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The Characteristics of Road Crashes on Indonesian National Roads Based on Integrated Road Safety Management System Data

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Abstract

The issue of traffic crashes in Indonesia continues to be a significant concern. In 2019, a total of 116,441 crashes were reported, resulting in 30,568 fatalities. Access to accurate data is crucial in lowering the fatality rate. The data were analyzed descriptively, categorized by crash type, and evaluated based on road configuration, geometric type, and surface conditions. The most frequent types of crashes on Indonesian national roads are rear-end crashes (25.64%), head-on crashes (21.95%), crashes at intersections (20.50%), pedestrian hit-and-runs (12.65%), and head-to-side crashes (8.01%). Head-on crashes showed correlation with undivided road, meanwhile rear-end crashes is more likely to occur on multi-lane roads. Predominantly, the crashes occurred on 2-lane 2-way undivided roads (54.28%), straight-aligned roads (81.36%), and roads with good surface conditions (94.92%). This crash data can serve as a foundation for formulating policies and initiatives aimed at enhancing road safety.

Keywords

road crash data, road type, geometric type, road surface condition, national road

1 Introduction

The World Health Organization (WHO) report shows that every year around 1.35 million victims die due to traffic crashes (WHO, 2018). Traffic crashes are the main cause of death for children, adolescents, and young people (aged 5–29 years) and are the 8th largest cause of death for all ages. More than half of the victims are Vulnerable Road Users (VRU), such as pedestrians, cyclists, and motorcyclists, since the needs of these groups are not facilitated in the traffic system in many countries, including Indonesia.

Traffic crash data in Indonesia in 2019 show that the number of crashes and fatalities remains high. The recorded traffic crashes fluctuated from 66,488 in 2010 to 116,441 in 2019, with an average of 102,364 crashes yearly. The average growth rate of national traffic crashes was 8% per year from 2010 to 2019, and the fatality rate reached 30,568 people (Indonesian Police Traffic Corps, 2019).

Efforts to reduce the number of traffic crashes and fatalities have been carried out through the United Nations (UN) declaration since 2011, through the Decade of Action (DoA) for Road Safety 2011-2020, with a target of reducing the fatality rate by 50% in 2020 (WHO, 2011). Through the WHO, the UN has again released the Second DoA for Road Safety 2021–2030 program with the same target, continuing to reduce the fatality rate by 50% in 2030, with basic data on the 2020 traffic crashes fatality rate (WHO, 2020).

The availability of reliable data is crucial to know how achievements have been made to reduce the fatality rate (Abdulhafedh, 2017). In general, in various countries, traffic crash data are obtained from the police (Chand et al., 2021; Tasios et al., 2019), which includes factual descriptions of traffic crashes involving road users, the vehicles involved, traffic movements, and environment conditions at the time of the crashes.

The Integrated Road Safety Management System (IRSMS) is one source of crash data in Indonesia. IRSMS is a system created and developed by the Republic of Indonesia Police Traffic Corps. As an integrated road safety system, this system provides traffic crash data, accompanied by supporting data such as collision diagrams, vehicles involved, time of incident, and so on, from all Regional or Subregional Police in Indonesia. Accident

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Record Form (ARF) in IRSMS is the main instrument for collecting data that is prepared to accommodate the interests of various stakeholders using a modified contributory factor system. All questions on the ARF are closed-ended type. In the IRSMS, there are 74 types of data and information on crash types (58 types) (Indonesian Police Traffic Corps, 2011).

IRSMS, the traffic crash data collection system, is a process for managing crash information that allows the whole picture to be drawn in detail and crash characteristics that occur in a location, region, or nationally to be processed. Obtaining data on crash characteristics will provide feedback on policies and actions that stakeholders must take in the field of road safety (Rabbani et al., 2021).

This paper will analyze the crash characteristics of National roads in Indonesia based on road configuration type, geometric type, and surface conditions. Several studies have examined the relationship between road configuration type (Malin et al., 2019), road geometry (Islam et al., 2018), and road surface condition (Mkwata and Chong, 2022; Park et al., 2017) with road crashes.

2 Methodology

In Indonesia, public roads are grouped according to the status: national, provincial, district, city, and village (Law No. 2 of 2022 (Government of the Republic of Indonesia, 2022)). The length of national roads based on 2022 data is 47,603 km (BPS-Statistics Indonesia, 2022; MPWH, 2022).

