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APPLICATION OF FUZZY-AHP IN GIS-BASED ANALYSIS FOR ROAD SAFETY INDEX MEASUREMENT

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Abstract

Maintaining the safety of road users is an absolute necessity. Therefore, the road must be safe, and road infrastructure is one of the most important aspects. Several studies suggested that different road infrastructures had different impacts on road safety. Therefore, this study was conducted with two (2) objectives, which are (i) to determine the degree of importance of factors influencing road safety and (ii) to derive the road safety index. This study proposed the application of Spatial-Multicriteria Decision Analysis, where Fuzzy-AHP was chosen as the technique to deal with uncertainty in criterion weighing. Findings revealed that the criteria with the highest degree of importance is Road Marking, with a weightage of 0.392, while the least important is Street Lighting, with a weightage of 0.028. The criterion weightage was then used in GIS proximity analysis to measure the safety index, which revealed that most roads in the study area have high and very high safety indexes. The indices were verified by interviews with an expert and site verification to see if the calculated indices were accurate. Thus, this study revealed the possibility of using Fuzzy-AHP and GIS methods in measuring safety index, which can be applied in the future.

Keywords: fuzzy-ahp, gis, mcda, proximity analysis, road safety

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INTRODUCTION

Road safety refers to the safe and secure travel of road users, including pedestrians, cyclists, public transportation riders, and motor vehicle drivers. Road safety can be influenced by factors like traffic volume, road geometry, bridge condition, business types, unsafe driving, traffic laws, police presence, warning signs, vehicle potential, and roadside emergency services (Teimourzadeh et al., 2020).

According to Sarani et al. (2018), since the early 1980s, Malaysia has struggled with road fatalities. There are numerous measures that many agencies have undertaken since there is a rising trend for fatality, and it must not be ignored. The trend of road fatality had changed from an ascending and positive trend in the 1990s to a gradual slope after 1996. In addition, the spatial distribution of road accident incidents in Malaysia between 2006 and 2015, with Selangor and Johor having the highest ratings due to their higher population density, with Shah Alam being an important city in Selangor. As it is one of the busiest cities in Selangor, there is a high number of vehicles on the roads daily, which could lead to road accidents (Shaadan et al., 2021).

Therefore, the purpose of this study is to suggest a methodology that could possibly be used for measuring road safety with Spatial-Multicriteria Decision Analysis (MCDA). When making any choice of decision about the geographical issues, the two (2) methods together were commonly used. Not only is one (1) criterion considered in the study of a geographical problem, but there are always multiple criteria, each of which has varying importance. GIS was used to conduct the spatial analysis, while MCDA was responsible for determining the weightage of the criteria. Road safety has been analyzed using GIS techniques, with the criteria that have been assigned along the roadway, which serves as the basis for the analysis.

LITERATURE REVIEW

Factors influencing Road Safety

There are several factors that influence road user safety. As stated by Ang (2020), there are seven (7) key factors of road infrastructure, which include (i) Road Geometry, (ii) Traffic Signs, (iii) Road Marking, (iv) Street Lighting, (v) Road Shoulder Width, (vi) Road Barriers, and (vii) Traffic Signal. These factors were developed by Ang (2020) and were used as the basis for the road safety measurement for this study. However, it still needs to be validated. Therefore, similar studies were reviewed to see if the factors by Ang (2020) are sufficient to measure road safety. Table 1 lists the factors that were used in measuring road safety based on the road infrastructure from previous studies. From Table 1, the inconsistencies of chosen factors (later called criteria in this study) can be seen based on the author’s interest in road infrastructure to be used. In this study, all the listed road infrastructures will be chosen as the criteria that will be used to determine road safety for both study areas.

