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Application of Spatial Multi-Criteria Analysis and Least-Cost Path on The Highway Route Planning (Case Study of Bawen – Yogyakarta Highway)

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Abstract: *Infrastructure planning ideally considers the geotechnical aspects and physical conditions of the infrastructure development location and must be able to support regional development. One kind of spatial analysis technique, which has the capabilities to integrate various regional characteristics associated with its suitability for a particular use, is spatial multi-criteria analysis. By using Bawen - Yogyakarta Toll Road Plan as a case study, this research is intended to apply route planning that takes into account regional characteristics, through the involvement of Spatial Multi-Criteria Analysis, Analytic Hierarchy Process, and Least Cost Path analysis. The analysis results then compared with the government preferred route to see its advantages and disadvantages.*

Study results show that the generated route from the analysis has several advantages over the government preferred route while also having some shortcomings. The advantages of route analysis results compared to government preference routes include: better able to avoid earthquake and landslide-prone areas, better support to the preservation of protected areas, has more areas with flat to gentle topography, and have smaller additional construction cost as the consequences of the intersection with existing roads, rivers, and railways, In terms of affected land-use, generated route also has minimum negative impacts on the sustainability of agricultural land in the study area.

The shortcomings of the analysis result are: not yet able to avoid flood and volcanic eruptions-prone areas as well as government's preferences route, higher land acquisition cost estimation, and less support for industrial and tourism activities in the research area. Improvement of analysis methods, data, and cost assessment strategy is needed to obtain better results and more appropriate modeling and analysis, in order to support regional infrastructure planning and development.

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1. INTRODUCTION

Regional disparities between the western region and eastern region of Indonesia become the primary focus in the infrastructure development planning of the Indonesian Government. In this regard, the challenge of contemporary Indonesian infrastructure development is on how to reduce disparities and balance growth and development. Having to achieve this expectation, the Strategic Plan of the Ministry of Public Works and People's Housing 2015-2019 mandates that infrastructure development must integrate on the inter-regional, inter-sectoral, and inter-governmental levels. This mandate is realized in the form of the Strategic Development Area concept (SDA), which becomes the basis of infrastructure development in Indonesia. Ministry of Public Works divides the Indonesian territories into 35 SDA's, where every SDA has a specific planning policy according to the potential and problems that exist in each region.

One of the planned SDA in Java Island is the Integrated Growth Center Yogyakarta-Solo-Semarang SDA (Strategic Plan Ministry of Public Works and Housing 2015-2019). Various infrastructure is planned to build in this SDA, where is one of them is Bawen – Yogyakarta Toll Road. Given that SDA-based infrastructure development must be followed, the determination of the Bawen - Yogyakarta Toll Road route should take into account those integration aspects. Road construction should be integrated with regional development plans undertaken by provinces and districts traversed by the planned toll road. Also, toll road existence must also be able to support the existence of economic, social, and tourism activities in the region.

The realization of integrated road planning requires formulation, analysis, and evaluation techniques that can involve these considerations. Multi-Criteria Evaluation is one of the analysis and evaluation techniques that can be used for that purpose. The role of Multi-Criteria evaluation in decision making has a long history, ranging from the traditional form (e.g., conventional mediation) to the form of modern automated programming through the help of computers and information technology (Köksalan, Wallenius, & Zionts, 2013). This development also includes spatial and regional planning through the development of Spatial Multi-Criteria Analysis (Malczewski, 2006). In spatial multi-criteria analysis (SMCA), regional indicators become the criteria used as the basis for determining the toll road route. Through analysis of the involved criteria, toll road alternative scenarios can be made, followed by an evaluation to determine which are the best scenarios, in the context of integration of infrastructure development and regional development.

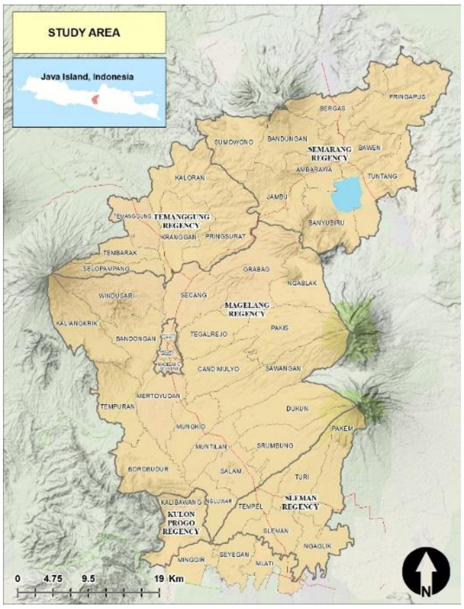
However, the factors and criteria involved in SMCA need to be formulated in advance of hierarchical urgency, since the importance of each factor is different from one to another. The urgency of each involved factor can be formulated using experts judgment techniques. Various techniques have been developed to determine the urgency of factors from the experts, but one of the most commonly used is the Analytic Hierarchy Process (AHP), developed by Wind & Saaty (1980). AHP can produce weight values and scores of involved factors and criteria that can be inputted in SMCA to find alternative solutions to the problems faced, followed by an evaluation to determine which one is the best. SMCA and AHP integration for site selection application has been conducted by many authors either in transportation route planning (Atkinson et al., 2005; Beukes, Vanderschuren, & Zuidgeest, 2011; Abdi et al., 2009; Keshkamat, Looijen, & Zuidgeest, 2009; Effat & Hassan, 2013) or other fields of study (Sánchez-Lozano & Bernal-Conesa, 2017; Mishra, Deep, & Choudhary, 2015; Bunruamkaew & Murayam, 2011). Thus, through a combination of SMCA and AHP, a toll road route plan that reflects not only the information integration of the involved criteria but also the experiences and preferences of the stakeholders involved in toll road infrastructure development can be obtained. By looking at the gap, this study combines SMCA with AHP as a tool to see an effective and efficient evacuation route based on Least Cost Path analysis.

2. DATA AND METHODS

2.1. Study Area

The study is conducted at several subdistricts in Central Java Province and Yogyakarta Special Region, Indonesia, which likely will be traversed by Bawen - Yogyakarta Toll Road. These sub-districts are within the administrative area of Semarang Regency, Temanggung Regency, Magelang Regency, and Magelang City, which are part of the Central Java Province. As for Special Region of Yogyakarta, the study area covers some sub-districts of Sleman Regency and Kulonprogo Regency (Table and Figure 1).

Table and Figure 1. Study Area



Regency/District	Sub-District		
Semarang	Bergas	Jambu	Sumowono
	Bawen	Banyubiru	Ambarawa
	Bandungan	Tuntang	Pringapus
Temanggung	Kaloran	Kranggan	Tembarak
	Temanggung	Pringsurat	Selopampang
Magelang	Secang	Tegalrejo	Pakis
	Grabag	Candimulyo	Borobudur
	Windusari	Sawangan	Salam
	Kaliangkrik	Tempuran	Sawangan
	Bandongan	Mertoyudan	Srumbung
	Ngablak	Mungkid	Dukun
	Ngluwar	Muntilan	
Magelang City	North Magelang	South Magelang	Central Magelang
Sleman	Tempel	Pakem	Minggir
	Turi	Ngaglik	Seyegan
	Sleman	Mlati	
Kulon Progo	Kalibawang		

2.2. Route Planning Criteria

Criteria in SMCA is the basis for determining the evaluated object is to meet the requirements or not. Criteria, sub-criteria, and alternatives criteria for toll road route planning in this study are derived from a literature review of similar research (Atkinson et al., 2005; Effat & Hassan, 2013; Kushari, Mulyono, & Hendratno, 2015; and government regulations. The results of the criteria formulation are presented in Table 2.