Data on traffic crashes on national roads were obtained from the Data Bank of the Directorate General of Highways, Ministry of Public Works and Housing of the Republic of Indonesia, sourced from the IRSMS database of the Republic of Indonesia Police Traffic Corps. Based on traffic crash data on national roads from 2012 to March 2019 sourced from IRSMS, there were 287,593 traffic crash data records. After processing the data, 6,204 (2.16%) crashes were recorded, but the type of crash was not identified. Hence, the data used in this paper were recorded at 281,389 from 01 January 2012, to 31 March 2019.

The traffic crash data contain general data, including crash numbers, severity (fatal, serious injuries, minor injuries), place of crash (province, name of road, city/subregional police), time of the crash (date, month, year), weather conditions, and crash location coordinates (longitude, latitude). IRSMS crash data are also retrieved with data on road function, class, type, geometry, pavement condition, speed limit, road grade, or slope.

The crash data cover all provinces in Indonesia, except for Jakarta, which does not have national roads. Therefore, the analysis is based on data from 33 provinces. The data were subject to descriptive analysis, with all crash incidents categorized by type. Subsequently, the features of the most common crashes were examined based on road configuration, geometric type, and surface conditions.

Each data set underwent a normality test to determine the appropriate type of analysis for the next step. Following the normality test, a correlation analysis was performed to identify the most influential variables for each type of crash. This analysis focuses on the most frequent accident types and utilizes statistical analysis using Minitab Version 21.1.0. The criteria for determining the strength of correlation are based on the correlation coefficient value and apply the following criteria:

1. Correlation coefficient value of 0.00–0.25 = very weak relationship.
2. Correlation coefficient value of 0.26–0.50 = moderate relationship.
3. Correlation coefficient value of 0.51–0.75 = strong relationship.
4. Correlation coefficient value of 0.76–0.99 = very strong relationship.
5. Correlation coefficient value of 1.00 = perfect relationship.

3 Analysis and discussion

3.1 General characteristics of road crashes on national roads

In general, road crashes are divided into two groups: crashes on road segments and crashes at intersections. A total of 283,148 crashes occurred on national roads in Indonesia. Fig. 1 provides a comprehensive overview of the most common types of traffic crashes that occur on Indonesian national roads. The data indicates that rear-end crashes accounted for 25.67% (72,673) of the total, followed by head-on crashes at 21.97% (62,209), and crashes at all intersections at 20.52% (58,109). Additionally, 12.66% (35,850) of the crashes involved pedestrians being hit by vehicles, while 7.95% (22,513) were head-to-side crashes. The remaining incidents were categorized as run-off-road (4.94% or 14,001), collision with a vehicle parked on the road (2.89% or 8,181), side-swipe (2.75% or 7,800), and collision with permanent objects on the road (0.64% or 1,812).

In the IRSMS database, two types of head-to-side crashes were identified: 15,658 (5.53%) crashes occurred during

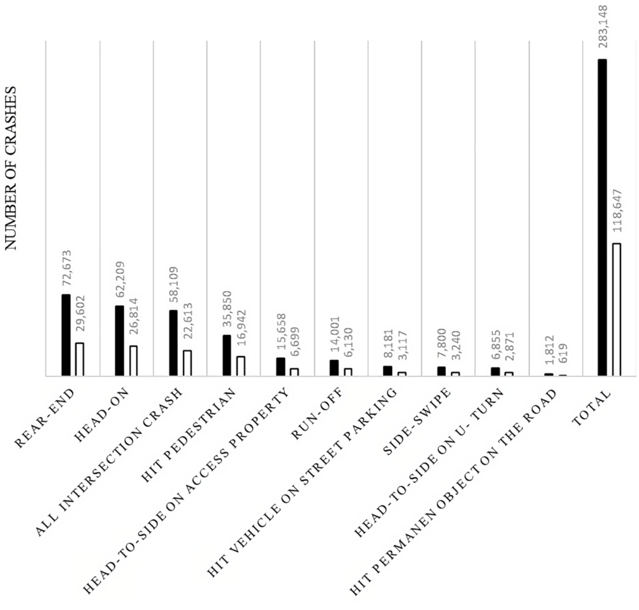

Fig. 1 Types of crashes that occur on Indonesian National Roads

head-to-side crashes on access property, and 6,855 (2.42%) crashes happened while turning at U-turns. Together, these two types of crashes accounted for 22,513 (7.95%) of all traffic crashes across all crash classes. These crashes typically occur when a vehicle making a turning movement is struck from the side by another vehicle moving straight.