Table 1: The Criteria of Road Infrastructure in Determine Road Safety

Author	Road Geometry	Traffic Signs & Signals	Road Marking	Street Lighting	Road Shoulder Width	Pavement Condition
(Ang, 2020)	/	/	/	/	/	
(Kanuganti et al., 2017)	/	/	/		/	/
(Budzyński et al., 2018)	/					
(Fancello et al., 2019)	/	/	/	/		/
(Martins & Garcez, 2021)	/	/				/
(Echchelh et al., 2015)		/	/			
(Nkurunziza et al., 2021)	/				/	

Spatial-MCDA in Measuring Road Safety

Nowadays, GIS has been implemented to solve various problems, one of which is related to road safety. Based on several research, the most popular techniques that have been used to measure road safety are the Multicriteria Decision Analysis (MCDA), Analytical Hierarchical Process (AHP), and Data Envelopment Analysis (DEA) method.

According to a previous study by Martins and Garcez (2021), the MCDA method is suggested for analyzing road safety over several time periods and dimensions. It compiles multiple multicriteria and multiperiod approaches for measuring road safety indicators over time. Human factors, accident causes and severity, road characteristics and conditions, and other elements are all interacting to determine a road's criticality. As a result, it is important to consider road or traffic incidents from a variety of angles. In addition, the decision maker's preferences can be taken into account while evaluating road performance across many criteria when employing the MCDA techniques. Based on the research paper written by Mohammad Azlan and Naharudin (2020), the combination of AHP and GIS methods could be used to measure road safety. There has been extensive use of a combination of the two (2) methods in spatial decision-making.

In the analysis of geographical problems, multiple criteria are constantly involved, and the relative weight of each criterion can be changed and vary. Therefore, the role of AHP is to derive the weightage for the criteria, and GIS's function is to employ the weightage in the geographical analysis. The words geographical problems and geographical analysis had the same meaning as spatial problems and spatial analysis.

GIS can address real-world issues, including road safety measurement. Since the 1990s, MCDA has been widely used in spatial planning, with recent trends extending to multi-criteria spatial decision support systems. This approach evaluates urban and regional development plans using methodologies that consider multiple dimensions and well-specified criteria (Ferretti & Montibeller, 2016). Spatial-MCDA is one of the methods to be used because the criteria that have been selected play the role of measuring whether the road is safe or not. Spatial-MCDA had various weighting methods that could aid in decision-making, including rating, ranking, and pairwise comparison. A simple way to figure out the weightage of the criteria is to put them in line with how important they are to the decision-maker. This is called the ranking method (Malczweski & Rinner, 2015). The ranking method is a simple technique used to determine the weightage of criteria in decision-making situations. It involves estimating the weightage of criteria based on a scale from 0 to 100, with the most essential criteria scoring 100. Lower criteria are given weights, and the least important criteria are scored. Pairwise comparison, developed by Saaty in 1980, uses a scale from 1 to 9 to rate preferences based on a pair of criteria.

Saaty (1990) came up with the AHP method, which is widely used nowadays in decision-making using GIS. The AHP can be used to evaluate the relative roles of qualitative and quantitative criteria. Over time, it has become an important method for dealing with problems of selection and prioritization, which involve many criteria (Kostagiolas, 2012). Ruslan et al. (2023) explains that AHP, which is known as a part of MCDM, is made up of techniques that are good for ranking an important management issue. The method also lets the user check for and get rid of inconsistencies in the opinions or judgments through a consistency test. According to Liu et al. (2020) and Othman et al. (2021), AHP is a widely used MCDA technique. It uses the pairwise comparison to figure out the weightage of criteria and the preferences of different options in a structured way. However, uncertainty might exist in any MCDA technique. Hence, fuzzy sets have been added to AHP because subjective judgments during comparisons can be difficult to make correctly. This is called Fuzzy-AHP. Fuzzy-AHP is used to make decisions for real-world issues, especially for the selection of problems. The methods are grouped into four (4) parts of making the Fuzzy-AHP model. First, it represents the display of the relative significance for pairwise comparison. Next, it is about the aggregating fuzzy sets for collective decisions and weightage or priorities. Then, it is about turning a fuzzy set into a clear value for the last comparison and, lastly, measuring the consistency of the judgments.