Table 2. Proposed Toll Road Route Planning Criteria (Analysis, 2018)

Factors	Criteria	Sub Criteria
Geotechnics	Soil	• Soil Texture
	Topography	• Slope
	Geology	• Rock Type
Environmental	Natural Protected Area	• Natural Protected Areas in Existing Spatial Plan
	Cultural Protected Area	• Distance from Archeological Cultural Heritage
Social	Land-use	• Existing Land-use
	Land Value	• Estimation of current Land Value
Regional Activity System	Regional Activity System	• Distance from Industrial Areas
		• Distance from Urban Growth Centers
		• Distance from Tourism Destinations
Safety and Additional Construction Cost	Disaster Hazards	• Landslide-Prone Areas
		• Flood-Prone Areas
		• Earthquake-Prone Areas
		• Volcanic Eruption Prone Areas
	Road Safety	• Slope direction (aspect)
	Additional Construction Cost	• Intersection with the road network
		• Intersection with the railway network
		• Intersection with the river network

2.3 Data Sources

Various geospatial data has been collected and processed (i.e., vector data digitization, map projection conversion, vector to raster conversion) into one spatial database (geodatabase) to meet the minimum requirements for analysis. Data used in this study came from primary sources through field surveys and secondary data obtained from various agencies and institutions (Table 3).

Table 3. Data Sources (Analysis, 2018)

Data Type	Data Sources	Type of Data
Land-use	Visual at Interpretation of 1.5 meters Orthorectified SPOT-6/7 Satellite Imagery acquired 2016 to 2017 (National Geospatial Agency – National Institute of Aeronautics and Space)	Secondary Data
Topography and Slope	8 meters IFSAR DEM generated from TERRASAR-X SAR Imagery (National Geospatial Agency – National Institute of Aeronautics and Space)	Secondary Data
Natural Protected Areas	Existing Regency Spatial Plan (Regency Regional Planning Board)	Secondary Data
Cultural Protected Areas	Temples and Archeological Site Mapping Resulted from Degroot & J Klokke (2010) study.	Secondary Data
Volcanic Eruption Hazard	Volcanic Eruption Hazard Map from National Geological Agency	Secondary Data
Landslide Hazard	Landslide Hazard Map from National Geological Agency	Secondary Data
Flood Hazard	Flood Prone Map from Existing Regency Spatial Plan (Regency Regional Planning Board)	Secondary Data
Earthquake Hazard	National Earthquake Hazard Map 2017 (Ministry of Public Works and Housing)	Secondary Data
Soil Texture	250 meters of global soil texture data from SOILGRIDS (ISRIC – *World Soil Information*)	Secondary Data
Land Value	Land Value Map published in 2015 by the National Land Agency	Secondary Data
Rock Type	Remote Sensing based Geologic Map at 1:50.000 Scale (National Geological Agency)	Secondary Data
Industrial, Tourism and Growth Center location	Field Survey, Existing Regency Spatial Plan	Primary and Secondary Data
Road Network	National, Provincial, and Regency Road Network Map published in 2015 by the Ministry of Public Works and Local Government.	Secondary Data
Railway Network	National Topographic Map at Scale 1: 50.000 Published in 1915 by Nederland Indie Topographic Survey Agency, verified by field survey because the railway network in the study area has been closed at 1976, though there is a government plan to reactivate it in the future.	Primary and Secondary Data
River Network	National Topographic Map at Scale 1:25.000, SPOT-6/7 Satellite Imagery Visual Interpretation	Secondary Data
Government’s preferred Route Plan of Bawen – Yogyakarta Toll Road	Latest official Report of Bawen – Yogyakarta Toll Road Development (Ministry of Public Works and Housing)	Secondary Data

2.4 Data Standardization and Normalization

Determination of the optimal toll road route based on SMCA involves a series of criteria, sub-criteria, and alternatives that have a different scale and value measurement. These scale and value differences will affect the accuracy of the analysis results if it is not standardized into standard value (Drobne & Lisec, 2009). Therefore, before the analysis, any alternatives of sub-criteria were assigned and reclassified into a relative scoring scheme (from 1 to 9). The assumption used is, the higher the score of the alternative criteria, the more it is not suitable as a toll road route. Standardization parameters and references are presented in Table 4.

Table 4. Cost Value Standardization

Factor	Criteria	Sub-criteria	Alternative	Cost Value	Cost Classification References
Geotechnics	Soil	Soil Texture	0 -30% Sandy Soil	9	Natural Breaks Classification
			30 -80% Sandy Soil	5	
			80 -100% Sandy Soil	1	
	Geology	Rock Type	Quartenary Deposits (alluvium, kolluvium), breccia	1	Expert Judgment
			Extrusive Igneous and Sediment Rock (sandstone, tuff)	5	
			Intrusive Igneous Rock (andesite, Granite, Dyorite)	9	
Environment	Natural Protected Area	Natural Protected Area Type	Non-Conservation Area	1	Modified from Kushari et al. (2015) and Expert Judgment
			Conservation Forest, National Park	9	
	Cultural Protected Area	Distance from Temples	0 - 500 meters	9	Expert Judgment
			> 500 meters	1	
Social	Land-use	Land-use Type	Shrubs, Bare land, Grassland	1	Modified from Kushari et al. (2015)and Expert Judgment
			Mixed Garden,	3	
			Rice Fields, Poultry, Plantation	5	
			Sparse Settlements, Cemetery,	7	
			Industrial Area, Economic Services, Historical Places, Dense Settlements, Lake	9	
	Land Value	Land Value	7,000 - 180,000 Rupiahs	1	Natural Breaks Classification
			180,000 - 2,100,000 Rupiahs	5	
			> 2,100,000 Rupiahs	9	
Regional Activity System	Regional Activity System	Distance from Industrial Area	0 - 5 kilometers	1	Equal Interval Classification
			5 - 10 kilometers	5	
			> 10 kilometers	9	
		Distance from Urban Growth Centers	0 - 5 kilometers	1	
			5 - 10 kilometers	5	
			> 10 kilometers	9	
		Distance from Tourism Locations	0 - 5 kilometers	1	
			5 - 10 kilometers	5	
			> 10 kilometers	9	
Road Safety and Additional Construction Cost	Additional Construction Cost	Intersection with Road Network	Non Road Area	1	Expert Judgment
			Local Road	3	
			Regency Road	5	
			Provincial Road	7	
			National Road	9	
		Intersection with Railway Network	Non-Railway Area	1	
			Railway Area	9	
		Intersection with River Network	First River Order	1	Expert Judgment
			Second to Third River Order	3	
			Fourth River Order	5	
			Fifth River Order	7	
			Sixth to Seventh River Order	9	
	Natural Hazards	Landslide Hazards	Non Hazard Area	1	Construction Standards Number. 007/BM/2009, and Expert Judgment
			Low Hazard Area	3	
			Moderate Hazard Area	5	
			High Hazard Area	9	
		Flood Hazard	Non Hazard Area	1	
			Low Hazard Area	3	
			Moderate Hazard Area	5	
			High Hazard Area	9	
		Earthquake Hazard	PGA 0 - 0.25 g	1	
			PGA 0.25 - 0.3 g	3	
			PGA 0.3 - 0.4 g	5	
		Volcanic Eruption Hazard	Non Hazard Area	1	
			Hazard Zone I	3	
			Hazard Zone II	5	
			Hazard Zone III	9	

