SELECTING AN OPTIMAL ROAD CROSSING ROUTE USING SPATIAL ANALYTICS: A CASE STUDY OF THE EAST COAST RAIL LINK (ECRL)

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CIVIL ENGINEERING

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By

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24305

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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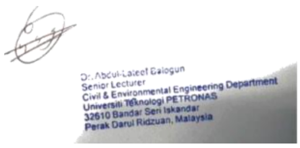

(Dr. Abdul-Lateef Babatunde Balogun)

UNIVERSITI TEKNOLOGI PETRONAS

BANDAR SERI ISKANDAR, PERAK

JANUARY 2021

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ASHVIN SHIVANANTHAN

ABSTRACT

Optimal route selection is one of the many issues faced by engineers nowadays. In this study, the problem arises when the ECRL alignment severs the connection of a particular road in the district of Setiu, Terengganu. Three overpass options had been designed by the engineers to overcome this issue. The aim of this study was to select the best overpass solution to reinstate the connectivity of the road crossing by using GIS and to compare conventional methods of optimal route selection against GIS methods. Several factors were considered in this study, namely, slope angle, soil class, topographical maps, land use, roads, and rivers. An AHP questionnaire was created and distributed to 5 experts in the field of optimal route selection to determine the weightage and influence of each factor in this study. The factors were then reclassified before integrating them with the GIS spatial analyst tool to generate the suitability map. AHP and F-AHP weightages were computed based on the results from the survey and then integrated with GIS by using the weighted overlay and fuzzy overlay tools to generate the optimal route selection suitability maps. The results obtained indicated that F-AHP produced a more accurate and feasible result compared to AHP. Also, when comparing conventional methods to GIS methods, it was found that both methods deemed that overpass option 2 was the best solution to reinstate the connectivity of the severed road crossing.

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LIST OF ABBREVIATIONS

GIS	Geographical Information System
AHP	Analytical Hierarchy Process
F-AHP	Fuzzy Analytical Hierarchy Process
MCDM	Multi-Criteria Decision Making
MCDA	Multi-Criteria Decision Analysis
USGS	United States Geological Survey
FAO	Food and Agriculture Organization
UNESCO	United Nations Educational, Scientific and Cultural Organization
CI	Consistency Index
CR	Consistency Ratio

CHAPTER 1

INTRODUCTION

1.1 Background of Study

The Malaysian Government, as part of its overall transport plan have proposed to connect Kuala Lumpur and Port Klang to the East Coast through a strategic railway network. One of the major transportation projects planned for the East Coast Economic Region (ECER) is the East Coast Rail Link (ECRL), which is envisaged to comprehensively serve all the main centres of the East Coast Region and at the same time connect this network to the overall rail network in Peninsular Malaysia. With this in place, the East Coast Region will be effectively connected to the main centres of Peninsular Malaysia**,** which will then be part of the national rail system providing a safer, more reliable, and integrated service for the movement of passengers and goods.

Previously, the ECRL that was signed in 2016 passes through Kota Bharu, Kuala Terengganu, Kuantan, Mentakab, Bentong and ends at Gombak. However, after the suspension period, a supplementary agreement was signed on 12th April 2019, where the alignment was shifted southwards**,** traversing through Mentakab**,** Jelebu**,** Bangi and Putrajaya before ending at Port Klang as shown in Figure 1.1. The proposed new ECRL alignment is divided into 3 sections as follows;

i) Section A – Kota Bharu to Dungun (New Alignment): Ch 0+000 to Ch210+460
ii) Section B – Dungun to Mentakab (Existing Alignment)**:** Ch 210+460 to Ch421+160
iii) Section C – Mentakab to Port Klang (New Alignment): Ch 421+160 to Ch563+6

Figure 1.1: Proposed New ECRL Alignment

The proposed alignment in the state of Kelantan commences at Kota Bharu and ends at the border of Kelantan and Terengganu. The length of the alignment in Kelantan covers an approximate distance of 43.8km. The railway alignment predominantly transverses through paddy fields, plantations, existing roads (i.e. State Roads, Federal Roads, Local Road and Minor Road) and rivers. Click or tap here to enter text.

The alignment then continues further towards the southeast direction traversing through villages and swampy areas. The railway alignment consists of elevated, at grade and tunnels sections. Fourteen (14) numbers of major Federal and State roads crossings were identified along the alignment in Kelantan. The alignment involves four (4) districts in Kelantan i.e. Kota Bharu, Bachok, Pasir Puteh and Machang. There are two (2) proposed stations in Kelantan, namely Kota Bharu and Pasir Puteh Stations. The list of JKR road crossings is as tabulated in Table 1.1.

Table 1.1: List of JKR Road Crossings in the State of Kelantan

No.	**Chainage (m)**	**District**	**JKR Road Crossings**	**Type**
1.	1,403.01	Kota Bharu	FT 8 Jalan Kuala Kerai	Federal Road
2.	2,522.31		FT 208 Jalan Tendong - Mulong	Federal Road
3.	4,426.88		FT3 Lebuhraya Kota Bharu-Kuala Krai	Federal Road
4.	6,425.07		D114 Jalan Peringat Nilam Puri	State Road
5.	8,445.91		D113 Jalan Padang Lengkuas	State Road
6.	9,237.02		D126 Jalan Kadok - Padang Kala	State Road
7.	12,663.73		D14 Jalan Melor Ketereh	State Road
8.	18,171.41	Pasir Puteh	D14 Jalan Bukit Akar - Kok Lanas	State Road
9.	19,898.44		D136, Jalan Selising - Kok Lanas	State Road
10.	30,876.61		D159 Jalan Jeram Pasu	State Road
11.	32,823.90		D16 Jalan Cherang Tuli	State Road
12.	34,763.87		D20 Jalan Pasir puteh- Gong Kelih	State Road
13.	36,636.54		D160 Jalan Gaal - Kampung Bukit	State Road
14.	40,021.14		FT4 Timur - Barat Highway	Federal Road

The proposed railway alignment in state of Terengganu continues from Kelantan – Terengganu state border line and the consultancy services package for HSS terminates at Bukit Besi (Dungun) with an approximate distance of 166.6km. The railway alignment traverses predominantly across paddy fields, roads (i.e. State Roads, Federal Roads, Local Road, Minor Road and Expressways) and rivers.

The alignment also passes through built up villages, residential areas, forests and swamps. The railway alignment consists of elevated, at grade and tunnels sections with thirty-one (31) number of crossings, which were identified as Federal JKR Roads, State JKR roads and LLM Expressways. The list of the crossings is as tabulated in Table 1.2.

Table 1.2: List of JKR Roads Crossings in the State of Terengganu

No:	Chainage (m)	District	Road crossings	Type
1.	49,339.94	Besut	T163 Jalan Pelangat - Lata Tembakah	State Road
2.	52,443.55		T5 Jerteh - Keruak (Besut)	State Road
3.	55,190.64		T159 Jalan Gong Nering - Darau (Setiu)	State Road
4.	58,441.06		T142 Jalan Jabi - Pasir Akar ()	State Road
5.	68,187.62		FT1697 Jalan Felda Selasih	Federal Road
6.	78,239.22	Setiu	T140 Jalan Padang Serai	State Road
7.	80,519.58		T140	State Road
8.	88,689.55		T138 Jalan Ulu Seladang	State Road
9.	104,819.463		FT1695 Jalan Felda Chalok Barat	Federal Road
10.	107,655.14		T151 Jalan Kg Sungai Bari - Jeneris	State Road
11.	109,157.70		FT 3 Federal Route 3 Kota Bharu - Kuala Terengganu (AH18)	Federal Road
12.	119,125.06		FT3, Jalan Kota Bharu - Kuala Terengganu	Federal Road
13.	119,665.76		FT247 Jalan Sungai Tong-Kuala Berang	Federal Road
14.	131,078.37	Kuala Terengganu	E8 East Coast Expressway	Expressway
15.	133,738.75		T9 Jalan Akob/ Jalan Kuala Berang	State Road
16.	134,307.86		T132 Jalan Kg Tanjung Ketom	State Road
17.	135,238.07		T101 Jalan Kampung Atas Tol	State Road
18.	135,738.50		T170 Jalan Kg Pelam / Kg Bkt Aman / Kg Bukit Lawang	State Road
19.	139,231.47	Marang	(LPT2) Jalan Bukit Payung - Temelong	Federal Road
20.	141,588.89		T102 Jalan Alor Limbat	State Road
21.	143,189.48		T101 Jalan Kampung Atas Tol	State Road
22.	144,705.10		FT14 Jalan Kuala Berang	Federal Road
23.	150,234.60		T40, Jalan Wakaf Tapai - Marang	State Road

No:	Chainage (m)	District	Road crossings	Type
24.	150,486.49		T105 Jalan Kem Perkhemahan Chador Marang	State Road
25.	154,458.33		T2, Jln Marang - Wakaf Tapai	State Road
26.	156,746.07		T112 Jalan Pulau Kerengga - Pengkalan Berangan,	State Road
27.	197,255.56	Dungun	T114, Jalan Tok Kah - Lintang	State Road
28.	200,147.36		T114, Jalan Tok Kah - Lintang	State Road
29.	202,472.08		T114, Jalan Tok Kah - Lintang	State Road
30.	203,657.63		FT132, Jalan Bukit Besi - Dungun	Federal Road
31.	210+285.97		FT3, Jalan Paka, Jalan Kemaman - Dungun	Federal Road

Based on the study and site visit conducted, a total of one hundred and forty-three (143) road crossings were identified in the state of Kelantan and seven hundred and eleven (711) road crossings for the state of Terengganu. The summary of identified road crossings for the State of Kelantan and Terengganu are as tabulated in Table 1.3 and Table 1.4. Appropriate road access (i.e. RUB, ROB, VBC and Frontage Road/Realignment) are proposed to reconnect the severed roads to allow continuation of local traffic flow.

Table 1.2: Summary of Road/Track Crossings in the State of Kelantan

No	Road Type	Total Number of Crossings
1	Federal Road	4
2	Expressway	0
3	State Road	10
4	Local Road	2
5	Minor/Track Road	127
TOTAL		**143**

Table 1.3: Summary of Road/Track crossings in the state of Terengganu

No	Road Type	Total Number of Crossings
1	Federal Road	9
2	Expressway	1
3	State Road	21
4	Local Road	2
5	Minor/Track Road	678
TOTAL		**711**

Upon identifying the severed road crossings, the design consultants were given a task to reinstate the connectivity of the roads. They are required to study the severed roads and propose an appropriate design solution such as overpasses, underpasses and VBC (Vehicular Box Culvert). An overpass is an existing road crossing that crosses above the ECRL alignment with the new proposed bridge structure. It is proposed to be used when the existing road level is higher than the rail level. The minimum vertical clearance required from rail track to soffit of the bridge is 6.55m. An underpass is when an existing road crossing that crosses under the ECRL alignment. It is proposed to be used when the existing rail level is higher than the existing road level. The minimum vertical clearance required from road level to rail is 5.4m. A VBC is an opening created under an embankment that allows vehicles to pass through from one side to another. Severed road crossings will be connected through a box culvert under ECRL if there are no other alternative route for traffic to cross and if the height clearance permits. There are two types of VBC's, the first one requires a minimum height clearance of 4.5m for earth tracks and the second type requires a minimum height clearance of 5.4m for metalled or paved roads.

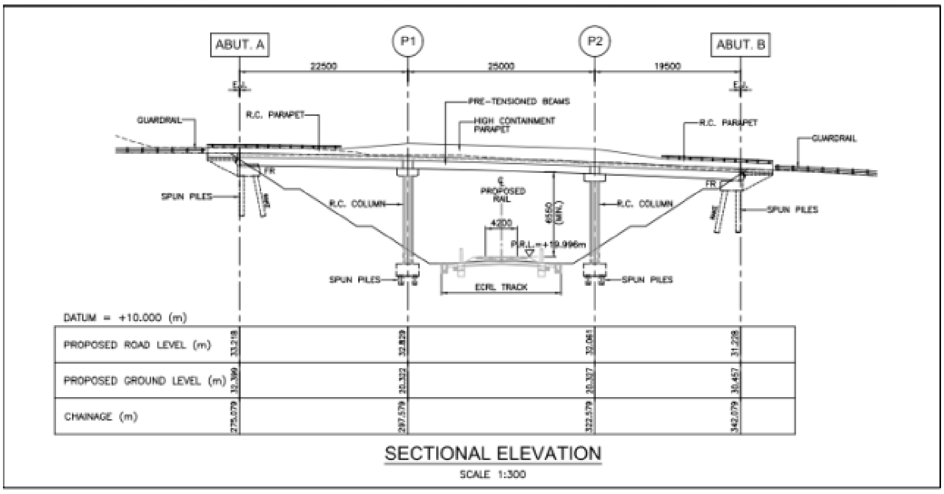

Figure 1.2: Sectional Elevation of Overpass

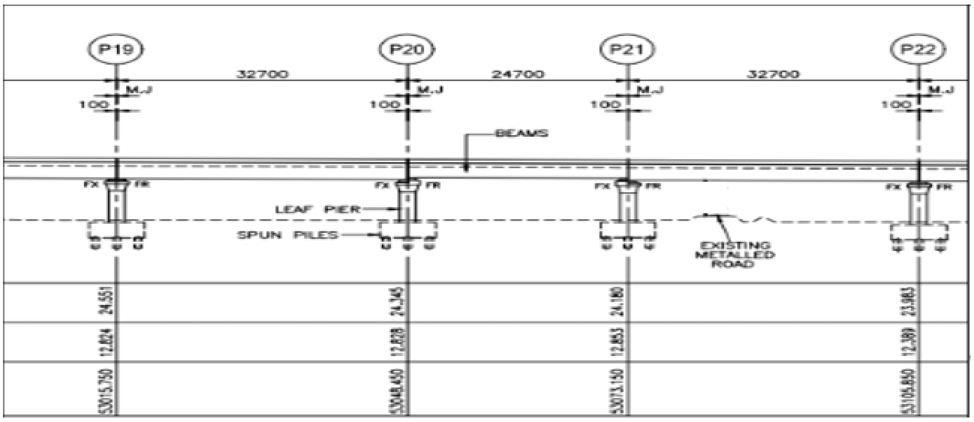

Figure 1.3: Sectional Elevation of Underpass

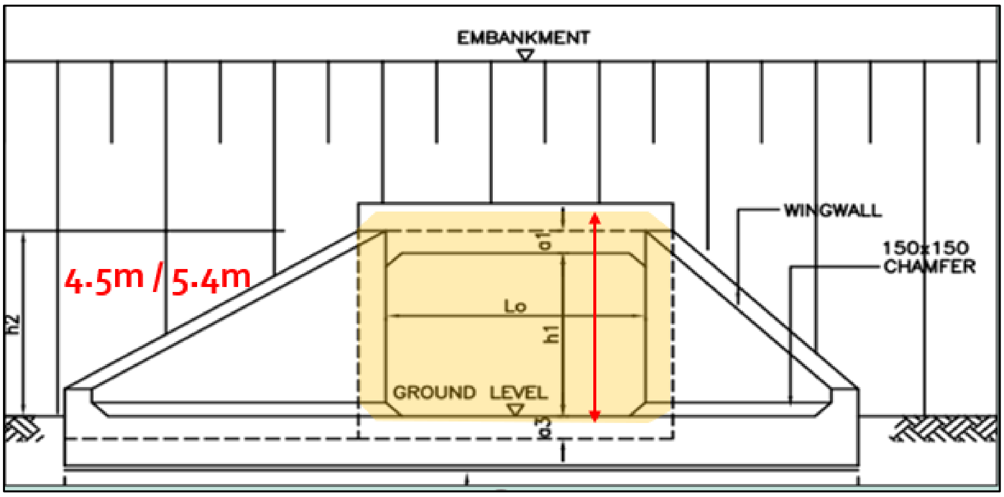

Figure 1.4: Typical cross section of Vehicular Box Culvert

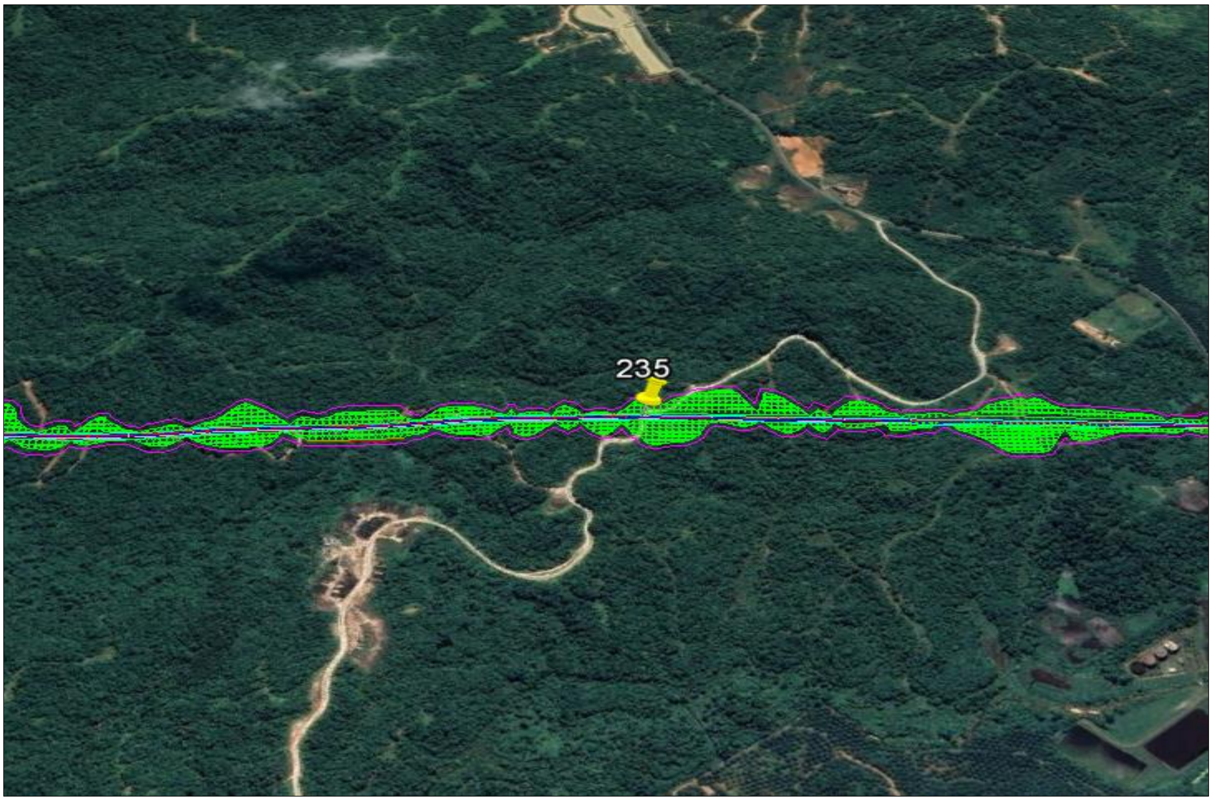

Figure 1.5: Bird’s eye view of road crossing 235

The figure above shows one of the 850 road crossings that were severed by the ECRL alignment. Road crossing 235 is located at the district of Setiu, Terengganu. Road crossing 235 is a minor road (earth track) that was severed by the ECRL alignment. To reinstate the connectivity of this road, an overpass must be provided due to the nature of its location. This road crossing is located at a rather hilly terrain. It would be rather challenging to provide a frontage road as the ground levels at this location are inconsistent. This would make it difficult for vehicles like cars, lorries, tractors to travel on a terrain like this. Moreover, this road passes through a cut area, meaning that the road level is higher than the rail level of the ECRL alignment. Being in a cut area, it is not feasible to provide a box culvert or an underpass as the design treatment for this road as the rail profile must be raised by approximately 30 metres high to span over the road crossing through existing high ground. Hence, an overpass is the best design treatment for road crossing 235. Next, this road leads to a vegetable plantation located in the district of Setiu, Terengganu and unfortunately, the road is also the only access route to that plantation. Therefore, the road cannot be closed. Thus, an alternative route (overpass) must be provided to reinstate the connectivity of the road to make sure the goods can be transported. As mentioned earlier, the engineers were given a task to reinstate the connectivity of each road by proposing an appropriate design treatment. After thorough analysis and studies, an overpass was deemed as the best solution to reconnect the road.

