Geographical Information System for Mapping Accident-Prone Roads and Development of New Road Using Multi-Attribute Utility Method

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Abstract— **The means of transportation development which are not offset by adequate roads construction will lead the traffic density exceeds the volume capacity of the roads. This will cause the access road difficult to pass thus often raises the risk of traffic congestion and lead to traffic accidents. This paper will discuss the use of Geographical Information System (GIS) technology in analyzing spatial data and attribute data (geoprocessing layer) in the form of mapping accident-prone roads and mapping dense traffic lanes as an alternative to the development of new road using Multiple-Attribute Utility Theory (MAUT) method. Geoprocessing layer test conducted on the roads in Gresik District, Indonesia shows the accident-prone roads mapping points, with the average yield of low-risk accident-prone roads are 58%, 24% are low-risk accident-prone roads and 18% roads condition are high-risk accident-prone roads. Geoprocessing for alternative development of new road as the consequences of the density of traffic lanes, in which the uncrowded road categories are 36%, dense road 32% and very dense roads 32%. This system can be used by the government of Gresik District as the decision makers to plan for the alternative development of new road area, therefore traffic density can be minimized.**

Keywords— ***GIS; MAUT; geoprocessing, layer, dense traffic lanes; accident-prone lanes***

I. INTRODUCTION

Gresik is an industrial area with a dense population. It is also categorized as an area that frequently passed by light vehicles to heavy vehicles. The highways in Gresik District reach 626.6 Km, which are consist of 67.62 Km state roads. 32.80 Km provincial roads and 525.84 Km district roads. From the total length of the district roads, the 25.30% are in good condition, the 44.37% are categorized as medium damaged roads, the 30.33% are lightly damaged roads and the 30.33% are heavily damaged roads category [1].

The unbalanced comparison between the volume of vehicles and the road capacity causes several traffic congestions, especially during rush hours. This is due to the lack of equal distribution of traffic density. In addition, traffic congestion is one of the factors that increase the number of accidents. Congestion in Gresik is affected by the roads condition and the traffic volume especially during peak hours. It frequently happens in the center of economic activity such as markets, schools, terminals, industries and parking lots in the roadside.

Geographical Information System (GIS) is designed to address this issue. It has the ability to map and analyze spatial data with spatial analysis as well as time analysis (temporal analysis) that generates an integrated analysis covering all aspects [2]. Informed decision-making and problem solving rely on effective communication, exchange of ideas and information, the type and amount of necessary information available to overcome the particular decision problem related to the complexity of the situation [3]. Spatial decision problems often require a lot of viable alternatives that can be evaluated based on multiple criteria. Spatial decisions are multi-criteria in nature [4].

The previous research as in [5] —Identification and Analysis of Accident Black Spots Using GIS stated that accident-prone areas occur because road users do not grasp the road condition, based on the number of accidents in the last three years using *ArcGIS software*. Other previous studies as in [6] — Prioritization of Accident Black Spots using GIS stated that the number of driving accidents throughout the world is estimated 3,00,000 people died and 1–1,5 million people were injured. Human population and the increasing number of vehicles are the main cause of driving accidents, by using *ArcGIS software* the largest number of those accidents is marked with black spot.

Geoprocessing layer or Spatial analysis in this paper use Multi-Attribute Utility Theory (MAUT) method to map accident-prone roads based on the parameter of road data, dense road data, and accident occurrence data. This method is also used for mapping dense traffic roads based on their parameters such as the number of industries, schools, markets, and parking lots. Prior to the using of MAUT method, the weight and the priority value were firstly set up to each criterion. Then the calculation process will be conducted using MAUT method.

This paper can be useful for further researchers as a reference to develop mapping technology using web-GIS based which can help people to find out information concerning accident-prone points and dense traffic lanes. Through this system, the government of Gresik as the decision makers can develop plans of new road areas, therefore the density of traffic lanes can be minimized. This is also an alternative to roadworks to reduce the number of accidents. This system can also help the government

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to install traffic controller tools and more particularly at certain points that identified as accident-prone as a warning system to people so they will be more cautious.