As a widely known way to deal with unpredictability, fuzzy sets, which were first proposed by Zadeh in 1965, are combined with AHP to make Fuzzy-AHP. This combined method maintains the benefits of AHP and has been used a lot (Mardani, Jusoh, & Zavadskas, 2015, as cited in Liu et al., 2020). In order to make a fuzzy-AHP model, the method that the user needs to set up is a comparison matrix, combine multiple judgments, check for consistency, and clear up the fuzzy weightage. AHP sets up a problem in a hierarchical way, with a goal at the top, followed by criteria, sub-criteria, and options (Saaty, 1990, as cited in Liu et al., 2020). The hierarchy gives the experts a big-picture view of the context's complicated interactions and helps them figure out if things on a similar level are similar. The weights of the elements are then found by comparing them pair by pair using nine (9) level scales. However, pairwise comparison, which is the heart of AHP, adds uncertainty because it needs the opinions of experts. In real life, experts might not be able to give exact numbers to their preferences because they do not have enough information or skills (Chan & Kumar, 2008; Xu & Liao, 2013, as cited in Liu et al., 2020).

Nevertheless, adding fuzzy sets to AHP helps the decision-maker make the process of calculation easier because there are different fuzzy sets, and the operations that go with them are complicated. AHP methods like the Eigen vector method and the geometric mean cannot be used directly to figure out the weights or preferences from a fuzzy pairwise comparison. There have been numerous ideas for how to make a Fuzzy-AHP model. There are differences in terms of its most important aspects, strengths, and weaknesses. Fuzzy-AHP has not been studied much, as far as we know, except by Kubler et al. (2016), as cited in Liu et al. (2020), who talks about how it can be used. Based on the overview of the explanation in the previous paragraph, Fuzzy-AHP has been chosen as the method for measuring road safety. The selection of criteria and sub-criteria fulfilled one of the requirements for using the Fuzzy-AHP method. Just using AHP might have some limitations.

METHODOLOGY

Figure 1 shows the flowchart of this study, which begins with the preliminary study and continues until visualization. The first stage is the preliminary study, in which the selection of criteria for measuring road safety was conducted based on previous studies as well as experts' interviews. The next stage is Data Acquisition, which is divided into two (2) parts, which are Fuzzy-AHP and GIS methods. In Fuzzy-AHP, the first step is to develop a hierarchical structure representing the dependencies between the criteria, followed by obtaining the expert's choice. In GIS data collection, field data collection was used to capture the data for the chosen road infrastructure. The next stage is Data Processing, which involves weightage calculation, defuzzification for ranking, spatial data editing, and spatial dataset of criteria. Afterward, the spatial analysis was continued to determine the road safety index, and the output obtained was the road safety index. Next, for the analysis, two (2) analysis tasks were performed: to analyze areas with high and low road safety index and to compare the road safety index in the study area. Lastly, there is the visualization phase for the map of the road safety index.