Observing the evidence of numerous direct entries to and exits from national roads, which are presumed to be property access points leading to houses, shops, offices, and places of worship along these highways, these locations represent a point of conflict with straight-moving vehicles resulting from turning movements.

In Fig. 1, the data depict the occurrences of fatal and serious crashes on national roads. From 2012 to March 2019, 118,647 fatal and serious crashes were reported, constituting approximately 42.16% of all national road traffic crashes. Within the fatal and serious categories, the distribution of crash types is as follows: 29,602 (24.95%) rear-end crashes, 26,814 (22.60%) head-on crashes, 22,613 (19.06%) all intersections crashes, 16,942 (14.28%) pedestrian hit-and-runs, 6,699 (5.65%) head-to-side on access property, 6,130 (5.17%) run-off crashes, 3,117 (2.63%) collision with a vehicle parked on the road, 3,240 (2.73%) side-swipe, 2,871 (2.42%) head-to-side on U-turn, and 619 (0.52%) collision with a permanent object on the road.

The crash data for national roads provide valuable insights into the distribution of proportions, as shown in Fig. 1, demonstrating that the proportions of fatal and serious categories mirror those of the overall crash category.

Additionally, Table 1 presents summary statistics of all national road crash data for the 33 provinces, categorized by variables: crash type, road configuration, and road surface condition. All the variable data underwent normality testing using the Kolmogorov-Smirnov test in Minitab Version 21.1.0. The significance value for each variable was obtained from the test. The results showed that only the "good road surface condition" and "2/2 UD road type" variables follow a normal distribution, while the others do not. This suggests a violation of parametric testing, so the

Table 1 Summary statistics for all provinces' data

Variable	Indicator	Total count	Mean	StDev	Minimum	Maximum
Type of accident	Head-on	33	1,884.00	2,261.00	55.00	10,984.00
	Rear-end		2,168.00	4,040.00	40.00	18,179.00
	Head-to-side on access property		477.00	845.00	4.00	3,850.00
	Side-swipe		234.80	440.70	0.00	1,906.00
	Pedestrian hit-and-run		1,078.00	1,602.00	32.00	6,574.00
	All intersection crashes		1,753.00	3,339.00	37.00	15,510.00
	Run-off		420.70	570.00	28.00	2,434.00
	Head-to-side on U-turn		210.20	337.70	2.00	1,630.00
	Collision with a vehicle parked on the road		246.60	394.90	5.00	1,787.00
	Collision with permanent objects on the road		54.20	75.20	0.00	300.00
Length of road configuration type (Km)	1 way	33	5.24	8.52	0.00	39.38
	2/2-UD		1,310.00	639.00	230.00	2,678.00
	4/2-UD		26.90	69.20	0.40	398.80
	4/2-D		92.60	95.70	13.90	435.60
	6/2-D		8.25	12.32	0.00	53.74
Length of road surface condition (Km)	Good condition	33	1,328.00	606.00	301.00	2.420.00
	Other condition		114.60	116.90	1.50	591.90

correlation test between variables will be conducted using the nonparametric Spearman rank correlation test.

3.2 Distribution of crashes by road configuration type

Table 2 shows the distribution of traffic crashes on national roads categorized by crash type and road configuration. 11,815 (4.17%) of the crashes were recorded with incomplete information. The majority of the crashes, 231,025 (81.59%), took place on two-way road configurations, with 153,679 (54.28%) occurring on two-lane two-way undivided roads (2/2 UD), 46,579 (16.45%) on four-lane two-way divided roads (4/2 D), and 26,631 (9.41%) on four-lane two-way undivided roads (4/2 UD). Additionally, 40,308 (14.24%) crashes occurred on one-way roads, with the highest number of crashes, 24,424 (8.63%), recorded on two-lane one-way roads. The correlation test results between the two most common crashes (head-on and rear-end) and road types are detailed in Table 3.

3.2.1 Distribution of rear-end crashes by road type

Table 2 displays the distribution of rear-end crashes categorized by road type. The data reveals that out of the total rear-end crashes, 70,225 (96.22%) had complete road-type information. In contrast, incomplete road-type information was noted in 2,758 (3.78%) crashes, which accounted for less than 5% of the total rear-end crashes.

