University, West Lafayette. <https://docs.lib.purdue.edu>
- [6] Umer, A., Hewage, K., Haider, H. and Sadiq, R. (2016) Sustainability Assessment of Roadway Projects under Uncertainty Using Green Proforma: An Index-Based Approach. *International Journal of Sustainable Built Environment*, **5**, 604-619. <https://doi.org/10.1016/j.ijsbe.2016.06.002>
- [7] Griškevičiūtė, A.G. and Griskevičienė, D. (2016) The Influence of Transport Infrastructure-Structure Development on a Sustainable Living Environment in Lithuania. *Procedia Engineering*, **134**, 215-223. <https://doi.org/10.1016/j.proeng.2016.01.062>
- [8] Islam, M.B. and Kanitpong, K. (2008) Identification of Factors in Road Accidents through In-Depth Accident Analysis. *IATSS Research*, **32**, 58-67. [https://doi.org/10.1016/S0386-1112\(14\)60209-0](https://doi.org/10.1016/S0386-1112(14)60209-0)
- [9] Schoor, O.V., Niekert, J.L.V. and Grobbelaar, B. (2001) Mechanical Failures as a Contributing Cause to Motor Vehicle Accidents—South Africa. *Accident Analysis & Prevention*, **33**, 713-721. [https://doi.org/10.1016/S0001-4575\(00\)00083-X](https://doi.org/10.1016/S0001-4575(00)00083-X)
- [10] Baskara, S.N., Yaacob, H., Hainin, M.R. and Hassan, S.A. (2016) Accident Due to Pavement Condition—A Review. *Journal Teknologi*, **78**, 75-82. <https://doi.org/10.11113/jt.v78.9494>
- [11] Ramos, G., Perandones, J.M., Alonso, M., Plaza, J. and Vega, H. (2008) RANKERS Final Report. Ranking for European Road Safety, Specific Targeted Research, or Innovation Project. TREN-04-FP6TR-S07.36996/001678-2008 Final Report D0.
- [12] Dewanti (1996) Traffic Accident Characteristic in Yogyakarta. *Media Teknik—UGM Yogyakarta*, **3**, 33-37.
- [13] Pignataro, L.J. (1973) Traffic Engineering Theory and Practice. Prentice Hall, Inc., Upper Saddle River.
- [14] Haddon, J.W. (1968) The Changing Approach to the Epidemiology, Prevention, and Amelioration of Trauma: The Transition to Approaches Etiologically Rather than Descriptively Based. *American Journal of Public Health*, **58**, 1431-1438.
- [15] Ministry of Transportation (2016-2018) Indonesia Land Transport Statistics. <http://www.dephub.go.id/public/images/uploads/posts/buku-statistik-1-2018.pdf>
- [16] The National Transport Safety Committee of Indonesian. Report of an Investigation Traffic Accident and Road Transport 2007-2020. <http://knkt.dephub.go.id>
- [17] Suprayoga, G.B., Witte, P. and Spit, T. (2020) Identifying Barriers to Implementing a Sustainability Assessment Tool for Road Project Planning: An Institutional Perspective from Practitioners in Indonesia. *Journal of Environmental Planning and Management*, **63**, 2380-2401. <https://doi.org/10.1080/09640568.2020.1724083>
- [18] NHTSA (2015) Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey. <https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812115>
- [19] Loce, R.P., Bernal, E.A., Wu, W. and Bala, R. (2013) Computer Vision in Roadway Transportation Systems: A Survey. *Journal of Electronic Imaging*, **22**, Article ID: 041121. <https://doi.org/10.1117/1.JEI.22.4.041121>
- [20] Wegman, F. and Goldenbeld, C. (2006) Speed Management: Enforcement and New Technologies (No. 5). Institute for Road Safety Research, SWOV, Leidschendam.