Routing the highway development by using SuperMap Least Cost Path Analysis (LCPA) and Multi-Criteria Decision Analysis (MCDA) and its assessment toward spatial planning

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Abstract. Highway as road network connectivity plays an important component in regional development that can overcome inter-regional development gaps. Spatial planning and cost priorities of the highway projects must be considered when examining the optimal highway routes, especially in areas that have varied slope characteristics like in Sukabumi-Cianjur area. Therefore, analysis and modeling are needed to show the choice of effective and efficient highway routes amid environmental condition in the region. Least Cost Path Analysis (LCPA) and Multi-Criteria Decision Analysis (MCDA) can be used to determine the optimal route of a road network. This modeling uses various criteria such as topography, geology, land use, and multi-hazard areas with three MDCA and LCPA simulation models. Based on the suitability of highway development with spatial planning in 2030 using scoring assessment, the optimal highway route from Sukabumi-Cianjur is LCPA-MDCA 1 with total score 69.06 and 49% length of the route that is suitable. Meanwhile LCPA-MDCA 3 shows total score 65.6 with 48.8% length that is suitable, and the least optimal route is LCPA-MDCA 2 with total score 65.48 and 44.6% length of the route that is suitable.

1. Introduction
Land use planning is usually dependent on an efficient corridor and main road network system [1]. Transportation accessibility is one of the important factors in city development and has been a key in sustainable city development [2]. The connectivity of the road network plays a vital role in spatial structure of city area, especially related to socio-economics activities within the city [3]. Transportation development, as one of infrastructure development indicator, has positive correlation with the regional development [4]. Therefore, regional development can be enhanced by building transportation infrastructure such as highway within the area.

The connectivity conception itself in Indonesia include as manifestation at RPJMN (Rencana Pembangunan Jangka Menengah Nasional/National Middle Range of Development Planning) 2015-2019 that must to be implemented and become one of vision in Nawa Cita, namely the strength of national connectivity [5]. One of the project that is studied and included in National Strategic Project 2019 is the development of Sukabumi-Cianjur-Padalarang Highway. This highway is planned will have 31,98 km long that started from the last IV section of Bogor-Ciawi-Sukabumi (Bocimi) Highway in Priangan Jaya Village, Sukaraja District, Sukabumi Regency and ended in Sukasirna Village, Sukaluyu District, Cianjur Regency. There are six traces that has been studied, namely from Sukaraja, Sukabumi Regency through Warungkondang, Cilaku, Cianjur, Karangtengah, and Sukaluyu. However, it needed
efficient and effective planning with considering the connectivity aspect, accessibility, and mobility so that it can influence the socio-economic development enhancement [6].

Highway route design is a difficult process due to the complex structure of the environment [7]. It is a very complicated process requiring many different criteria for various areas to be evaluated simultaneously, include of geographical, social, economic, and environmental aspects with their obstacles [8]. The environmental and cost priorities of the highway projects must be considered when examining the most suitable highway routes [7]. Therefore, geographic information system with SuperMap Least Cost Path Analysis (LCPA) dan Multi-Criteria Decision Analysis (MCDA) model approach is used to determine the optimal route of Sukabumi-Cianjur highway effectively and efficiently. Recent progress in studies of least-cost paths has shown great promise in making realistic applications [9]. This method using the algorithm for finding the cheapest route (least cost path) between two nodes. In the application, this method is arranged by multi-criteria decision that considering several variables, namely topography, geology, land cover, and multi-hazard for finding the optimal route in case of network road development. Moreover, this study will assess the suitability of highway development with spatial planning in study area in 2030.

2. Method

This research was conducted in two regencies, namely Sukabumi Regency and Cianjur Regency. Geographically, these areas located in 60 46' 23" S – 60 58’ 44" S and 1060 56' 21” - 1070 19’ 1” E. As National Strategic Project 2019, there are six areas that studied for the Sukabumi-Cianjur Highway development, namely Sukaraja, Warungkondang, Cilaku, Cianjur, Karangtengah, and Sukaluyu.

The determination of the optimal route of Sukabumi-Cianjur Highway is conducted using SuperMap Least Cost Path Analysis (LCPA) and Multi-Criteria Decision Analysis (MCDA) method. Least-cost modeling is based upon a GIS raster called a cost-surface (otherwise known by combinations of cost, friction, permeability, or resistance and layer, grid, map, raster, or surface) [10]. Least cost path analysis as a distance operation will calculate the value of multivariable to examine the path between two points or locations. In this analysis, as its name, the least-cost-path will determine the “cheapest” and the shortest path through the least value between the source and destination point.