2.5 AHP Based Weighting

Criteria and sub-criteria weighting in this study were conducted using the Analytic Hierarchy Process (AHP) method developed by Wind & Saaty (1980). In this study, the AHP analysis was conducted on two levels: first, AHP at the sub-criteria level (applied to sub-criteria incorporated in disaster risk criterion, regional activity system criterion, and additional construction cost criterion), and AHP at the criteria level (Figure 2). Topographic factors are not involved in AHP and SMCA because topographic factors will be used as a horizontal and vertical factor according to the modeling approach used, which is an anisotropic approach (to be described in subsequent chapters).

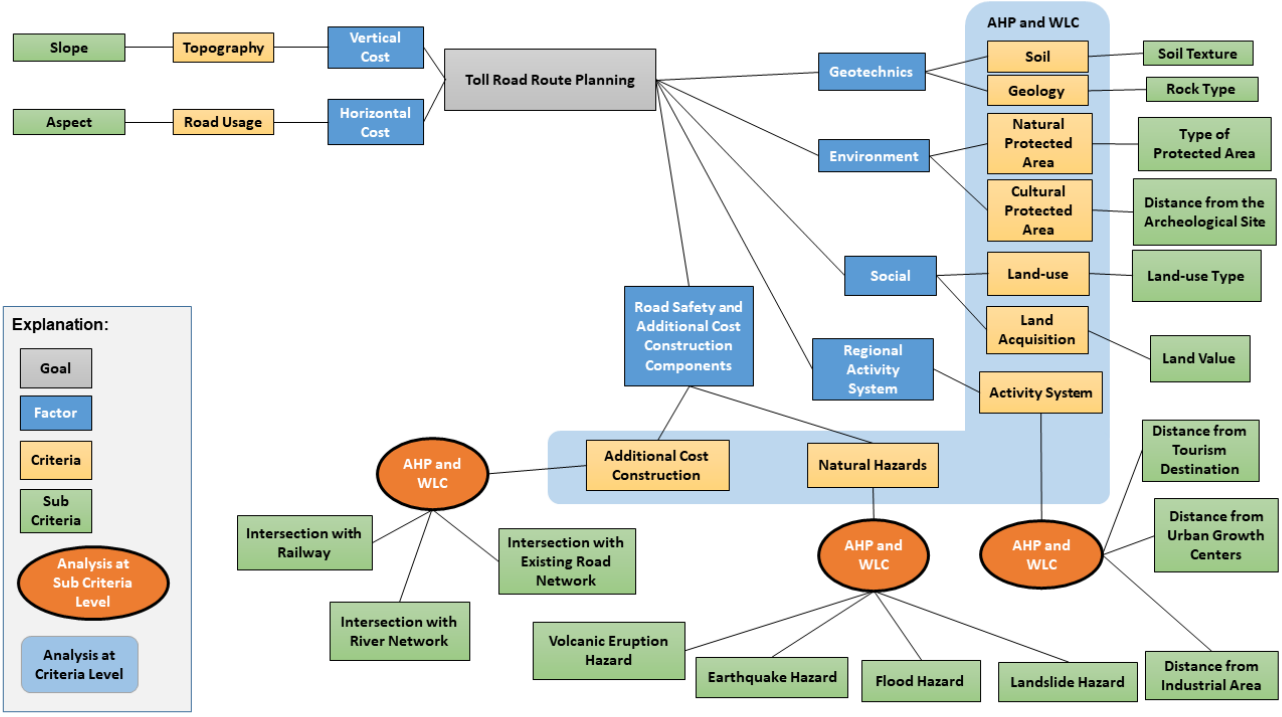


Figure 2. Hierarchy of Criteria (Analysis, 2018)

As input from AHP is the result of a questionnaire survey and interview with three experts from the Ministry of Public Works and Housing and one transportation practitioners. The result of the questionnaire was then arranged in the pairwise comparison matrix. From the obtained pairwise comparison matrix, the priority vector and its consistency index can be calculated. The value of the obtained priority vector is then used as the weight value of the criteria if the consistency index is less than 0.1. The final weight value from the obtained weight of each respondent then is calculated using the geometric mean formula.

2.6 Spatial Multi-criteria Analysis (SMCA)

SMCA is implemented in Geographic Information System (GIS) through Map Algebra operation based on the raster data structure. SMCA requires the weight value of each criterion and sub-criteria to determine which criteria are more important to determine the most optimal toll road route. This weight value is derived from the AHP process described in the previous sub-chapter. The analytic method used to determine the best route of the toll road plan in this study is using the least-cost path (LCP) method. LCP is a technique to determine the shortest cost distance from one location to another based on a raster surface data called Accumulated Cost Surface (Douglas, 1994). Douglas (1994) defines Accumulated Cost Surface (ACS) as a dasymmetric representation in the form of a grid model of the Earth's surface, which refers to how much resources to spend or how much of the frictions must be passed over the model of the earth's surface. In this study, ACS is derived from the cumulative cost raster (called Cumulative Cost Surface/CCS) obtained from SMCA. CCS was obtained from the map overlay result of various baseline data (see Table 3) that have been given standardized score values and weight values in accordance with the AHP results. Several SMCA algorithms have been developed to obtain CCS. One of them is the Weighted Linear Combination (WLC) technique, which has been implemented in most of Geographic Information System software available on the market and used for this study.

ACS calculation within the GIS can be based on two approaches, namely the isotropic approach and anisotropic approach (Yu, Lee, & Munro-Stasiuk, 2003). The Isotropic Approach is an approach in which the movement of calculation of cost accumulation in all directions is considered equal, while the anisotropic approach considering the movement of cost accumulation in all directions (both horizontal and vertical) has different implications to cost accumulation. In the context of road planning, some authors such as Collischonn & Pilar (2000) and Yu et al. (2003) argue that the anisotropic approach is more appropriate than the isotropic one. This opinion departs from the fact that less step and sinuous slopes are preferred than slopes that are short but steep. Either In isotropic or anisotropic approach, ACS calculations require CCS data obtained from WLC operation result. In the anisotropic approach, the difference is that in addition to requiring CCS information, anisotropic operations also require two other input data, which are a horizontal and vertical factor. The horizontal factor determines the horizontal friction, which will increase the cost of the horizontal movement direction (0 to 360 degrees), while the vertical factor determines the vertical friction, which will increase the cost in upward vertical movement (0 to 90 degrees), or downward vertical movement (0 to -90 degrees).