II. Research Methodology

GIS can be defined as geoprocessing layer that has been processed into a form that is useful to the recipient. Geoprocessing layer in GIS uses separate thematic maps or data sets referred to as a map layer, coverage, or level. Object oriented GIS are alternative to layer approach in which the objects are intended to closely represent real-world elements. Regardless of spatial data, the ultimate goal of GIS is to provide support for spatial decisions with multi-criteria decision making [7]. *Geoprocessing layer* of this paper uses MAUT method to map accident-prone roads based on the parameters of road data, dense traffic lanes data and accident occurrences data, as well as mapping dense traffic roads based on the data parameter on the number of industries, schools, markets and parking lots. Prior to the using of MAUT method, the weight and the priority value were firstly set up to each criterion. Then the calculation process was conducted using MAUT method.

A. Parameter of Analysis

The data outlined in layers and tables subsequently determined the weight and the priority value in each parameter criterion to be used for the analysis using MAUT method [1].

- Analysis of map information of accident-prone roads' points. The parameter of this analysis determined by inputting weight in the road layer data, dense layer, and traffic accident layer as shown in Table I to Table III. The parameter priority value used is shown in Table IV.

Table I. Criterion Weight of Road Layer

Road Condition	Weight
Heavily Damaged Road	5
Medium Damaged Road	3
Good	1

Table II. Criterion Weight of Dense Traffic Lanes Layer

Density Level (on average per day)	Weight
0.91-0.1	5
0.81-0.90	4
0.71-0.80	3
0.61-0.70	2
0.51-0.60	1

Table III. Criterion Weight of Traffic Accident Layer

Total Accident Rate (death)	Weight
≥101	5
76-100	4
51-75	3
26-50	2
1-25	1

Table IV. Parameter Priority Value

Parameter	Priority Value	Total Criterion
Road Layer	20	3
Traffic Density Layer	50	5
Traffic Accident Layer	30	5

- Analysis to display the alternative information of new roads development as a consequence of the dense traffic lanes. Parameter on this analysis is determined by inputting weight on the road layer data as shown in Table 1, the number of industry layer, school layer, market layer, parking lots layer and terminal layer as shown in Table 5 to Table 8 below. The parameter priority value used is as shown in Table 9.

Table V. Criterion Weight of Industry Layer

Total Numbers of Industrial Sites on Criterion Road	Weight
≥21	5
16-20	4
11-15	3
6-10	2
≤5	1

Table VI. Criterion Weight of School Layer

Total Numbers of Schools on Certain Road	Weight
≥21	5
16-20	4
11-15	3
6-10	2
≤5	1

Table VII. Criterion Weight of Market Layer

Total Numbers of Markets on Certain Road	Weight
≥21	5
16-20	4
11-15	3
6-10	2
≤5	1

Table VIII. Criterion Weight of Parking Lot Layer

Total Numbers of Parking- Lot on Certain Road	Weight
≥21	5
16-20	4
11-15	3
6-10	2
≤5	1

Table IX. Parameter Priority Value

Parameter	Priority Value	Total Criterion
Road Layer	20	3
School Layer	20	5
Market Layer	20	5
Parking Lot Layer	20	5
Industry Layer	20	5

B. Geoprocessing Layer

The initial step in the process of geoprocessing layer is digitizing the analog map to input all the data attributes, parameters, and criteria. They will keep in the form of shape files (*.shp) which will be a layer. Then the buffer process was conducted to create a polygon from the layer area. After the layer buffer was formed, a union process was conducted to unite main layer data with area layer. The layer produced from the union process consists of several layers which were out of the reach from the real layer. They were thrown away using intersect process. The process of analyzing accident-prone roads is shown in Fig.1, while the analytical process of the dense traffic lane is shown in Fig.2.