Least-cost path analysis (LCPA) allows designers to find the “cheapest” way to connect two locations within a cost surface which can be computed by combining multiple criteria, and therefore by accounting for different issues (environmental impact, economic investment, etc.) [1]. The cost is multivariable, which real model of problems, such as the function of time, suitability, and risk reduction. The cost must, therefore, be calculated in different ways, such as a measure of the distance from a terrestrial resource, alternative measures of physical ease of access, or using the cultural logic that people use to choose where they travel. Commonly employed least-cost path (LCP) analysis relies on the underlying cost matrix [11]. To calculate least-cost routes across a cost-surface, most GIS least-cost modelling approaches convert the raster cost-surface into a weighted lattice graph for processing [10]. Meanwhile,

Multi-Criteria Decision Analysis or Spatial Multi-Criteria Evaluation is one of the decision support system analysis in regional planning that using a simulation model and several criteria and factors [12]. The criteria that chose is a conceptual model that considered an important variable in regional determination. Cost raster are calculated using the following formula below, where \((e)\) are the accumulated-cost between neighbouring vertices \((a,b)\) defined as the product of the mean cost value \((c)\) and the Euclidean distance \((d)\) between the centroids of the neighbouring cells.

\[
e_{a,b} = \frac{c_a + c_b}{2} 	imes d_{a,b}
\]

While this paper uses the Multi-Criteria Decision Analysis (MCDA) to support the analysis of LCPA [13], did not use any multi-criteria processing to determine the path. Processed the cost surface in order
to determine the suitability level [13]. Meanwhile, [14] use the same principle of MCDA before process the LCPA. They used the weighting criteria to determine the suitability area for cycling path in Singapore. [14] used nine criteria to create suitability analysis, namely slope, pedestrian traffic, major roads, education institution, community facilities, the presence of retail amenities, employment area, the presence of MRT/LRT station, and bus stops.

This research used four main variables, there are geology, slope area, land use, and multi-hazard index. Geology data was collected from Geology Survey Agency, slope area was collected from the ALOS-PALSAR DEM processing, land use of 2017 scale 1:50,000 collected from Geospatial Information Agency, and multi-hazard index (landslide hazard, earthquake hazard, and flood hazard) was collected from National Agency of Disaster Reduction. The usage of these variables was referred to as the basic requirement in highway building which consider the economic, safety, environment, and social aspects.

The area that will be developed requires to fulfill the safety requirements from hazard/disaster, economic benefit, morphology stability, and the regional allotment so that it needed the standardization for each variable by giving the suitability score. This process was conducted by using Multi-Criteria Decision Analysis (MCDA) method. Table 1 visualizes the score for each variable.

| Table 1. Score of variables MCDA [15,16] |
|------------------------------------------|
| No | Variables | Classification | Score |
|----|-----------|----------------|-------|
| 1  | Land use  | Water body     | 10    |
|    |           | Shrubs         | 2     |
|    |           | Primer Forest  | 9     |
|    |           | Cultivation    | 4     |
|    |           | Village settlement building | 6 |
|    |           | City settlement building | 5 |
|    |           | Paddy field    | 3     |
| 2  | Geology (lithology) | Basaltic-Andesit | 6 |
|    |           | Alluvial        | 1     |
|    |           | Andesit Hornblende | 8 |
|    |           | Andesit         | 7     |
|    |           | Claystone       | 3     |
|    |           | Sandstone-siltstone | 3 |
|    |           | Tuff and breccy | 2     |
|    |           | Young volcanic stone | 5 |
|    |           | Cantayan        | 3     |
|    |           | Mount Gede Breccia sediment | 4 |
|    |           | Old volcanic stone | 6 |
| 3  | Slope area *(°)* | 0-2 | 1 |
|    |           | 2-5            | 2     |
|    |           | 5-8            | 3     |
|    |           | 8-11           | 4     |
|    |           | 11-15          | 5     |
|    |           | 15-19          | 6     |
|    |           | 19-23          | 7     |
|    |           | 23-36          | 8     |
|    |           | >36            | 9     |
| 4  | Multi-hazard Index | 0-0.33 | 1 |
|    |           | 0.33-0.66      | 5     |
|    |           | 0.66-1         | 10    |
Input variables in MCDA processing will be made into cost surface information through three different simulations. The difference of each simulation lies in the weighted of each variable (land use, geology, slope, and multi-hazard index). The rule of these weighted was referred to [15,16]. The rule of how weighted given was depending on the expected condition LCPA result. Table 2 shows the weight of each variables in the three simulations.