Implementation of the horizontal and vertical factor to extracting the ACS using anisotropic approach can be done by determining the horizontal factor and vertical factor tables first. This horizontal and vertical factor table will be used as the basis to determine the cost value of the friction in horizontal movement (slope direction) and vertical movement (slope gradient). For this study, horizontal friction is considered in the analysis to facilitate the selection of road routes that avoid sunrise and sunset direction, so when the toll road is in the operational stage, the road users will not experience visibility problems due to glare disruption. Whereas, vertical friction is a representation of the increased cost due to terrain slope gradient changes, either during the road construction stage or road operational stage. The horizontal and vertical factor tables used in this study developed from the result of Yu et al. (2003) study and presented in Table 5. The INF value in the vertical factor table indicates that the cost to pass the area with a given slope is too large, so the area that has that kind of slope will be impassable. An overview of the performed analysis process is presented in Figure 3.

Table 5. Vertical and Horizontal Factor Used for Anisotropic Route Extraction (Analysis, 2018)

Vertical Factor		Horizontal Factor	
Slope (Degrees)	Cost Value	Aspect (Degrees)	Cost Value
(-45) - (-90)	INF	0 - 22.5	1
(-25) - (-45)	32	22.5 - 67.5	7
(-15) - (-25)	9	67.5 - 112.5	9
(-12) - (-15)	7	112.5 - 157.5	3
(-9) - (-12)	5	157.5 - 202.5	1
(-3) - (-9)	3	202.5 - 247.5	7
0 - (-3)	1	247.5 - 292.5	9
0 - 3	1	292.5 - 337.5	3
3 - 9	3	337.5 - 360	1
9 - 12	5		
12 - 15	7		
15 - 25	9		
25 - 45	32		
16 - 90	INF		

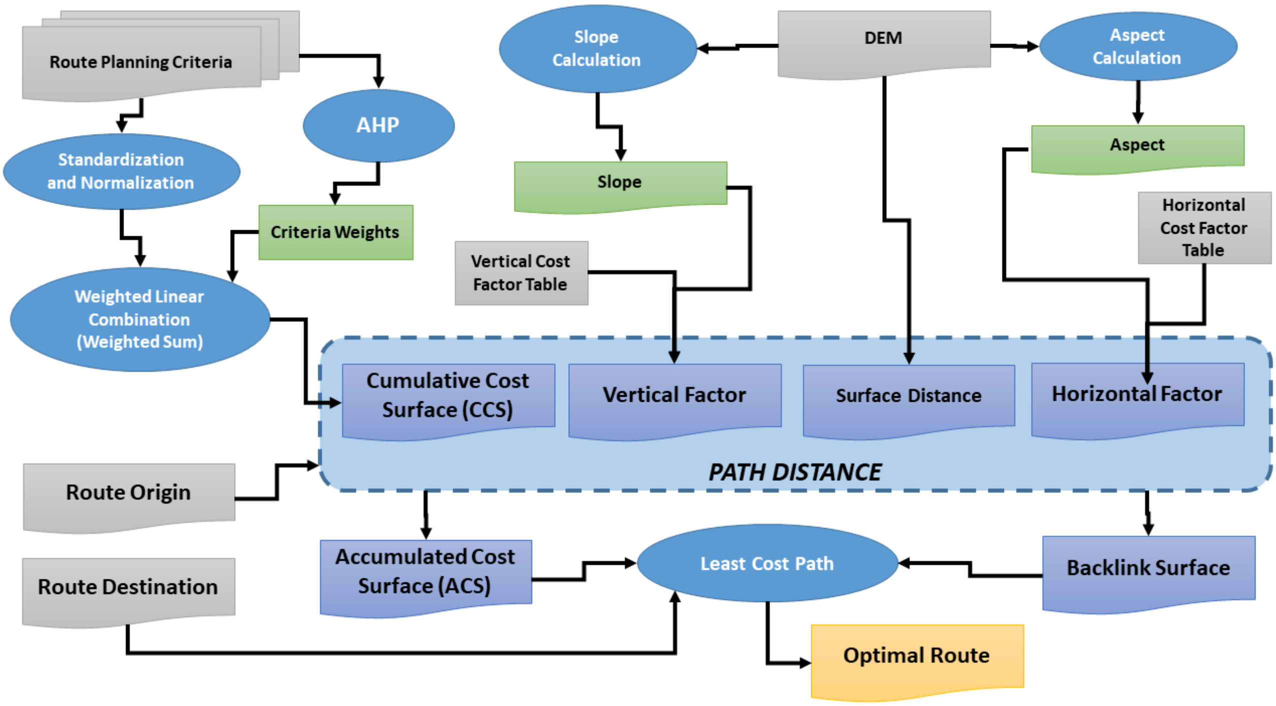


Figure 3. Optimal Toll Road Route Analysis Workflow (Analysis, 2018)

2.7 Comparison and Evaluation of the Analysis Results

Route comparison and evaluation in this study is done to find out to which extent the routes generated from SMCA and LCP is better than the government's preferred route. Comparison and evaluation are performed by looking to some indicators that affect: (1) ease of construction; (2) risk in the operational phase of the toll road; and (3) integration and support to regional development. Details of the comparison and evaluation indicators are presented in Table 6.

Table 6. Evaluation Indicators (Analysis, 2018)

Factors	Criteria	Comparison and Evaluation Indicators
Ease of Construction and Level of Investment Cost	Land-use	- The extent of land-use type passed by the route
	Topography	- The extent of the slope passed by the route
	Protected Area	- The extent of the protected area passed by the route
	Land Value	- Estimation of land acquisition cost along the route
	Existing Transportation Network	- Number of the intersection with the road - Number of the intersection with railway
	Sungai	- Number of the intersection with river
	Road Geometry	- Route Length
Risk in Operational Phase of Toll Road	Road Safety	- The extent of terrain aspect passed by the route
	Natural Hazards	- The extent of Earthquake prone area passed by the route - The extent of volcanic eruption prone area passed by the route - The extent of Landslide prone area passed by the route - The extent of the flood-prone area passed by the route
Integration with Regional Development	Integration with Regional Development	- Proximity to Industrial Areas - Proximity to Urban Growth Centers - Proximity to Tourism Destinations - Proximity to Archeological Protected Sites

3. RESULTS AND DISCUSSION

3.1. Criteria Standardization and AHP Results

Standardization of alternative criteria value in this study was conducted by reference to three sources of information, namely: (1) existing similar research and literature, (2) government rules and laws about road management, and (3) discussions with experts which be done simultaneously with AHP survey. For criteria mapped in discrete geographic objects (vector data), standardized cost value assignment is performed by converting object information (which is nominal data) to value (ratio data), in accordance with literature and expert recommendations, whereas cost value assignment for criteria mapped in continuous geographic fields is performed by classifying those values into standardized values. Complete visualization of the standardization result for each sub-criterion is presented in Figure 4.