1.2 Problem Statement

The figure below from google earth shows the 3 overpass options proposed to reinstate the connectivity of road crossing 235. The task at hand is to select the best overpass among the 3 options by using GIS applications. The options are labelled as the following:

Option 1: Blue

Option 2: Yellow

Option 3: Pink

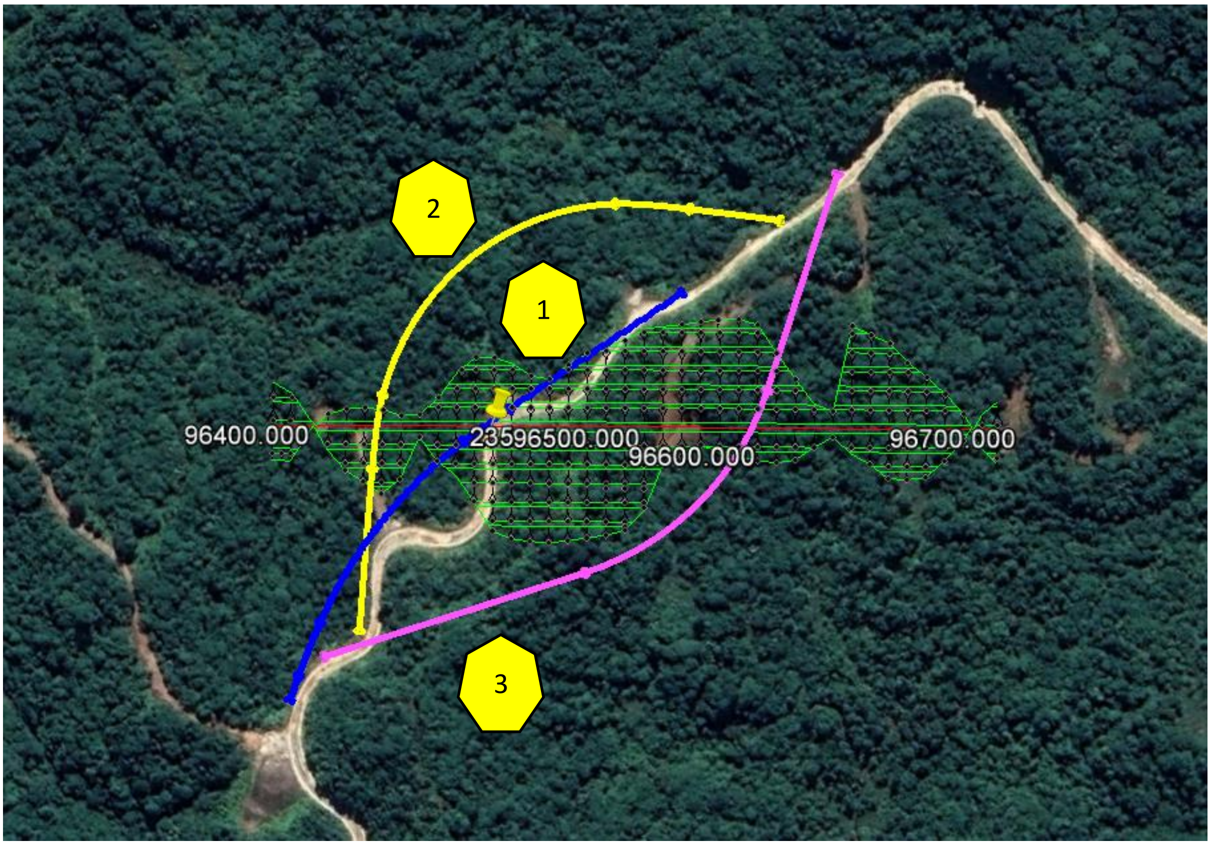

Figure 1.6: Overpass Options

1.3 Objectives

The sole purpose of this research is to witness how Geographical Information System (GIS) and Spatial Analytics can aid in optimal route selection.

The aims and objectives of this tasks are listed below:

1. To use GIS to determine the optimal road crossing.
2. To choose the best overpass to reinstate the connectivity of the road crossing.
3. To reinstate the connectivity of the severed road crossing from the ECRL alignment.
4. To compare the results of route selection using GIS against conventional methods.

1.4 Scope of Study

In this research study, the aim is to study how GIS aids in the optimal route selection process. At the end of this study, the results of this research will be compared to the same study conducted using conventional methods in route selection process. This study will cover the scope and benefits of using GIS in optimal route selection and determine whether it is more efficient to use GIS against conventional methods for route selection studies. GIS-MCDA (Multi-Criteria Decision Analysis) will be used in this study in the process of making decisions whereby several criterions will be listed down and be compared among one another. Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (F-AHP) will be used to determine the weightage of each criteria and this will be done by several experts in the related field of study. Lastly, a weighted overlay and fuzzy overlay analysis will be done using the spatial analyst to select the best route for road crossing 235.

CHAPTER 2

LITERATURE REVIEW

2.1 Geographic Information System (GIS)

Geographic Information System (GIS) is a software program that captures, stores, checks and displays data related to the Earth's surface location. It is the framework for data collection, management, and analysis. GIS can view various types of data on a single map such as routes, structures, and vegetation. GIS, rooted in geographic science, integrates several types of data. It analyses spatial places and uses maps and 3D scenes to organize layers of information into visualizations.

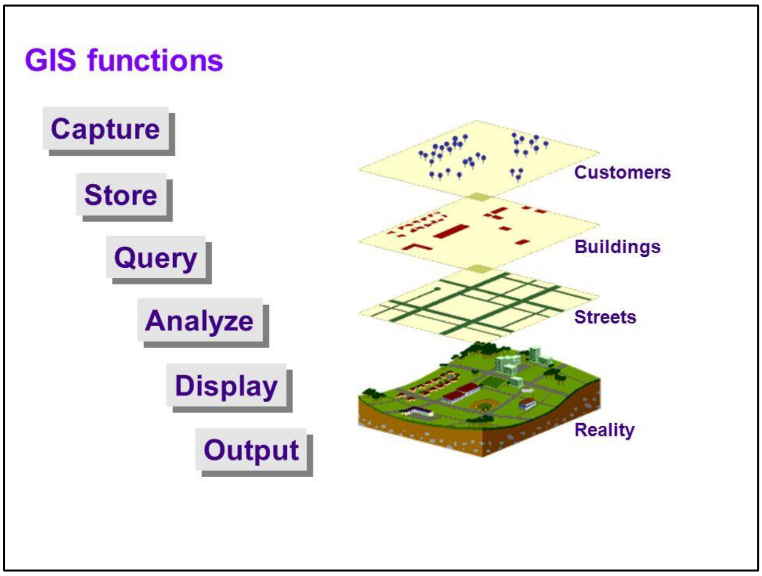

Figure 2.1: Functions of GIS

GIS provides clearer insights into data, such as trends, relationships, and circumstances through this unique feature, which lets users make better decisions. The conventional method of aligning highways and is a tedious and time-consuming process which involves a lot of manual labour and is rather expensive (Gitau & Mundia, 2017). GIS, on the other hand offers a much easier approach and is used by organizations in nearly every sector to construct maps that interact, analyse, exchange information, and develop solutions worldwide and this is changing the world's way of working. GIS allows us to identify problems, monitor change, perform forecasting, understand trends and manage and respond to events. In earlier days, conventional road routing included the use of bulk paperwork and the use of baseline information that was not so reliable and definitive. With resources for understanding and collaboration, GIS technology applies geographic science. This application helps people accomplish a common goal which is to obtain actionable information from all data types. There are 4 types of resources which are maps, data, spatial analysis, and apps. For the data layers and analytics people need and want to work with, maps are the geographic container. GIS maps are easily shared and embedded in apps, and accessible by virtually everyone from anywhere around the world. As for data, GIS incorporates several different kinds of data layers using spatial location. Most of these data has a geographic element. GIS data includes imagery, features, and base maps linked to spreadsheets and TABLEs. Spatial analysis lets you assess suitability and potential, estimate and forecast, view, and understand, and much more, lending new insights to our experience and decision-making.

2.2 Advantages of GIS

GIS is a software that comes with many benefits. One of the most important advantage of this software is that it helps humans make better decisions. This is because of its ability to combine and analyse more than one variable of a problem before finding the best solution to the issue. GIS functionalities are useful for combining different datasets, performing analysis and modelling for optimum route position. These functionalities resolve multiple barriers to an optimised route based on different parameters (Abousaeidi et al., 2016) Another benefit of this software is that it helps save time and cost. A common example would be to select a route to a destination, GIS has the functionality to overlay and generate more than one map and help pick or select the fastest and best route to the destination.

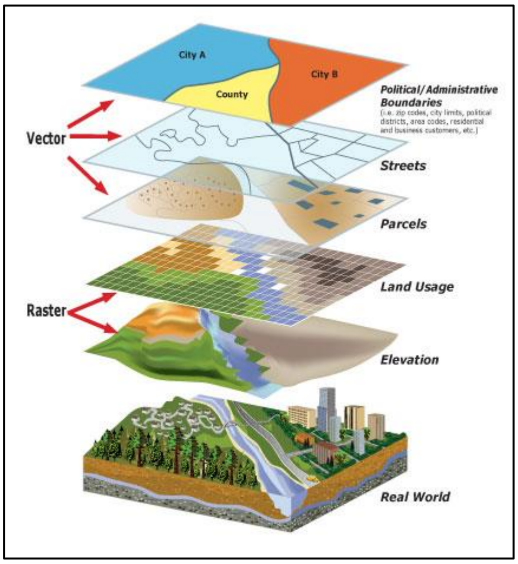

Figure 2.2: GIS Overlay Function

GIS software allows the spatial data and network system to represent real data in the production of different types of maps and the benefit of this is its ability to generate many maps when describing actual route networks in order to reach destinations as quickly as possible (Gitau & Mundia, 2017). In addition to that, adopting advanced technologies such as remote sensing and GIS offers precise and synoptic spatial and temporal datasets on vegetation and land cover, surface hydrology, and aerosols for wider areas in a time-and cost-effective manner (Abousaeidi et al., 2016). Next, GIS based infographics and maps help tremendously in understanding situations and telling a story. It is a new language that aids in communication among various organisations, teams, and agencies. The GIS software has a user-friendly interface that helps organizations to easily connect and communicate with other applications (Pandey et al., 2013). Moving on, GIS also offers better geographic information recordkeeping. In this modern world, the prime objective of many organisations is to preserve authoritative records on the condition and improvement of geography which is also known as geographic accounting. Moreover, GIS offers a powerful platform to handle systems with full transaction support and reporting tools and these systems are rather similar in concept to other types of information systems in terms of data management (Pandey et al., 2013). Another benefit of GIS is that it helps in managing geographically. GIS helps the user to easily spatial information without having to go through vast amounts of confusing data. It is so much easier to recognize the geography of a specific area than to attempt to analyse raw data (AYCHILUHIM, 2019). Traditional road routing in the past included the use of bulk paperwork and the use of baseline information that was not as reliable and definitive. In most cases, there was a lack of reliable knowledge on land cover, vegetation patterns, geomorphology, hydrogeology, drainage patterns, air, water and noise quality, socioeconomics, etc (Gitau and Mundia, 2020).

2.3 Importance of Road Networks

A road is a paved path that connects two locations from one another which vehicles can use, and transportation is the most basic function of a road. Since it optimises connectivity, an efficient road increases the socioeconomic functionality and quality of life in every populated area, allowing for long-term and all-inclusive development for people living in remote areas (Gitau & Mundia, 2017). This function can be divided into two categories which are mobility and accessibility. Every road has its own purpose according to its position either in the national, regional, state or town network. Roads consists of one or two carriageways, with one or more lanes each and any sidewalks and road verges associated with them. Other examples of roads include freeways, expressways, and parkways. Road networks play a very important role in the development of a nation. While the advent of new communication avenues has made virtual networking increasingly necessary today, a good and stable transport network remains crucial. Roads lead decisively to economic development and growth and offer major social benefits. To make a nation grow and develop, they are of essential value. Furthermore, the provision of access to jobs, social, health and education services makes the road network important for the fight against poverty. Road networks in Kenya is a key component of Kenya's service sector, both in terms of its contribution to jobs and income generation and its role in foreign trade (Aldagheiri, 2009). They are of critical importance to make a nation grow and prosper. Roads are opening more areas and stimulating economic and social growth. Road infrastructure, which is regarded as a crucial prerequisite for any country's social and economic growth and it is utterly essential to develop and upgrade the road network to boost economic efficiency (AYCHILUHIM, 2019). The proper development of the transport road network not only reduces the cost of transportation, both in terms of money and time, but also helps in the integration of various regions within the (Aldagheiri, 2009). The road is important to move goods and critical public transport to citizens, the road network is related to increasing the national functioning land both in the road network country and the local road network (Hyun, In-Joon and Sun-Heung, 2009). Transportation facilitates the movement of people and commodities, as well as influencing development and economic activity patterns by allowing access to productive lands and hard-to-reach populations. It is also multifaceted and responsive in that its success has an impact on public policy issues such as resource use, social equity, land use, urbanisation, economic development, and safety and security (Velmurugan et al., 2011).

2.4 Analytical Hierarchy Process

In this research, the MCDA method that will be used is the Analytical Hierarchy Process (AHP) and Fuzzy Analytical Hierarchy Process (F-AHP). The Analytical Hierarchy Procedure (AHP) is a tool for arranging and evaluating complex judgments using math and psychology. It AHP is a pairwise comparison method is used to calculate the weightage or importance of each criteria that have been classified within the MCDA(Saaty, 1984).

Relative intensity	Definition	Explanation
1	Equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgements	When compromise is needed
Reciprocals	Reciprocals for inverse comparison	

Figure 2.3: Saaty's Pairwise Scale

It consists of three main parts which are the purpose or issue an individual is attempting to solve, the possible solutions which are called alternatives and the parameters or factors by which you will judge the alternatives. The parameters will be compared two at a time by stakeholders or experts related to the field of the problem. By using AHP, we can convert these evaluations into numerical values which can be compared to all the parameters. Once all the parameters are compared, numerical priorities are calculated for each of the alternative options. Below is a visual representation of all the steps.

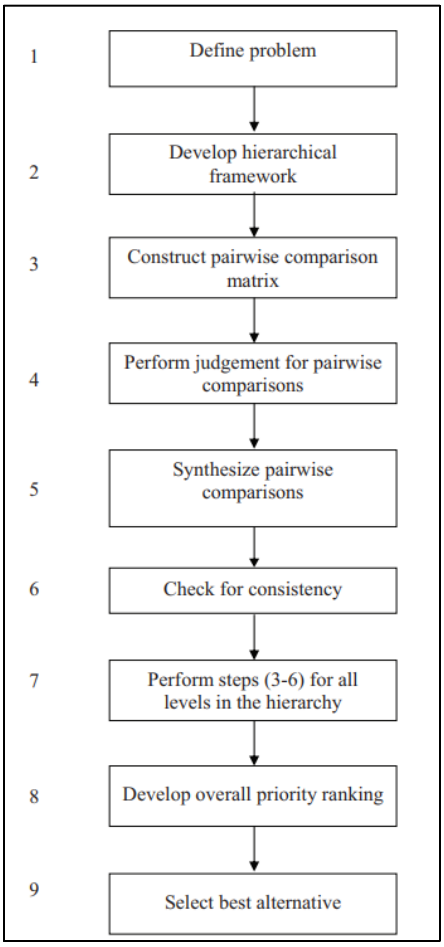

Figure 2.4: Steps of the Analytical Hierarchy Process

It is very important to use a combined approach of GIS-MCDA rather than using GIS alone in studies like this. This is because using GIS alone is difficult to solve problems that have multiple criteria, thus, leading to inaccurate results. To address these limitations, we integrate GIS with MCDA. According to (Marinoni, 2004), the incorporation of AHP into the Geographic Information System (GIS) integrates decision support approach with efficient visualization and mapping capabilities which, in turn, can significantly promote the development of maps for land use. AHP is a GIS based MCDA ensures that highway alignment is most suitable to avoid prone high-risk areas such as sand dunes, stream crossings, fault zones, etc .... in addition to environmental conservation constraints and cost (Ziaei & Hajizade, 2011).

2.5 Fuzzy Analytical Hierarchy Process

Fuzzy Analytic Hierarchy Process (F-AHP) is a fuzzy logic-based Analytic Hierarchy Process (AHP) system. The (F-AHP) method is identical to the AHP method. The (F-AHP) method simply converts the AHP scale into a fuzzy triangle scale that is used to determine the weightage of the involved parameters. (F-AHP) was created because assigning a single number from the pairwise scale to any term was not justified. For example, moderate has been assigned the value 3 and 4 is the intermediate value of moderate and strong. But the values between 3 and 4, for example, 3.5 is not justified and does not fall into a specific category. Because of these issues, the concept of fuzzy numbers was introduced. The AHP is typically used in applications that involve virtually instantaneous decisions. It does not account for the variability that comes with mapping people's judgments to a rating scale and the fuzzy set theory is used to incorporate AHP to decide the best option, in order to solve the limitations of the AHP (Tella & Balogun, 2020). In 2020, a study was conducted to determine the flood susceptibility areas in Ibadan, Nigeria by using the spatial analytics integrated with AHP and F-AHP and the study proved that AHP was outperformed by (F-AHP) as (F-AHP) showed clearer results (Sánchez-Lozano et al., 2013).

2.6 Multi-Criteria GIS analysis (GIS-MCDA)

Multi-criteria decision making is one method that is used to support the analysis of several factors by the people in charge of making decisions. MCDA is used to objectively analyse and compare various parameters that are often contradictory to pick the best possible solution for any kind of problem. MCDA techniques are well-known decision support methods for dealing with complex decision constellations that require consideration of technical, economic, ecological, and social factors (Vahidnia et al., 2008). It is particularly helpful if you have a wide variety of stakeholders with competing interests, beliefs, and objectives. There are many problems related to geographic nature out there and the best probable way to tackle this issue is a combined approach of GIS and MCDA. This is because spatial issues usually involve a set of alternatives that contradict with one another. By using this combined approach that converts and merges the geographical data and value assessments, spatial problems can now be solved easily.

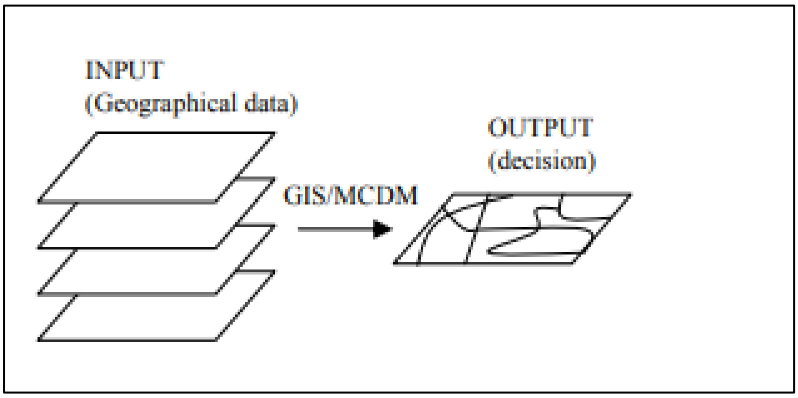

Figure 2.5: Spatial Multi Criteria Decision Analysis

GIS-based MCDA is used in a a variety of decision-making and management contexts, including environmental planning and ecology management, urban and regional planning, and transportation planning (AYCHILUHIM, 2019)There are many examples of GIS-MCDA applications that do not only relate to route selection but also applications like, land suitability, site selection and impact assessments. Multi Criteria Decision Making (MCDM) is a mechanism by which geographical data and value judgments are transformed and combined to determine a set of alternatives with respect to the applicable criteria (Malczewski, 2006). This technique incorporates all important spatial parameters and demonstrates the most appropriate location on a map for a certain land use (Gitau and Mundia, 2020). Multi-criteria decision analysis based on GIS offers versatility that can be used to analyse, understand, and reassess a decision issue (Malczewski, 2006). Multi-criteria decision analysis is a good way to rank the degree of impact of various driving factors in the route planning process, such as engineering, social, economic, and environmental (Wahdan et al., 2019). Geographical data models, the spatial component of the assessment criteria and decision alternatives in the evaluation of criteria must be considered to perform this analysis. The GIS – MCDM combination creates an excellent research tool that allows for the development of a robust cartographic and alphanumeric database, which can later be used by multi-criteria methodologies to simplify problems to solve and facilitate the use of multiple (Wahdan et al., 2019) Using GIS and MCDM techniques to help decision-makers can increase the reliability and efficacy of spatial decision-making (Abousaeidi et al., 2016).

2.7 Previous studies of GIS in Optimal Route Selection

As mentioned earlier, it is very important to use the combined approach in studies like optimal route selection. There have been many studies that have previously been conducted using GIS-MCDA in the field of optimal route selection not only related to roads specifically, but also in general. There were a few differences between those studies, namely the type of MCDA method used, type of datasets and criteria and the route goal of the conducted research. A study was conducted in Egypt by using remote sensing data and GIS-Based Least Cost Path Model with the aid of AHP to design an optimum highway route (Balogun et al., 2012). A study was conducted by using the GIS modelling approach to determine the fastest delivery routes for perishable goods (Balogun et al., 2012). A GIS-assisted study of optimal urban route selection based on multi criteria approach in Baghdad, Iraq (Ahmed & Hwy, 2009). In this study, AHP was used to determine the weightage of the criteria(Ahmed & Hwy, 2009). Moving on, another study was conducted where a GIS-based raster model was proposed to evaluate the alignment of natural gas pipelines and create an ArcGIS 9.2 interface for this model and use GIS tools to develop LCP for a corridor in the desert environment of the Sinai Peninsula to connect the three cities namely, Taba City, Nekhel City, and El Shatt City (Effat & Hassan, 2013). Next, a case study of Moiben-Kapcherop-Kitale Road was conducted by Gitau and Mundia (2020), where they used GIS modelling and AHP to determine the optimal road route location. Another study was conducted related to optimal route selection using virtual reality and GIS (Hyun, In-Joon and Sun-Heung, 2009). However, in this study, a GIS-MCDA approach was not used. Instead they evaluated the routes based on 4 criterions, namely society, economy, technology, and environment. Lastly, a research was carried out to determine the optimal oil pipeline route using GIS, community participation in weight derivation and disaster mitigation (Yildirim et al., 2006)

2.8 Conventional methods vs GIS methods

In this modern world, time and cost are two important factors that cannot be taken for granted. Engineers are looking to conduct experiments in the most efficient way without having to spend too much time and money and still being able to produce exceptional results. The same concept is applied in optimal route selection where people nowadays because by using GIS a lot of the work is made easier when compared to using conventional or traditional methods. The traditional or conventional method in optimal route selection is rather inconvenient and time consuming (Yildirim et al., 2006) The conventional method of optimal route selection emphasizes more focus on the design rather than the surrounding factors that may be affected or should be considered. In developing countries, traditional route planning has been solely focused on topographical aspects such as gradient and curvature (Gitau & Mundia, 2017). In earlier days, conventional road routing included the use of bulk paperwork and the use of baseline information that was not so reliable and definitive (Zhang & Workflow, 2014). Conventional routing methods are difficult to use and yield inaccurate results (Zhang & Workflow, 2014). The lack of a breakthrough in the conventional design pattern is one of the major factors affecting the degree and performance of Chinese highway design and system, particularly in terms of the lack of high-tech content (Zhang & Workflow, 2014). By using conventional methods, a lot of factors are not considered during optimal route selection. In most cases, there was a lack of reliable knowledge on land cover, vegetation patterns, geomorphology, hydrogeology, drainage patterns, air, water and noise quality, socioeconomics, etc (Gitau and Mundia, 2020).

