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Vision Zero Community: A Mixed-Method Case Study on Engineering Intervention For Road Safety at Pulau Indah Highway, Klang

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ABSTRACT

This study utilizes a Vision Zero Community framework to analyse the Pulau Indah Highway (West Port, Klang) in identifying fatal crashes causes and proposing appropriate safety measures. Malaysia's industrial port-access highways still have tremendously high fatal and serious-injury crashes. Mainly, this is because of high vehicle speeds, the mixing of different types of traffic, and poor visibility at night. A Vision Zero Community oriented engineering approach was the backdrop of this study which analysed the safety of the Pulau Indah Highway (West Port, Klang) with the aim to unveil major causes of fatal crashes and suggest measures that would be based on research of this area. A mixed-method methodology was adopted that analysed fatal crashes data from the Jabatan Kerja Raya (JKR) spot-speed measurements collected with a radar speed gun on weekdays and weekends, field observations, and online questionnaire survey of road users (n = 400). Analysis of $n = 7$ fatal crashes and speed data shows that 85th percentile speeds exceed 100 km/h during weekends. The findings show that straights and dry road segments were the most frequent locations for fatal collisions, with loss-of-control and rear-end collisions predominating, particularly in dimly lit areas at night. The speed analysis revealed consistently high operating speeds, with speeds exceeding the posted limits, particularly during weekends. Excessive speeding, dangerous heavy-vehicle behaviour, inadequate lighting, and poor pavement conditions were among the survey's main causes of fatal collisions, and it was widely accepted that the safety precautions in place had limited effectiveness. According to the study, the most important strategy to reduce the likelihood of deadly collisions on the Pulau Indah Highway is through speed restriction. Installing Automated Speed Enforcement (ASE) in conjunction with high-friction surface treatments and targeted roadway lighting upgrades is suggested as a workable and locally appropriate engineering solution that aligns with the Vision Zero principles that would clearly improve road user safety in the real world.

Keywords: Vision Zero; Automated Speed Enforcement; Speed Management; Road Safety Engineering

Nomenclature

σ	Standard deviation (km/h)

Abbreviations

PDRM	Polis Diraja Malaysia
HGVs	Heavy Good Vehicles
JKR	Jabatan Kerja Raya
AwAS	Automated Awareness Safety System
LMICs	Low-and Middle-Income Country
VMS	Vehicle Message Sign
ASE	Automated Speed Enforcement
HFST	High Friction Surface Treatment

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1.0 INTRODUCTION

Road transport has played a significant role in the socioeconomic growth of Malaysia by facilitating the flow of commodities [14]. On the other hand, traffic crashes have increased, particularly in industrial and port areas, due to the quick speed of industrial expansion and the growing number of cars. Over 400,000 traffic crashes were reported in 2022, with Selangor at the top of the list due to the large concentration of industrial and logistics activities [PDRM, 2022]. In addition to causing fatalities, traffic crashes can result in significant financial costs, lost productivity, and long-term societal repercussions.

Industrial highways are mixed traffic areas with heavy goods vehicles (HGVs), passenger cars, and motorcycles operating at the same time, thus they are facing safety problems only. [9] and [8] analysed the matter and came to the conclusion that different vehicle sizes, speeds, and operational behaviour are the factors that considerably increase the traffic conflicts and crashes severity. Infrastructure-related deficiencies such as darkness, lack of proper roadside safety barriers, inadequate recovery zones, and poor road geometry have been cited as the major reasons for Malaysia's industrial routes to be the site of severe and fatal crashes [12], [17].

Furthermore, vision is especially limited during nighttime operations, and these situations result in even more incidents being reported. According to [19], many HGVs in Malaysia lack adequate reflective markings, making them less visible and increasing the likelihood of rear-end collisions. In logistics-intensive contexts, human issues such as driver weariness, speeding, and lack of safety awareness among commercial drivers are frequently combined with poor cars and infrastructure [12], [20].

Industrial locations continue to have high crashes rates despite the implementation of several law enforcement and public education initiatives, which highlight the shortcomings of the traditional safety systems. As a result, Malaysia included the Vision Zero principle in its Road Safety Plan 2022–2030 [18], stating that all road users, planners, engineers, and authorities share responsibility for road safety and that no crashes-related fatality is acceptable [11]. In keeping with this approach, the Vision Zero Community concept demonstrates community-led, area-based initiatives that integrate engineering, behavioural modification, and stakeholder collaboration [14].

Vision Zero has been the talk of the town in policy discussions but still holds limited applicability in Malaysia's high-risk industrial highway surroundings. [2] pointed out that community-based Vision Zero applications are scarcely investigated, especially in logistics-captive areas where operational needs, human behaviour, and infrastructure limitations interact.

1.1 Executive summary

This research is conducted along a major industrial highway corridor in Klang, Selangor where the crashes resulting in fatality and severe injury are still common, and it examines the conditions of road safety. The study discusses safety problems caused by the mix of different types of vehicles, high speed, poor road design, lack of visibility, and little safety infrastructure. The Vision Zero Community framework facilitates the study which makes use of a mixed-method approach comprising of data analysis on road crashes and fatalities from the Jabatan Kerja Raya (JKR), speed studies, site observations, and questionnaire surveys among several groups of road users.