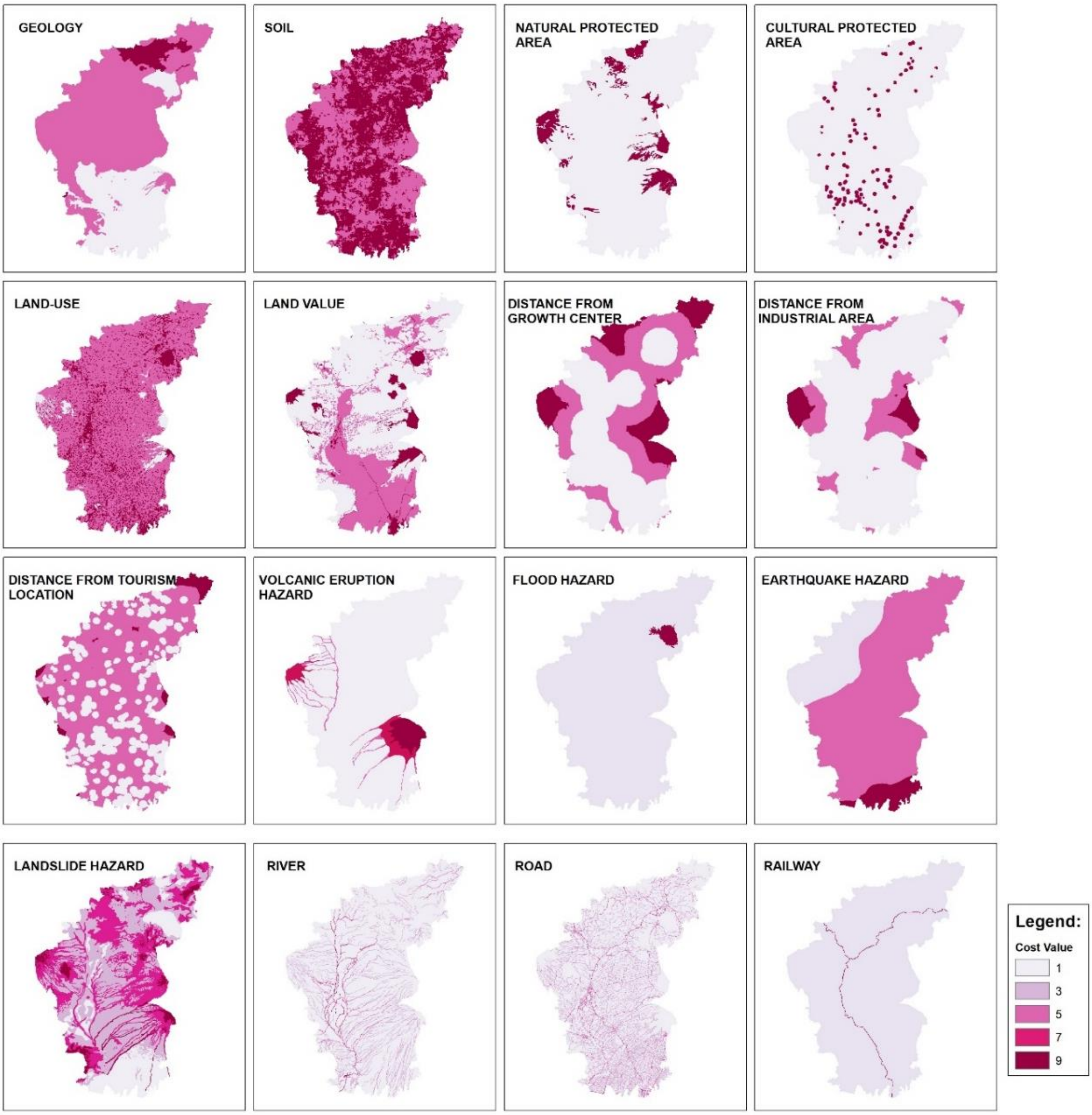


Figure 4. Standardization Results (Analysis, 2018)

The AHP processing in this study was conducted after the compilation of the questionnaire by experts has been completed. The AHP is performed to obtain the value of the eigenvector used as the weighting value of the criterion. The confidence level of the eigenvector value in AHP itself is measured from the Consistency Index (CI) obtained from the analysis. Based on the obtained result, the CI obtained for each respondent indicates a value below 0.1, which can be interpreted that the AHP analysis for each respondent is consistent. Thus the obtained eigenvector can be used as the criteria weight value. Eigenvalues (weights) calculation result of the criteria along with its consistency index value is presented in Table 7.

Table 7. AHP Results (Analysis, 2018)

Criteria	Ministry of Public Works			Transportation Expert	Geometric Mean Weights	Normalized Geometric Mean
	Expert 1	Expert 2	Expert 3	Expert 4		
Geology	0.1949	0.1231	0.0481	0.0817	0.10	0.11
Soil	0.1839	0.1122	0.0350	0.0376	0.07	0.08
Natural Protected Area	0.1675	0.1496	0.1529	0.1596	0.16	0.18
Cultural Protected Area	0.1653	0.1415	0.1529	0.1596	0.15	0.17
Land-use	0.1341	0.1065	0.1529	0.1298	0.13	0.14
Land Value	0.0191	0.0445	0.0171	0.0210	0.02	0.03
Regional Activity System	0.0228	0.0201	0.1529	0.1386	0.06	0.06
Natural Hazards	0.0691	0.2787	0.1529	0.2523	0.17	0.18
Additional Construction Cost	0.0434	0.0239	0.1354	0.0199	0.04	0.05
Total Weights	1	1	1	1	0.90	1.00
Consistency Index	0.07	0.08	0.09	0.07		

From the results of the AHP analysis described above, the final criteria and sub-criteria weights can be determined. In this study, the final weights computed from the normalized weights resulted from the geometric mean operation. Before inclusion as input for CCS generation, the decimal format's final weight values are converted to a percentage by multiplying it with 100 value. Conversion to percentage is applied to avoid the reduction effect of the final cost value (due to the multiplication operation of cost value with weight value). As for the final weight value of sub-criteria is determined from the division of the concerned criteria, in accordance with the proportion of the weight value of each sub-criterion. The final weight value of criteria and sub-criteria that has been converted to the percentage scale is presented in Table 8.