| LCPA Model | Multi-hazard Index | Land use | Slope Area | Geology |
|------------|--------------------|----------|------------|---------|
| 1          | 25                 | 25       | 25         | 25      |
| 2          | 30                 | 40       | 20         | 10      |
| 3          | 10                 | 10       | 35         | 45      |

The cost surface that has been processed then will then be referenced for the cost distance determination. In this stage, we will be choosing two nodes that represent the origin point and destination node. These two nodes will become a connection for the least-cost path route that simulated in this research case, the origin node was located in Sukaraja District, meanwhile, the destination node located in Sukaluyu District referred to the National Strategic Project 2019 of Sukabumi-Cianjur Highway Development. The flowchart work of this research was demonstrated in Figure 1.

![Flowchart Work](image)

Table 3. Land Use Weight for Highway Development with Spatial Planning

| Classification          | Score (%) |
|-------------------------|-----------|
| Production Forest       | 40        |
| Cultivation             | 60        |
| Village settlement      | 40        |
| City settlement         | 40        |
| Dry Land Agriculture    | 90        |
| Wet Land Agriculture    | 80        |
| Flood Plain             | 0         |
| Industrial Zone         | 100       |

Meanwhile, the Table 3 shows the weighted of each land use to spatial suitability planning in 2030 and to determine which route mostly suitable or optimum for the highway development. The calculation for determining its suitability is conducted using the scoring assessment with following formula (Formula 2), where ($S$) is the total suitability of highway development spatial planning, ($l$) is the length of each
land use segment in the route modelling, \((L)\) is the total length of the route, \((W)\) is the weight of each land use spatial planning.

\[
S = \sum_{k=0}^{n} \frac{l_{a,b}}{L_{a,b}} W_{a,b}
\]  

(2)

3. Result and Discussion

SuperMap Model Least Cost Path Analysis (LCPA) that shows the optimal route of Sukabumi-Cianjur Highway was created from the modeling Multi-Criteria Decision Analysis (MCDA). MCDA modeling of Sukabumi-Cianjur Highway was conducted through four main variables, there are geology, slope area, land use, and multihazard index and simulated with three simulations. While Terh & Cao (2018) used four simulations to create the suitability model according to the preferences of stakeholders such as public, government planner, transportation expert, and combined stakeholder, this research used three simulations according to the weighted score for each criterion. The first model emphasizes the equal weighted for all factors. Meanwhile, the second and third model emphasize the factor of landuse and the geology, respectively, to create the suitability. Figure 2 represents the result of the MCDA modeling of Sukabumi-Cianjur Highway with three simulations.

![Figure 2](image)

In Figure 2, the result of the MCDA model was represented by the colour gradation from green-cream-red. The green colour shows the area with MCDA high score, cream colour shows the MCDA moderate score, and red colour shows the MCDA low score. From those three simulations, generally, the area which has high cost surface value agglomerated in two zones, namely in southern and northern Sukaraja.
District and Warungkondang District. Simulation 3 shows the extent area with cost surface value that greater than model simulation 1 and 2. The distribution of cost surface value area from Sukaraja District node to Sukaluyu District node generally shows the same value represented by the red colour area. Then, the determination of the route will be done at the cost distance surface stage, where LCPA algorithm will find the area with high cost surface value. The high cost surface value will be referenced and priority for the route selection.

![Figure 3](image)

**Figure 3.** The result of cost distance (left): model cost distance 1 (a), cost distance 2 (b), cost distance 3 (c). The result of cost backlink (right): model cost backlink 1 (a), cost backlink 2 (b), cost backlink 3 (c)

![Figure 4](image)