The study aims at pinpointing the leading factors of fatal traffic crashes, evaluating the possible countermeasures, and proposing the appropriate engineering-based interventions that are in accordance with the Vision Zero principles and the local conditions. The area of focus is mainly on the engineering solutions for the selected industrial corridor, while enforcement and educational measures are not considered. The researchers faced limitations such as spatial specificity, difficulties in accessing data, and lack of real-world application during the study.

The study adds to the body of knowledge by addressing a major gap in the literature on the application of Vision Zero Community principles in Malaysian industrial highway regions. As part of Malaysia's national goal of zero road fatalities by 2030, the results are meant to support achievable decisions based on the data for the benefit of the local population, industry, and government [18].

2.0 LITERATURE REVIEW

Vision Zero is a road safety concept that aims to wipe out all traffic-related fatalitys and serious injuries altogether by acknowledging that humans will always make mistakes and that the roads must be built in such a way that no fatalitys will result from such mistakes [21]. Started in Sweden in 1997, Vision Zero has over time come to be regarded as a full-scale global approach to road safety that combines and requires collaboration between all stakeholders [11].

High-income countries provide human-based evidence for the effectiveness of the Vision Zero approach. Sweden's adoption of Vision Zero has led to an astounding 65% reduction in road fatalitys, which is mainly a direct result of the implementation of safer road designs, rigorous speed control, and the use of various car safety technologies [5], [3]. The Netherlands too has undergone a significant drop in fatal crashes through mainly infrastructure measures that protect the most vulnerable road users, such as the widespread use of roundabouts, segregated paths for cyclists, and traffic-calming features.

The Malaysia Road Safety Plan 2022–2030, which aims to cut traffic fatalities and injuries by 50% during the Decade of Action, incorporates the Vision Zero concepts [18]. Due to heavy traffic and the fact that trucks, vehicles, and motorcyclists share the roads, the industrial highway corridors that link to the ports and logistical hubs are the most impacted [19]. According to [12] and [17], the routes utilised for trucks and expressways in Malaysia consistently highlight the same significant issues that prevent effective illumination, suitable signage, and roadside recovery as the primary causes of serious and deadly incidents during night operations.

The central part of Vision Zero's execution is the use of engineering-based interventions. The changes in road design and layout, such as the introduction of roundabouts, pedestrian and cyclist safety zones, and improved road marking and signage, have been proven to have a large effect on the reduction of both, frequency and severity of crashes. In the case of roundabouts, they have been linked to a 50% drop in collisions and a 30% cut in fatalitys as compared to traditional traffic light crossings [21]. These interventions are even more necessary in places where there is a mixture of vehicles with different speeds and where there are a lot of conflict points.

Speed management is yet another vital part of the Safe System strategy. Findings from studies show that cutting speed limits down to 30 to 50 km/h in either high-risk or mixed-traffic areas could lead to a decline in fatalities by nearly 40% [3]. The use of automated enforcement technologies such as fixed and mobile speed cameras has boosted compliance even further. In Sweden, speed cameras have been the cause for a 30% cut in fatality crashes and a 25% decline in the number of serious injuries [21]. Malaysia, on the other hand, has also put into practice the Automated Awareness Safety System (AwAS), which is effective in controlling both speeding and red-light violations at the high-risk spots [16]. Vehicle safety features are also a big factor in crashes severity reduction. Automatic emergency braking alongside lane-keeping assistance and electronic stability control systems have shown that they completely minimize the collision occurrence and the injury severity by a great deal. Automatic emergency braking alone has been said to cut rear-end collisions down by about 50% [3]. Nonetheless, the adoption and cost of such technologies are not uniform in low- and middle-income countries (LMICs). In addition to engineering and technology, recent studies show that community involvement is essential to accomplishing Vision Zero's objectives. Local communities have the ability to identify unique risk concerns and increase public acceptance of safety precautions. The My Safe Road Programme in Malaysia has demonstrated that community involvement makes road safety measures far more effective because they are tailored to the local conditions [14]. As part of the Vision Zero Community framework, [2] noted that it is crucial for lower and middle-income nations, especially those where industrial and logistics operations predominate, to adopt global best practices.

Although there is strong evidence to support Vision Zero, there are still significant gaps in the study. First, not enough research has been done to show how Vision Zero practices can be sustained over the long term, particularly in areas that are industrializing quickly [2-3]. Second, most empirical information comes from high-income countries; little or no study has been done on how to adapt and make engineering and technology measures affordable for LMICs, such as Malaysia. Third, the creation of scalable and organized community participation methods that will be utilized in the execution of Vision Zero remains unfinished. Finally, the part that post-crashes care plays within the Vision Zero frameworks, particularly in places with limited resources, has not been the focus of much academic research.