Table 8. Criteria and Sub-criteria Final Weights (Analysis, 2018)

Criteria	Sub Criteria	Criteria Weights	Sub-Criteria Weights
Geology		11	
Soil		8	
Natural Protected Area		18	
Cultural Protected Area		17	
Land-use		14	
Land Value		3	
Natural Hazards		18	
	Volcanic Eruption		5.61
	Landslide		6.80
	Earthquake		4.53
	Flood		1.45
Regional Activity System		6	
	Distance from Urban Growth Center		2.21
	Distance from Industrial Area		3.49
	Distance from Tourism Destination		0.52
Additional Construction Cost		5	
	Intersection with Railway Network		1.23
	Intersection with Road Network		1.85
	Intersection with River Network		1.47

The result of consensus drawing from several experts using AHP and geometric mean in this study favored criteria of natural hazards, protected area existence, land use, and geological condition. Thus, the LCP analysis will be more sensitive to the above criteria than other criteria. This sensitivity is apparent after comparison with the government's preferred route, where the LCP generated route cannot identify feasible and effective routes when viewed from regional activity system criterion and the land value criterion. The route generated from the LCP analysis ideally should be sensitive to the regional activity system criterion because the Bawen - Yogyakarta Toll Road is expected to support regional development and tourism activities in the study area. LCP generated route ideally should also be sensitive to the variation of land value over the study area because it will be related to the role of minimizing the complexity of land acquisition as one of the leading problems of toll road development in Indonesia.

The relative value assignment strategy of cost (cost score) also plays a vital role in addition to the weighting strategy of the criteria itself. This statement can be understood from the results of the route comparison on the additional construction cost criterion. The weight value of the additional construction cost criterion is relatively smaller than the other criteria, but the route obtained from the LCP analysis generated intersection number with rivers and roads less than the government's preferred route. Thus, the cost value assignment strategy for the additional construction cost criterion is sufficient.

The level details of the data used are one of the aspects that also need to be considered further. For example, this study uses the Land Use Map at Scale 1: 10,000, where is in this data, the built-up land-use is still visualized as area (e.g., residential area or industrial area). This data may not be detail and useful enough as the input in SMCA and LCP application for route planning. As can be seen from the analysis results, the route generated from LCP analysis has not shown adequate sensitivity compared to the government's preferred route for the residential area, although the criterion weight value is quite high. This insensitivity happens because the score assignment of the residential area has been done based on its relative density, in accordance with the level of the details of those data. If detailed information that can be used as a basis for determining cost score in a more precise way is available (such as the number of buildings per block), cost models and LCP analyzes may be more sensitive to the variation in the cost value of each criterion, and then can have significant implication to the improvement of the analysis and modeling.

The use of anisotropic approach (ArcGIS path distance algorithm) in this research is capable of generating a toll road route that has the cost as low as possible. As shown by the comparison results of topographic aspects in Table 8, the route of the LCP analysis can find areas with the topography as flat as possible, to minimize the cost when compared with the government's preferred route. Nevertheless, the results obtained are still can be debated further, especially in the analysis results around Bawen Sub District, Ambarawa City, and Rawa Pening Lake Area. The anisotropic approach, which considers slope gradient as a vertical cost factor, tends to favor flat topography with the slope of a small slope as the area with the best suitability for toll road routes. However, in the case of Bawen - Yogyakarta toll road, the government study route has chosen to avoid Rawa Pening Lake area, although topographically, the Rawa Pening Lake area is entirely appropriate. The government may want to avoid the complexity of construction costs associated with the soil engineering treatment in the Rawa Pening Lake area, which tends to be soft and has low engineering capacity to support road infrastructure. This fact has not been well anticipated by the model generated from this study since the soil criterion in this study is based only on the percentage of the sandy texture of the soil and has not considered other soil characteristics (due to lack of data), such as effective soil depth.

If we refer to similar studies, among others by Ismail & Jusoff (2009), Beukes et al. (2011), and Chandio et al. (2012), these studies found that multi-criteria spatial analysis and LCP can provide effective and efficient route analysis results in terms of distance and time spent to travel, as well as minimal risk in terms of construction and operational cost. However, the criteria involved in those studies were not as much as the criteria used in this study. Consideration of more criteria will make the cost model have more complicated behavior, and there is a possibility to produce route analysis results that do not meet some of the criteria under consideration (as can be seen from the results of this study), although it is also there is the possibility that complex model will better represent the complexity of the cost conditions in the field.

The results of this study indicate the complexity of those mentioned complex behavior of the cost model above, which results in the non-fulfillment of some of the criteria. This finding confirms similar studies using relatively numerous criteria, as did by Keshkamat et al. (2009) and Kushari et al. (2015). Both studies also confirm the dynamic LCP analysis results as a result of involving more criteria in the preparation of the cost model, which resulted in some evaluation indicators are not fulfillment.

Apart from the disadvantages of the analysis results, the modeling methods applied in this study along with the results that have been obtained indicate the potential that the analytical methods and techniques that have been applied can be utilized and developed further to support the transportation route planning, that can be more sensitive to various criteria, not only physical criteria but also to the sustainability of environmental functions, besides supporting the regional development.

3.2. Criteria Standardization and AHP Results

CCS model generated based on input: (1) result of standardization and classification of criteria and sub-criteria; and (2 weight value of each criterion and sub-criterion. Model design and execution is performed within the ArcGIS Desktop 10.6 software using weighted sum geoprocessing operations. The weighted sum operations are carried out at two levels. First, at the sub-criteria level for disaster risk criteria, regional activity system criteria and additional construction cost criteria, and second, at criteria level that integrates the cost values of the geology, soil, protected areas, land use, land values, regional activity system, natural hazards, and additional construction costs criteria.