CHAPTER 3

METHODOLOGY

The main objective of this study is to use GIS and multi-criteria decision analysis (AHP and F-AHP) to determine the best overpass to reinstate the connectivity of the severed road and then evaluate the results against the conventional methods of optimal route selection. The objective was achieved after following a series of workflows. The workflows can be simplified into three Namely, the overall workflow, primary workflow, and secondary workflow.

3.1 Overall Workflow

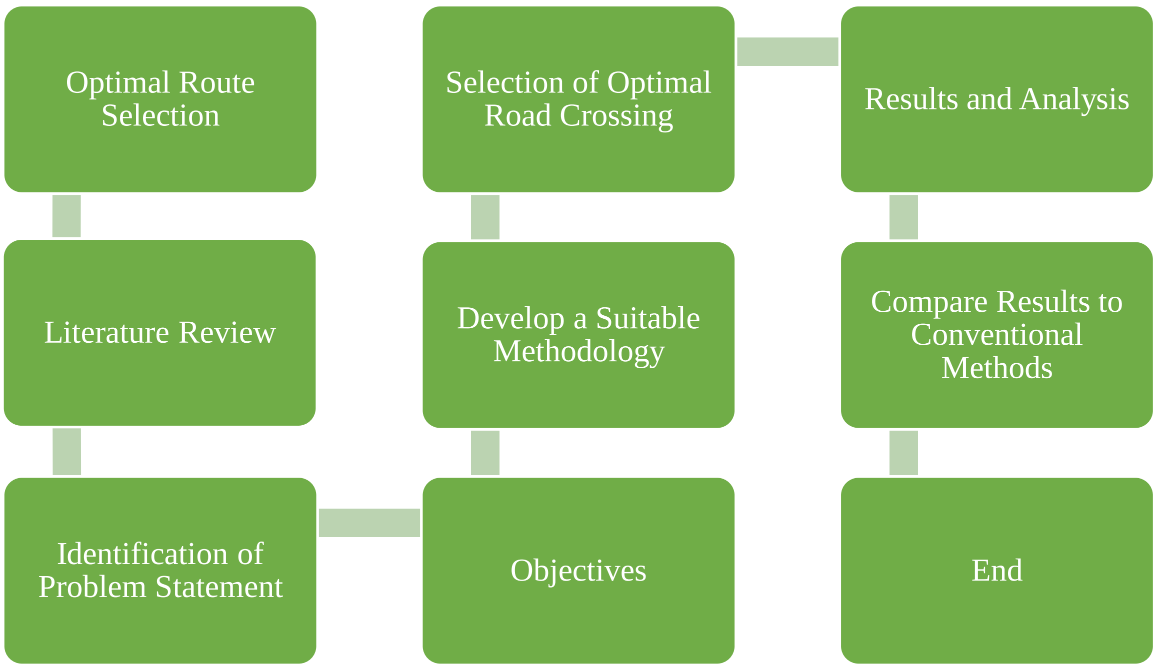

Figure 3.1: Overall Workflow

3.1.1 Primary Workflow

The primary workflow demonstrates the protocol for evaluating the data gathered from the decisions of the experts. In this process, the questionnaire will be circulated to decision-makers who are well acquainted with optimal route selection and their factors, as well as the decisions taken, will all be based on their judgment on the relative significance and value of the elements.

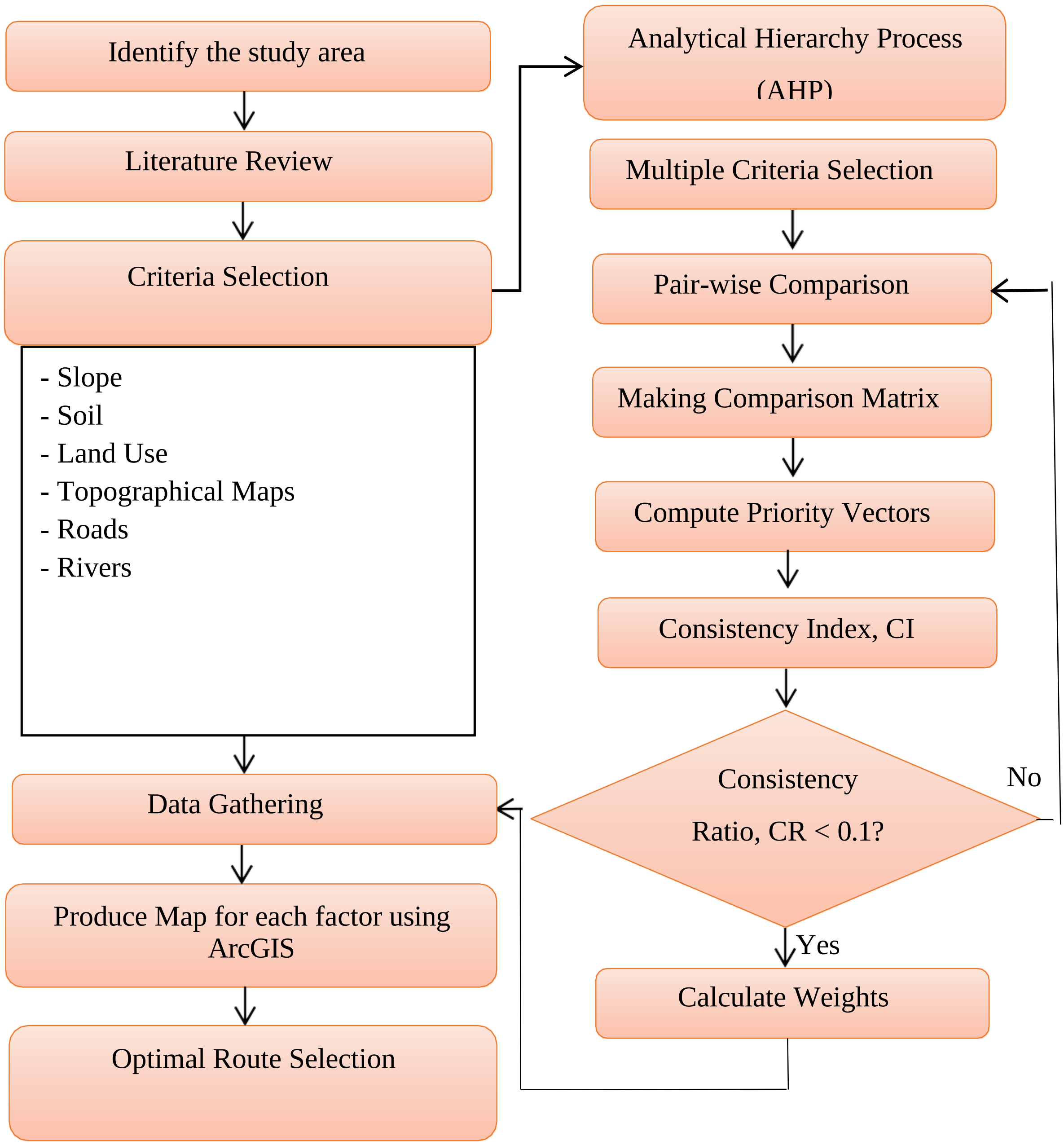

Figure 3.2: Primary Workflow

3.1.2 Secondary Workflow

The secondary workflow demonstrates the mechanism of the fuzzy algorithm being integrated into the output of the AHP obtained upon completion of the survey carried out. During the procedure, the value obtained in AHP for each factor will be reassigned using the fuzzy pairwise scale.

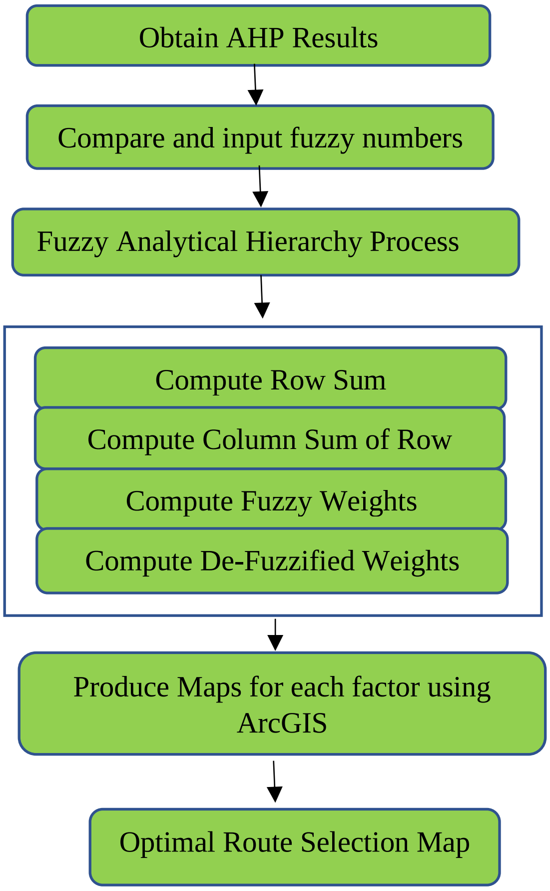

Figure 3.3: Secondary Workflow

3.2 Study Area

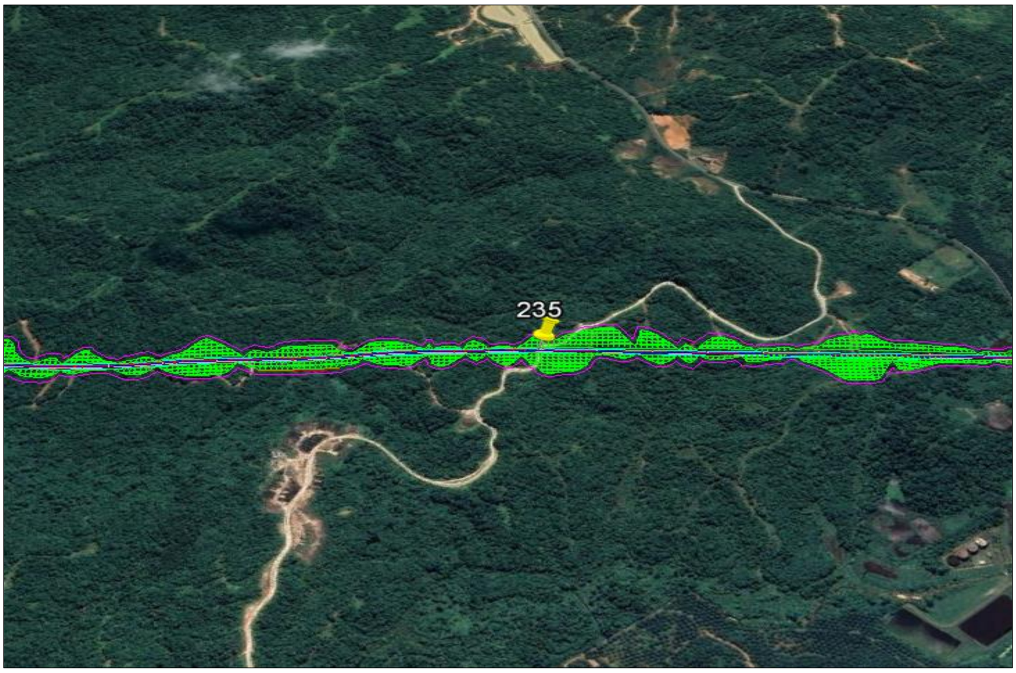

Figure 3.4: Location of Study

The above FIGURE shows the study area of the location. This road is located at the district of Setiu, Terengganu. This road leads to a plantation and has been severed by the ECRL alignment. There is no existing alternative route available to access the plantation, thus, its connectivity must be reinstated. Below are some salient details of the road crossing:

Table 3.1: Salient Details of Road Crossing 235

Road Crossing No	235
Road Name	Unnamed
State	Terengganu
District	Setiu
Chainage (CH)	96+493.02
Coordinates	5°27'41.65"N 102°46'40.40"E
Type of Road	Minor Road
Type of Track	Earth Track
Type of Terrain	Hilly
Ground Level from Datum	46.8127m
Rail Level from Datum	28.8560m

3.3 Identifying Criterions & Datasets

The GIS data used for this study include the slope, elevation, land use, topographical maps, roads, and rivers. All these data will be housed in the geodatabase that will be created in ArcGIS 10.5. Below is a TABLE of the datasets and its source.

Table 3.2: Datasets & Sources

No	Data	Source
1	Slope	Digital Elevation Models (USGS)
2	Soil	FAO Soils Portal
3	Land Use	Landsat 8 from Earth Explorer (USGS)
4	Topographical Maps	Digital Elevation Model
5	Roads	Digitized from Google Earth Pro
6	Rivers	Digital Elevation Model

a) Slope

The slope factor is one of the most important factors when it comes to optimal road route selection. In this case study, the road is an overpass, meaning that the road is designed to be above the railway track. The slope will help us determine the start and end point of the overpass as the gradient must be sufficient and safe for vehicles to pass through the road. The proposed overpass should not be constructed through areas with a steep incline. If the slope in the study area is high, it influences the project's economics since the risk of landslides along railway tracks increases (Panchal & Debbarma, 2017). Thus, making slope an important criterion in determining the constructability of the overpass.

b) Soil

Soil class is an important factor in studies related to road route selection. The soil class of the existing terrain must be studied thoroughly before selecting the optimal route to reinstate the connectivity of the severed road as the soil must be feasible to construct a road on top of it. The topsoil should be soft, but the strata beneath should be firm enough for the base to stand on. As a result, soil is considered as an important factor that influences the sustainability of an overpass construction (Panchal & Debbarma, 2017).

c) Land Use

Another significant aspect that influences the route planning process is the research area's land use. Instead of passing through farm and forest areas, the road could pass through barren land (Panchal & Debbarma, 2017). The different land-use classes will be used to present the different terrains over the study area. As we know land use can include, residential, transportation, recreational, commercial, and public use. Once the land use map is generated, engineers can then avoid all these areas and choose the best possible place to place the new road.

d) Topographical Maps

Topographical maps are used to represent a certain ground surface or terrain. The maps display symbols that represent such features as streets, building, streams, and vegetation. These maps can be obtained from Google Earth and it presents the elevation in the form of raster. With elevation, the highest and lowest points around the study area will be determined. This is important because it will be very costly to place roads at a high area and at the same time if the ground level is too low, the road will not be able to pass the rail. and it will be easy to work out the cut and fill values. By using topographical maps, engineers will have a better view and understanding when deciding which areas are best to be avoided when placing or constructing a new road connection from one place to another.

e) Roads

Roads are a pathway that vehicles use as a mode of transportation. It is important to identify the roads surrounding the study area as building an overpass may disrupt the connectivity of the road which results in the disruption of the traffic flow.

f) Rivers

Rivers also play an important role in optimal route selection. It is important to identify the rivers located at the study area as it is best to avoid building overpasses with proximity to rivers as it may result in floods. The planned overpass location should not be located near streams or areas where the water level is high. High water levels around the construction site are undesirable since they cause potential issues during construction (Saaty, 1984).

3.4 Analytical Hierarchy Process (AHP)

A significant step in assessing the decision-making process is the calculation of relative weights for each criterion. It is possible to evaluate the weighting of the criteria as the importance applied to the assessment criteria, which specifies their priority for the other criteria considered. In each option, the weightage must be calculated between all the parameters variables since they have different targets according to the goals and objectives. The Analytical Hierarchy Process (AHP), developed by (Saaty, 1984) is a pairwise comparison method that is used to organize and analyse complex decisions. This pairwise comparison method is used to determine the weightage of the listed parameters for this research. This assessment was developed in three stages, where stage 1 is the development of the comparison matrix. The basis for assessing the relative value of the chosen parameters using Saaty's scale will be done by a team of experts working in this field of study for this analysis. An AHP survey prepared and distributed to them to gain their respective inputs. Stage 2 is to normalize the advanced pairing matrix from previous comparisons and stage 3 is to determine the weight of each factor considered.

Scale of importance	Meaning
1	Equal preference
3	Moderately preference
5	Essential preference
7	Strong preference
9	Absolute preference
2,4,6,8	Expression of intermediate values

Figure 3.5: Saaty's pairwise comparison scale

i. **Step 1: Pair-Wise Comparison**

A survey was conducted with 5 experts in the field of optimal route selection to determine the weightage and importance of the 6 respective criterions. In that survey, they ranked each criteria by using Saaty's pairwise comparison scale shown in TABLE 3.3 . Below is an example of the step-by-step calculation for AHP.

Table 3.3: Example of Pairwise Comparison Matrix

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	1	1/5	7	1	1	5
Slope	5	1	1	8	8	6
Land Use	1/7	1	1	1/4	1/4	5
Topographical Maps	1	1/8	4	1	1	1
Roads	1	1/8	4	1	1	1
Rivers	1/5	1/6	1/5	1	1	1

ii. Step 2: Column Total

Table 3.4: Column Calculation

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	1	0.2	7	1	1	5
Slope	5	1	1	8	8	6
Land Use	0.14	1	1	0.25	0.25	5
Topographical Maps	1	0.125	4	1	1	1
Roads	1	0.125	4	1	1	1
Rivers	0.2	0.167	0.2	1	1	1
Column Total	8.34	2.61	17.2	12.25	12.25	19

iii. Step 3: Normalization of Criteria and Weights

Table 3.5: Normalized Criteria and Weights

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers	Weights (decimal)	Weights (%)
Soil	0.12	0.076	0.41	0.082	0.082	0.263	0.172	17.2
Slope	0.6	0.38	0.058	0.653	0.653	0.316	0.443	44.3
Land Use	0.017	0.38	0.058	0.02	0.02	0.263	0.126	12.6
Topographical Maps	0.12	0.048	0.232	0.082	0.082	0.053	0.103	10.3
Roads	0.12	0.048	0.232	0.082	0.082	0.053	0.103	10.3
Rivers	0.024	0.064	0.011	0.082	0.082	0.053	0.053	5.3
Total							1	100

iv. Step 4: Calculate Consistency Index

To calculate the consistency index, this formula must be used,

$$CI = \frac{\lambda - n}{n - 1}$$

Figure 3.6: Consistency Index Formula

Where n is the number of factors considered in this study, 6

v. Step 5: Calculate Consistency ratio (CR)

To calculate the consistency ratio, this formula must be used,

$$CR = \frac{CI}{RI}$$

Figure 3.7: Consistency Ratio Formula

Where CI is the consistency index and RI is the random consistency index

Table 3.6: Random Consistency Index

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

If the value of the CR is more than 10%, some changes must be made in the pairwise comparison to obtain a CR value less than 10% for the result to be applicable.

3.5 Fuzzy Analytical Hierarchy Process (F-AHP)

After completing the analysis of the Analytical Hierarchy process (AHP) as explained in the previous section, the results will be used to conduct the Fuzzy Analytical Hierarchy Process (F-AHP).

Saaty scale	Definition	Fuzzy Triangular scale
1	Equal importance	(1,1,1)
3	Weak importance	(2,3,4)
5	Fair importance	(4,5,6)
7	Strong importance	(6,7,8)
9	Absolute importance	(9,9,9)
2	intermediate values	(1,2,3)
3		(2,3,4)
4		(3,4,5)
8		(6,7,8)

Figure 3.8: Fuzzy Pairwise Scale

The objective is to replace the whole numbers with the fuzzy triangular scale. As shown the Figure 3.8, the triangular consists of three values, namely, the lowest, middle, or median and the highest value.

Upon replacing the whole numbers with the fuzzy triangular scale, the next step is to compute the fuzzy geometric mean. This can be computed using the equation in Figure 3.9.

$$A_1 \otimes A_2 \otimes A_n = (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) \ldots \otimes (l_n, m_n, u_n) = (l_1 l_2 l_n, m_1 m_2 m_n, u_1 u_2 u_n)$$

$$\text{Geometric Mean} = (l_1 l_2 l_\text{n}, m_1 m_2 m_\text{n}, u_1 u_2 u_\text{n})^{-n}$$

Figure 3.9: Geometric Mean Equation

And A_1, A_2, and A_n are all represented by the criterions and *l*, *m* and u represent the lowest, middle and highest values of each factors, respectively. The next step is to calculate the fuzzy weights, w_i which is represented by the equation in Figure 3.10.

$$w_i = r_i \otimes (r_1 \oplus r_2 \oplus r_3) = (lw_i, mw_i, uw_i)$$

Figure 3.10: Fuzzy Weights Equation

In this equation, w_i represents the fuzzy weight and r_i represents the geometric mean. The following step is to calculate the defuzzied weights to obtain crisp numerical values by using the centre of area equation to get the average weight. The equation used is shown in Figure 3.11.

$$A_w = \frac{\mathrm{l}wi + \mathrm{m}wi + \mathrm{u}wi}{3}$$

Figure 3.11: Average Weights Equation

where A_w represents the average weight. The average weights were then normalized so that the normalized average weights, N_i can be computed by using the equation in Figure 3.12.

$$N_i = \frac{Aw}{\sum_{i=1}^{n} Aw}.$$

Figure 3.12: Normalised Weights Equation

3.6 Building Geodatabase

This step involves digitizing and generating all the data collected and housing it in a geodatabase before carrying out the weighted overlay analysis and the fuzzy overlay analysis. The datasets were obtained in the form of shapefiles, existing maps, and satellite image data. The geodatabase includes slope angles, soil, topographical maps, roads, rivers, and land use data. All the datasets were reformatted to same cell size according to the size of the study area. Figure 3.13 summarises the research methodology of building a geodatabase.