3.0 METHODOLOGY

3.1 Research design and framework

In order to provide a comprehensive picture of the dangers to fatal road safety and develop engineering-based remedies that would function in a highway corridor of an industrial area that serves a large port, this study employed a variety of methods to make the roads safer. The mixed-method approach was chosen in order to acquire both meaningful context and robust analysis by combining objective data on crashes and speeds with road user impressions. In accordance with the goals of the study, the methodological framework was broken down into three sequential stages:

i. identifying the factors leading to fatal injuries
ii. assessing the measures to be implemented
iii. choosing effective interventions supported by empirical data and previous research.

3.2 Study area

The study focused on the Jambatan Muhibbah segment and was carried out in a high-risk industrial port-access corridor location in West Port, Klang. The segment is a dual-carriageway with three lanes per direction, a posted speed limit of 80 km/h, and a high composition of heavy goods vehicles (HGVs) due to its function as a primary port-access route. The location was selected primarily due to the wide variety of vehicles that use the road, including passenger cars, motorbikes, and heavy commercial vehicles, as well as the serious collisions and fatalities that have previously happened there. This example was chosen for a Vision Zero-oriented engineering review because of the infrastructure's shortcomings, which included bad pavement, insufficient illumination, and no motorcycle facilities at all. Figure 1 shows the location map of Pulau Indah Highway.

Figure 1. Location Map of Pulau Indah Highway

3.3 Crashes and fatality data analysis

The main reasons behind the fatal injuries were determined through the analysis of crashes and fatality records procured from the JKR. The data set comprised many features like crashes severity, time and date, road user type, crashes place, road geometry, surface condition, lighting, and environmental factors. The data were cleaned and organized with the help of spreadsheet-based analysis, and then descriptive statistical methods were used to find out the patterns connected with fatal and severe injury crashes. Geographic coordinates (latitude and longitude) were utilized for a more accurate and localized interpretation of risk factors.

3.4 Spot speed analysis

The radar speed gun was utilized to conduct a speed of movement investigation over the entire length of the route. The same route and weather circumstances were used for both weekday and weekend speed observations. In order to assess speed characteristics, fluctuating speeds, and compliance, the speed data was examined using statistical techniques that are frequently employed in traffic engineering.

To display the average speed of autos at that particular location, the arithmetic mean speed was computed using equation (1). The standard deviation, as derived in equation (2), was used to quantify speed variability, which illustrates the variation in vehicle operating speeds and the likelihood of interaction in mixed traffic conditions. Equation (3) was used to obtain the standard error of the mean, which was used to assess the dependability of the predicted mean speed. Additionally, the cumulative frequency distribution was utilized to calculate the 85th percentile speed, which is frequently used to describe typical traffic speed and support speed control assessments.

To improve the statistical reliability of the observed speed characteristics, all speed-related metrics were examined in SI units, and sample adequacy was verified at a 95% confidence level.

The arithmetic mean speed, V_{mean}, was determined using Equation (1),

$$V_{mean} = \frac{\sum FV}{\sum F} \qquad \text{(km/h)} \qquad (1)$$

where V is the observed vehicle speed and F is the frequency of vehicles travelling at speed V.

The speed variability of the traffic stream was quantified using the standard deviation, σ, as given in Equation (2),

$$\sigma = \sqrt{\frac{\sum(FV^2)}{\sum F} - (\frac{\sum(FV)}{\sum F})^2} \qquad \text{(km/h)} \qquad (2)$$

where V represents the observed vehicle speed and F denotes the corresponding frequency.

The reliability of the estimated mean speed was evaluated using the standard error of the mean, SE, expressed in Equation (3),

$$SE = \frac{\sigma}{\sqrt{n}} \qquad \text{(km/h)} \qquad (3)$$

where $\sigma$is the standard deviation of spot speeds and $n$is the total number of observed vehicles.

3.5 Road user survey

A structured questionnaire survey was conducted to collect user impressions regarding safety and preferences for mitigation among major road user groups. The main groups were motorcyclists, heavy vehicle drivers, passenger car drivers and pedestrians. A target sample size of 400 was estimated on the basis of a target population (N = 20,000), which refers to the estimated average daily volume of regular road users along the Pulau Indah Highway, with a 95% confidence level and 5% margin of error. Respondents were screened based on their frequency of usage of the Pulau Indah Highway to ensure that only regular users were included in the survey. Data collection was done through the internet over a period of one month.

The questionnaire consisted of four parts: respondent characteristics, causes of crashes perceived, current safety measures, and proposed interventions supported by stakeholders. The five-point Likert scale quantified the levels of agreement, while open-ended responses were subjected to thematic analysis to identify additional safety issues. Descriptive statistics were applied to the responses to summarise the data and to support the ranking of mitigation measures by user preference and perceived effectiveness.

3.6 Determination of suitable mitigation measure

In order to develop technical changes that align with the Vision Zero ideals, the approach was culminated in a meticulous synthesis of contemporary literature and empirical findings (2021-2026). The identified fatal injury routes, such as high speed, poor nighttime visibility, roadway departure severity, and heavy vehicle impacts, were linked with the countermeasures that had been shown to be successful and discovered in peer-reviewed research and technical guidelines. The interventions were chosen based on their efficacy in lowering fatalities and serious injuries, the local circumstances that support their implementation, and the operational features of a port-access corridor that align with these treatments.