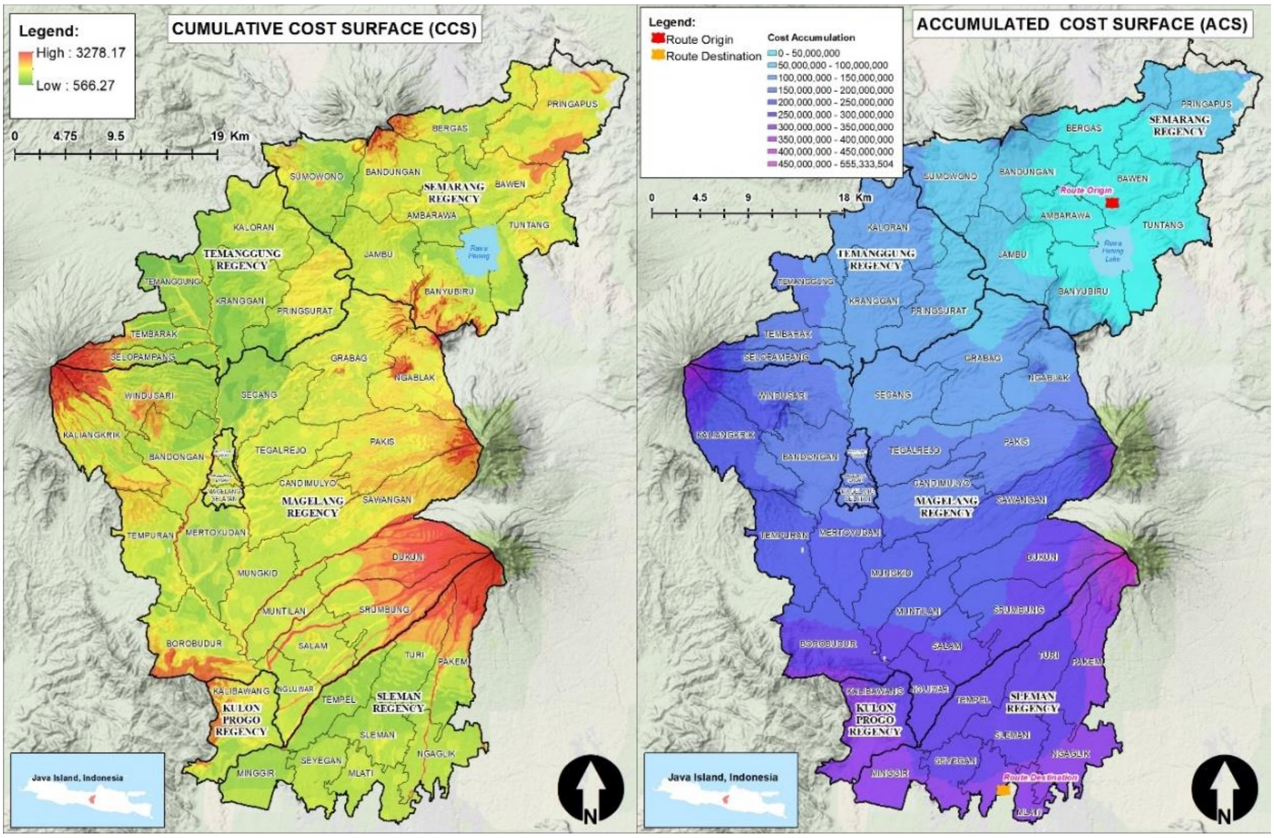


Figure 5. CCS and ACS Results (Analysis, 2018)

The ACS model is constructed using input data consisting of: (1) initial location of road plan; (2) DEM of research area; (3) CCS model that has been produced; (4) horizontal factor table; and (5) vertical factor table. Processes performed within the ArcGIS path distance algorithm (presented in Figure 5 along with CCS result), which can be described as follows:

1. Based on the initial location of the route plan and specified DEM, the algorithm calculates the surface distance from the initial location to all research areas.
2. Aspect is derived from the specified DEM, followed by a cost value assignment for each mapped direction angle in every pixel with reference to the horizontal factor table. This sub-dataset is called horizontal cost.
3. Slope is derived from the specified DEM, followed by a cost value assignment for each mapped slope angle in every pixel with reference to the vertical factor table. This sub-dataset is called vertical cost.
4. CCS Cost Model is then multiplied by the horizontal cost.
5. Through the iteration process, the accumulated sum of the cost of each pixel from the origin pixel then is summed, and the summation result of every two pixels is multiplied by surface distance value and vertical cost value between the evaluated pixels.

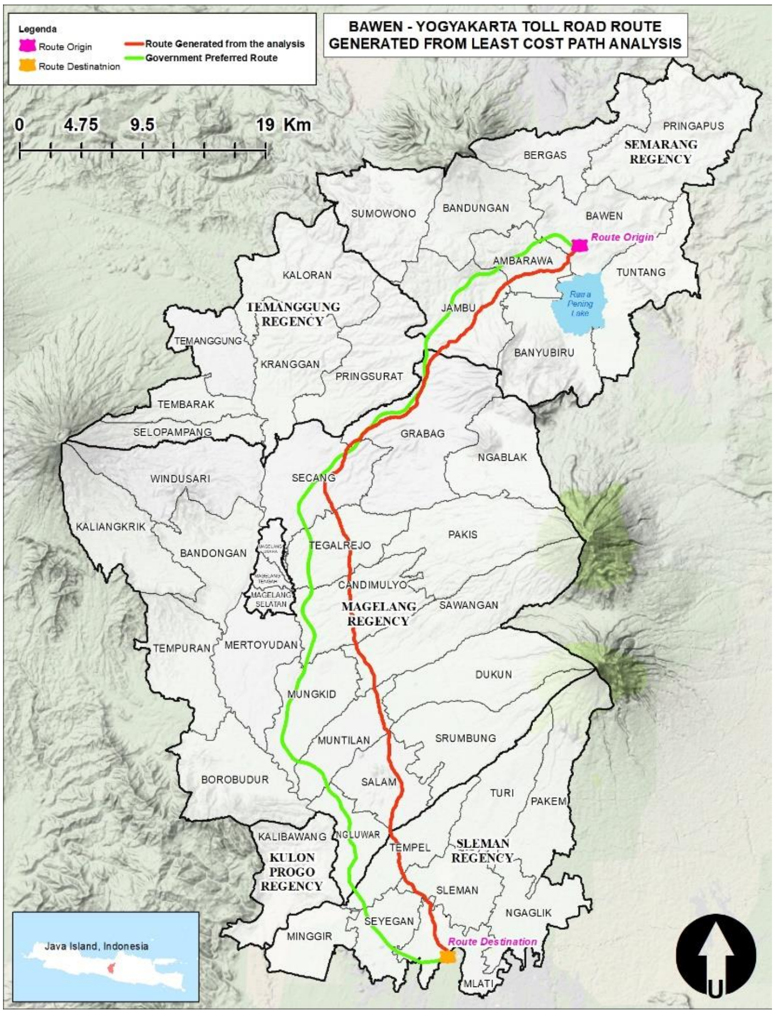


Figure 6. LCP Routing Result (red line) Compared to Government’s Preferred Route (Green Line)

Least cost path (LCP) analysis is an optimal path determination analysis technique based on pixel-pixel searches across the study area, using criteria: (1) the shortest distance from the origin location to the destination location; along with (2) the lowest accumulation of cost. LCP requires input data consisting of (1) the result of the ACS model, (2) backlink data obtained from ACS generation, and (3) the destination point, which is the end location of the path to be extracted. The backlink data is a raster data indicating the direction of movement of the ACS data (quantified by the pixel value of backlink data ranging from 1 to 8 to represent the eight directions of possible horizontal movement) from the origin point to the destination point. The result of LCP analysis that has been done is presented in Figure 6.

3.3. Comparison and Evaluation Results

Obtained Toll Road Route from LCP analysis then compared and evaluated versus government's preferred route. To properly evaluate the affected areas, the generated route from LCP analysis and the government's preferred route has been buffered 80 meters either on the right side or to the left side of the route. Buffering of 80 meters is assumed to be sufficient to cover the necessary road space (own road space, road benefit space, and road monitoring space). The results of the performed evaluation are presented in Table 9.