**Figure 4.** The result of optimal route Sukabumi-Cianjur using LCPA.

The green line visualized LCPA 1, LCPA 2 visualized by the blue line, and the bold red line visualized the last LCPA 3. The optimal route of highway based on the LCPA 1 model was created 44.2 km length. LCPA 2 model was formed 43.88 km length. Meanwhile, the LCPA model 3 was created 43.99 km. The length that formed from these models was not different from the length of the highway planned by the Ministry of Public Work and Housing of Indonesia as long 31.98 km. The LCPA 1 and LCPA2 also have the long junction each other in Sukaluyu District. Meanwhile, near the origin node area, the route has not a junction. The distribution of the LCPA model 3 route was different from the two other models. Its result difference can be understood because of the difference in cost surface value in MCDA 1, MCDA 2, and MCDA 3. The similarity between LCPA 1 and LCPA 2 can be recognized because of the similarity of cost surface value distribution result of MCDA. This similarity caused the route result seems similar.
The result of scoring assessment for suitability of highway development with spatial planning in 2030 that has been created in Table 4, shows that LPCA-MDCA model 1 is the most suitable for the optimal route with the total score 69.06. The route mainly crossed dry land agriculture land use that has the high scoring because it is easily acquired to be converted as highway for the public interest. In addition, the model relatively crossed the village settlement and city settlement land use and potential to be obstacles (social conflict). However, it is not significant enough (12.6%) compared to the length of the route that crossed the dry land agriculture and wet land agriculture land use (49%). LPCA-MDCA model 3 (total score 65.60) mainly crossed the wet land agriculture and dry land agriculture land use which is easily acquired to be converted, and the length of the wet land agriculture and dry land agriculture land use (48.8%) is more significant rather than the length of the route passing through village settlement and city settlement (14.1%). The least suitable or least optimal route based on the suitability of highway development is LPCA-MDCA model 2, with a total score 65.48. LPCA-MDCA model 2 mainly crossed the agricultural land use (44.6%). However, the route relatively crossed village and city settlement where the length of the route that passing through village settlement and city settlement (9.2%) more significant for the suitability of highway development in this model. Overall, the weight of dry land agriculture and wet land agriculture in the suitability of highway development with spatial planning is the essential variable to choose the most suitable or optimal route for highway development.

| Score | Length (m) | Suitability of Highway Planning to Spatial Planning |
|-------|------------|---------------------------------------------------|
|       | Production | Forest | Cultivation | Village Settlement | City Settlement | Dry Land Agriculture | Wet Land Agriculture | Flood Plain | Industrial Zone | Total |
| Highway 1 | 241.40 | 5352.90 | 4651.80 | 9197.50 | 22901.30 | 1397.50 | 531.20 | 0.00 | 4427.36 |
| Highway 2 | 685.90 | 7918.30 | 3711.90 | 6544.61 | 875.60 | 23418.10 | 599.00 | 0.00 | 4375.34 |
| Highway 3 | 0.00 | 633.10 | 3744.3 | 11851.6 | 5095.30 | 21101.5 | 776.1 | 746.2 | 43948.1 |
| Highway 1 | 0.22 | 7.25 | 4.20 | 8.31 | 46.55 | 2.53 | 0.00 | 0.00 | 69.06 |
| Highway 2 | 0.63 | 10.86 | 3.39 | 5.98 | 1.80 | 42.82 | 0.00 | 0.00 | 65.48 |
| Highway 3 | 0.00 | 0.86 | 3.41 | 10.79 | 10.43 | 38.41 | 0.00 | 1.70 | 65.60 |

4. Conclusion
The optimal route for the Sukabumi-Cianjur highway development model can be done using the Least Cost Path Analysis (LCPA) – Multi Criteria Decision Analysis (MCDA) method. This paper provides the framework to assess the other routing of the highway using different criteria. The relative important thing from this model is the determination of the factor, criteria, and the weighted score to model the analysis. Each problem will use different inputs to process the best result. Therefore, further assessment can use different factor and weighted score to analyze the Multi-Criteria Decision Analysis. This method is a good tool to understand how multivariable can contribute to the development of the highway. LPCA modeling results with three simulation models show that the length of the highway is 44.2 km for the LCPA 1 simulation model, 43.88 km for the LCPA 2 simulation model, and 43.99 km for the LCPA 3 simulation model. Moreover, this paper also proposes the assessment model of highway model to the spatial planning regulation to know which model is the best to develop. Based on the result for suitability of highway development with spatial planning in 2030, it shows that LPCA-MDCA model 1 is the most suitable for the optimal route because the length of the dry land agriculture and wet land agriculture in the route is 49%, where the agriculture land use is easily acquired to converted for highway development. LPCA-MDCA model 3 showed the length of the route that passing through the dry land agriculture and wet land agriculture is 48.8%. The least suitable or least optimal route is LPCA-MDCA model 2, where the length of the route that crossed the dry land agriculture and wet land agriculture is 44.6%. In conclusion, this model has a good potency to incorporated in Indonesian planning project since the flexibility in determination of factor and criteria to result the appropriate understanding with
5. References

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