4.0 RESULTS AND DISCUSSION

4.1 Fatal crashes characteristics

A thorough analysis of the fatal crashes records based on the JKR produced a fairly similar picture about the distribution of fatal crashes on the industrial road corridor that was the subject of the investigation. The weather was dry, and most of the fatalities occurred in straight-level sections of the road, suggesting that occurrences were not primarily caused by bad weather or poor pavement. The primary causes found were operational and human issues. Runaways, collisions, and side contact were the most frequent forms of fatal incidents, and they were strongly associated with high speed, insufficient headway, and dangerous interactions between mixed traffic streams. Inadequate visibility at night is a key risk factor, as evidenced by the fact that a large portion of the fatal incidents occurred in regions that were reported to have poor lighting or no street lights at all. These results lead to the conclusion that, although geometric design does not directly cause collisions, it nevertheless has a significant role in increasing the severity of crashes, particularly on straight roads and at high speeds. Table 1 shows the results of fatal injuries data collected from the JKR across different variables.

Table 1: Results of Fatal Injuries Data from Jabatan Kerja Raya (JKR, 2025)

No	Type of injuries	Month	Road condition	Weather	Type of crashes	Road geometry	Road surface	Road Defects	Lighting
1	Fatality	4	Flat	Good	Lost Control	Straight	Dry	Not applicable	Daytime
2	Fatality	6	Settle down	Good	Brushed againts each other	Straight	Sandy	Dusty	Poorly lit
3	Fatality	6	Flat	Good	Collision with a roadside object	Straight	Dry	Not applicable	Poorly lit
4	Fatality	6	Flat	Good	Rear end collision	Straight	Dry	Not applicable	Poorly lit
5	Fatality	6	Flat	Good	Brushed againts each other	Straight	Dry	Not applicable	Poorly lit
6	Fatality	6	Flat	Good	Rear end collision	Straight	Dry	Not applicable	No street light
7	Fatality	8	Flat	Good	Crushed	Straight	Unknown	Unknown	unknown

4.2 Data from spot speed study

Spot speed studies were carried out on weekdays and weekends, and Figures 2, 3, and 4 demonstrate how the operating speed behaviour along the research corridor changed over time. The quantity of traffic congestion and demand has a significant impact on the operating speed during weekdays. All of the weekday speed data were roughly centered in the moderate speed range, according to the frequency histogram and frequency distribution curve (Figures 2 and 3). However, during the morning and midday hours, the 85th percentile speeds (P85) for both entering and exiting traffic frequently exceeded 80 km/h, while the 98th percentile speeds (P98) approached or even surpassed 90 km/h, indicating the presence of high-end speeding behavior even in moderate traffic conditions. Figure 3, where the cumulative frequency curves show a slow rightward shift at higher speed ranges, supports this pattern.

The leftward shift of the frequency distributions in Figure 2 and the less steep slopes of the cumulative frequency curves in Figure 4 both show a discernible decrease in the average speeds throughout the peak hours of the weekday evening. Due to heavy traffic and congestion, the average speeds during this period typically decreased to between 50 and 53 km/h. In stop-and-go situations, there is more speed heterogeneity, which raises the risk of crashes through short headways, frequent lane changes, and close interactions between mixed traffic streams. On the one hand, slower speeds result in less severe impacts.

The larger range of the histograms and the steeper frequency distribution curves in Figures 2 and 3, on the other hand, demonstrated a clear contrast with weekend speed features, which corresponded to significantly greater operating speeds and wider variance. Drivers were able to accelerate to significantly higher speeds because there was almost no traffic during weekend mornings and afternoons. Weekend average speeds frequently above 85 km/h, but cumulative frequency curves in Figure 4 show that P85 and P98 rates frequently exceeded 100 km/h, demonstrating the prevalence and persistence of speeding.