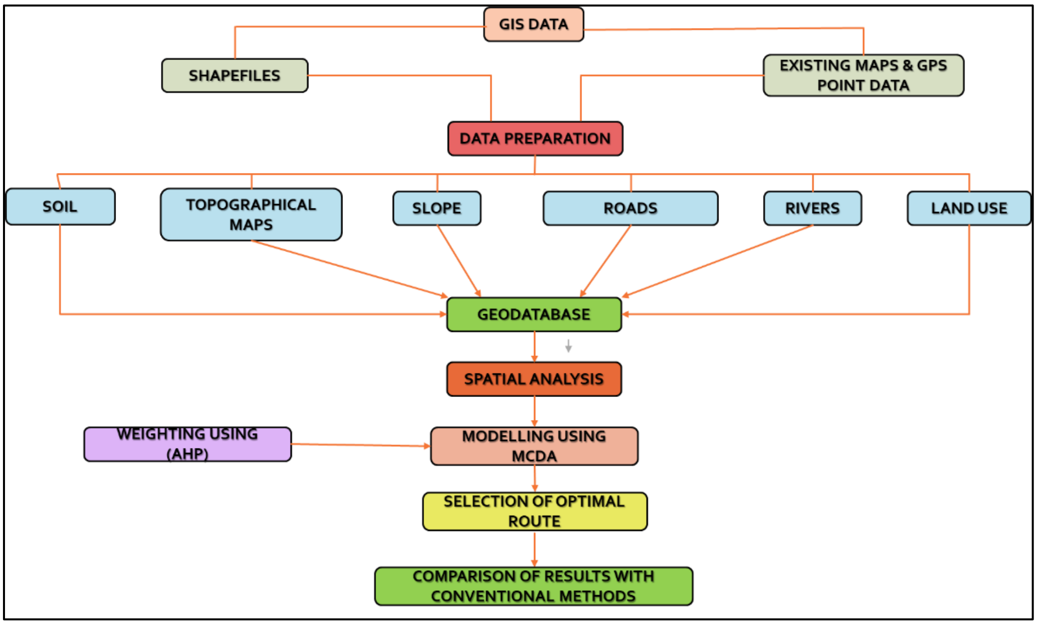

Figure 3.13: Flowchart of Methodology (GIS method)

3.6.1 Slope Angle Map & Elevation Map

The slope angle map and elevation map in ArcGIS 10.5 can be generated from ArcToolbox. It can be generated by executing the following steps:

Slope Angle: ArcToolbox > Spatial Analyst Tools > Surface > Slope

Elevation: ArcToolbox > Spatial Analyst Tools > Surface > Contour

The data used to generate this map was obtained from the Digital Elevation Model (DEM) file that was downloaded from the Earth Explorer/United States Geological Survey (USGS).

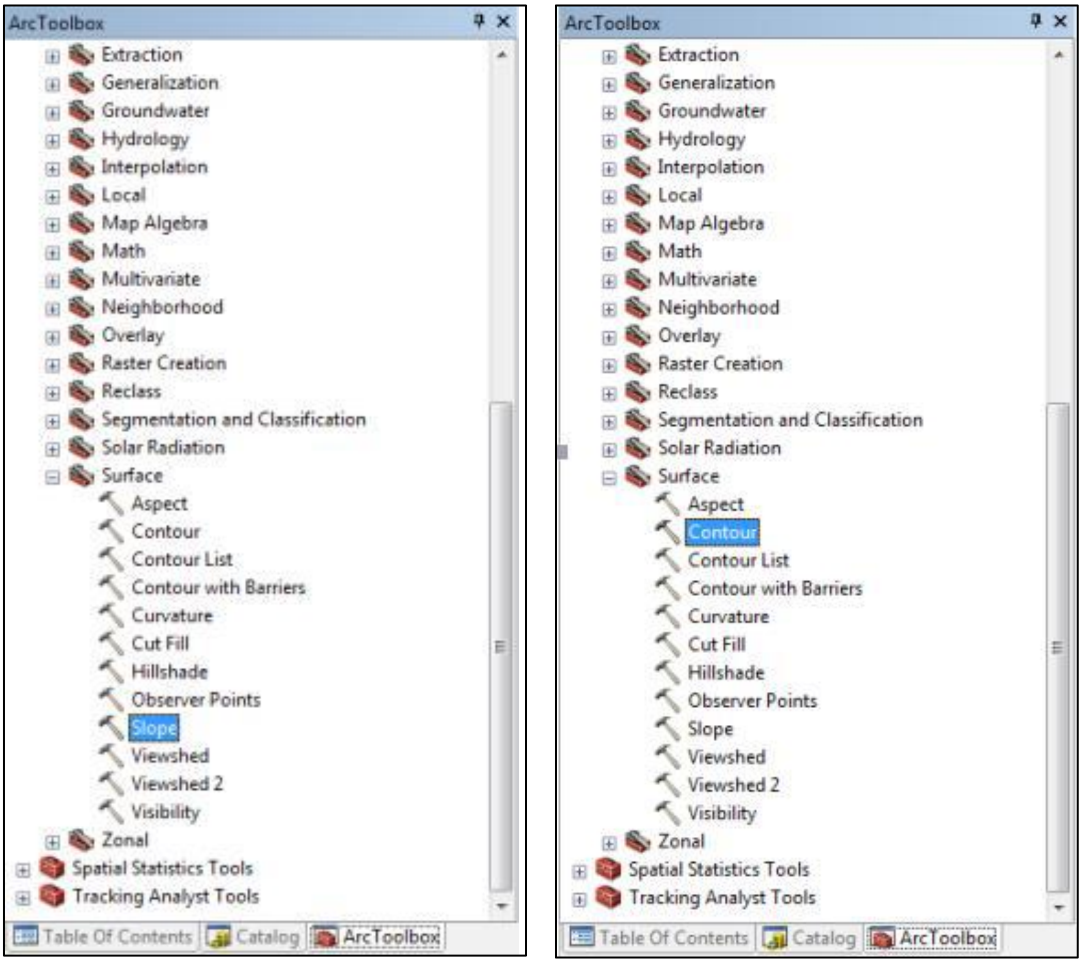

Figure 3.14: Slope and Elevation Tools

3.6.2 Land Use

The data used to generate the land use map was obtained from USGS. A landsat 8 image with 7 bands was downloaded and the data was exported into ArcGIS 10.5, and the following process was carried out:

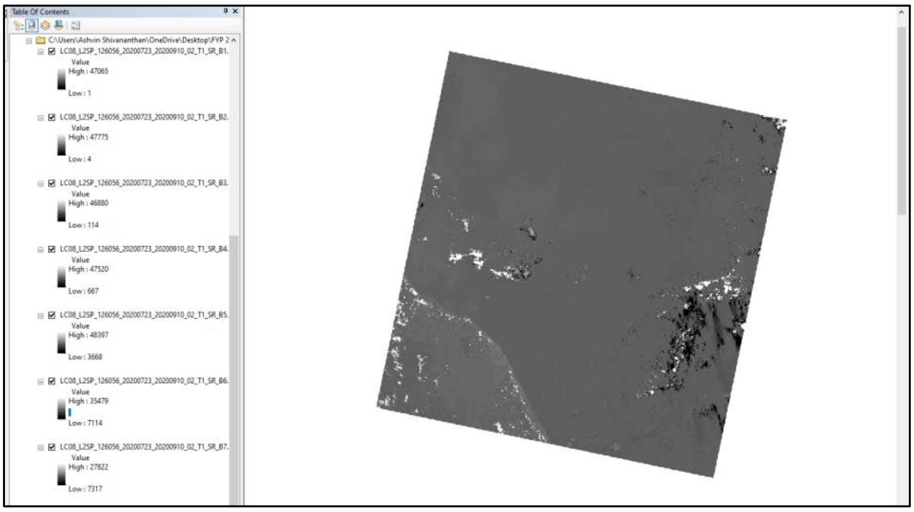

Figure 3.15: Landsat 8 Image

Composite Bands: Windows > Image Analysis > Select bands 1-7 > Composite bands

Once the composite bands were formed, it was then clipped according to the location of the study area. The output is shown in the Figure 3.16:

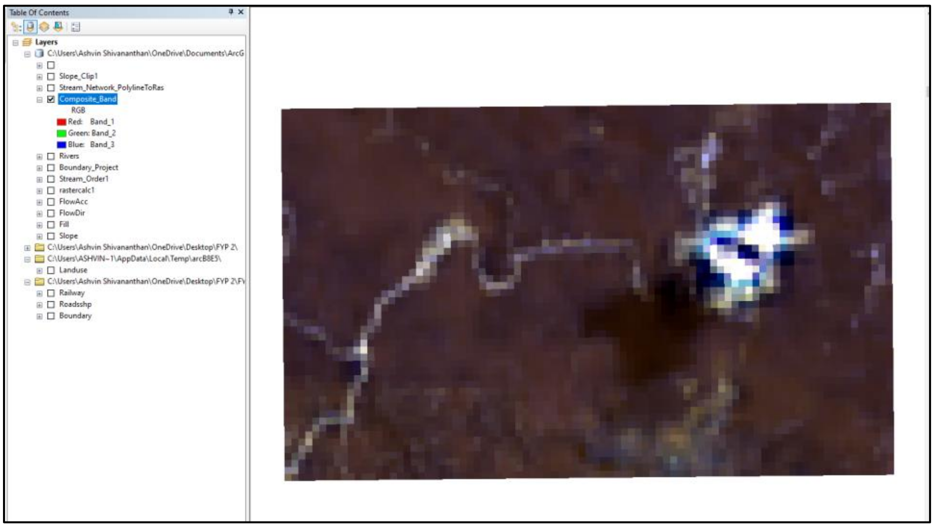

Figure 3.16: Clipped Composite Band Image

Upon clipping the image according to the size of the study area, the image classification process was carried out. There are two types of image classification namely, unsupervised classification supervised classification. To carry out this process, the image classification tool must be enabled, and the following process must be carried out:

Unsupervised: Classification > Iso Cluster Unsupervised Classification > Training Sample Manager > Draw Polygon > Save

Supervised: Classification > Load Training Samples > Maximum Likelihood Classification

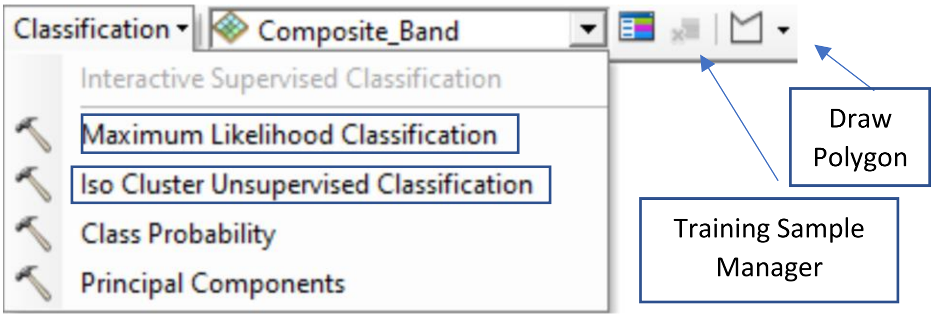

Figure 3.17: Image Classification Tools

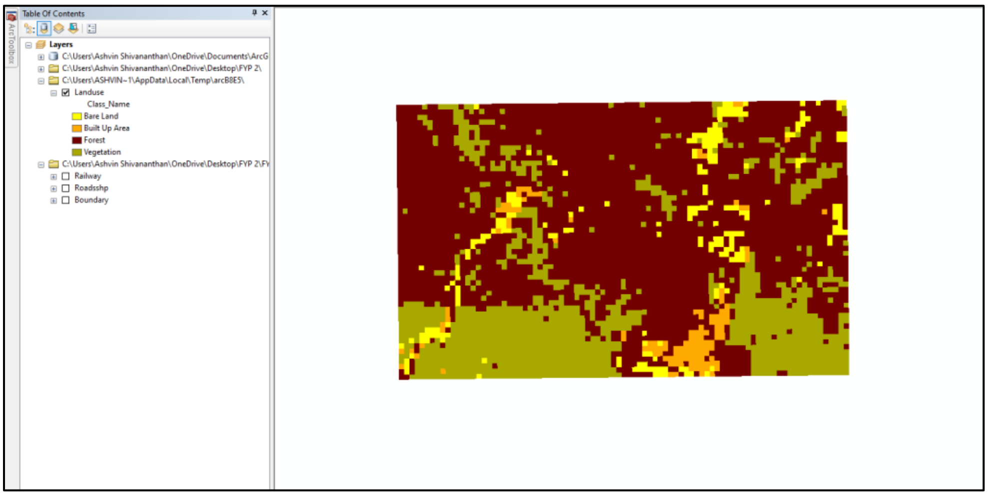

Figure 3.18: Land Use Output

3.6.3 Road Map

For the road map, an image of the study area from google earth was exported into ArcGIS 10.5. The road map was then digitized by following these steps:

Create Shapefile: Catalog > Folder > Create shapefile > Roads

Roads: Editor > Start Editing > Roads.shp > Attributes > Polyline > Stop Editing > Save Edits

Road Density: ArcToolbox > Spatial Analyst Tools > Distance > Euclidean Distance

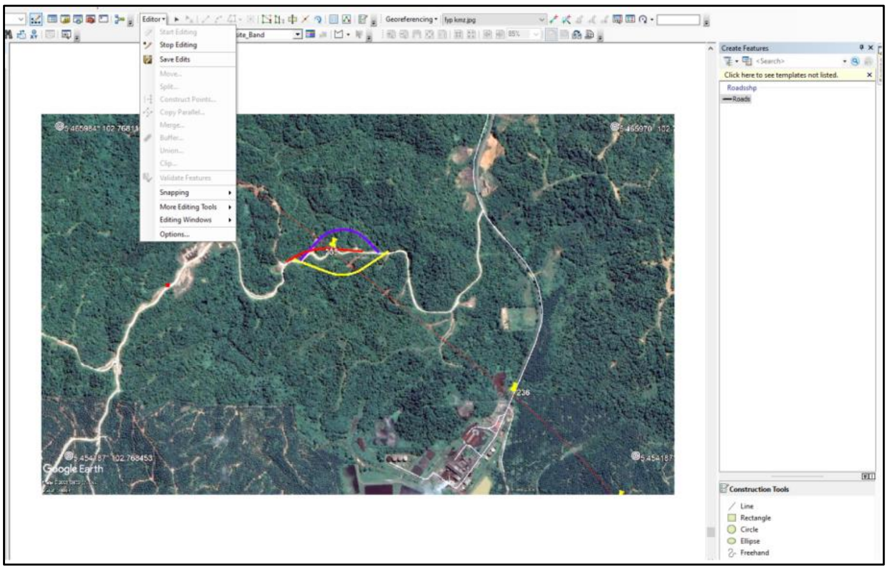

Figure 3.19: Road Map Tools

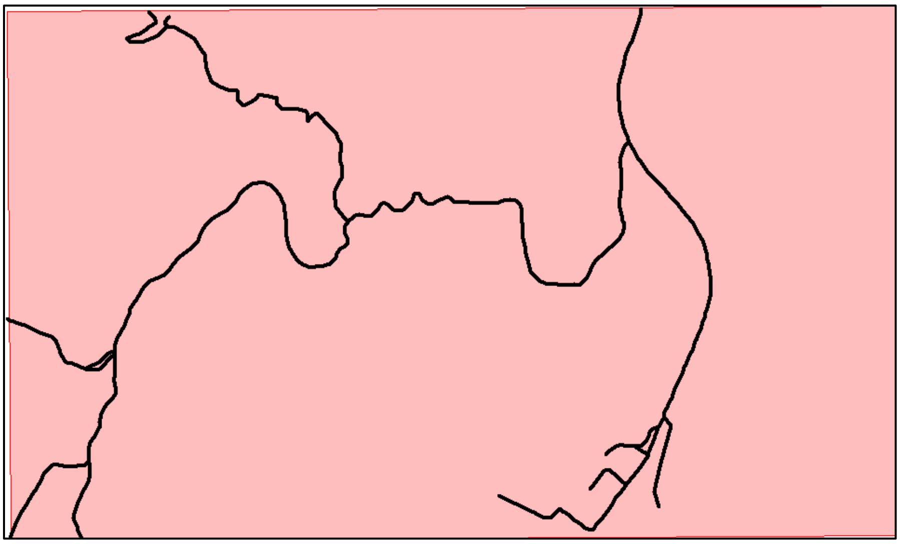

Figure 3.20: Digitized Road Map

3.6.4 Soil Map

The soil map was generated by retrieving the world soil map from FAO/UNESCO soil map of the world. The data was exported into ArcGIS 10.5. Then, the clipping tool was used to clip out the soil map of the according to the size of the study area.

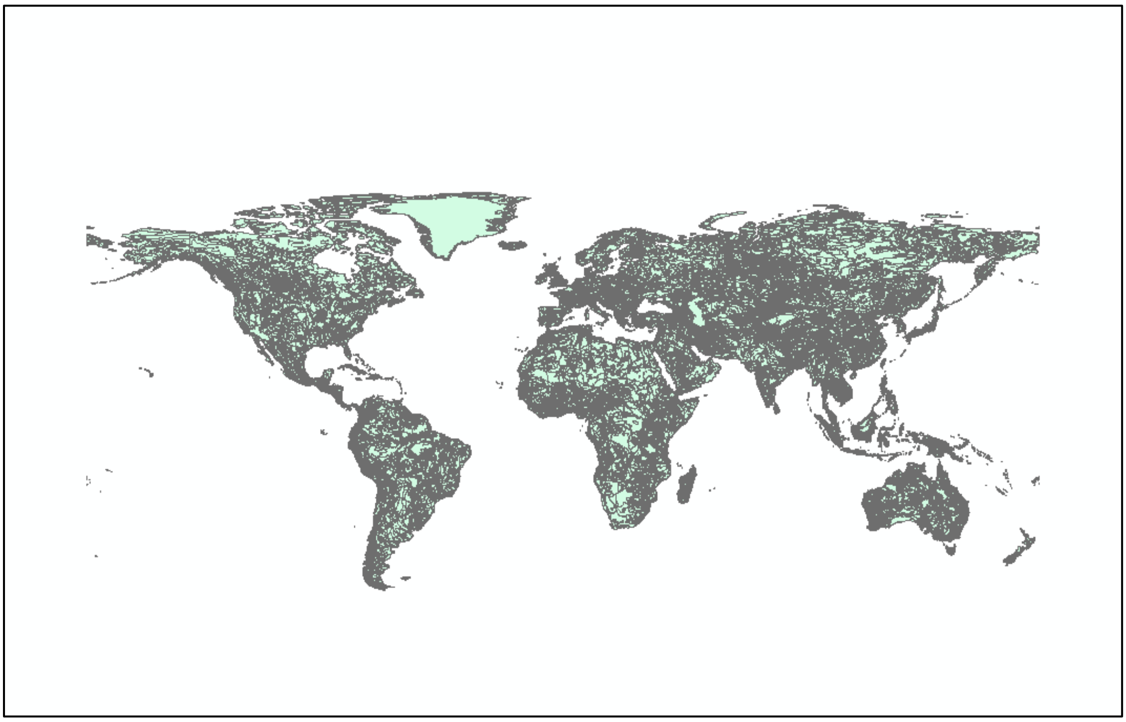

Figure 3.21: World Soil Map

3.6.5 River Map

The river map was generated from the DEM data that was downloaded from the Earth Explorer/United States Geological Survey (USGS). The following steps were followed to generate the river map:

Fill: ArcToolbox > Spatial Analyst Tools > Hydrology > Fill

Flow Direction: ArcToolbox > Spatial Analyst Tools > Hydrology > Flow Direction

Flow Accumulation: ArcToolbox > Spatial Analyst Tools > Hydrology > Flow Accumulation

Stream Order: ArcToolbox > Spatial Analyst Tools > Hydrology > Stream Order

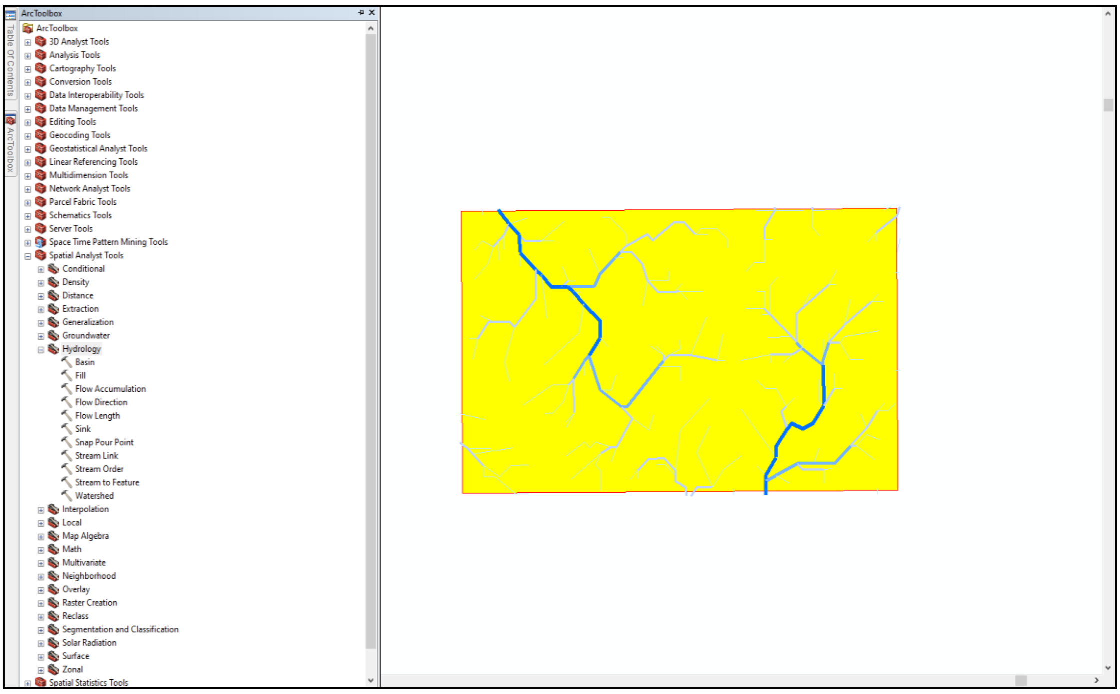

Figure 3.22: River Map Tools

3.7 Scoring of Classified Thematic layers

For the AHP model to be integrated into the GIS structure, the thematic layers must be classified and ranked. The scoring system will be based on the weightage input that was obtained from the experts' evaluation based on their expertise in the field of optimal route selection. Upon producing the thematic layers for each criterion, the percentage weights calculated (AHP) will be assigned to each factor.