The majority of rear-end crashes by road configuration type occurred on two-way roads. Specifically, the highest number of crashes, 50,080 (68.62%), were recorded on two-lane two-way undivided (2/2 UD) roads. Additionally,

Table 2 Distribution of crashes by road type

Code	Road type	All crashes		Rear-end		Head-on		Head-to-side on access property		Head-to-side on U-turn		Run-off	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0	NA	11,815	4.17	2,758	3.78	3,318	5.33	531	3.37	232	3.34	539	3.85
1	2-lane, 2-way, undivided	153,679	54.28	50,080	68.62	33,996	54.63	8,403	53.33	4,627	66.53	4,150	29.64
2	4-lane, 2-way, undivided	26,631	9.41	3,484	4.77	6,044	9.71	2,445	15.52	329	4.73	1,011	7.22
3	4-lane, 2-way, divided	46,579	16.45	5,281	7.24	7,385	11.87	2,264	14.37	898	12.91	4,704	33.60
4	6-lane, 2-way, undivided	718	0.25	62	0.08	130	0.21	53	0.34	10	0.14	62	0.44
5	6-lane, 2-way, divided	3,418	1.21	641	0.88	520	0.84	260	1.65	17	0.24	821	5.86
6	1-lane, 1-way	11,795	4.17	4,355	5.97	2,155	3.46	781	4.96	161	2.31	480	3.43
7	2-lane, 1-way	24,424	8.63	5,483	7.51	7,828	12.58	885	5.62	636	9.14	1,596	11.40
8	3-lane, 1-way	2,652	0.94	659	0.90	625	1.00	92	0.58	33	0.47	264	1.89
9	4-lane, 1-way	1,437	0.51	180	0.25	228	0.37	44	0.28	12	0.17	374	2.67
	Total	**283,148**	**100.00**	**72,983**	**100.00**	**62,229**	**100.00**	**15,758**	**100.00**	**6,955**	**100.00**	**14,001**	**100.00**

Table 3 Correlation test between type of crashes and type of road ($N = 33$)

Type of crashes	Type of road	Correlation	P-value	Note
Head-on	1 way	0.108	0.549	Insignificant
Head-on	2/2 UD	0.427	0.013	Significant
Head-on	4/2 UD	0.435	0.011	Significant
Head-on	4/2 D	0.136	0.449	Insignificant
Head-on	6/2 D	0.378	0.030	Significant
Rear-end	1 way	0.381	0.029	Significant
Rear-end	2/2 UD	0.008	0.966	Insignificant
Rear-end	4/2 UD	0.520	0.002	Significant
Rear-end	4/2 D	0.552	0.001	Significant
Rear-end	6/2 D	0.653	0.000	Significant

there were 5,281 (7.24%) crashes on four-lane two-way divided (4/2 D) roads, and 3,484 (4.77%) crashes on four-lane two-way undivided (4/2 UD) roads. As for one-way road types, there were 5,483 (7.51%) crashes on two-lane one-way roads and 4,848 (5.97%) crashes on one-lane one-way roads.

According to Table 3, there is a strong correlation between rear-end crashes and 4/2 UD road types. Similarly, Yan et al. (2005), who analyzed the characteristics of rear-end collisions at intersections, also showed that the risk of rear-end crashes is more likely to occur on roads with more lanes.

Based on the overall data, there is a high incidence of rear-end crashes on 2/2 UD roads. However, after conducting a correlation test, it is evident that there is no correlation between these crashes and the data broken down by each province. The heightened rate of rear-end crashes on 2/2 UD roads can be confidently attributed to the large number of access points along the national roads, leading to the abrupt deceleration of vehicles and subsequent rear-end collisions.

In the case of Indonesian National roads, there is a strong correlation between rear-end collisions and the increasing number of lanes. This is likely due to the higher traffic volume associated with more lanes. Yan et al. (2005) also noted in their study that as traffic volume increases, so does the risk of rear-end crashes.

3.2.2 Distribution of head-on crashes by road type

Table 2 gives information on the distribution of head-on crashes categorized by road configuration type. According to the data, 40,170 (64.55%) head-on crashes happened on two-way undivided roads. Among these, the majority, 33,996 (54.63%), occurred on two-lane two-way undivided (2/2 UD) roads. Additionally, 6,044 (9.71%) head-on crashes were recorded on four-lane two-way undivided (4/2 UD) roads and 130 (0.21%) on six-lane two-way undivided (6/2 UD) roads.