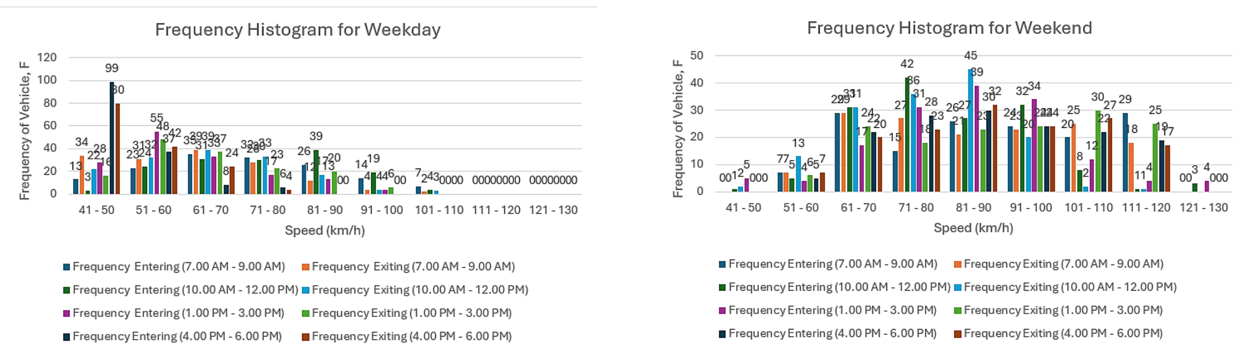

Figure 2(a). Frequency Histogram of Vehicle for Weekday and Weekend

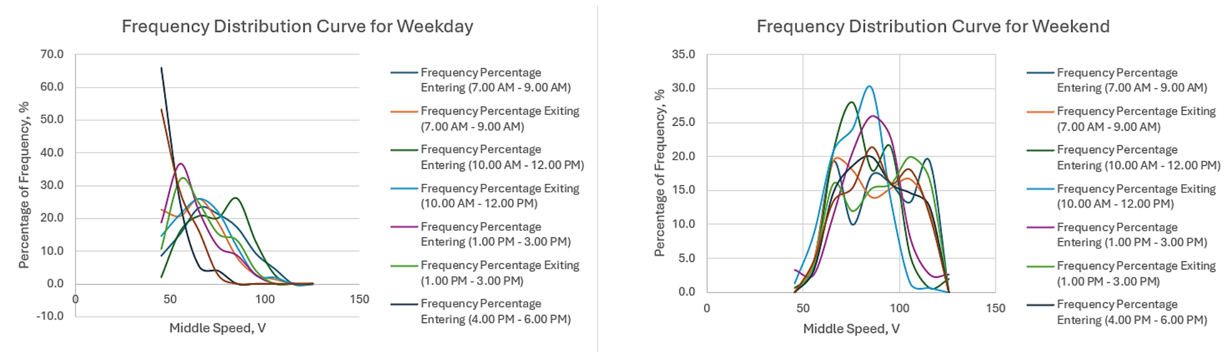

Figure 2(b). Frequency Distribution Curve of Vehicle for Weekday and Weekend

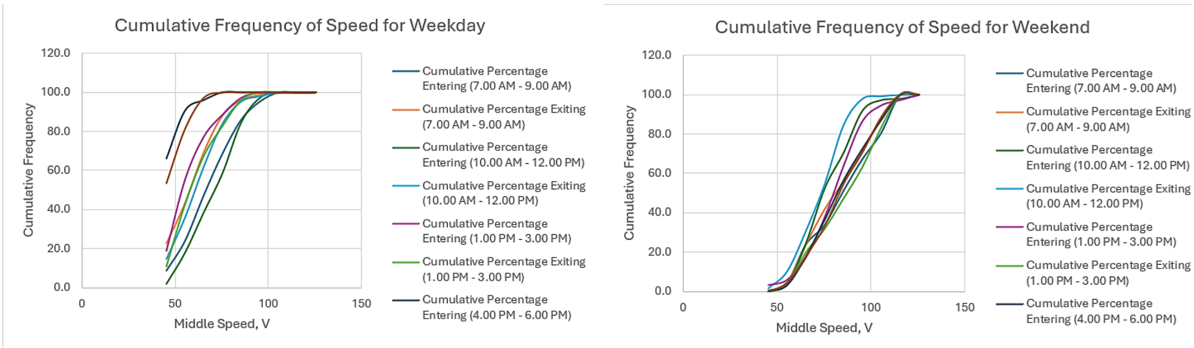

Figure 2(c). Cumulative Frequency of Speed of Vehicle for Weekday and Weekend

Overall, two safety risk mechanisms were clearly identified by the combined reading of the frequency histograms, distribution curves, and cumulative frequency plots (Figures 1–3). On weekdays, the risk of crashes is primarily associated with traffic congestion, which can lead to conflicts and speed variations. On weekends, however, the danger is primarily associated with excessively fast driving and high speed differences in the context of fluent traffic. These findings not only highlight the problem of speed control, but they also highlight the necessity of their combined harsh and ineffective enforcement tactics in the face of conflict-prone weekday peak times as well as high-speed weekend conditions.

4.3 Survey and feedback from port users

Table 2 presents demographic characteristics and travel-related attributes of the survey respondents, including age, gender, frequency of highway usage, mode of transportation, and purpose of travel. The information provides an overview of the respondent profile and establishes the relevance of the sample in representing typical users of the Pulau Indah Highway. Understanding these characteristics is important for contextualising the perceptions and opinions on road safety issues discussed in the subsequent sections.

The demographic profile shows that the highest percentage of respondents is in the age group of 18 to 45 years, with 72.6% of the total sample comprising of these people. This indicates that most of the participants are road users who are active and in the working age group. In gender terms, male respondents (54.5%) are a bit more than female respondents (45.5%), which will help in understanding travel behaviour and safety perceptions. When it comes to highway usage, over 50% of the respondents said that they use the Pulau Indah Highway every day or at least once a week, which is a good indication of their being exposed to, and at risk of, actual traffic conditions.