3.8 Generating Suitability Map

To generate the suitability map, all the thematic layers will be rasterized and will be combined using the Weighted Overlay and Fuzzy Overlay methods where the AHP and F-AHP percentage values will be assigned to each factor. These thematic layers were multiplied by the weight of each individual factor and then added together to produce a final suitability map to determine the optimal route selection. Moreover, the average results of the AHP survey conducted will be used to generate one suitability map instead of generating 5 different suitability maps based on each experts' point of view.

The criterions must be reclassified before they can be overlayed on one another to generate the suitability map. This was done by using the Reclassify tool in the ArcToolbox.

Reclassify: ArcToolbox > Spatial Analyst Tools > Reclass > Reclassify

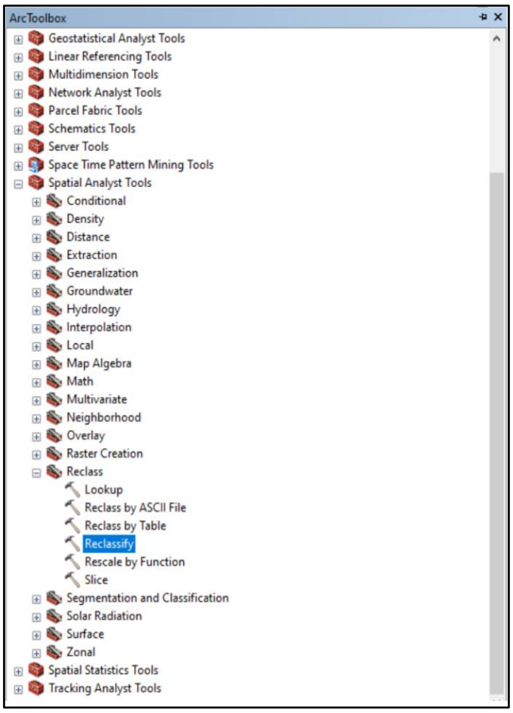

Figure 3.23: Reclassification Tool

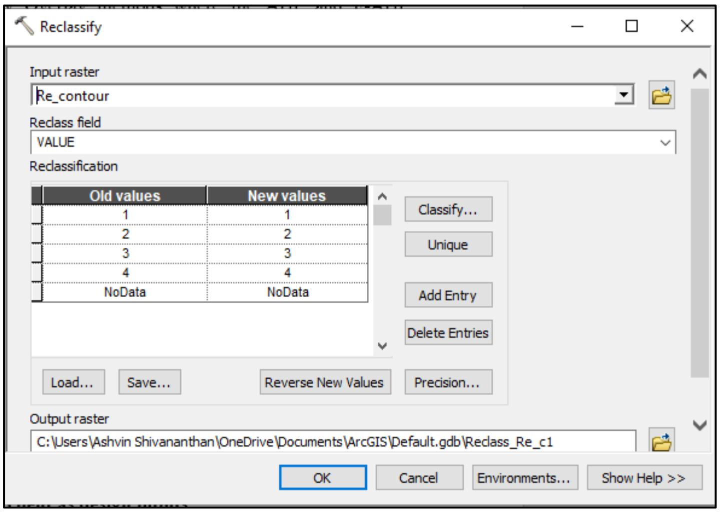

Figure 3.24: Reclassification of Factors

This process was done for all the factors involved in generating the suitability map to determine optimal route selection.

Upon completion of the reclassification process, the weighted overlay and fuzzy overlay processes were carried out to generate the final suitability map.

Weighted Overlay: ArcToolbox > Spatial Analyst Tools > Overlay > Weighted Overlay

Fuzzy Overlay: ArcToolbox > Spatial Analyst Tools > Overlay > Fuzzy Overlay

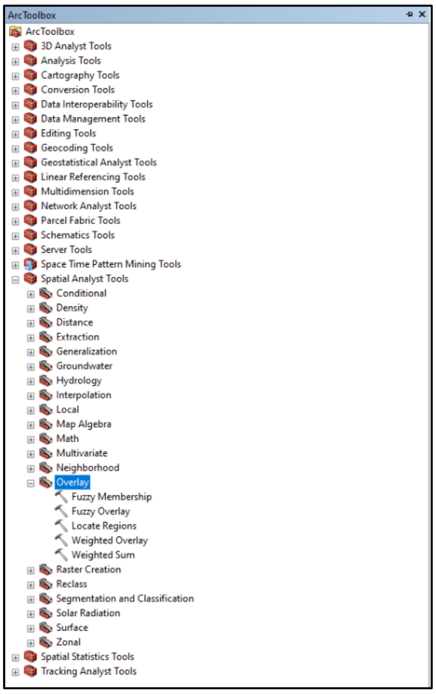

Figure 3.25: Overlay Tools

3.9 Methodology (Conventional Method)

Upon completing this case study, the results of GIS methods will be compared to conventional methods. For comparison purposes, the methodology of conventional methods should be included in this chapter. The methodology of this project is as below:

1. **Received LIDAR Data from the client as design inputs**
   A LIDAR survey/data is procured by the client and is then passed to us consultants for the designing of the alignment.

2. **Identification of road crossings affected by the alignment**
   The next step is to identify all the road crossings that have been affected by the ECRL alignment. This can be done by using the survey/data given by the clients by using the AutoCAD software. We can also cross reference our work by checking for road crossings using Google Earth.

3. **Identification of road type**
   Once all the road crossings have been identified, we then must identify the types of roads that have been affected. We will be checking if the road is a major/minor road, earth/metaled road and etc.

4. **Design treatment of road**
   After collecting all the required data and information, our next task is to thoroughly study the road crossings and propose the best design solution for each road crossings. In this case, I have proposed an overpass/road over bridge solution for road crossing 235 as I deem it to be the best solution.

5. **Design checking by client, Road Safety Audit and Independent Checking Engineers**
   Once the design solutions have been completed, it will all be submitted to our clients, RSA (Road Safety Auditor) and ICE (Independent Checking Engineers) for checking. If everything is in order, we will be allowed to proceed to the next stage. If there are comments, then we will have to amend them accordingly and resubmit it to them for checking.

6. **Engagement with corresponding Authority Agencies according to location of rail alignment-road crossing**

   For this stage, we will be preparing slides and drawings to be presented to the related authorities. The purpose of preparing slides is to clarify and provide justifications to the authorities regarding our design proposals for each road crossing.

7. **Revised Design (If any), submission & approval of road crossing design by relevant Authority Agencies**

   Once the drawings have been checked by the respective authorities, they will then send the consultants their respective comments and amendments will be made accordingly. This cycle will then be repeated until there are no further comments from the authorities and the design is then approved.

8. **Execution of Road Mitigation on site**

   Start of construction and temporary traffic diversion and traffic management plan.

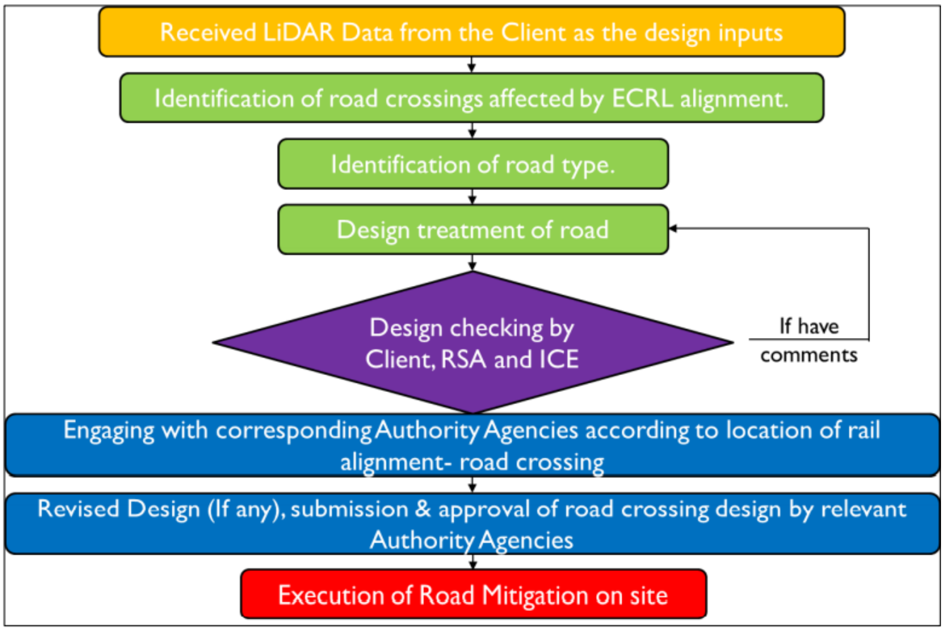

Figure 3.26: Flowchart of Methodology (Conventional Method)

3.10 Project Timeline (Gantt Chart)

Final Year Project II (FYP II)

No.	Details/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Collecting Data & Conducting Survey																	
2	Submission of Progress Report																	
3	Optimal Route Selection Mapping & Modelling																	
5	Submission of Draft Dissertation																	
6	Submission of Dissertation (Softbound)																	
7	Viva Pre-recorded video submission																	
8	Viva Q&A																	
9	Submission of Project Dissertation (Hardbound)																	

Milestones	
Administrative Requirement	

3.11 Key Project Milestone

Week 1-6	• Collecting Data and Conducting Survey
Week 7	• Submission of Progress Report
Week 7-10	• Optimal Route Selection Mapping and Modelling
Week 11	• Submission of Draft Dissertation
Week 12	• Submission of Dissertation (Softbound)
Week 13	• Viva Pre-recorded video submission
Week 14	• Viva Q&A
Week 15-17	• Submission of Project Dissertation (Hardbound)

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 AHP Results

For this study, a survey was carried out to determine the importance and weightage of each criteria against one another. A total of 5 experts working on this project participated in this survey where they had ranked each factor by using Saaty's pairwise comparison scale. Upon receiving the inputs from the experts, the AHP process was carried out by following the procedures explained in 3.4. in this section, the results of the AHP analysis will be displayed in the form of the pairwise comparison matrix and the computed weightages will be displayed in the form of tabulations and bar charts. The results of the conducted survey are as below:

4.1.1 AHP 1

Matrix		Soil 1	Slope 2	Land Use 3	Topographical Maps 4	Roads 5	Rivers 6
Soil	1	1	1/7	1/7	1/5	3	1
Slope	2	7	1	3	3	7	9
Land Use	3	7	1/3	1	1/3	7	9
Topographical Maps	4	5	1/3	3	1	7	9
Roads	5	1/3	1/7	1/7	1/7	1	1
Rivers	6	1	1/9	1/9	1/9	1	1

Figure 4.1: Pairwise Comparison Matrix (AHP 1)

	Criterion	Comment	Weights	+/-
1	Soil		4.9%	2.2%
2	Slope		41.5%	20.4%
3	Land Use		19.9%	8.7%
4	Topographical Map		27.3%	14.5%
5	Roads		3.2%	1.3%
6	Rivers		3.3%	0.9%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10		question section ("+" in row 66)	0.0%	0.0%

Eigenvalue				Lambda:	6.495		MRE:	44.3%
Consistency Ratio	0.37	GCI:	0.29	Psi:	1.7%	CR:	7.9%	

Figure 4.2: Weightage Table (AHP 1)

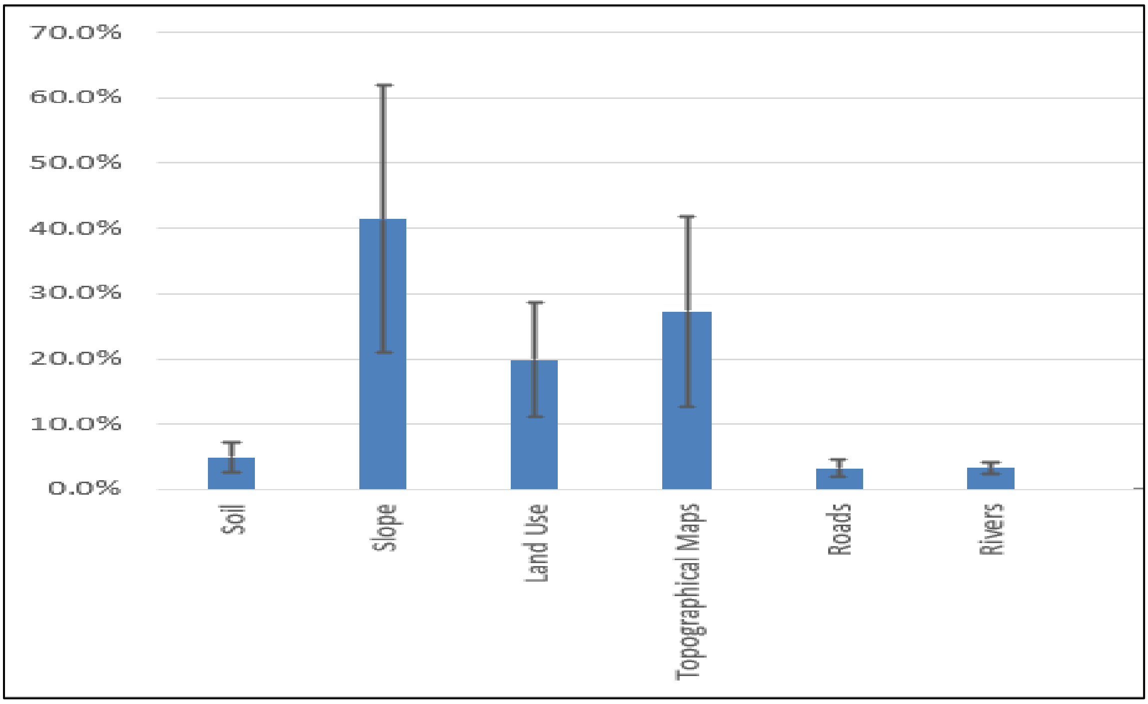

Figure 4.3: Weightage Bar Chart (AHP 1)

4.1.2 AHP 2

Matrix		Soil 1	Slope 2	Land Use 3	Topographical Maps 4	Roads 5	Rivers 6
Soil	1	1	1	3	1	6	6
Slope	2	1	1	1	1	9	5
Land Use	3	1/3	1	1	1/2	3	2
Topographical Maps	4	1	1	2	1	3	2
Roads	5	1/6	1/9	1/3	1/3	1	1/8
Rivers	6	1/6	1/5	1/2	1/2	8	1

Figure 4.4: Pairwise Comparison Matrix (AHP 2)

	Criterion	Comment	Weights	+/-
1	Soil		29.0%	13.1%
2	Slope		25.1%	10.8%
3	Land Use		13.2%	5.7%
4	Topographical Map		19.6%	6.0%
5	Roads		3.5%	1.7%
6	Rivers		9.6%	8.0%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10		question section ("+" in row 66)	0.0%	0.0%

Eigenvalue			Lambda:	6.633	MRE:	51.3%
Consistency Ratio	0.37	GCI: 0.36	Psi: 5.0%	CR: 10.1%		

Figure 4.5: Weightage Table (AHP 2)

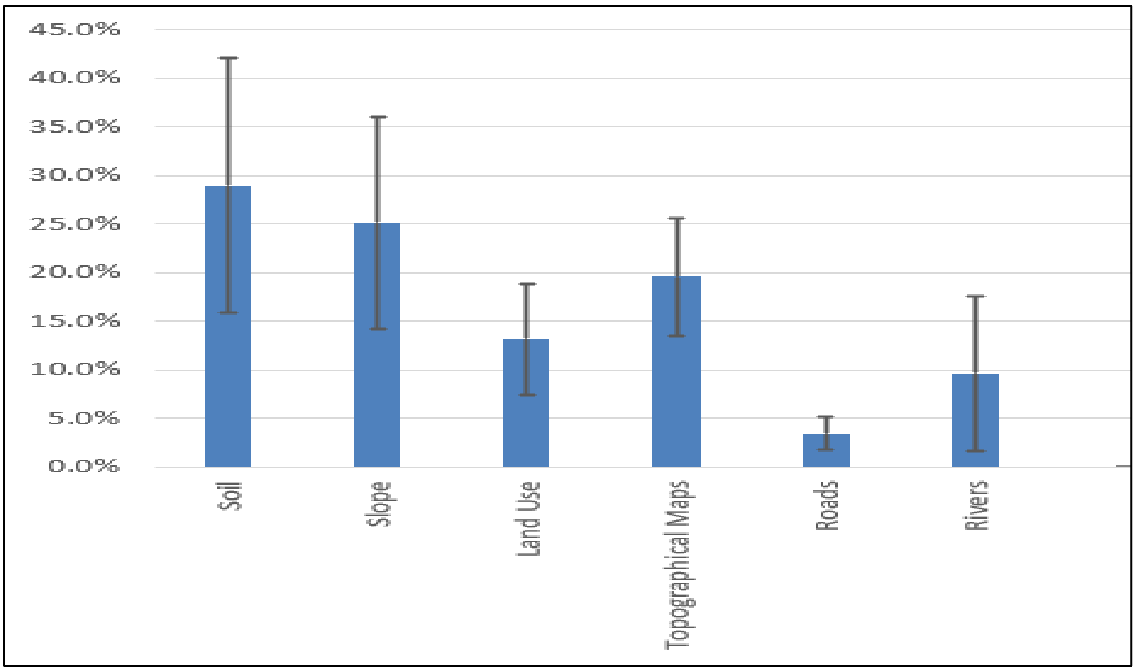

Figure 4.6: Weightage Graph (AHP 2)

4.1.3 AHP 3

Matrix

		Soil 1	Slope 2	Land Use 3	Topographical Maps 4	Roads 5	Rivers 6
Soil	1	1	2	1/9	1/9	6	6
Slope	2	1/2	1	1/9	1/9	3	3
Land Use	3	9	9	1	1	9	9
Topographical Maps	4	9	9	1	1	9	9
Roads	5	1/6	1/3	1/9	1/9	1	1
Rivers	6	1/6	1/3	1/9	1/9	1	1

Figure 4.7: Pairwise Comparison Matrix (AHP 3)

	Criterion	Comment	Weights	+/-
1	Soil		9.4%	4.8%
2	Slope		5.4%	1.6%
3	Land Use		39.9%	20.4%
4	Topographical Maps		39.9%	20.4%
5	Roads		2.7%	1.1%
6	Rivers		2.7%	1.1%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10		question section ("+" in row 66)	0.0%	0.0%

Eigenvalue				Lambda:	6.538		MRE:	45.5%
Consistency Ratio	0.37	GCI:	0.31	Psi:	0.0%	CR:	8.6%	

Figure 4.8: Weightage Table (AHP 3)

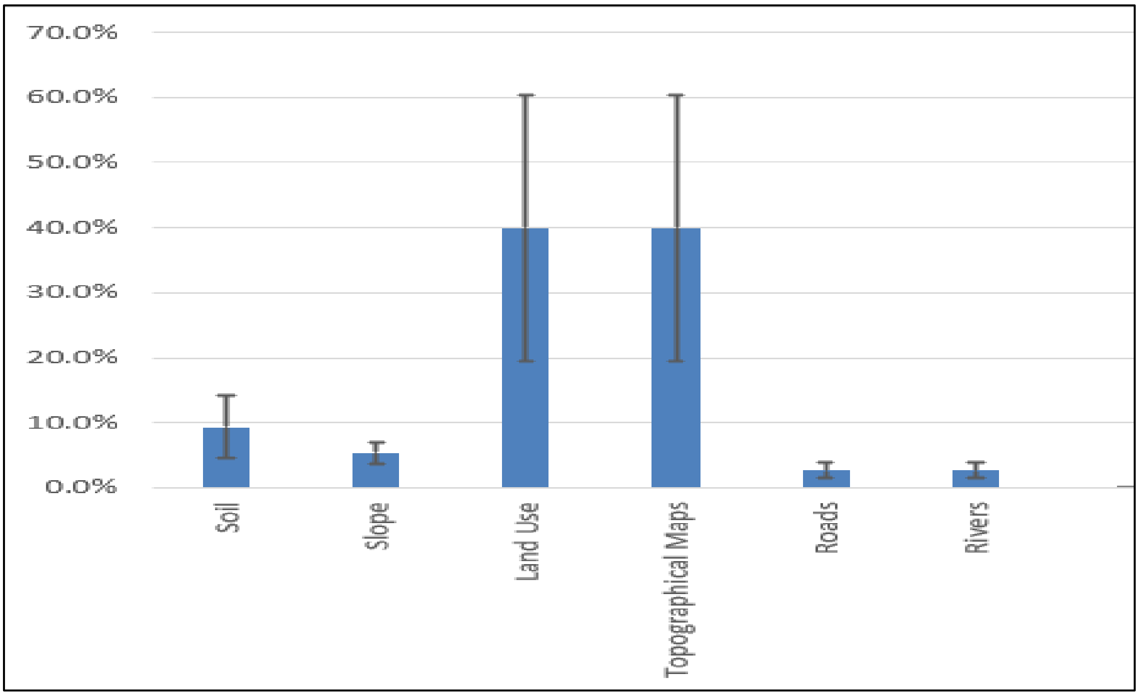

Figure 4.9: Weightage Graph (AHP 3)