According to the data, 7,905 crashes occurred on two-way divided roads, with 7,385 (11.87%) on four-lane two-way roads and 520 (0.84%) on six-lane two-way divided (6/2 D) roads. However, a detailed explanation for why head-on crashes occur on divided roads was not found. The most likely reason for this is that the vehicle loses control and crosses the road divider into the opposite lane. Another potential cause of head-on crashes on divided roads is the implementation of contraflow traffic management.

The data in Table 2 also reveals an intriguing insight: 10,836 (17.41%) of the head-on crashes occurred on one-way roads. Specifically, 7,828 (12.58%) crashes took place on two-lane one-way roads, 2,155 (3.14%), 625 (1.004%) on one-lane roads, and 228 (0.37%) on four-lane one-way roads. However, the data do not provide any explanation for the causes of these head-on crashes on one-way roads.

Table 3 indicates a strong correlation between head-on crashes with 2/2 UD and 4/2 UD road types, with correlation values of 0.427 and 0.435, respectively. On Indonesian national roads, the high correlation of head-on crashes on undivided roads is attributed to collisions between overtaking vehicles and vehicles traveling in the opposite direction. It is important to address the management of undivided road types to mitigate this type of crash.

3.2.3 Distribution of head-to-side crashes on property access by road type

The distribution of head-to-side crashes on national roads is detailed in Table 2, specifically for turning movements at locations identified as property access. It was noted that 531 (3.37%) crashes had incomplete information regarding the type of road. Conversely, 15,227 (96.63%) crashes had complete data required to assess the road type that predominantly contributed to head-to-side crashes.

Table 2 presents three types of roads that significantly contribute to head-to-side crashes during maneuvers to and from property access. These road types include two-lane two-way undivided (2/2 UD) roads, which accounted for 8,403 (53.33%) recorded crashes, four-lane two-way undivided (4/2 UD) roads, which saw 2,445 (15.52%) crashes, and four-lane two-way divided (4/2 D) roads. Among the one-way roads, the two-lane one-way road type experienced the highest number of crashes at 885 (5.62%), followed by the one-lane one-way road type at 781 (4.96%).

3.2.4 Distribution of head-to-side crashes on U-turns by road type

Table 2 presents the breakdown of head-to-side crashes that occur during U-turns. It was observed that approximately 3.14% of all head-to-side crashes did not include information about the type of road. The dataset is deemed fairly comprehensive, as nearly 96.64% of the records contain road-type information, which is vital for in-depth analysis.

In Table 2, it is evident that nearly 71.40% of head-to-side crashes involving turning vehicles took place on two-way roads. Within this category, the majority of crashes occurred on two-lane two-way undivided roads (2/2-UD) with 4,627 crashes accounting for 66.53%, followed by 898 crashes (12.91%) on four-lane two-way divided roads (4/2-D), and

329 crashes (4.73%) on four-lane two-way undivided roads (4/2-UD). On the other hand, head-to-side crashes on one-way roads totaled 842 (12.11%). Among these, 636 crashes (9.14%) happened on two-lane one-way roads, and 161 crashes (2.13%) occurred on one-lane one-way roads.

3.2.5 Distribution of run-off-road crashes by road type

A single crash of this nature refers to a loss of control (SVRoR: Single Vehicle Run-off-Road) and is one of the relatively common types of crashes on national roads in Indonesia. From 2012 to March 2019, 14,001 (4.94%) run-off-road crashes were reported among the total crashes on national roads. Table 2 shows the three main categories of run-off-road crashes based on road type: crashes on two-way undivided roads, run-off-road crashes on two-way divided roads, and run-off-road crashes on one-way roads.

On two-way undivided roads, 29.64% of crashes occurred on two-lane roads, 7.22% on four-lane roads, and 0.44% on six-lane roads. On divided roads, 33.60% of crashes occurred on four-lane roads and 5.86% on six-lane roads.