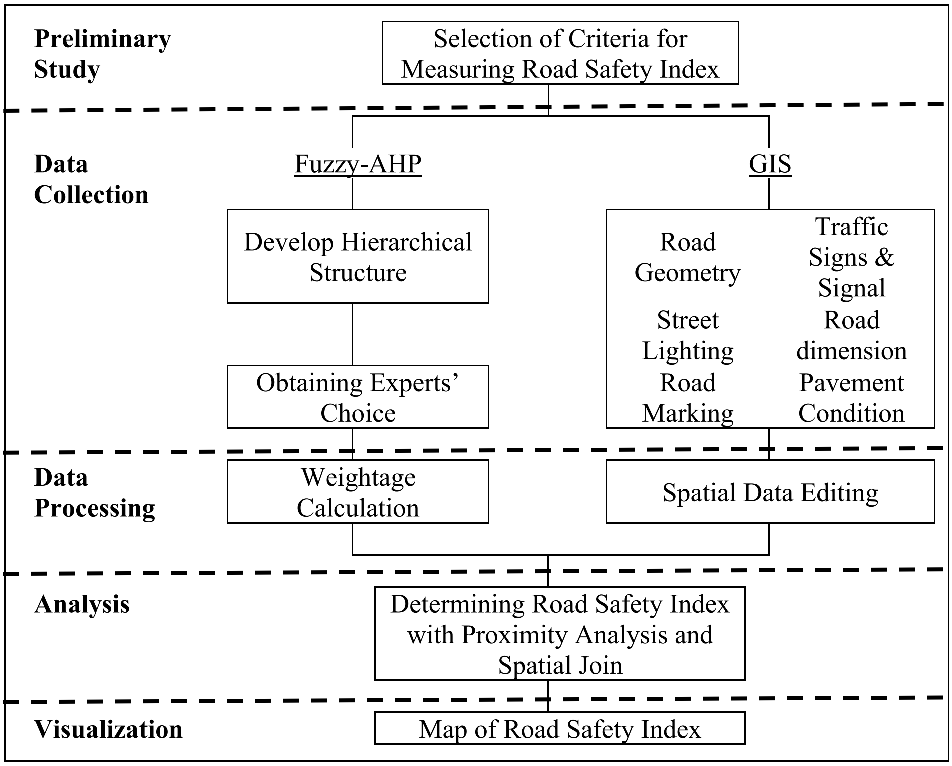

Figure 1: Research Framework

Selection of Criteria for Measuring Road Safety

In this study, the criteria that were chosen focus on the road infrastructure. The criteria may have sub-criteria to assist in analyzing road safety for road users. The criteria and sub-criteria for measuring road safety can be seen in Table 2. They were adapted from related research and journals, as described in Table 1.

Table 2: The List of Chosen Criteria and Sub-Criteria for this study

CRITERIA	SUB-CRITERIA
Road Geometry	Sight Distance
	Sharp Curve
	Drainage Provision
Traffic Signs and Signal	-
Road Marking	Road Marking Paint
	Thickness
	Laying
Street Lighting	-
Road Shoulder Width	Shoulder Width
	Quality of Shoulder
	Pavement Edge Failure
Pavement Condition	Pothole
	Cracking
	Rutting

Data Collection

The road network dataset, road infrastructure features dataset, and weightage value from experts are the data needed for this study. The road network dataset was obtained from the open-source website, while the road infrastructure features dataset was obtained by collecting data in the field by using pre-installed mobile applications on smartphones. Then, the weightage values for every sub-criterion may be obtained from local agencies or local departments. The information about the data needed is listed in Table 3.

Table 3: List of Data Requirement in this study

Method	Type	Name	Format	Use	Sources
Primary Data Collection	Aspatial Data	Expert's Choice of Criteria Values	Text Forms	To define the weightage value	Experts
	Spatial Data	Feature of Road Infrastructure	Shapefile	To represent road infrastructure along the road	Field Survey
Secondary Data Collection	Spatial Data	Road Network	Shapefile	To represent the specific road involved	Open-Source Website
	Spatial Data	Land Used	Shapefile	To get the boundary of the land of the study area	Open-Source Website

GIS Data Collection

By doing the field data collection, the location for each of the road infrastructures listed in Table 2 was obtained. The data was obtained by using a mobile GIS data collector application that was installed on the smartphone.

Fuzzy-AHP Data Collection

The step in conducting Fuzzy-AHP involves the development of a hierarchical structure and designing and obtaining an expert's choice. The expert's choice needs to be taken to obtain the rating to assist in the weightage calculation. This step needs to be utilized in this study to solve the issues with a proper process. Based on Malczewski & Rinner (2015), the values that will be used to evaluate the criteria will be treated as the most important part of the decision analysis in this chosen technique. It requires the coming up of criteria for judging the set of choices or alternatives. Figure 2 shows the key components of a problem situation that has been set up in a hierarchical structure. The goal will be at the top of the hierarchical structure, which is the Road Safety Index. Then, the hierarchy goes down to the criteria, which are the road infrastructure, until it reaches the sub-criteria.