Table 2: Demographic Characteristics

Variable	Category	n	Percentage (%)
Age	18 – 25	95	23.8
	26 – 35	100	25.0
	36 – 45	95	23.8
	46 – 55	3	15.7
	56 and above	47	11.8
Gender	Male	218	54.5
	Female	182	45.5
Highway usage frequency	Daily	66	16.5
	Once a week	78	19.5
	2-3 times a week	88	22.0
	A few times a month	93	23.3
	Rarely or never	75	18.8
Main mode of transport	Car	160	40.0
	Motorcycle	161	40.3
	Lorry / Truck	79	19.8
Main purpose of using highway	Work	106	26.5
	Transporting Goods	159	39.8
	Personal travel	131	32.8
	Others	4	0.9

As far as mode of transportation is concerned, cars and motorcycles make up most of the traffic and account for more than 80% of the respondents, while heavy vehicles like lorries take up almost 20% indicating the industrial and freight-oriented nature of the corridor. With respect to travel purpose, the highway is mainly used for commuting and transporting goods which together account for over two-thirds of the total respondents. The demographic profile ultimately reveals that the survey data were collected from the frequent and relevant users of the highway; thus, enhancing the credibility of the findings on road safety perceptions being drawn.

Table 3 presents respondents' level of agreement on key factors believed to contribute to traffic crashes and fatal injuries on Pulau Indah Highway. The results are measured using a five-point Likert scale to summarise public perception regarding driver behaviour and roadway/environmental conditions. The response options are defined as SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree and SA = Strongly Agree.

The results show that there is broad agreement among the respondents that factors pertaining to driver behaviour and the road environment have a major impact on the frequency and severity of crashes. Over 95% of poll respondents agreed that speeding raises the likelihood of crashes, viewing it as the primary cause of collisions. Additionally, two other suggested criteria that garnered very similarly high levels of agreement were speeding by large cars and dangerous lane changes. This suggests that heavier vehicles are involved in more serious crashes. Poor road surface condition and inadequate street lighting were also agreed upon with very high levels among the infrastructure-related factors, suggesting that road defects and reduced visibility at night are thought to be the cause of loss-of-control crashes and the severity of these crashes. At the very least, it was acknowledged that human behaviour is the most often cited cause of crashes, with careless and distracted driving being the primary culprit. Other than that, it was accepted that the absence of road barriers and the scarcity of road signs have a somewhat detrimental impact on the severity of crashes, although not as much as the human variables listed above.

The respondents' opinions about the effectiveness of the present road safety measures being put in place on the Pulau Indah Highway are summarized in Table 4. The degree to which road users believe the current controls, such as signage, enforcement, road design, and emergency response, are sufficient to reduce safety threats is shown in this table. The response options are defined as SD = Strongly Disagree, D = Disagree, N = Neutral, A = Agree and SA = Strongly Agree.

Table 4 summarizes the respondents' opinions about how adequate the current safety measures are. It was shown that most respondents did not think the existing safeguards were sufficient. The idea that emergency response, speed enforcement, road design, and signs are adequate was rejected by more than 70% of respondents. However, the widespread belief that speeding is a serious safety risk is correlated with the absence of speed enforcement in this situation. Considering the findings indicate that there is a considerable disparity in road users' perceptions of the safety precautions that have been implemented, indicating the need for improvement.

Table 3: Perceived Causes of Traffic Crashes and Fatal Injuries

Item	SD	D	N	A	SA
Speeding contributes to traffic crashes	0	0	18	170	212
Heavy vehicles speeding / unsafe lane changes contribute to fatal crashes	1	3	5	156	235
Poor road surface (potholes/uneven pavement) contributes to loss of control/severe crashes	2	3	3	166	226
Inadequate street lighting at night reduces visibility and increases risk	0	1	12	164	223
Reckless/distracted driving contributes to fatal crashes	2	0	4	169	225
Lack of proper road signage/warnings increases crashes severity	1	2	28	173	195
Lack of road barriers (guardrails) contributes to fatal crashes	1	7	31	176	185

Table 4: Perceived Adequacy of Existing Road Safety Measures

Item	SD	D	N	A	SA
Road signage and warning signs are adequate	146	155	55	29	15
Speed enforcement is sufficient	149	158	46	30	17
Road design and layout are safe	147	151	51	29	22
Emergency response is quick and effective	141	160	52	30	17
Overall existing safety measures are sufficient	146	159	54	27	14

Table 5 shows the respondents' agreement on proposed mitigation strategies aimed at reducing crashes frequency and severity on Pulau Indah Highway. The table highlights the level of support for improvements related to engineering measures, enforcement actions, and safety awareness initiatives.

Table 5 summarizes the level of respondents' consent regarding various mitigation strategies that were proposed. The agreement was nearly unanimous for all the suggested actions. The improvement of the road surface condition and the enhancement of the road lighting were the most supported measures, which show that the participants were really convinced that the infrastructure improvements would drastically reduce the chances of crashes. Other measures such as increased enforcement, better road signage, installation of road barriers, and running road safety awareness campaigns received strong support as well. The results imply that the respondents are in favour of a mixed strategy that includes improvements in engineering, enforcement, and public education for the betterment of road safety.

Table 6 presents the categorised themes obtained from the open-ended responses on factors contributing to crashes on Pulau Indah Highway. The results are compiled into major themes and reported as percentages to reflect the most frequently mentioned issues among respondents. Table 7 summarises respondents' suggested improvements to enhance safety on Pulau Indah Highway based on an open-ended question. The responses are grouped into key improvement categories and presented in percentage form to indicate priority areas perceived by road users.