4.1.4 AHP 4

Matrix

		Soil 1	Slope 2	Land Use 3	Topographical Maps 4	Roads 5	Rivers 6
Soil	1	1	3	1	7	1/3	1
Slope	2	1/3	1	1	5	1/5	1/3
Land Use	3	1	1	1	3	1	1
Topographical Maps	4	1/7	1/5	1/3	1	1/9	1/2
Roads	5	3	5	1	9	1	1
Rivers	6	1	3	1	2	1	1

Figure 4.10: Pairwise Comparison Matrix (AHP 4)

	Criterion	Comment	Weights	+/-
1	Soil		18.7%	6.8%
2	Slope		10.0%	5.6%
3	Land Use		16.4%	7.0%
4	Topographical Map		4.1%	2.4%
5	Roads		31.9%	14.6%
6	Rivers		18.8%	8.1%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10		question section ("+" in row 66)	0.0%	0.0%

Eigenvalue			Lambda:	6.595	MRE:	47.7%
Consistency Ratio	0.37	GCI: 0.35	Psi: 3.3%	CR: 9.5%		

Figure 4.11: Weightage Table (AHP 4)

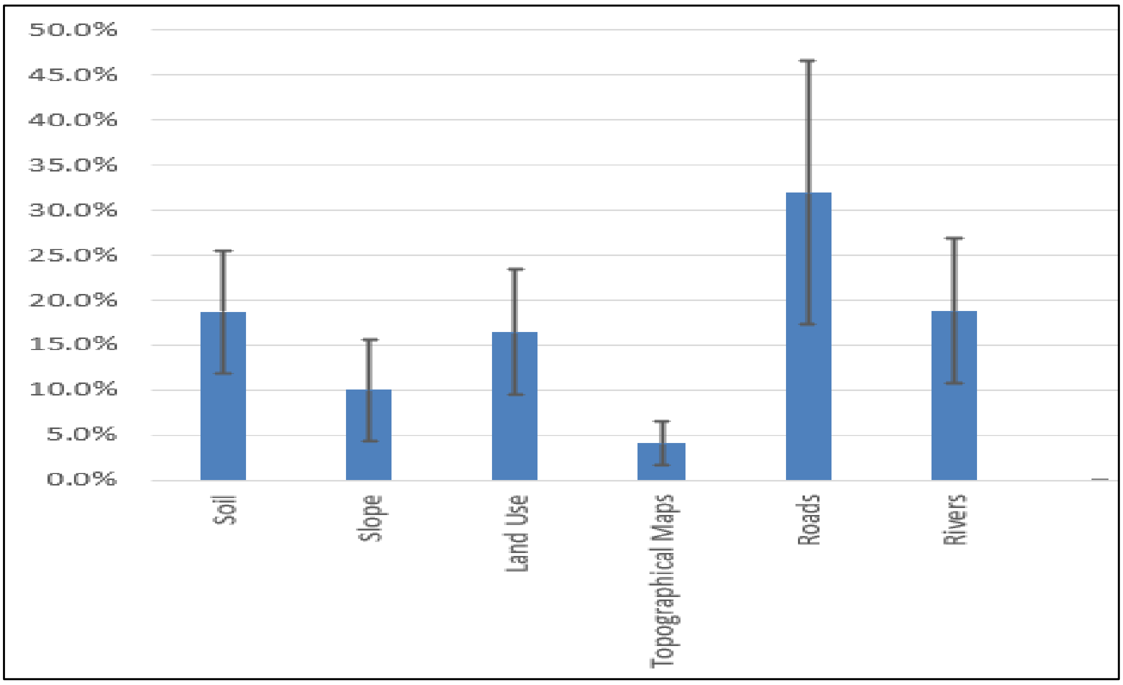

Figure 4.12: Weightage Graph (AHP 4)

4.1.5 AHP 5

Matrix		Soil 1	Slope 2	Land Use 3	Topographical Maps 4	Roads 5	Rivers 6
Soil	1	1	1/5	2	1	1	3
Slope	2	5	1	4	8	8	6
Land Use	3	1/2	1/4	1	1/2	1/2	2
Topographical Maps	4	1	1/8	2	1	3	3
Roads	5	1	1/8	2	1/3	1	1
Rivers	6	1/3	1/6	1/2	1/3	1	1

Figure 4.13: Pairwise Comparison Matrix (AHP 5)

	Criterion	Comment	Weights	+/-
1	Soil		11.7%	2.8%
2	Slope		53.9%	26.5%
3	Land Use		7.5%	3.2%
4	Topographical Maps		13.5%	5.3%
5	Roads		8.0%	3.8%
6	Rivers		5.4%	2.1%
7			0.0%	0.0%
8			0.0%	0.0%
9		for 9&10 unprotect the input sheets and expand the	0.0%	0.0%
10		question section ("+" in row 66)	0.0%	0.0%

Eigenvalue				Lambda:	6.430		MRE:	41.0%
Consistency Ratio	0.37	GCI:	0.25	Psi:	11.7%	CR:	6.9%	

Figure 4.14: Weightage Table (AHP 5)

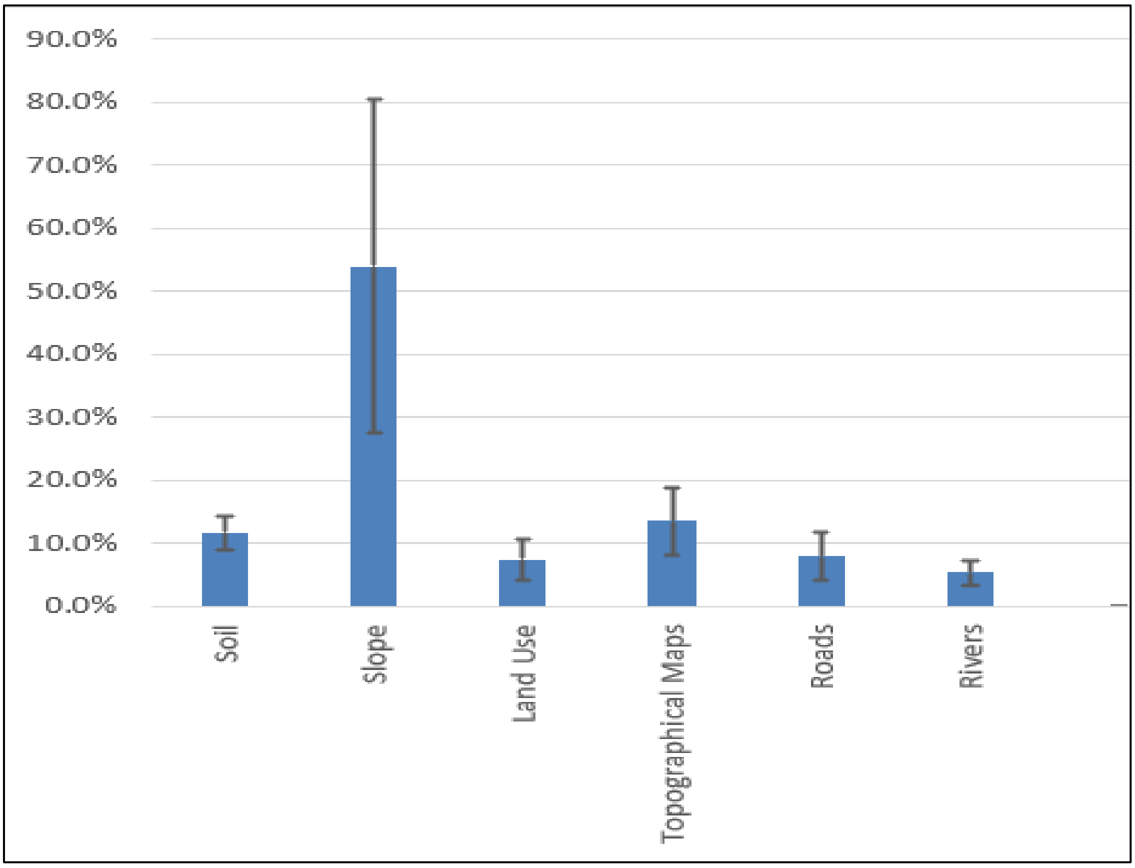

Figure 4.15: Weightage Graph (AHP 5)

4.1.6 Average AHP Results

Table 4.1: Average Weightage of AHP Results

Factors/Criterions	Average Weights (%)
Soil	15
Slope	27
Land Use	19
Topographical Maps	21
Roads	10
Rivers	8

The average of the 5 AHP results was computed and is shown in the above TABLE. The experts have ranked the factors as slope being the most influential factor among the 6 factors, carrying 27% of the weightage, followed by topographical maps which be represented by elevation (21%), land use (19%), soil (15%), roads (10%) and lasty, rivers carrying 8% of the weightage. These AHP results was then integrated with the ArcGIS weighted overlay function to produce the suitability map to determine the best overpass.

4.2 F-AHP Results

4.2.1 F-AHP 1

Table 4.2: Fuzzified Pair-wise Comparison Matrix (F-AHP 1)

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	(1,1,1)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(2,3,4)	(1,1,1)
Slope	(1,1,1)	(1,1,1)	(2,3,4)	(2,3,4)	(6,7,8)	(9,9,9)
Land Use	(6,7,8)	(1/4,1/3,1,2)	(1,1,1)	(1/4,1/3,1,2)	(6,7,8)	(9,9,9)
Topographical Maps	(4,5,6)	(1/4,1/3,1,2)	(2,3,4)	(1,1,1)	(6,7,8)	(9,9,9)
Roads	(1/4,1/3,1,2)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)
Rivers	(1,1,1)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)

Table 4.3: De-Fuzzified & Normalised Weights (F-AHP 1)

Factors/Criterions	Fuzzy weights wi	Normalised Weights
Soil	0.06	0.06/1.04 = 0.06
Slope	0.34	0.34/1.04 = 0.33
Land Use	0.25	0.25/1.04 = 0.24
Topographical Maps	0.31	0.31/1.04 = 0.30
Roads	0.04	0.04/1.04 = 0.04
Rivers	0.04	0.04/1.04 = 0.04
Total	1.04	1

4.2.2 F-AHP 2

Table 4.4: Fuzzified Pair-wise Comparison Matrix (F-AHP 2)

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)	(5,6,7)	(5,6,7)
Slope	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(9,9,9)	(4,5,6)
Land Use	(1/4,1/3,1,2)	(1,1,1)	(1,1,1)	(1/3,1/2,1)	(2,3,4)	(1,2,3)
Topographical Maps	(1,1,1)	(1,1,1)	(1,2,3)	(1,1,1)	(2,3,4)	(1,2,3)
Roads	(1/7,1/6,1/5)	(1/9,1/9,1/9)	(1/4,1/3,1,2)	(1/4,1/3,1,2)	(1,1,1)	(1/9,1,8,1/7)
Rivers	(1/7,1/6,1/5)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/3,1/2,1)	(7,8,9)	(1,1,1)

Table 4.5: De-Fuzzified & Normalized Weights (F-AHP 2)

Factors/Criterions	Fuzzy weights wi	Weights
Soil	(0.30,0.29,0.28)	0.29
Slope	(0.28,0.25,0.22)	0.25
Land Use	(0.13,0.13,0.16)	0.14
Topographical Maps	(0.17,0.20,0.21)	0.19
Roads	(0.03,0.03,0.03)	0.03
Rivers	(0.08,0.09,0.10)	0.09
Total		1

4.2.3 F-AHP 3

Table 4.6: Fuzzified Pair-wise Comparison Matrix (F-AHP 3)

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	(1,1,1)	(1,2,3)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(5,6,7)	(5,6,7)
Slope	(1/3,1/2,1)	(1,1,1)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(2,3,4)	(2,3,4)
Land Use	(9,9,9)	(9,9,9)	(1,1,1)	(1,1,1)	(9,9,9)	(9,9,9)
Topographical Maps	(9,9,9)	(9,9,9)	(1,1,1)	(1,1,1)	(9,9,9)	(9,9,9)
Roads	(1/7,1/6,1/5)	(1/4,1/3,1,2)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)
Rivers	(1/7,1/6,1/5)	(1/4,1/3,1,2)	(1/9,1/9,1/9)	(1/9,1/9,1/9)	(1,1,1)	(1,1,1)

Table 4.7: De-Fuzzified & Normalized Weights (F-AHP 3)

Factors/Criterions	Fuzzy weights wi	Weights
Soil	(0.08,0.09,0.10)	0.09
Slope	(0.05,0.04,0.07)	0.05
Land Use	(0.41,0.41,0.39)	0.40
Topographical Maps	(0.41,0.41,0.39)	0.40
Roads	(0.03,0.03,0.03)	0.03
Rivers	(0.03,0.03,0.03)	0.03
Total		1

4.2.4 F-AHP 4

Table 4.8: Fuzzified Pair-wise Comparison Matrix (F-AHP 4)

Factors/ Criterions	Soil	Slope	Land Use	T. Maps	Roads	Rivers
Soil	(1,1,1)	(2,3,4)	(1,1,1)	(1/8,1/7,1/6)	(1/4,1/3,1,2)	(1,1,1)
Slope	(1/4,1/3,1,2)	(1,1,1)	(1,1,1)	(4,5,6)	(1/6,1/5,1/4)	(1/4,1/3,1,2)
Land Use	(1,1,1)	(1,1,1)	(1,1,1)	(2,3,4)	(1,1,1)	(1,1,1)
Topographical Maps	(1/8,1/7,1/6)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1,1,1)	(1/9,1/9,1/9)	(1/3,1/2,1)
Roads	(2,3,4)	(4,5,6)	(1,1,1)	(9,9,9)	(1,1,1)	(1,1,1)
Rivers	(1,1,1)	(2,3,4)	(1,1,1)	(1,2,3)	(1,1,1)	(1,1,1)

Table 4.9: De-Fuzzified & Normalised Weights (F-AHP 4)

Factors/Criterions	Fuzzy weights wi	Normalised Weights
Soil	0.11	0.11/1.38 = 0.08
Slope	0.11	0.11/1.38 = 0.08
Land Use	0.56	0.56/1.38 = 0.41
Topographical Maps	0.04	0.04/1.38 = 0.03
Roads	0.35	0.35/1.38 = 0.25
Rivers	0.21	0.21/1.38 = 0.15
Total	1.38	1

4.2.5 F-AHP 5

Table 4.10: Fuzzified Pair-wise Comparison Matrix (F-AHP 5)

Factors/Criterions	Soil	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil	(1,1,1)	(1/6,1/5,1/4)	(1,2,3)	(1,1,1)	(1,1,1)	(2,3,4)
Slope	(4,5,6)	(1,1,1)	(3,4,5)	(7,8,9)	(7,8,9)	(5,6,7)
Land Use	(1/3,1/2,1)	(1/5,1/4,1/3)	(1,1,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)
Topographical Maps	(1,1,1)	(1/9,1,8,1/7)	(1,2,3)	(1,1,1)	(2,3,4)	(2,3,4)
Roads	(1,1,1)	(1/9,1,8,1/7)	(1,2,3)	(1/4,1/3,1,2)	(1,1,1)	(1,1,1)
Rivers	(1/4,1/3,1,2)	(1/7,1/6,1/5)	(1/3,1/2,1)	(1/4,1/3,1,2)	(1,1,1)	(1,1,1)

Table 4.11: De-Fuzzified & Normalised Weights (F-AHP 5)

Factors/Criterions	Fuzzy weights wi	Weights
Soil	(0.12,0.11,0.11)	0.11
Slope	(0.55,0.49,0.48)	0.51
Land Use	(0.06,0.07,0.06)	0.06
Topographical Maps	(0.13,0.13,0.13)	0.13
Roads	(0.08,0.13,0.13)	0.11
Rivers	(0.06,0.50,0.06)	0.06
Total		1

4.26 F-AHP Average Results

Table 4.12: Average Weightage of F-AHP results

Factors/Criterions	Average Weights (%)
Soil	13
Slope	24
Land Use	25
Topographical Maps	21
Roads	9
Rivers	8

The average of the 5 F-AHP results were computed and is shown in the above TABLE. However, the F-AHP results vary compared to the AHP results. As for the F-AHP results, the most influential factor among the 6 factors, carrying 25% of the weightage is the land use factor, followed by the slope factor (24%), topographical maps, represented by elevation (21), soil (13%), roads (9%) and lasty, rivers carrying 8% of the weightage. These F-AHP results was then integrated with the ArcGIS fuzzy overlay function to produce the suitability map to determine the best overpass.

4.3 Results of GIS methods

4.3.1 Slope Map

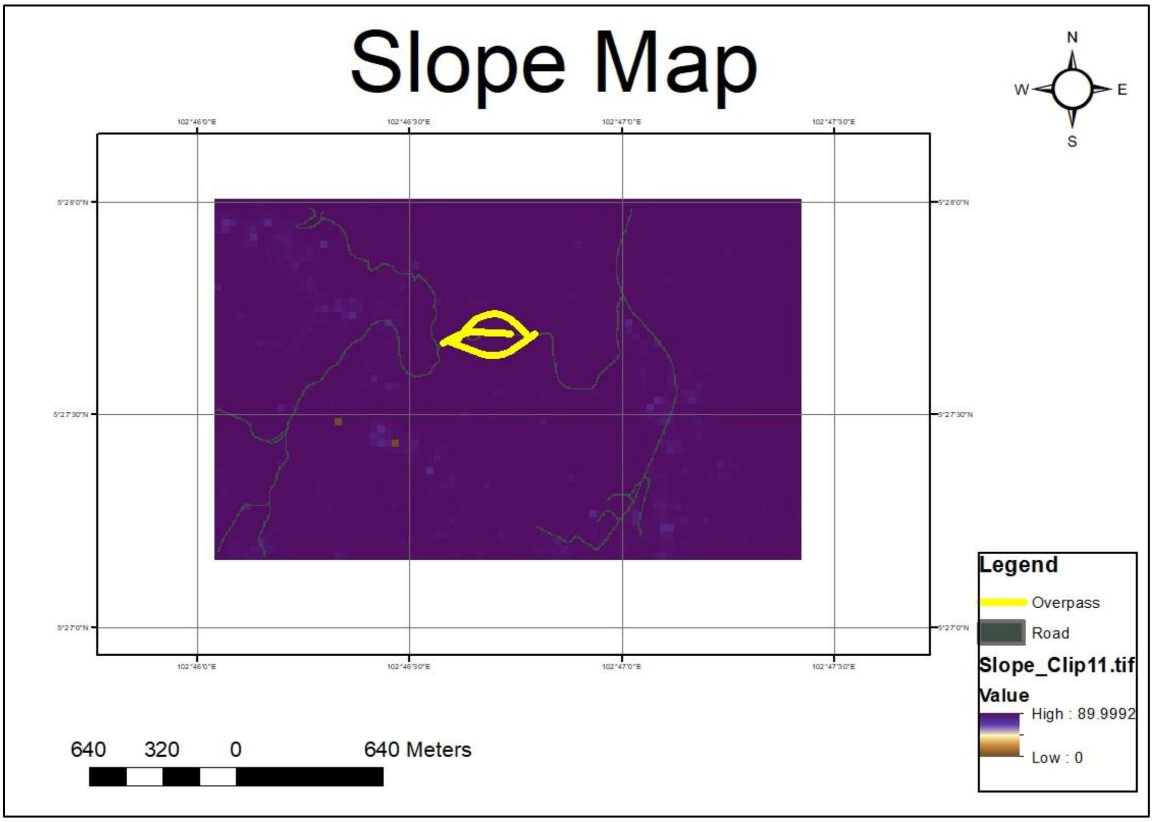

Figure 4.16: Slope Map

The figure above represents the slope map that was generated by using the raw DEM data obtained from USGS. The slope map shows us that the study area is located at a very hilly terrain as the area is mostly covered in purple colour. The purple shade indicates that the slope angle is more than 45° and the pixels in brown indicate that those areas have a very low slope angle varying from 0° to 45°. Based on the AHP and F-AHP results, the experts' opinion say that slope is one of the most important factors in determining an optimal route. However, this map indicates that the three overpasses that were designed are all located at the area which have a high slope angle. Thus, the influence of the slope factor on the 3 overpasses are irrelevant in this case study.