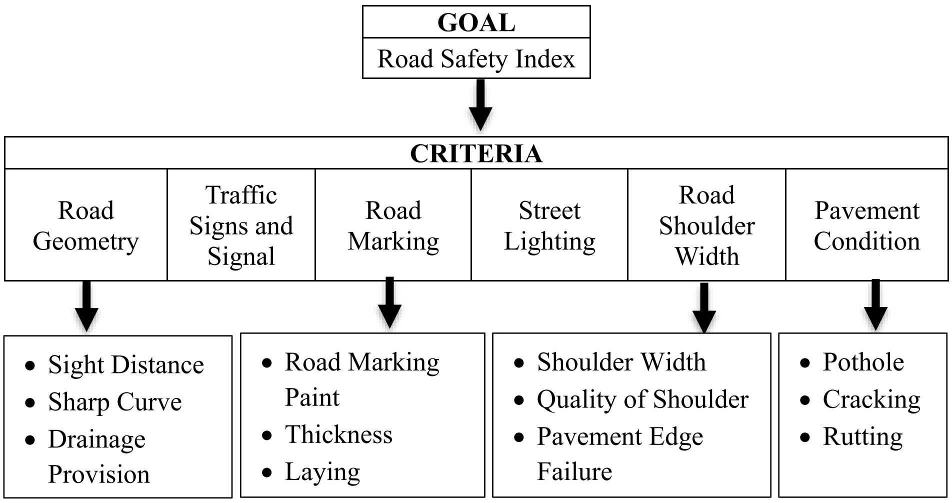

Figure 2: The Hierarchical Structure for this study

Criterion Weightage Calculation by using Fuzzy-AHP

For weightage calculation, the Pairwise Comparison technique has been utilized. The pairwise comparison method is a technique for selecting the best option from several possible choices by contrasting them in pairs. Since this study is trying to determine which roads are the safest, more than one (1) parameter has been included in the ranking method. There are five (5) steps to calculate the weightage and one (1) last step to obtain the final rank. For the first step, based on Kanuganti et al. (2017), to utilize the Pairwise Comparison in Fuzzy-AHP, the 9-point scale needs to be fuzzified. The values from 1 – 9 will be assumed to be triangular symmetrical, the internal pair and odd integers will be differentiated, and the edge values along the scale will be adjusted. Table 4 shows the Fuzzy Scale of Relative

Importance. The next step was to create the pairwise comparison matrix. The calculation method that has been chosen for this study was the Geometric Mean method by Buckley, 1985. Geometric Mean is used to calculate the weightage values. Then, the numeric values in the pairwise comparison matrix were replaced by fuzzification numbering values.

Table 4: Fuzzy Scale of Relative Importance (Kannan et al., 2013)

Crisp Values	Judgment Definition	Fuzzified Value
1	Equal	(1, 1, 1)
3	Moderate	(2, 3, 4)
5	Strong	(4, 5, 6)
7	Very Strong	(6, 7, 8)
9	Extremely Strong	(9, 9, 9)
2,4,6,8	Intermediate values	(1, 2, 3) (3, 4, 5) (5, 6, 7) (7, 8, 9)

Determining the Road Safety Index

In this study, proximity analysis was used to identify the road infrastructure that existed along the specified road. The road safety index was determined using the criteria weightage summation method. The spatial join has been used to make the process easier. The data on the road network and the features of events were combined with the aid of spatial join tools. Both data have been merged spatially in the workspace. Therefore, the criteria of event features were situated along the road dataset, which has been determined and recorded in the attribute table. To determine how many infrastructures of the road had existed along the road, the spatial join was used to combine both attribute tables.