In the category of two-way undivided roads, 29.64% of crashes occurred on two-lane two-way undivided roads (2/2-UD), and 7.22% on four-lane two-way undivided roads (4/2-UD). Moving on to divided roads, 33.60% of crashes transpired on the four-lane two-way divided road (4/2-D) and 5.86% on the six-lane two-way divided road type (6/2 D). Meanwhile, in the one-way road category, 11.40% of crashes occurred on two-lane one-way roads, 3.43% on one-lane one-way roads, 2.67% on four-lane one-way roads, and 1.89% on three-lane one-way roads.

3.3 Distribution of crashes by road geometric types

In Table 4, the distribution of crashes on Indonesian National roads based on IRSMS data by road geometric types is presented. The data indicates that 280,782 crashes (99.17%) were documented with road geometric type information, while the remaining 0.83% lacked such data. Notably, the highest number of crashes occurred on roads with a straight geometric type. However, it is important to note that the IRSMS does not specify whether the "straight" geometric type refers to flat or steep ascent/descent roads. Out of the total crashes, 230,366 (81.36%) were recorded on roads with the straight geometric type, while 21,795 crashes (7.70%) were associated with the curve geometric type.

Based on the location of the crashes, Table 4 shows that 253,947 (89.69%) crashes occurred on road segments and 26,839 crashes (9.48%) occurred at intersections. Of the intersection crashes, 11,754 (4.15%) were at T-intersections and 9,446 (3.14%) at X-intersections. However, due to limited data on the detailed geometric conditions of Indonesian National roads in each province, further correlation analyses of the relationship between crashes and geometric type were not conducted. Yan (2005) noted that the risk of a rear-end collision doubles when a horizontal curve and grade are present simultaneously. The analysis also indicates that as the speed limit increases, the risk of rear-end crashes rises, especially when the speed limit exceeds 40 mph.

3.3.1 Distribution of head-on crashes by road geometric types

It was recorded that 774 or 1.24% of the total head-on crashes lacked information on road geometric conditions. The majority of head-on crashes, totaling at 51,392 (82.59%), occurred on straight-aligned roads, while 3,735 (6.00%) crashes took place on curved roads.

This trend may be attributed to drivers attempting overtaking maneuvers on straight road sections, while head-on crashes on curved roads are often a result of limited visibility. Additionally, the substandard carriageway width on curved sections of many national roads in Indonesia may lead vehicles to encroach into oncoming lanes, increasing the risk of head-on crashes. Regarding intersection types, T-junctions recorded the highest number of head-on crashes at 2,633 (4.23%), followed by X-junctions with 2,067 (3.34%) crashes.

3.3.2 Distribution of head-to-side crashes on property access by road geometric types

The data completeness of head-to-side crashes at locations considered as property access is impressive, with 15,522 crashes, accounting for 98.50% of the data, as shown in Table 4. The high frequency of head-to-side crashes on two-lane two-way undivided (2/2-UD) roads is likely due to the relatively narrow space and the lack of adequate supporting facilities for safe turnarounds.

Geometrically, the majority of head-to-side crashes occurred on straight road segments, totaling at 12,975 crashes (82.34%). The second highest number of head-to-side crashes, 937 (6.17%), occurred on curved road segments. Additionally, 1,429 crashes (9.26%) took place at road intersections.

It is important to note that head-to-side crashes that occur on bridges and in tunnels deserve special attention. Although these types of crashes make up a very small percentage (0.73%), it is still a concerning statistic, especially in these particular locations, unless these areas are frequently used for recreational purposes.

Table 4 Distribution of crashes by road geometric type

Code	Road geometric type	All crashes		Rear-end		Head-on		Head-to-side on access property		Head-to-side on U-turn		Run-off	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0	NA	2,362	0.83	1,517	2.08	774	1.24	236	1.50	57	0.82	151	1.08
1	Straight	230,366	81.36	59,811	81.95	51,392	82.59	12,975	82.34	5,538	79.63	11,330	80.92
2	Curve	21,795	7.70	5,778	7.92	3,735	6.00	973	6.17	668	9.60	1073	7.66
3	Tunnel	39	0.01	191	0.26	4	0.01	2	0.01	7	0.10	5	0.04
4	Bridge	1,747	0.62	283	0.39	338	0.54	113	0.72	36	0.52	85	0.61
5	Zigzag	130	0.05	41	0.06	11	0.02	5	0.03	1	0.01	20	0.14
6	Y-junction	2,619	0.92	501	0.69	652	1.05	162	1.03	85	1.22	115	0.82
7	Roundabout	1,211	0.43	222	0.30	263	0.42	39	0.25	45	0.65	97	0.69
8	X-junction	9,446	3.34	1,729	2.37	2,076	3.34	538	3.41	184	2.65	516	3.69
9	T-junction	11,754	4.15	2,590	3.55	2,633	4.23	610	3.87	298	4.28	519	3.71
10	Double T-junction	1,323	0.47	238	0.33	292	0.47	76	0.48	31	0.45	57	0.41
11	Multi	356	0.13	82	0.11	59	0.09	29	0.18	5	0.07	33	0.24
	Total	**283,148**	**100.00**	**72,983**	**100.00**	**62,229**	**100.00**	**15,758**	**100.00**	**6,955**	**100.00**	**14,001**	**100.00**