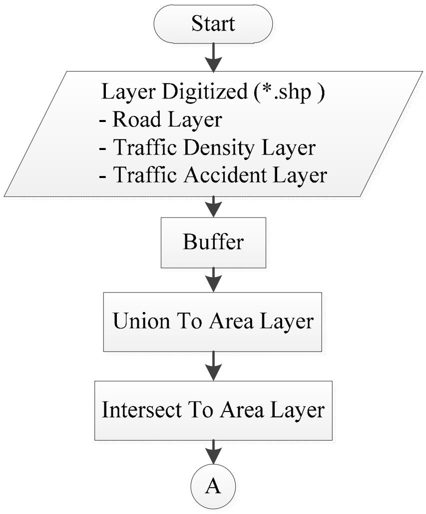

Fig. 1. Geoprocessing layer of accident prone roads

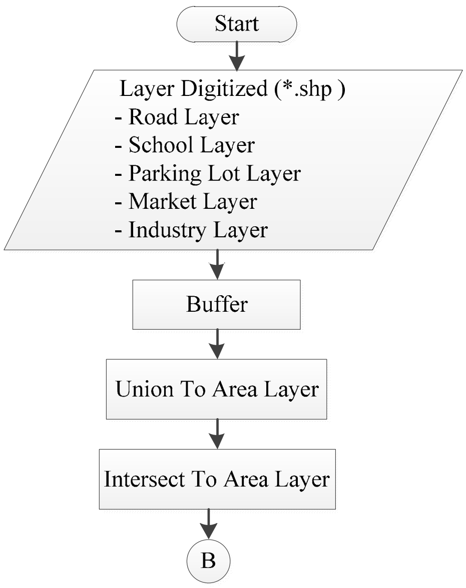

Fig. 2. Geoprocessing layer of alternative development of the new road

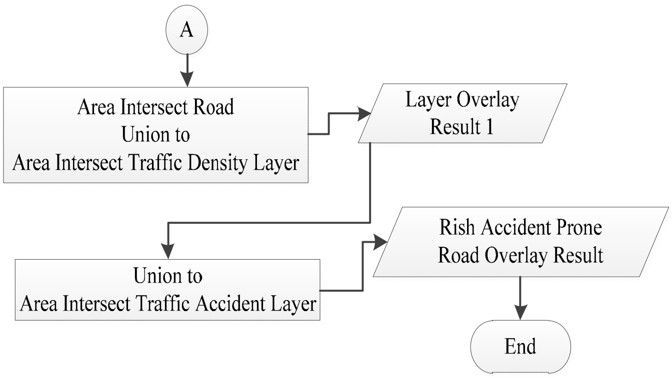

Fig.3. Overlay result of accident-prone road

The intersect layer resulted from the process shown in Fig.1 and Fig.2, which is to be used for the layer union process in each layer intersect that serves to get the overlay layer. The layer which is to be used for the analysis of accident-prone roads as shown at the overlay layer process in Fig.3 and the layer to be used for the analysis of new road development alternative as a result of the dense traffic lanes as shown in overlay layer process in Fig.4.

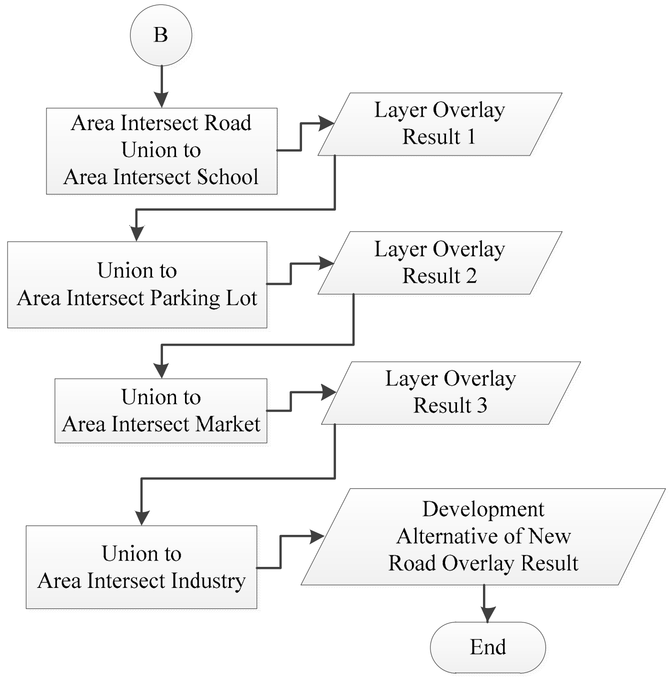

Fig.4. Overlay result of alternative development of new road as a consequence of dense traffic lanes