4.3.2 Land Use Map

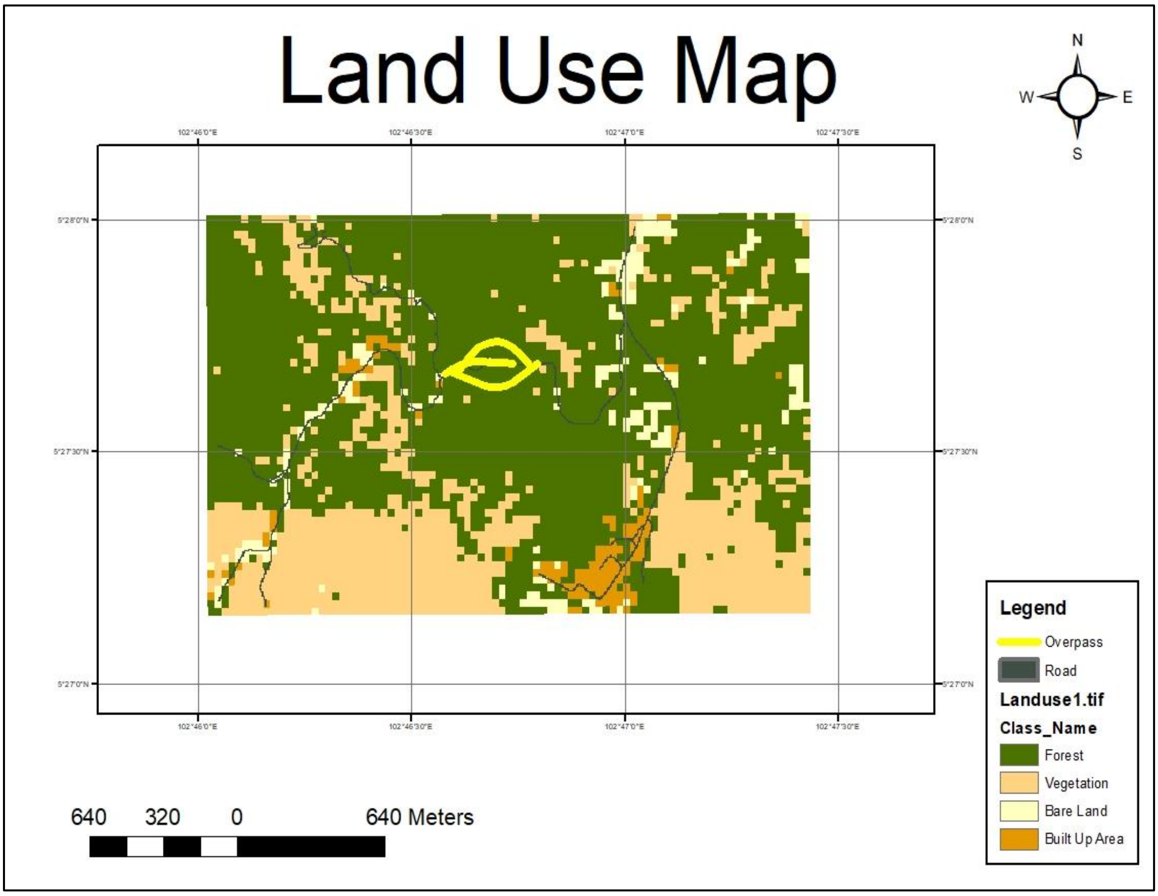

Figure 4.17: Land Use Map

The figure above represents the land use map that was generated in the ArcGIS 10.5 software. The data used was a Landsat 8 image retrieved from USGS. The study area consists of four land use classes namely, bare land, built up are, forest and vegetation. The study is mostly surrounded by forests, followed by vegetation, bare land very little built up area. The study area could not be classified into more land use factors due to its location being a very rural area. Upon completion of the map generation, the land use data was reclassified to rank the respective classes before conducting the weighted and fuzzy overlay analysis. The classes were ranked bare land, forest, vegetation and built area from highest to lowest priority indicating that the area with bare land is the most suitable to place an overpass followed by forests, vegetation and built-up area.

4.3.3 Elevation Map

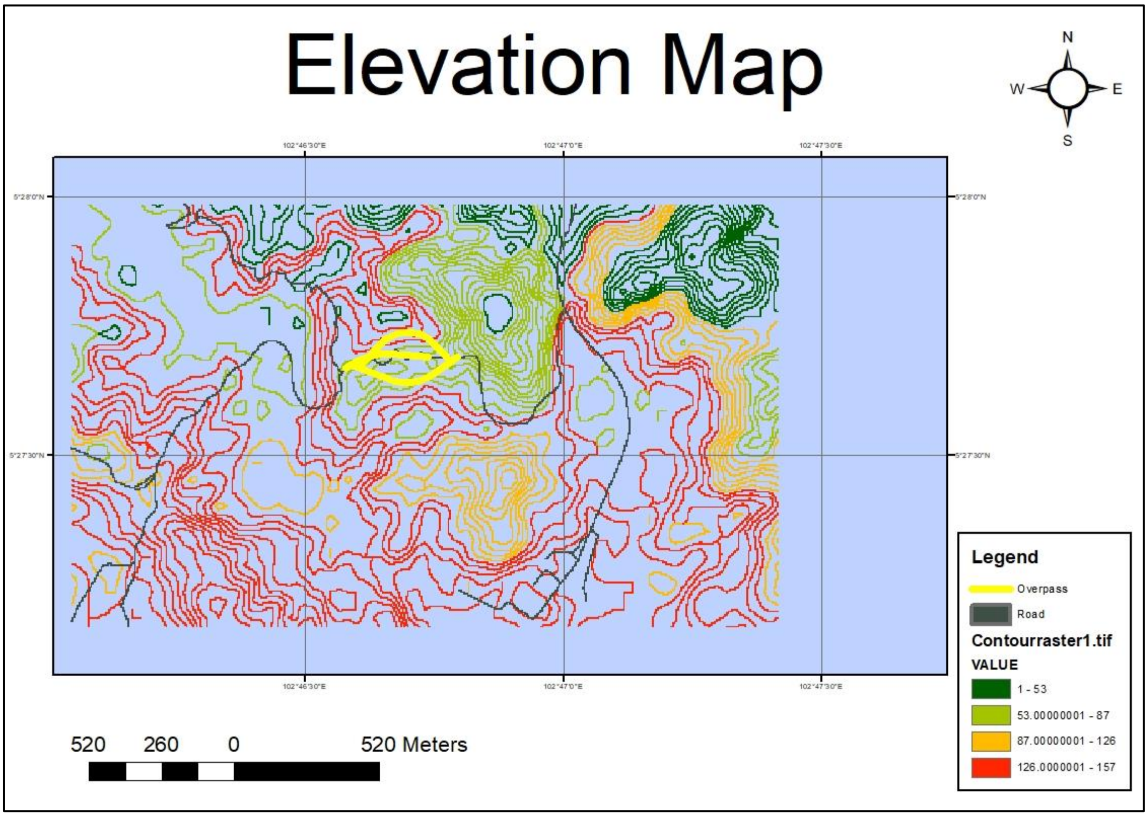

Figure 4.18: Elevation Map

The figure above represents the elevation map that was generated in the ArcGIS 10.5 software. The data used to generate this map was the raw DEM data that was obtained from USGS. In this map, the elevation is represented by using the contour tool. The map indicates the lowest elevation to be 0m and the highest elevation to be 157m and the elevation is very high at the South West region. The map also indicates that the study area is located at a rather hilly terrain. Thankfully, all 3 overpasses are located at an elevation of 90m and below as a very high location will not be feasible to construct an overpass and the cost to do so will be rather expensive. The elevation factors were divided into 4 classes where the areas with high elevation were ranked as the least suitable to place an overpass and the areas with low elevation were ranked as the most suitable to place an overpass.

4.3.4 Soil Map

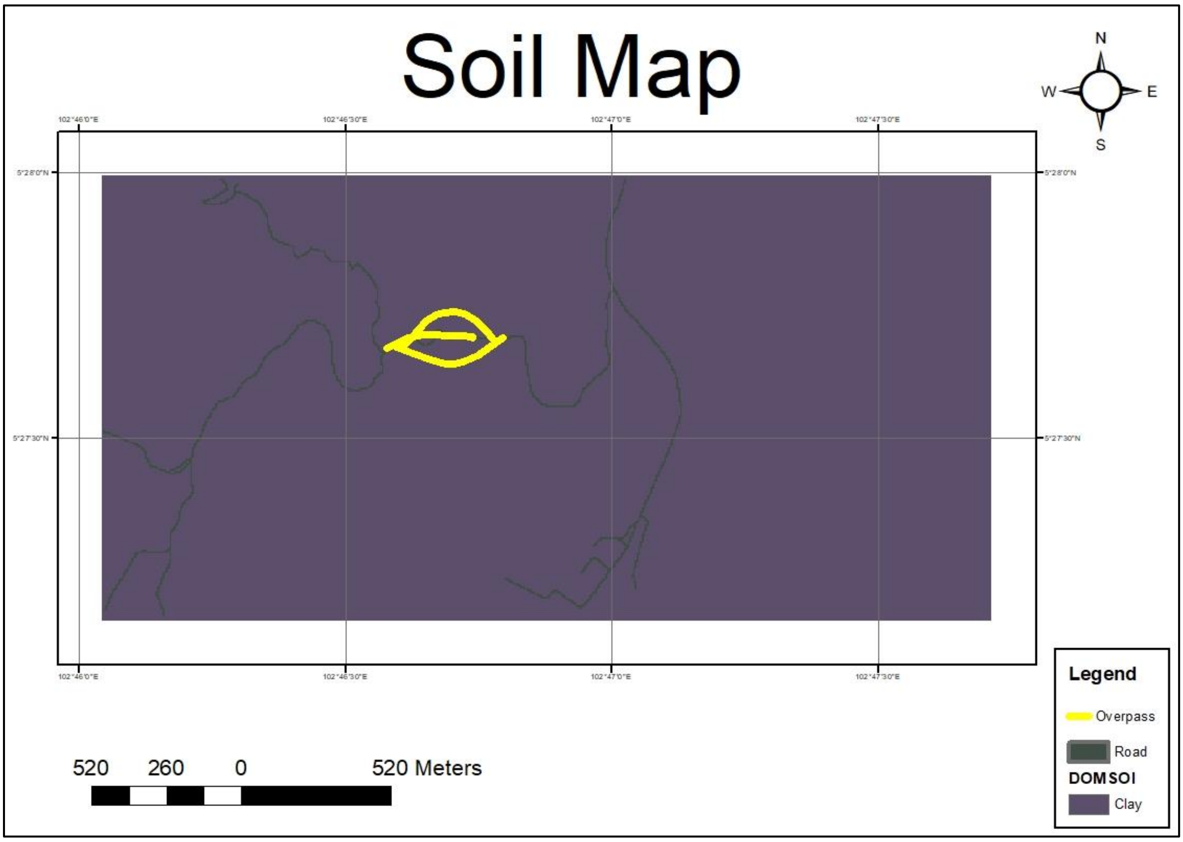

Figure 4.19: Soil Map

The above figure represents the soil map of the study area. The data was downloaded from Food and Agriculture Organization of the United States. The soil map of the world was downloaded and imported into the ArcGIS 10.5 software. From there, the data was clipped according to the size of the study area and the results are displayed in Figure 4.19. The results show that there is only one soil class found, orthic acrisols which is also known as clay. The reason only one soil class was found is mainly due to the size of the study area. The study area is rather small as it is only $3km^{2.}$ Based on the average AHP results, the soil class factor was ranked 4^{th} out of the 6 factors but since there was only one soil class found in the study area, the soil class factor now irrelevant in the decision-making analysis to determine the best overpass solution.

4.3.5 River Map

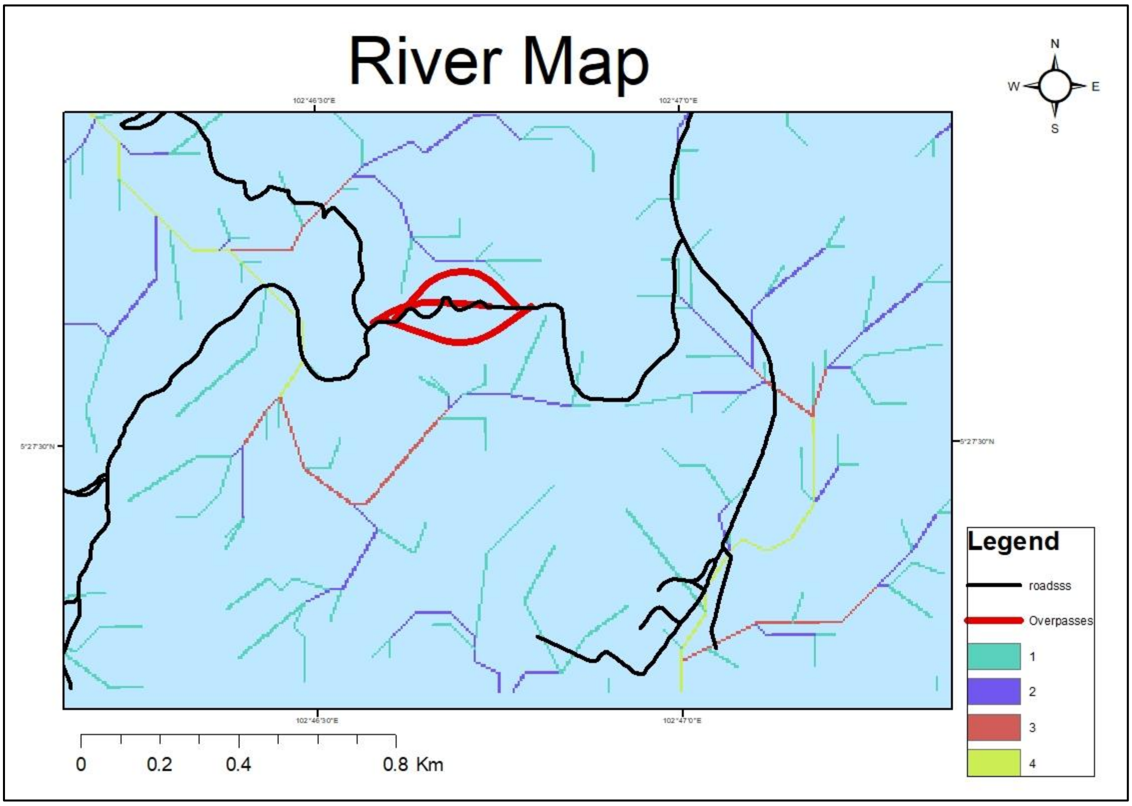

Figure 4.20: River Map

The figure above represents the river map of the study area. The stream order was able to be generated by using the raw DEM data obtained from USGS. The headwater branches which are the smaller streams gets ranked as 1 and if two streams of the same rank meet at a confluence, then starting from that confluence, the order is increased. Also, if a stream with a lower order meets with a higher order, the stream with the higher order is maintained. This helps us distinguish between the major and minor rivers. In the river map above, there are 4 levels of headwaters where the minor rivers are represented by the grey lines (1) and the major rivers are represented by the yellow lines (4). During the reclassification process, all the rivers were classified as low importance before carrying out both the overlay analysis. This is because, constructing an overpass with proximity to streams is quite dangerous as that area could be a possible flood prone area.

4.3.6 Road Density Map

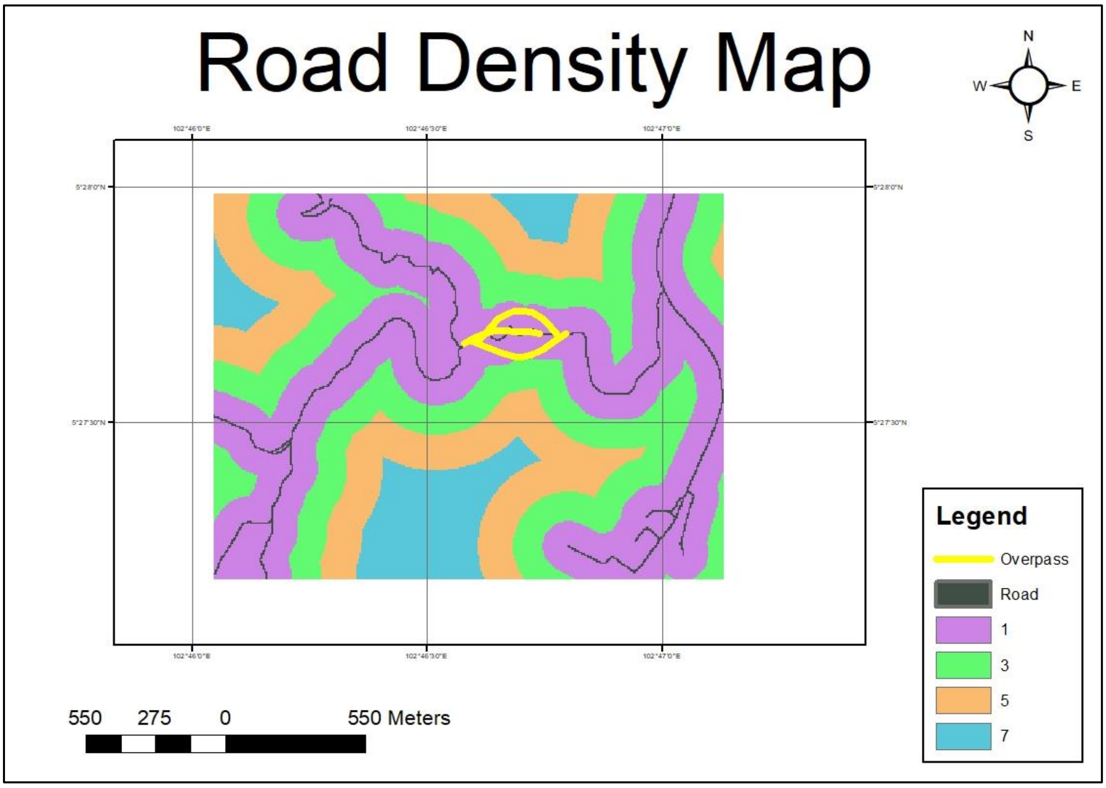

Figure 4.21: Road Density Map

The figure above represents the road density map. This map was generated by digitizing the existing roads into ArcGIS by using a google earth image as a reference. A buffer was then created by using the Euclidean distance tool on the digitized roads to generate the road density map. This buffer helps us determine the proximity of the road to the existing railway track and other existing roads, making sure there is enough distance and no clashes when constructing an overpass. The legend indicates the buffer distance is km of the roads from the lowest to highest.

4.3.7 Weighted Overlay Map

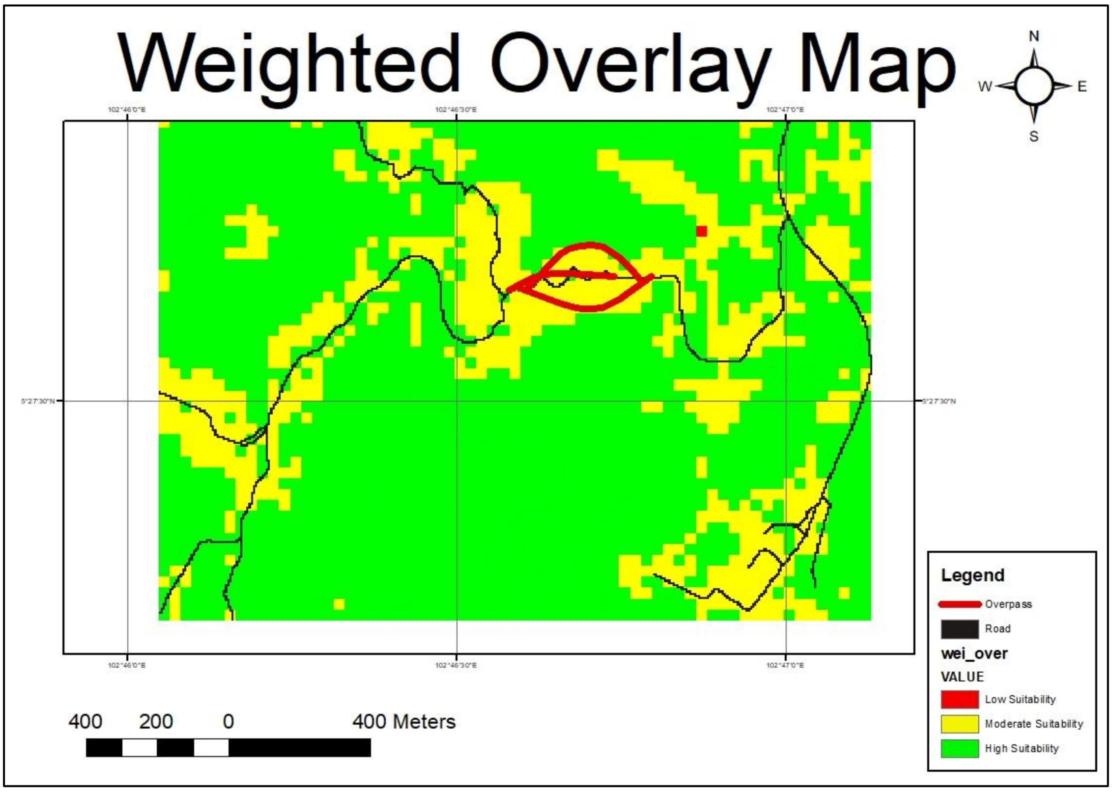

Figure 4.22: Weighted Overlay Map

Figure 4.22 represents the weighted overlay map generated using the average AHP results computed from the 5 experts that participated in the survey conducted for this case study. 6 factors were ideally supposed to be overlayed on one another. The factors were the slope, elevation, soil, land use, rivers, and roads. However, the slope and soil factors were excluded for the overlaying process as they are irrelevant in this study. these two factors are defined as irrelevant because of the size of the study area. The area of study is rather small area is small, resulting in similar slope angles and same soil classes around the study area and thus, rendering those factors as irrelevant.

Since the slope and soil class factors were excluded from the overlaying process, their weightages were added and evenly distributed to the remaining 4 factors to carry out the overlaying process. The weighted overlay map was produced with elevation carrying 31% of the weightage, land use (30%), roads (20%) and rivers 19%.

The map was classified into three classes of suitability which were low, moderate, and high. The map indicates that all 3 overpasses are located at an area of moderate suitability. Based on the map, it is rather difficult to determine the best overpass as there is no significant difference proving that one overpass option is better than the other. To conclude, the AHP results integrated with the weighted overlay analysis did not produce and clear result in achieving the objectives of this study, which is to determine the best overpass to reinstate the connectivity of the severed road.