Table 5: The Road Safety Index Classification

Classification	Value of Index			Symbolization
Very High	0.8	-	1.0	
High	0.6	-	0.79	
Average	0.4	-	0.59	
Low	0.2	-	0.39	
Very Low	0	-	0.19	

In this study, the road safety index was computed with the help of summary statistics, as the attribute of the criteria dataset was included with its own weightage value. The data from the tables' fields have been summarized using summary statistics. The sum of the weightage value has then been normalized or standardized between 0 and 1 value. The 0 represents the lowest index, and 1 represents the highest index. The lowest and highest index values can be found by normalizing the value of the safety index. Here, it could be seen that this study used the normalized value to measure the road safety index. For further analysis, the index value will then be reclassified into five (5) classes using the Equal Interval classification method, as shown in Table 5.

The highest and lowest index values that have been determined have been used to determine road safety for both study areas. If the index value is high, it represents the road is safe, but if the index value is low, it represents the road is unsafe. Here, it could be seen that the road safety index can be determined by using the Fuzzy-AHP and GIS method to analyze the efficiency of road safety. By obtaining the index value, it can be used for further actions as to improve the road infrastructure that had affected the safety of road user.

RESULTS AND DISCUSSION

The first results are the weightage of criteria and sub-criteria that were calculated by using Fuzzy-AHP. The finding for the weightage is quite different from previous studies. Kanuganti et al. (2017) showed that the top three (3) most important sub-criteria were Cracking and continuing, with Sharp Curves and Potholes. As for the Sight Distance, it has been ranked as the 4th most important sub-criteria. It differs from this study in the 1st rank was the Road Marking Paint and continues with Sight Distance and Traffic Signs and Signal. As for the 4th rank, it was the Pothole.

Table 6: Weightage of Main Criteria and their Sub-Criteria

Main Criteria	Weightage	Sub-Criteria	Weightage	Overall Priorities	Rank
Road Geometry	0.185	Sight Distance	0.659	0.122	2
		Sharp Curve	0.098	0.018	12
		Drainage Provision	0.244	0.045	8
Traffic Signs and Signal	0.121			0.121	3
Road Marking	0.392	Road Marking Paint	0.670	0.262	1
		Thickness	0.149	0.058	6
		Laying	0.181	0.071	5
Street Lighting	0.028			0.028	10
Road Shoulder Width	0.116	Shoulder Width	0.494	0.057	7
		Quality of Shoulder	0.139	0.016	13
		Pavement Edge Failure	0.367	0.043	9
Pavement Condition	0.159	Pothole	0.764	0.121	4
		Cracking	0.103	0.016	14
		Rutting	0.133	0.021	11
Total	1.000			1.000	

In addition, Fancello et al. (2019) indicate that Sight Distance is the most important factor for road safety, followed by the condition of the road surface and traffic flow. Another study by Nkurunziza et al. (2021) basically focuses on Road Geometry, which includes the lane width, curve radius, sight distance, super-elevation, and grades, which are the longitudinal slope. As mentioned in the previous study, there is an inconsistency in rating the safety parameters. Lane width has been rated at 74%, curves have been rated at around 80%, sight distance at 96%, and 5% for super-elevation. In conclusion, there are different rankings for each sub-criteria due to the different sub-criteria that have been assigned as the factors to measure the safety of roads.