3.3.3 Distribution of head-to-side crashes on U-turns by road geometric types

The data completeness for Head-to-side crashes on U-turns is high, with 99.18% containing information on geometric conditions. Table 4 indicates that the majority of head-to-side crashes on U-turns occurred on straight road sections, accounting for 5,538 crashes or 79.63% of the total. In contrast, only 668 crashes (9.60%) occurred on road curve sections.

3.3.4 Distribution of run-off-road crashes by road geometric types

In Table 4, the distribution of run-off-road crashes by road geometric types is presented. It is worth noting that 98.82% of run-off-road crash data includes information on the geometric condition. This high level of completeness makes the data reliable for evaluating run-off-road crashes by road geometric types.

The data reveals that the two geometric types of roads with the highest occurrences of run-off-road crashes are straight road sections, accounting for 11,330 (80.92%) crashes, and road curves, totaling at 1,073 (7.66%) crashes. Furthermore, 1,357 (9.69%) run-off-road crashes took place at intersections, while the remaining incidents occurred on bridges and in tunnels, with 85 (0.61%) and 5 (0.04%) crashes, respectively.

3.4 Distribution of crashes by road surface conditions

Table 5 shows the distribution of crashes based on the type of road surface condition. The report indicates that 268,273 (94.92%) crashes took place on roads with good surface conditions, potentially attributed to drivers exceeding the speed limit under these favorable conditions. Additionally, 8,815 (3.11%) crashes occurred on poor road surfaces featuring potholes, roughness, corrugation, and rutting, while 953 (0.34%) crashes transpired on slippery, wet, dusty, and flooded road surfaces. These findings slightly differ from the research conducted by Malin et al. (2019), which suggested that the relative risk of crashes was higher in very wet and slippery road conditions.

The available data on the surface condition of National roads in the 33 provinces is less comprehensive compared to the data in Table 5. This data only indicates whether the roads are in good (stable) or bad (unstable) condition, which raises concerns about the accuracy of the correlation analysis between crash-type data and road surface condition data. Although a correlation analysis can still be conducted, there is uncertainty about its ability to accurately reflect the real-world scenario. Therefore, this paper will not pursue further correlation analysis between crash data and road surface condition data.

3.4.1 Distribution of rear-end crashes by road surface conditions

According to Table 5, out of the total 72,983 rear-end crashes recorded, 97.75% had information regarding road surface conditions, while 2,372 (3.25%) crashes were incomplete with data on road surface conditions. Table 5 indicates that 68,273 (93.55%) rear-end crashes occurred on good road surface conditions. Only 1.37% of rear-end

Table 5 Distribution of crashes by road surface condition

Code	Road surface condition	All crashes		Rear-end		Head-on		Head-to-side on access property		Head-to-side on U-turn		Run-off	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
0	NA	4,607	1.63	2,372	3.25	1,446	2.32	331	2.10	161	2.31	307	2.19
1	Good	268,773	94.92	68,273	93.55	59,008	94.82	15,119	95.94	6,560	94.32	12,502	89.29
2	Pothole	3,923	1.39	965	1.32	676	1.09	151	0.96	120	1.73	279	1.99
3	Rough	540	0.19	107	0.15	79	0.13	20	0.13	17	0.24	741	5.29
4	Corrugation	4,295	1.52	1,001	1.37	811	1.30	89	0.56	55	0.79	86	0.61
5	Wet	5	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
6	Rutting	57	0.02	7	0.01	25	0.04	1	0.01	3	0.04	3	0.02
7	Slippery	743	0.26	212	0.29	149	0.24	38	0.24	37	0.53	69	0.49
8	Dusty	188	0.07	42	0.06	33	0.05	8	0.05	2	0.03	7	0.05
9	Flooded	17	0.01	4	0.01	2	0.00	1	0.01	0	0.00	7	0.05
	Total	283,148	100.00	72,983	100.00	62,229	100.00	15,758	100.00	6,955	100.00	14,001	100.00

crashes were in the poor road surface category. However, it is important to note that damaged roads still contribute to rear-end crashes on Indonesian national roads.