C. *Framework for Spatial with MAUT*

The method used to display the mapping information was MAUT method by determining the weight and the priority value for each parameter. GIS-based multi-criteria decision analysis is a process that combines and transforms spatial data into a resultant decision. The spatial layer is decision rule which defines a relationship between the processes of spatial data and attributes. The procedures use geographical data, the decision makers' preferences, data manipulation, and preferences according to decision rules. Considerations of critical importance for spatial with MAUT method are the GIS capabilities of data acquisition, storage, retrieval, manipulation, and analysis. Spatial layer with MAUT method is used to combine the ability of the geographical data and the decision maker's preferences into one-dimensional values of alternative decisions [8]. The most common is the additive model.

$$U(A_i) = \sum_{k=1}^{K} w_k \, u_k(x_{ik}), \qquad (1)$$

where $U(A_i)$ represents the utility of the alternative i, w_k represents the weight of the criterion k, and $u_k(x_{ik})$ is the utility of criterion k of alternative i given that the value of criterion j of alternative i is x_{ik}. The utility of each criterion is not necessary to be linear. The spatial analysis to map the accident-prone roads using MAUT method is shown in Fig.5

and the spatial analysis to map the development of new road alternative using MAUT is shown in Fig.6.

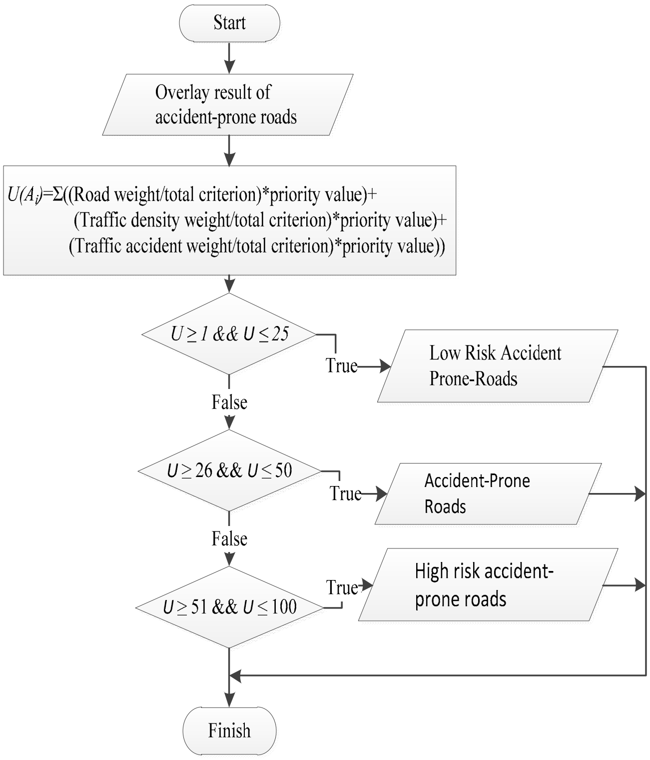

Fig.5. Geoprocessing layer flow of overlay layer on accident-prone road

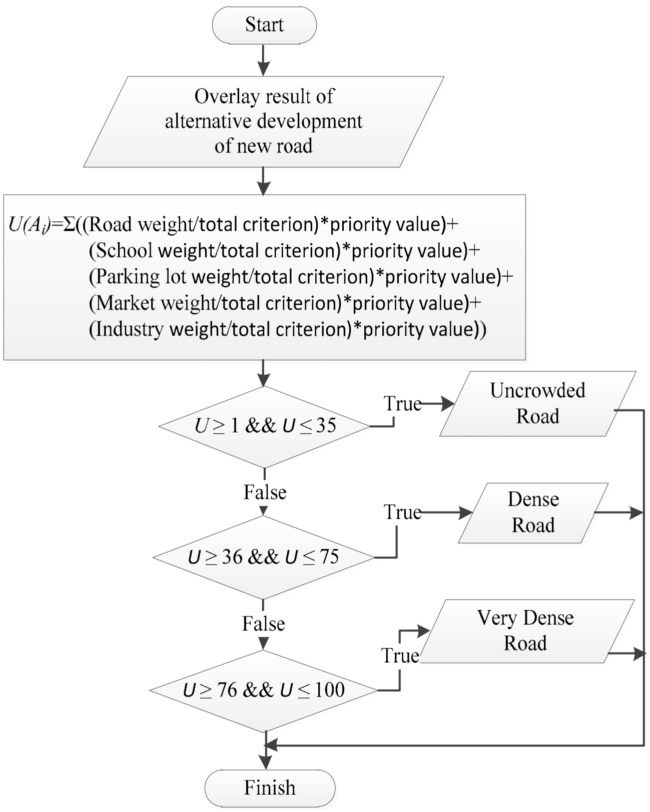

Fig.6. Geoprocessing layer flow of overlay layer for new road alternative development

III. Result and Discussion