Road Safety Index

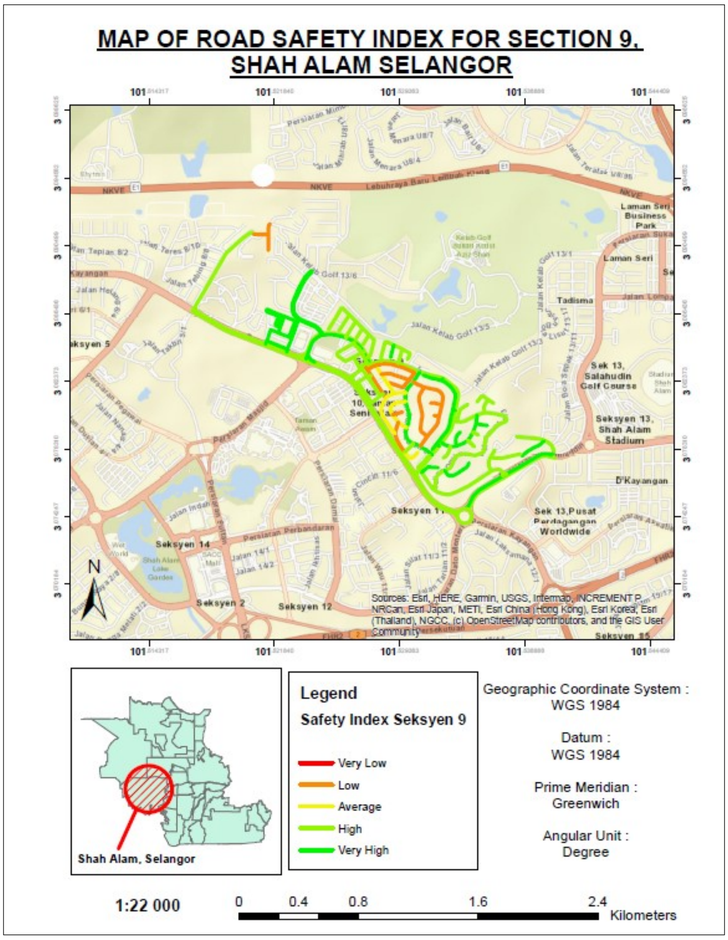

Figure 3: Map of Road Safety Index

Figure 3 shows the map of the road safety index for Section 9, Shah Alam Selangor. Most of the roads in Section 9 had a high index of road safety. There is part of Section 9 roads that are in a low and average index of road safety. Based on observation on site, in the area with the low and average safety index, there are parts of the road that had no Road Markings and had several poor

Pavement Conditions. Therefore, this is the factor that caused the index value to become low and average. Basically, most of the roads in Section 9 followed the specifications of road safety. There are almost 16 roads with a very high safety index and 33 roads having a high safety index. There are four (4) roads in Section 9 Shah Alam, which have an average value of safety index, and 11 roads with a low safety index.

Analyzing the Impact of Road Infrastructure Existence on Road Safety
According to site verification, the criteria of Road Marking and several Pavement Conditions are the reasons why the road being presented was an average in the safety index. Figures 4 and 5 and Tables 7 and 8 show different classes of the Road Safety Index. This analysis was conducted to test the impact of the existence and weightage of road infrastructure on the road safety index and validate the method chosen. As mentioned previously, road marking has the highest ranking among the overall sub-criteria. Therefore, if the road has no road marking, it will affect the index value and will make the index value of the road near the low safety index value.

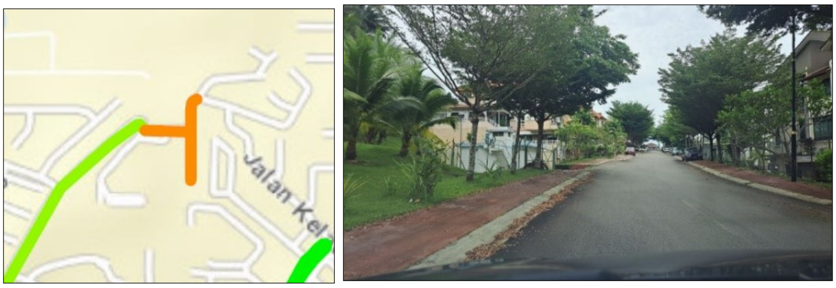

Figure 4: Example of Road without Road Marking

Table 7: Example of Road Safety Index for Road without Road Marking

Traffic Sign & Signal/ Street Lighting/Pavement Condition	Sight Distance	Sharp Curve	Drainage Provision	Road Marking Paint	Thickness	Laying	Shoulder Width	Quality of Shoulder	Pavement Edge Failure
	Exist	Exist	Exist	None	None	None	Exist	Paved	None
Weightage Value									
0.028	0.122	0.018	0.045	0	0	0	0.057	0.016	0.043
Sum of Weightage Value									
0.028	0.122	0.018	0.045	0	0	0	0.057	0.016	0.043