3.4.2 Distribution of head-on crashes by road surface conditions

Table 5 shows the breakdown of head-on crashes based on road surface conditions. Out of 1,446 crashes (2.32%), information on road surface conditions was missing for a certain percentage of them. The data reveals that 59,008 (94.82%) of the head-on crashes took place on roads with good surface conditions. Conversely, only 1,591 head-on crashes (2.56%) were reported on poor road surface conditions. Moreover, head-on crashes on slippery, dusty, and wet road surfaces accounted for 184 crashes (1.30%).

3.4.3 Distribution of head-to-side crashes on property access by road surface conditions

In Table 5, the data shows head-to-side crashes on Property Access by road surface condition. The table reveals that 330 crashes (2.10%) did not have complete information regarding road surface conditions, while 15,427 crashes (97.90%) had complete information on road surface conditions.

According to the data in Table 5, it is evident that 15,119 head-to-side crashes (95.94%) occurred on roads with good surface conditions. Conversely, a small percentage of head-to-side crashes (1.16%) was observed on roads with poor surface conditions such as potholes, rough surfaces, corrugation, and rutting. Similarly, crashes occurring in slippery, wet, and dusty conditions accounted for only around 0.30% of the total head-to-side crashes. This suggests that head-to-side crashes on national roads predominantly occur under favorable road conditions.

3.4.4 Distribution of head-to-side crashes on U-turns by road surface conditions

Of the total 6,955 head-to-side crashes on U-turn, 6,794 crashes (97.69%) were completed with road surface condition information. From the data, the majority of head-to-side crashes on U-turns, 6,650 crashes (94.32%) occurred on roads with good surface conditions. Only around 2.80% occurred on roads with poor road surface conditions such as potholes, rough, corrugation, and rutting.

3.4.5 Distribution of run-off-road crashes by road surface conditions

Table 5 presents the distribution of run-off-road crashes based on road surface conditions. Out of the total 14,001 run-off-road crashes, 13,694 crashes (97.80%) included road surface condition information. The data indicates that 12,502 run-off-road crashes (89.29%) occurred on roads with good surface conditions, while 1,109 run-off-road crashes (7.92%) happened on roads with poor conditions such as potholes, rough, corrugated, and rutted surfaces. Additionally, 83 run-off-road crashes (0.59%) took place in slippery, dusty, and flooded road conditions.

4 Conclusion

Based on the data recorded in the IRSMS, the characteristics of crashes on Indonesian National Roads can be concluded as follows:

Out of the 283,518 road crashes that occurred on Indonesian national roads, the top 5 types of crashes were as follows: rear-end crashes (25.64%), head-on crashes (21.95%), all intersection crashes (20.50%), pedestrian hit-and-runs (12.65%), and head-to-side crashes (8.01%). The proportion of fatal and serious crashes aligns relatively closely with the distribution of these 5 most frequent types of crashes.

The majority of crashes occurred on two-lane two-way undivided (2/2 UD) roads (54.28%) and four-lane two-way undivided (4/2 UD) roads (16.45%), with head-on crashes correlating with these road types. Rear-end crashes showed a strong correlation with four-lane two-way divided (4/2 D) roads, four-lane two-way undivided (4/2 UD) roads, and six-lane two-way divided (6/2 D) roads.

Based on road geometry type, the majority of crashes, 81.36%, occurred on straight roads, with 7.70% occurring on curved roads. This is likely due to drivers increasing speed on straight road sections, leading to a higher risk of rear-end crashes. Additionally, the high number of head-on crashes on straight sections is attributed to drivers attempting to overtake vehicles on straight road segments and being struck by oncoming vehicles from the opposite direction.

The data reveals that a significant proportion of traffic crashes occurring on Indonesian National roads, approximately 94.92%, occur on roads that are officially classified as being in good condition.

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