The study of open-ended responses (Tables 6 and 7) has provided additional support to the quantitative results. Among the different factors, driver behaviour came at the top of the list as the main reason for crashes, followed by poor road conditions and lack of light. The main improvement suggestions were based on proposals for stricter speed enforcement and better heavy vehicle management, improved road maintenance, enhanced lighting, and clearer signage. The responses call for a combination of measures that would target both behaviour and infrastructure problems.

Table 5: Respondents' Agreement on Proposed Safety Mitigation Measures

Item	SD	D	N	A	SA
Improve road lighting to reduce crashes risk	0	1	7	175	217
Strengthen enforcement (speed cameras) to reduce dangerous decisions	2	1	19	168	210
Add or improve road signage for safe driving decisions	1	3	15	180	201
Add road barriers (guardrails) to reduce severity	1	7	20	177	195
Road safety awareness campaigns improve awarenesss	2	5	20	171	202
Improve road surface conditions (reparing/patching/resurfacing) to reduce crashes	1	0	6	161	232

Table 6: Reported Contributing Factors from Open-Ended Responses

Contributing Factor	Percentage (%)
Driver behaviour (speeding, reckless / distracted driving, unsafe lane changing, heavy vehicles)	46
Road conditions (potholes, uneven pavement,, poor road surface/markings)	27
Inadequate lighting (poor visibility at night, unlit sections)	17
Lack of road signage / warnings	10
Total	100

Table 7: Reported Improvement Suggestions from Open-Ended Responses

Contributing Factor	Percentage (%)
Speed enforcement & traffic control (AES, speed cameras, patrols, strict action on speeding)	29
Heavy vehicle management (time restrictions, dedicated lanes, limit overtaking, inspections)	24
Road surface & maintenance (potholes, resurfacing, drainage, debris cleaning)	22
Road lighting improvement (continuous lighting, repair faulty lamps, reflective markings)	15
Road signage & markings (warning signs, reflective signs, VMS, road markings)	10
Total	100

4.4 Preferred and evidence-based mitigation measure

Comparative analysis of the suggested mitigation strategies indicates that the primary strategy to improve Pulau Indah Highway safety the most is lowering operating speed. Measured speed variance indicates that operating speeds increase significantly during off-peak and weekend periods when traffic is free-flowing, contributing to a higher risk of fatal and serious injury crashes. As a result, policies that influence drivers' speeding behaviour are put in place to significantly lower the frequency and severity of crashes.

The most effective safety measure for speeding-related collisions on highway corridors is currently Automated Speed Enforcement (ASE). According to [6], speed safety cameras are an effective and reliable technology that reduces speeding through consistent and ongoing enforcement. In contrast to temporary police patrols, ASE not only more accurately detects speeding infractions but also deters drivers who pose a risk to others from speeding.

A long-term assessment of the ASE system in New York City revealed that there is a reduction in speeding violations of 75% and in traffic crashes of 14%, indicating sustained behavioural change among drivers [7]. The same situation is supported by findings from the Insurance Institute for Highway Safety, which confirm that speed safety cameras effectively reduce both the incidence of speeding and serious injury crashes [7]. Research in Washington, D.C. has also shown that speed cameras are particularly effective in the case of major arterial roads during the off-peak period when excessive speeding is most common [1]. In this light, the installation of ASE at the places most prone to crashes along Pulau Indah Highway, coupled with corridor-based enforcement, clear signage, and open communication, is expected to produce the maximum deterrent and the minimum risk of crashes. A targeted technical countermeasure for approach and braking zones, as well as wet-risk areas where vehicle control depends on road friction, is High Friction Surface Treatment (HFST). Recent study has identified HFST as a strategy for achieving long-term skid resistance through improved epoxy binder systems that result in durable in-situ performance [13].

It has also been established that the aggregate and surface design play a major role in determining how long HFST lasts. Differential polishing has been shown to increase skid-resistant longevity by reducing wear loss and maintaining surface roughness. For optimal performance, blended aggregates containing 25–50% limestone are utilized instead of depending only on premium bauxite [10]. According to [15], HFST systems that use blended aggregates and modified epoxy binders are not only more economical but also exhibit better resistance to environmental deterioration, such as freeze-thaw impacts, as well as greater skid resistance and reduced aggregate loss. Therefore, HFST is recommended for the Pulau Indah Highway sites where friction is critical, using blended aggregate designs and optimized epoxy binders to minimize long-term maintenance loss and improve durability and friction performance.

Improved road lighting and targeted safety measures are common ways to reduce crashes during the night. [6] stated that lighting and visibility improvements make travel safer for all and notes that well-designed lighting can significantly reduce the number of nighttime collisions, particularly at intersections in both rural and urban areas.

Measured conditions and user feedback indicate that poor visibility is a contributing factor to risky nighttime driving along the Pulau Indah Highway. Therefore, it is recommended that the roadways be better illuminated in high-risk areas, such as intersections, industrial entrances, and places where nighttime crashes have occurred. Since modern LED lighting has the longest lifespan, the lowest energy consumption and the maximum luminous efficiency, it should be employed. Additionally, planned maintenance schedule will stabilize the illumination performance. By reducing crashes and boosting driver comfort and confidence, all of these factors combined are likely to create a safe environment for nighttime driving.