Figure 4 and Table 7 show the road that does not have Road Markings. Therefore, the weightage value for the sub-criteria of Road Marking Paint, Thickness, and Laying will be 0. For the Pavement Edge Failure, the failure does not exist; therefore, the safety index will be added up with the weightage value of 0.043. Therefore, the final safety index for this road was 0.329. Figure 5 and Table 8 show that the road was in great condition. The weightage value from the criteria and sub-criteria had increased the safety index of the road. The pavement edge failure existed, but it did not affect the safety index, as the weightage value was 0. If the Pavement Edge Failure does not exist, the safety index may be added up with the weightage value of 0.043. In this case, the Pavement Edge Failure had existed; therefore, the weightage value that needed to be added up was 0. However, as the value of the safety index is near to 1, therefore the road may be categorized as a high safety index.

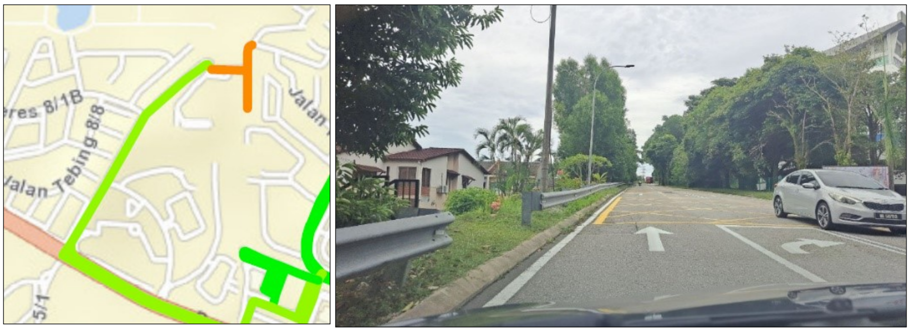

Figure 5: Example of Road with Road Marking

Table 8: Example of Road Safety Index for Road with Road Marking

Traffic Sign & Signal/ Street Lighting/Pavement Condition	**Sight Distance**	**Sharp Curve**	**Drainage Provision**	**Road Marking Paint**	**Thickness**	**Laying**	**Shoulder Width**	**Quality of Shoulder**	**Pavement Edge Failure**
	Exist	Exist	Exist	Exist	Exist	Exist	Exist	Paved	Exist
Weightage Value									
0.121	0.122	0.018	0.045	0.262	0.058	0.071	0.057	0.016	0
Sum of Weightage Value									
0.121	0.122	0.018	0.045	0.262	0.058	0.071	0.057	0.016	0

CONCLUSION

The aim of this study is to measure road safety by using an integrated method of Fuzzy-AHP and GIS. Utilizing Spatial-MCDA enables the integration of spatial aspects into the analysis. Spatial-MCDA provides an in-depth understanding of how spatial factors influence differences in road safety. In MCDA, relative weight is assigned to each criterion based on its relevance. In this study, the appropriate weightage value for road safety-related criteria has been determined.

These weighting values reflect the importance of each criterion in influencing road safety outcomes. By analyzing the identified criteria and their relative weights, the evaluation identifies which roadway segments have a high or low safety index. The findings of this study show that most roads in the study area have a high road safety index value, while only a few roads have an average value. This study focused on road infrastructure and related pavement conditions. Based on the analysis, it can be concluded that the road safety index is influenced by the existence of road infrastructure and the condition of road pavement. It is expected that the road safety index found in this study will have important effects on the assessment and future planning of road safety. The novelty of this study resides in its use of Fuzzy-AHP and GIS to measure the road safety index. The use of Fuzzy-AHP in this study allowed for a more comprehensive and precise analysis because it took into consideration all the criteria and expert judgments related to road safety issues. Also, by using GIS, things could be seen from the spatial perspective, which brings more insight into where and what factors specifically are responsible for the differences in road safety that occurred in both areas. By combining these approaches, a better evaluation could be done, which may contribute to the improvement of road safety and make educated choices about how to make improvements to the roads.

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