There are 432 geoprocessing layer roads were researched, which are consist of provincial roads, district roads, and the highways in Gresik District. The test was conducted using sampling method.

Geoprocessing layer is to determine the mapping of accident-prone roads using MAUT method, as the result presented in Fig.7. The condition of the road is categorized as heavily damaged road with the weight of 5 which refers to Table I. The daily average of traffic density of the road is 0.92583 on average per day with the weight of 5 which refer to Table II. Total traffic accident number occurrences on the road were 8 with the weight of 1 which refer to Table III. After all the parameters included then the calculation process performed using MAUT method which refers to (1) in which the priority value of the parameter refers to Table IV. The calculation result is U= 89. The result matches the flow in Fig.5 and it is concluded that Jl. Raya Cerme Lor Gresik, Indonesia is categorized as a very high-risk accident-prone road.

Case study at Jl. Raya Dampaan Gresik, Indonesia is shown in Fig.8. The condition of the road is categorized as a medium damaged road with the weight of 3, the daily average of traffic density of the road is 0 on average per day with the weight of 0. Total accident occurrences on the road were 0 accidents with the weight of 1. After all the parameters included then the calculation process performed which refers to (1) using priority value of the parameter, with calculated U= 26. The result matches the flow in Fig.5, therefore it is concluded that Jl. Raya Dampaan Gresik, Indonesia is categorized as a low-risk accident-prone road.

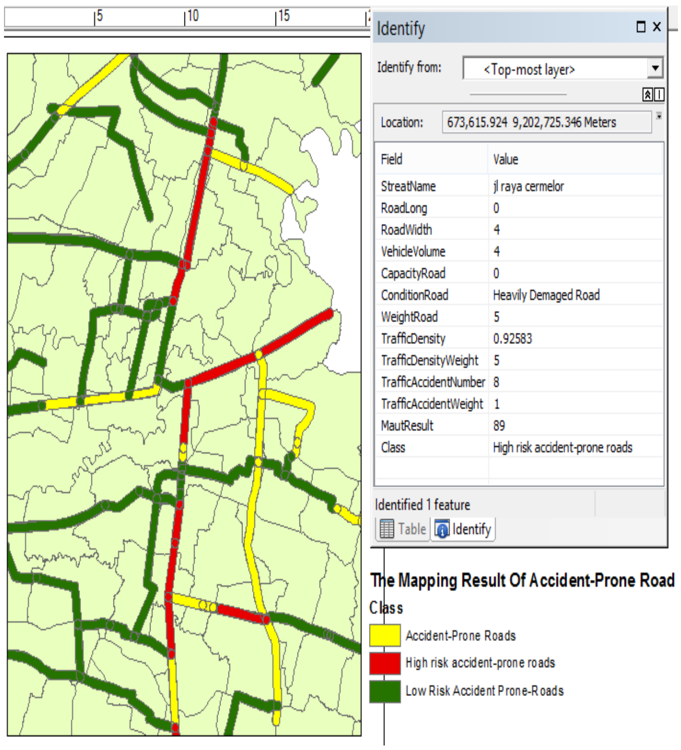

Fig.7. The mapping result of accident-prone roads (case study of high-risk accident-prone roads)