Table 9. Comparison and Evaluation Results (Analysis, 2018)

Criteria	Sub Criteria	Alternative Criteria	Route Generated from LCP	Government's Preferred Route
Land Use	Land-use Traversed by Route	Settlements	166. 59 Ha	128.1 Ha
		Industry and Services	3.6 Ha	2.4 Ha
		Government Facilities	0.2 Ha	0 Ha
		Forests	0 Ha	0 Ha
		Plantations	16 Ha	35.4 Ha
		Agricultural Areas	694.9 Ha	751. 2 Ha
		Mixed Gardens	216. 2 Ha	298.1 Ha
		Bare Lands	0.7 Ha	3.2 Ha
Slope	Route Slope	0 - 3 %	114. 41 Ha	95. 24 Ha
		3 - 9 %	514. 28 Ha	386. 1 Ha
		9 - 25 %	449. 21 Ha	620. 9 Ha
		> 25 %	31. 76 Ha	123. 3 Ha
Protected Area	Protected Areas Traversed by Route	Natural Protected Areas	0 Ha	0 Ha
		Cultural Protected Areas (300-meter radius from Temples)	111.3 Ha	122 Ha
Land Value	Land Acquisition Estimation	Land Value	4,188,176,199,328 IDR	3,581,766,068,528 IDR
Intersection with Existing Transportation Network	Intersection with National. Provincial and Regencies Road	National Roads	6 Intersections	5 Intersections
		Provincial Roads	4 Intersections	5 Intersections
		Regencies Roads	27 Intersections	30 Intersections
		Local Roads	102 Intersections	112 Intersections
	Intersection with Railway	Railway	4 Intersections	2 Intersections
		First River Order	45 Intersections	46 Intersections

Criteria	Sub Criteria	Alternative Criteria	Route Generated from LCP	Government's Preferred Route
Intersection With River Network	Intersection with River	Second to Third River Order	47 Intersections	49 Intersections
		Fourth River Order	12 Intersections	9 Intersections
		Fifth River Order	0 Intersection	8 Intersections
		Sixth to Seventh River Order	0 Intersection	0 Intersection
Road Geometry	Route Length	Total Route Length	69 Km + 408 m	76 Km + 720 m
Risk on Toll Road Operational Phase	Route Direction	North. South	30.45 km	24. 36 km
		North West. South East	13.35 km	17. 52 km
		South West. North East	19.39 km	26. 37 km
		West. East	6.22 km	8.46 km
	Volcanic Eruption Hazard	Hazard Zone 1	0 Ha	0 Ha
		Hazard Zone II	0 Ha	0 Ha
		Hazard Zone III	14.99 Ha	8.5 Ha
	Landslide Hazard	Hazard Zone 1	702.12 Ha	835 Ha
		Hazard Zone II	89.27 Ha	179.9 Ha
		Hazard Zone III	18.67 Ha	20.8 Ha
	Flood Hazard	Flood Prone Area	12.9 Ha	0 Ha
	Earthquake Hazard	Peak Ground Acceleration 0.25g -0.3g	63.9 Ha	79.7 Ha
		Peak Ground Acceleration 0.3g - 0.4g	945.1 Ha	1034.6 Ha
		Peak Ground Acceleration > 0.4g	100.1 Ha	111.2 Ha
Integration with Regional Development	Accessibility from Industrial Area	Proximity to Industrial Areas	73 Industry Locations	113 Industry Locations
	Accessibility from Urban Growth Centers	Proximity to Urban Growth Centers	10 Growth Centers (Ambarawa. Grabag. Temanggung. Kranggan. Secang. Muntilan. Salam. Tempel. Sleman. Pakem)	8 Growth Centers (Temanggung. Kranggan. Secang. Kota Magelang. Mertoyudan. Mungkid. Borobudur. Dekso)
	Accessibility from Tourism Destinations	Proximity to Tourism Destinations	129 Tourism Destinations	142 Tourism Destinations (includes Borobudur Temple)
	Accessibility from Cagar Budaya	Proximity to Temples and Archeological Sites	57 Archeological Sites	68 Archeological Sites

Note: Cells marked with green shade indicate the superior result

Development and implementation of transportation infrastructure. either in central or local governments can consider the results obtained from this study to conduct further evaluation of the Bawen

Toll Road - Yogyakarta route plan. as well as adopting the method to similar infrastructure projects. Route obtained from the study can also be integrated with government studies on road segments that are perceived as having not met the disaster threat criteria. environmental criteria. support for food security. and construction costs criteria.

The method of determining the trace used in this study. which includes SMCA. AHP. and anisotropic LCP analysis. is recommended to be incorporated in government's transportation planning activities. especially at the initial planning stage of the feasibility study. In addition to being able to provide route analysis through an automated process along with tools and evaluation techniques. this method can be extended to scenario-based route modeling. so various alternative scenarios can be proposed and further evaluated. which are most appropriate and feasible. Formalization of methods can be done in the form of legislation. technical guidance. or Standard of Procedures (SOP).

A comparison between isotropic and anisotropic approaches in determining the optimal route also needs to be studied and simulated further in future studies. This assessment is needed to ascertain which approach is the best in transportation infrastructure route planning. Assessments can be conducted in different regions with different regional characteristics to see how each approach performs. The testing of different LCP algorithms also needs to be applied. LCP analysis used in this research is using LCP Djikstra algorithm (Dijkstra. 1959) with a queen pattern (eight directions of movement). On the other hand. various LCP algorithms have been developed. for example. A* (Hart. Nilsson. & Raphael. 1968). Best First Search. A* Manhattan Heuristics. A* Diagonal Shortcut Heuristics. or LCP algorithms dedicated explicitly to road-based route planning such as SmartTerrain (Yu et al.. 2003) and Baek's Cut and Fill (Baek & Choi. 2017). The above LCP approaches and algorithms can be an alternative to determine transportation routes that may generate better results. Knight movement patterns (24 directions of movement) that have been implemented in the GRASS GIS software can also be studied further along with those various algorithms.

The development of a cost model based on actual cost is also recommended. Incorporation of actual cost into the cost model will have a strategic value. among others is: (1) projecting the real cost-benefit condition of the implementation of infrastructure development; (2) can be valuable information in preparing infrastructure development budget plans; (3) represents the condition of the cost that is closer to the actual conditions in the field. Real cost information for each criterion can be simulated using current cost standards. or based on experience/budget realization reports from toll road or other infrastructure projects that have been implemented.

4. CONCLUSION

Based on the obtained results. we can conclude that the utilization of an anisotropic approach in the toll road route planning can give the result of route analysis. which can minimize the cost. The cost model is getting more complex along with the addition of more criteria and may negate one criterion with other criteria. resulting in the insensitivity of route analysis to specific criteria. particularly on criteria that have low weight and/or criteria that use generalized data. Nevertheless. these findings are not fixed because there is a possibility that the cost model can be more sensitive to low weight criteria. as long as it is applied a proper cost assessment strategy and/or represents the real cost condition in the field.

The existence of criteria that have real cost values such as land value (which used in this study) can be useful to estimate the project budgets and costs. which is essential in the planning stage of infrastructure development programs. in order to obtain appropriate planning products.The obtained route from this study is also shorter about 8 kilometers compared to government's preferred route. allowing road users to save a certain amount of resources when the toll road has been operational. These findings indicate that there are alternative routes to government's preferred route. which is environmentally friendly and helpful to support food security sustainability.

This study still has some limitations related to the implementation of SMCA. LCP. and AHP analysis to support the route planning of the Bawen - Yogyakarta Toll Road. There are several criteria for toll road planning that still use a relatively subjective value assessment and have not been involved in research. both in terms of road planning regulations. toll road planning feasibility standards. and conditions and complexity of problems in the field. This research is carried out on a regional scale and uses publicly available data with different quality in terms of scale and updates.

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