4.5 Overall effectiveness and integration of mitigation measures

From the review of the literature, Automated Speed Enforcement (ASE) comes out on top as the best mitigation strategy since it is mostly based on strong evidence and it also directly controls the speed. Enforcement measures, however, when combined with engineering interventions, yield the greatest safety benefits. Treatments like High Friction Surface Treatment (HFST), roadway illumination, and pavement demarcation target vehicle control, visibility, and driver perception, thus, lowering both crashes chance and severity.

In short, the proposed mitigation strategy for Pulau Indah Highway takes a Safe System-oriented approach that combines speed management, surface friction improvement and visibility enhancement. These suggestions are backed by recent research (2021–2026) and are in line with the main risk factors found in this study. If these measures were taken together, they would be very effective in making the corridor a much safer place and in preventing fatalities and serious injuries.

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objectives of the research are to discover the causes that lead to traffic crashes on the Pulau Indah Highway, especially those that end up being fatal and causing serious injuries, assess the different actions that can be taken, and propose the best alternatives that are consistent with the Vision Zero approach. The research uses information from the JKR, different speed tests conducted at various places, and a survey combined together.

The outcomes of the study pointed out that speeding and unsafe driving habits are the main reasons for the fatalities on the Pulau Indah Highway. JKR analysis showed that a large number of fatal crashes take place on straight roads during dry weather, with loss of control and rear-end collisions comprising the two main categories of crashes. Poorly lit or unlit sections are often the locations of these crashes, and thus it can be concluded that the severity of crashes is a function of operating speed, behaviour of the driver, and illumination rather than weather or road complexity.

The spot speed investigations showed that large speed changes and operating speeds with high variance are typical. The risk of serious crashes is higher during off-peak and weekend hours since a very high percentage of P85 and P98 speeds were recorded. The speed limit increases the likelihood and severity of crashes in a traffic mix with a lot of heavy cars and motorbikes.

The majority of the participants pointed out that speeding, reckless and inattentive driving, unsafe heavy truck operation, insufficient lighting, bad road surface conditions, lack of signs, and weak enforcement as the main reasons for crashes. The close link between crashes data, speed measures, and road user perceptions gives more strength to the study’s conclusions. To sum up, the research indicates that it is necessary to have a multi-faceted approach to solve the safety problem of Pulau Indah highway. The controlling of speed is seen as the vital element in the reduction of fatalities and severe injuries, which is in agreement with the principles of the Safe System and Vision Zero.

5.2 Recommendation

The key safety measure along the Pulau Indah Highway should be speed management, according to the study's conclusions. Automated Speed Enforcement (ASE) is especially recommended in this case because it consistently reduces excessive speeding and provides consistent enforcement regardless of the time of day or traffic conditions. ASE should be stationed not only in high-risk places but also along the roads in between, as the times when the highest speed is seen during off-peak and weekend days.

Moreover, it is a must to carry out certain engineering measures to eliminate risks associated with the infrastructure that are pointed out in this paper. A major thing to do in this regard is to enhance the area's visibility and drivers' perception by raising the level of road lighting in places that are prone to nighttime crashes. It is also recommended that road surface is improved through resurfacing and application of high-friction surface treatments at the key spots where loss of control crashes often occur. The traffic signs, lane markings, and roadside barriers should be either upgraded or re-established to achieve better driver directing and reduced crashes impact.

Even though the findings are very reliable, the study has a few limitations. The past JKR crashes data, short-term collected spot speed measurements, and perception-based survey responses were all used in the analysis. These factors may not be able to fully depict the changing traffic behaviour over time or the long-run impact of specific measures. Therefore, it is to be noted that the findings reveal the existing conditions along the Pulau Indah Highway within the study duration, and this context should be applied to interpret them.

It is advised to handle heavy vehicle operations selectively since heavy vehicles play a major part in fatal incidents. It would entail stringent enforcement of lane discipline, limitations on risky overtaking maneuvers, and consideration of operational controls for a corridor that acts as the primary entrance to a significant port complex.

5.3 Limitations

This study provides preliminary insights based on available fatal crashes records from JKR (2025), which are limited in sample size and spatial coverage. The analysis is also based on short-term spot speed measurements and perception-based survey responses, which may not fully capture long-term traffic behaviour and variability. Therefore, the findings should be interpreted within the context of the study area and time period. Future research is recommended to incorporate larger datasets, longer observation periods, and additional validation through real-world implementation.

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AUTHORS CONTRIBUTION

Nur Firyal Batrisha Zahari was responsible for conceptualization, methodology development, investigation, data curation, formal analysis, validation, and writing the original draft of the manuscript. Elmi Alif Azmi contributed through supervision, methodology refinement, validation, project administration, provision of resources and funding acquisition, as well as reviewing and editing the manuscript.

DECLARATION OF COMPETING OF INTEREST

I declare that I have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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