4.3.8 Fuzzy Overlay Map

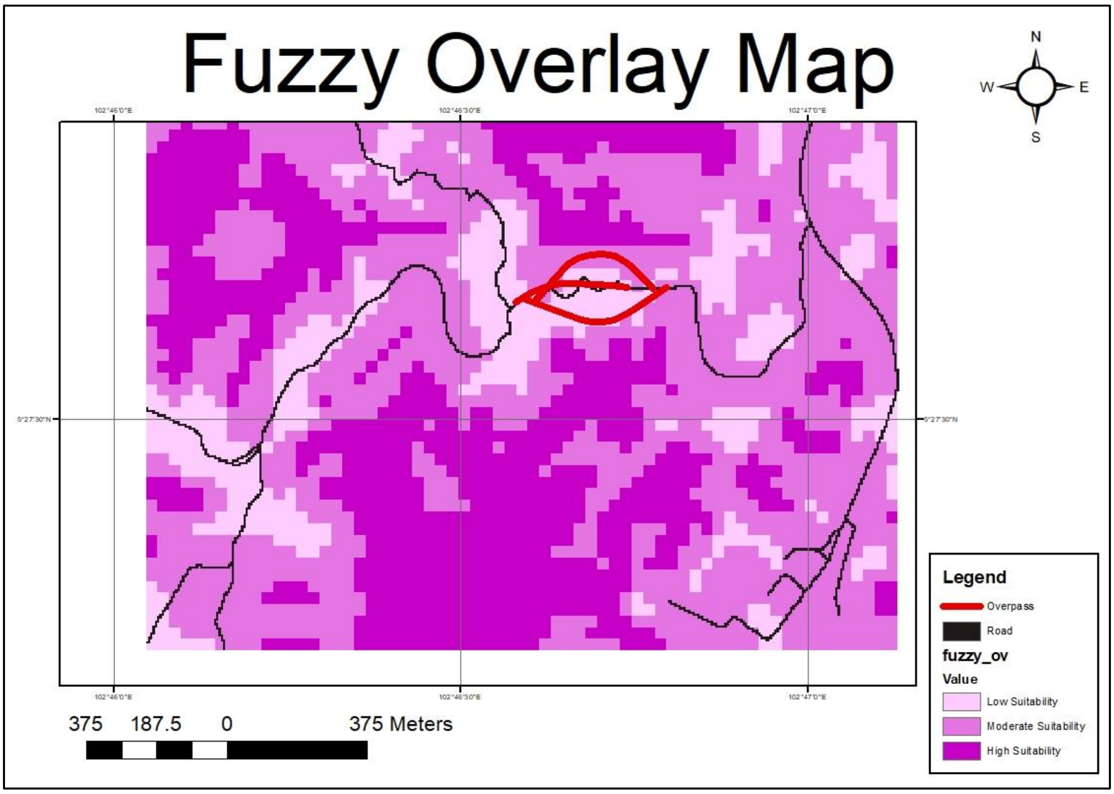

Figure 4.23: Fuzzy Overlay Map

Figure 4.23 above represents the fuzzy overlay map generated using the average F-AHP results computed from the 5 experts that participated in the survey conducted for this case study. Like the weighted overlay analysis, the slope and soil factors were excluded from the fuzzy overlay analysis due to their irrelevance. The fuzzy weights consist of land use (34%), elevation (30%), roads (19%) and rivers (17%). The fuzzy overlay analysis was carried out these weights and the fuzzy overlay map was produced.

Like the weighted overlay map, the fuzzy overlay map was classified into three classes of suitability which were low, moderate, and high. The map indicated that two overpasses were located at an area with rather low suitability and one overpass with moderate suitability and that overpass is overpass option 2. Based on this map, it is clear to deduce that overpass option 2 is the best overpass among the three as it is located at a better location compared to options 1 and 3. To conclude, the F-AHP results integrated with the fuzzy overlay analysis produced an optimum solution to this issue and thus, achieving the objectives of this study, which is to determine the best overpass to reinstate the connectivity of the severed road.

4.4 Results of Conventional Methods

Evaluation Criteria	Option 1 Length : 308.991 m			Option 2 Length : 387.995 m			Option 3 Length : 405.875 m		
	Remarks			Remarks			Remarks		
Alignment Geometry	Earthworks	Cut (m3)	23,262.30	Earthworks	Cut (m3)	3,926.13	Earthworks	Cut (m3)	112,466.43
		Fill (m3)	9,678.70		Fill (m3)	146,714.00		Fill (m3)	25,095.14
	Existing Road Configuration	Road Width : 7m Type : 2-ways Single Carriageway		Existing Road Configuration	Road Width : 7m Type : 2-ways Single Carriageway		Existing Road Configuration	Road Width : 7m Type : 2-ways Single Carriageway	
	Proposed ROB	Plantation Road	At-Grade : 208.042 m Elevated : 100.9492 m	Proposed ROB	Plantation Road	At-Grade : 303.07 m Elevated : 84.9244 m	Proposed ROB	Plantation Road	At-Grade :308.849 m Elevated :97.263 m
Land Cost (RM)	Additional land acquisition is required	18,226sq.m RM 100/ sq.m	1,822,600.00	Additional land acquisition is required	31,290sq.m RM 100/ sq.m	3,129,000.00	Additional land acquisition is required	26,725sq.m RM 100/ sq.m	2,672,500.00
Construction Cost* - Civil Works (RM)	Elevated (km)	0.10	RM3,960,000.00	Elevated (km)	0.08	RM3,363,006.24	Elevated (km)	0.09	RM3,564,000.00
	At-Grade (km)	0.21	RM4,410,000.00	At-Grade (km)	0.30	RM6,364,482.60	At-Grade (km)	0.31	RM6,485,826.90
	Retaning wall (m2)	620	RM496,000.00	Retaning wall (m2)	0	0	Retaning wall (m2)	525	RM420,000
	Total Cost		RM8,866,000.00	Total Cost		RM9,727,488.84	Total Cost		RM10,469,826.90
Social Impact	Causes socal disturbance due to the temporary diversion of the road. Temporary land acquisition needed			Temporary diversion not required			Temporary diversion not required		
Constructibility	Major constructability issues as the it has the longest bridge span. Earthworks of the ROB clashes with the embankent of the ECRL alignment. A retaining wall must be provided. A diversion should be provided as the ROB is designed based on the exisiting road Additional cost for land acquisition required			Minor constructibility issues as the bridge length is only 85m long. Retaining wall not needed			Major constructability issues as the it has the longest bridge span. Earthworks of the ROB clashes with the embankent of the ECRL alignment. A retaining wall must be provided.		

Figure 4.24: Excel tabulation of overpass options

The figure above represents the excel tabulation of overpass options to reinstate the connectivity of the severed road crossing. Just like the GIS method, the overpasses were compared against several factors namely, alignment geometry, land acquisition cost, construction cost, social impacts, and engineering and constructability. A traffic light assessment was carried out to determine the best overpass option. The Traffic Light Assessment is an evaluation format whereby the scoring or ranking system is based on the colours of the traffic light. Green is the highest, followed by yellow and red is the lowest. The Traffic Light Assessment was chosen as the evaluation format is rather simple and easy to compare options and deduce the best design solution.

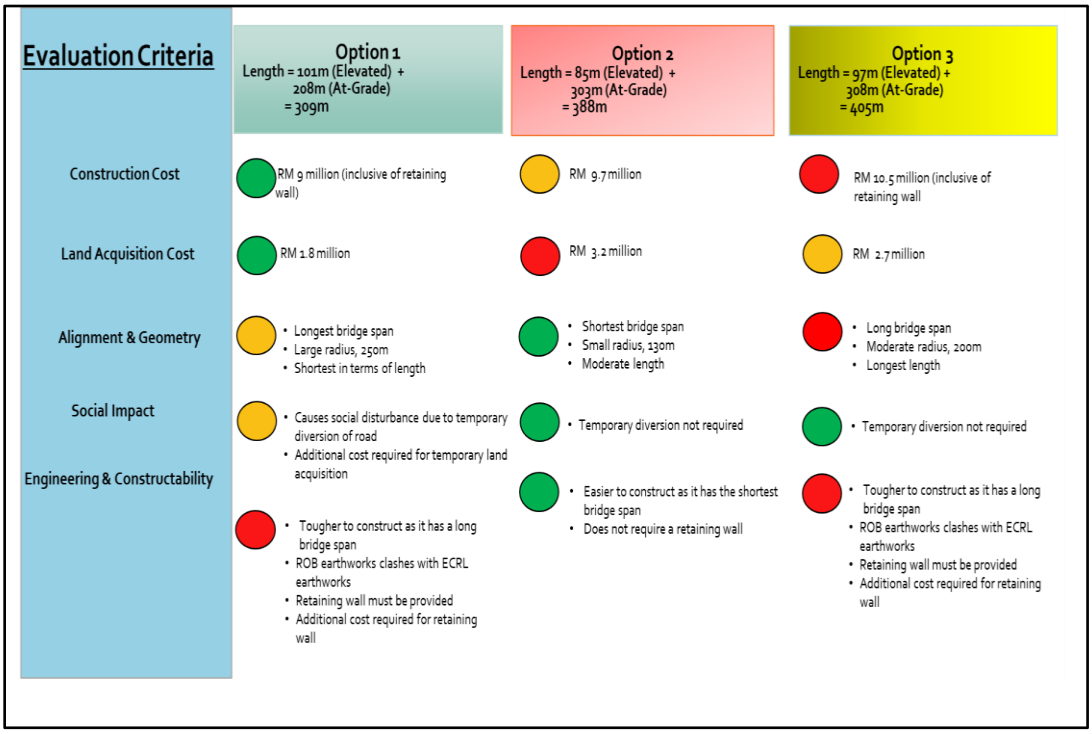

Figure 4.25: Traffic Light Assessment

From the traffic light assessment, the 5 factors were compared against one another and ranked according to the colours of the traffic light. In terms of construction cost, overpass option 1 has the lowest construction cost compared to options 2 and 3 despite requiring extra cost to build a retaining wall. The construction cost of overpass options 2 and 3 are higher than option 1 because it has a longer length. In terms of the land acquisition cost, option 1 is the lowest as it has the lowest volumes of cut and fill compared to option 2 and option 3. As for the alignment and geometry, option 2 seems like the best option as it has the shortest bridge, 85m span compared to option 1(101m) and option 3(97m). Having a longer bridge span makes it harder to construct and it also takes a longer time to complete it. For the social impact factor, option 1 causes social disturbance due to the need to divert the road temporarily as option 1 is design based on the existing road crossing. A temporary alternative must be provided while constructing the overpass whereas options 2 and option 3 do not require any temporary diversion as they do not affect any social impacts. The last evaluation criteria are in terms of engineering and constructability. For this criteria, option 1 and 3 are not advisable as they face several obstacles. For example, the earthworks of overpasses options 1 and 3 both clash with the embankment of the ECRL alignment, thus, a retaining wall must be provided to address this issue. Moreover, both these options have rather long bridge spans which makes it harder construct while option 2 has the shortest bridge span among the 3 options and its earthworks does not clash with the embankment of the ECRL.

After evaluating all 3 overpass options through the Traffic Light Assessment, overpass option 2 is deemed to be the best among the 3 options provided. This is because option 2 has the greatest number of green lights compared to the other 2 options. Although option 1 seems like the better option in terms of cost, it is still not advisable to go with that because the Traffic Management Plan (TMP) has not been considered. The temporary works would be undertaken by the contractor. Option 1 causes social disturbance as the existing road will have to be closed and a temporary alternative access must be provided during construction works, thus, option 2 is deemed the best design solution to reinstate the connectivity of road crossing 235.

4.5 Comparison of GIS and Conventional results

One of the main objectives of this case study was to compare between GIS methods and conventional methods in optimal route selection. Based on the results obtained, both methods suggested that overpass option 2 was the best solution for this issue. However, the GIS method had some limitations and downsides in this study due to the size of the study area. Two important factors were excluded from performing the overlay analysis because the size of the study area was too small, and the data provided from those two factors did not have any significance or variety. Moreover, out of the two GIS overlay analysis that were carried out, only one managed to provide a feasible solution to overcome this problem. As for the conventional method, the procedure was rather simple and straight forward as it was solely evaluated based on the design.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The main purpose of this study was to use the GIS approach and select the best overpass to reinstate the connectivity of the severed road crossing, road crossing 235. The factors considered were namely, slope, soil, land use, topographical maps, roads, and rivers. The AHP and F-AHP methods were used to assign optimal weightage to each factor and those factors were then reclassified to ease the process of spatial analysis.

In this study, the slope and soil factors were deemed as irrelevant due to the size of the study area. Two suitability maps were produced with the 4 factors, namely, land use, topographical maps which was represented by elevation, roads, and rivers. The results indicated that F-AHP managed to outperform AHP when integrated with GIS functions to produce a clear and feasible result compared to AHP. Moreover, both conventional and GIS methods indicated that overpass option 2 is the best solution to reconnect road crossing 235.

To conclude this case study, the objectives of this study has been achieved as the connectivity of road crossing 235 will be reinstated with the construction of overpass option 2. F-AHP produces more accurate results compared to AHP when integrated with GIS functions. Lastly, GIS methods are more suited for problems with a larger study area extent as more information will be obtained and problems can be solved by considering many geographical factors which will aid in producing accurate results. In addition to that, it saves engineers time from going to the site to collect raw data. Conventional methods however are more suited for problems with small study area because there will not be a variety of geographical datasets to compare from. Thus, making it better to resolve the issue by tackling it based on the design feasibility.

5.2 Recommendations

For future projects, the fundamentals and objectives of the projects must be clearly understood to ensure that the expected results are achieved. The GIS method should be implemented more on projects covering a large study area, for instance, district or even sates as GIS has variety of tools and functionalities that can compute data and produce results without having to spend too much time. However, the accuracy of the data obtained is very critical to the outcome of the case study. Thus, relevant data should be retrieved from sources that can provide the latest, updated and most accurate information. Apart from that, a combined approach of GIS and conventional methods should be implemented in optimal route selection as the study will cover the elements of design feasibility and geographical feasibility, to produce the most ideal solutions. Lastly, the GIS-MCDA concept should continue to be applied and implemented as it produces very accurate results.

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APPENDICES

SURVEY QUESTIONNAIRE

SELECTING AN OPTIMAL ROAD CROSSING ROUTE USING SPATIAL ANALYTICS: A CASE STUDY OF THE EAST COAST RAIL LNK

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ID : 24305

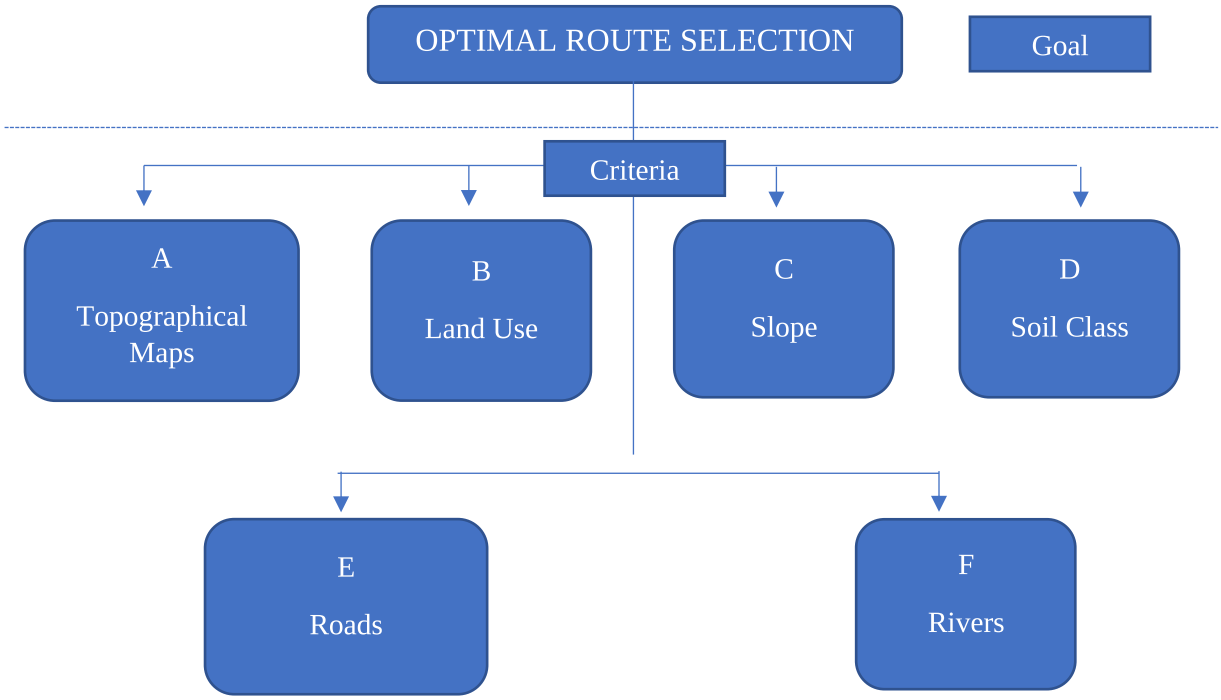
Course : Civil and Environmental Engineering

Supervisor : Dr Abdul-Lateef Babatunde Balogun

INTRODUCTION

This questionnaire is to assign weights to rank the factors that influence the optimal route selection by using Spatial Analytics. The readings that are obtained from each survey will be used to determine the best optimal road crossing route that crosses the railway alignment of the East Coast Rail Link. Spatial Decision Support System (SDSS) will be used as a decision-making tool to select the best overpass to reinstate the connectivity of the severed road. This will be actualized through the integration of Geographical Information System (GIS) and a Decision Support System (DSS) technique. In this study, a Multi-Criteria Decision Analysis (MCDA) – Analytical and Fuzzy Analytical Hierarchy Process (FAHP), will be used as a core in conducting DSS techniques. The DSS will aid in the identification of the most suitable overpass.

RANKING OF ROUTE SELECTION CRITERIA – ANALYTICAL HIERARCHY PROCESS (AHP) MODEL



INSTRUCTIONS

In this questionnaire, multiple factors are arranged in a comparison matrix as shown in Figure 1 below. You are required to compare each item in row with items in column. Each item needs to be compared in accordance to its relative importance/influence in causing flooding. After careful comparison, you will need to fill in the appropriate value given from Saaty's scales of relative importance table shown in Table 1 below, inside the cross cell of matrix.

For instance, comparing item A and item B, if item A is extremely more important than B, you rank "9" for value A (row) at correct cell (row 2; column 3). Similarly, for comparing item B and C. if item is less important than C, but item C has strong importance over B, you rank "5" for value C (row) at the correct cell (row 4; column 3). In the reverse statement (row 3; column 4), you need to fill in the reciprocal value, "1/5". All other cells should be filled accordingly by comparing one factor (row) against another (column), i.e. A and C, A and D, C and A, C and D, D and A, D and B, D and C.

Please be noted that comparing item A and item A will be the same, so the cell for row 2 column 2 (same as row 3 column 3; row 4 column 4; row 5 column 5) should be ranked as “1”.

	A	**B**	**C**	**D**
A	1	9		
B	1/9	1	1/5	
C		5	1	
D				1

Figure 1: Example of Comparison Matrix

Intensity if importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective(s)
3	Weak importance	Experience and judgement strongly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured, and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	Where compromise is needed
Reciprocals of the nonzero	If activity *i* has one of the above nonzero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

In the following matrix (Table 2), the six factors (A, B, C, D, E and F) are the criteria/factors to be considered for the optimal route selection. Please compare two factors is to be compared with at one time and fill the appropriate rating score in the cross cell. The six factors, A, B, C, D, E and F are represented by, soil class, slope, land use, topographical maps, roads and rivers.

A. Soil Class

Soil conditions may significantly affect the location of an overpass. Thus, the soil classes surrounding the study area must be determined in order to be able to identify the soil properties. By doing so, the soil strength can be identified and thus being able to determine if the soil will be able to support the overpass structure.

B. Slope

Slope is an important factor in route selection. It is important to know the existing elevation and the slope height surrounding the study area. This will help determine the best area to place the overpass to reinstate the connectivity.

C. Land Use

The different land-use classes will be used to present the different terrains over the study area and these will be used in the final judgment for the best alternative to select the best route path

D. Topographical Maps

Topographical maps are used to represent a ground surface or a terrain. The map includes symbols that represent such features as streets, buildings, streams and vegetation. Topographical maps can be obtained from Google Earth and present the elevations in a form of raster. The maps will help us determine the best location for the optimal route selection

E. Roads

Roads are a pathway that vehicles use as a mode of transportation. It is important to identify the roads surrounding the study area as building an overpass may disrupt the connectivity of the road which results in the disruption of the traffic flow.

F. Rivers

Rivers also play an important role in optimal route selection. It is important to identify the roads surrounding the study area as it is best to avoid building overpasses with close proximity to rivers as it may result in floods.

SECTION A: CRITERIA (FACTORS)

Factors/Criterions	Soil Class	Slope	Land Use	Topographical Maps	Roads	Rivers
Soil Class	1					
Slope		1				
Land Use			1			
Topographical Maps				1		
Roads					1	
Rivers						1

SECTION B: RESPONDENT PROFILE

Name:

…..………………………………………………………………………………….……

Organization/Company/Institution:……………………………………………………

Phone:………………………………………………………………….........……

Profession:

…………………………………………………………………………………………

Years of Professional Experience: < 2 / 3-5 / 6-10 / 11-15 / > 15 years

Position:……………………………………………………………………………...

Degree: Bachelor / Master / Doctorate / Other:

…………………………………………………

Date:

……………………………………………………………………………................

SECTION C: GENERAL QUESTIONS

1. To what extend do you think GIS could help in multi-criteria optimal route selection?

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   ………………………………………………………………………………
   ………………………………………………………………………………
   ………………………………………………………………………………
   ………………………………

2. Are there any other criteria/factors that you would consider when carrying out a survey for optimal route selection?

   ………………………………………………………………………………
   ………………………………………………………………………………
   ………………………………………………………………………………
   ………………………………………………………………………………
   ………………………………

3. Other comments and suggestions (Please provide comments and suggestions for the betterment of future development)
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………………………………………………………………………………………
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………………………………