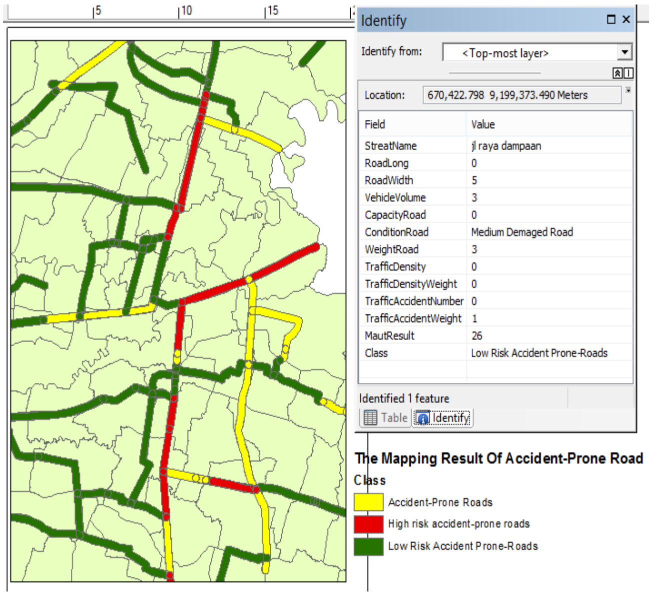

Fig.8. The mapping result of accident-prone roads (case study of low-risk accident-prone road)

Using MAUT method, geoprocessing layer considers the mapping of the alternative development of new road is a result of the dense traffic lane as shown in the result in Fig.9. The road is categorized as heavily damaged road with the weight of 5 that refers to Table I. The number of school on this road is 0 with the weight of 0, which refers to Table VI. The number of the markets on this road is 0 with the weight of 0, which refers to Table VII. The number of parking lot on this road is 0 with the weight of 0, which refers to Table VIII. The number of industries on this road is 24 with the weight of 5, which refers to Table V. After all the parameters included then the calculation process performed using MAUT method which refers to (1) in which the priority value of the parameter refers to Table IX with the calculated U = 53. The result matches the flow in Fig.6 and it is concluded that Jl. Raya Kedamean is categorized as a very dense road, therefore it is necessary to develop new road as the area around the road is categorized as an uncrowded traffic roads.

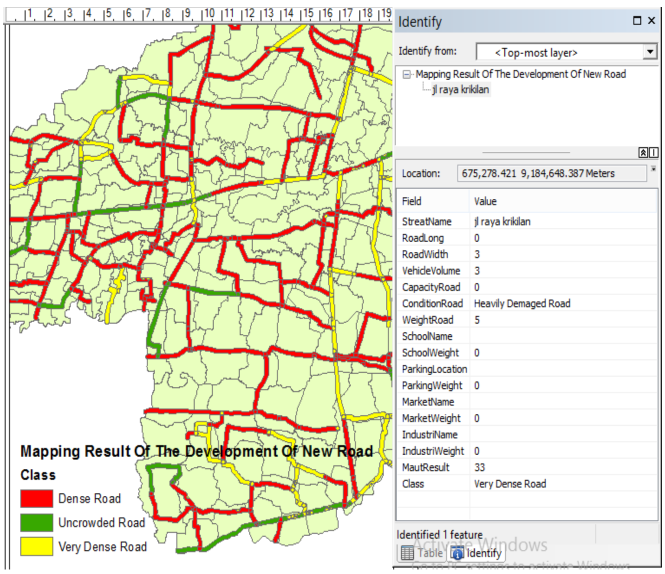

Fig.9. The result of geoprocessing on alternative development of new road as consequence of dense traffic lanes

IV. Conclusion

Based on the geoprocessing layer that has been done using MAUT method, the government of Gresik District as the decision makers can use this system as an alternative option to develop new road, by firstly consider certain lane points which not categorized as dense traffic lanes. These results will be used as a reference for further research to bring the system to the development of GIS application using web technologies.

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