SUITABILITY ANALYSIS OF SUBSEA PIPELINE ROUTE USING GIS

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Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2008

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.

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(LEE HUI YIENG)

ABSTRACT

The objective of this study is to analyze the least cost subsea pipeline route using GIS. A past project has been adopted in this research. The GIS-generated pipeline route is compared with the existing pipeline route designed using contemporary method. The subsea pipelines are used for hydrocarbon transportation from offshore platform to onshore plant. Criteria considered in least cost path are cost, pipeline routing criteria, installation method, safety and maintenance aspects. Factors affecting pipeline routing include bathymetry, submarine geographical features such as seabed conditions and slopes, obstructions such as coral reefs, wildlife preservation areas, as well as availability of existing services such as pipelines and platforms. Spatial Analyst extension in GIS is used to analyze all these factors through three basic steps and produce the best pipeline route through cost-weighted distance function. First step involves developing discrete cost surfaces in raster datasets from routing criteria datasets. Second step involves combining and weighing all discrete surfaces to create an accumulated cost surface. Third step involves developing least cost path between the source and destination along the accumulated cost surface. The result generated has shown similar alignment with the existing route. The GIS-generated route is 0.09km longer than the existing route. Although longer in length, the least cost route crosses less steep areas at length of three times more than the existing route. It crosses prawns' areas at 4% less than existing route as well. Therefore, the least cost path reduces the construction cost and increases the ease of construction as compared to the existing route. Hence, GIS-generated route satisfies the criteria of economical, least obstructions, safe and ease of construction in producing subsea pipeline route. Comparison between GIS method and contemporary pipeline routing method highlighted unique benefits of GIS that proved its feasibility in pipeline routing improvisation.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

This FYP research is carried out based on a pipeline routing of Petronas past project in year 2005. It aims to replace submarine pipeline for transportation of oil and gas production from the existing platform in offshore to a chemical plant which is situated on dry land. The location of study area is at Baram Delta Field, Offshore Miri, Sarawak, Malaysia as shown in Figure 1.1. The following three proposed pipeline routes will be analyzed:

- 16" WLDP-C to WLP-A pipeline route A
- 16" BADP-B to MCOT pipeline route B
- 16" WLDP-C to MCOT pipeline route C

Originally, these proposed routes were the results of manual design based on pipeline route selection criteria without using GIS. In this research, one of the spatial analyst tools - cost-weighted distance in GIS was used to generate optimum pipeline routes considering the same routing criteria. The GIS selected route would then be compared to the proposed routes in order to access the accuracy of the GIS analysis. A few other existing pipeline routes were also generated using GIS and compared with the existing ones to increase the confident level of the results.

Figure1.1: Study area is situated at Baram Field of East Malaysia

Data necessary for this project are the factors affecting the route selection process and the coordinates of plant and platforms that are to be connected by pipelines. The factors can be categorized into three main types: a) Topography, b) Routing obstacles, c) Environmental consideration and are summarized in detail as shown in **Table 1.1**.

Table 1.1: Pipeline Routing Criteria

Categories	Descriptions
Topography	1. Bathymetry
	2. Seabed slope
Routing Obstacles	1. Existing utilities • Pipelines • Cables
	2. Existing wells and platforms
	3. Types of seabed sediments • Low sonar reflectivity (very soft clay) • Moderate sonar reflectivity (silty clay) • High reflectivity patches (coarse sediments)
	4. Seabed features • Sonar contacts • Individual pockmarks • Debris area • Trawl/ anchors' scars (fishing areas)
Environmental Consideration	1. Turtle-nesting area
	2. Wild-life reserves
	3. Coral patches

In order to know these factors, hydrographic surveys need to be performed at the study area to gather relevant information as mentioned. The location of these hazardous factors need to be identified because they could create adverse effects on the proposed pipelines and by avoiding these effects, minimum construction cost in terms of length and construction easibility can be achieved.

1.2 PROBLEM STATEMENT

The oil and gas resources on land have been decreasing and focus was gradually shifted to exploring resources in sea. Therefore, offshore submarine pipeline need to be designed to carry the production from offshore platform to onshore. However, manual design of pipeline routes caused the following problems:

- Substantial amount of time for design process
- Resolved of complex engineering computations
- Delay of pre-cost estimate and actual unit costs are needed

Therefore, GIS is used to analyze the accuracy of GIS-generated route with the manually-designed route based on the specified routing criteria. Firstly, maximum gradient of bathymetry must not be exceeded to avoid pressure drop exceeding maximum value. Secondly, pipelines should be laid at a specified distance from obstructions such as existing utilities, platforms and wells in order to create no-go zone. Fishing area should also be avoided to reduce possibility of pipelines' damages caused by dropping of trawl or anchor. Thirdly, protected habitats should also be avoided. After ensuring all the criteria are satisfied, main emphasis is given to cost of construction. Hence, analysis of least cost path and the impacts on the submarine pipeline laying process need to be carried out in order to minimize installation, maintenance cost and avoid the hazards pose by these environmental factors.

1.2.1 PROBLEM IDENTIFICATION

The factors considered in the route selection analysis are discussed in detail.

A) Construction Cost

- This is the primary factor in analysis. Least-cost-path and minimum pipeline length should be of main consideration when the route selection criteria have been fulfilled.

B) Utility Conflicts

- There are many existing utilities like pipelines and cables buried or exposed on the seabed. Their location need to be identified to avoid conflicts or hitting between the proposed and existing services. However, if pipeline crossing is unavoidable, minimum vertical distance of 0.3m should be kept.

C) Seabed Soil Characteristic

- The roughness of seabed is defined by its sediments' sizes. Rough seabed soil is not preferable as pipeline route. A side scan sonar system is used to investigate the textural characteristic and reflective strength of seafloor. Higher reflectivity shows coarser sediments while low to moderate reflectivity indicate soft to silty clay.

D) Seabed Slope

- Large variations in seabed slope are not desirable because the chances and impacts of scouring due to hydrodynamic loads are big. This causes instability of the subsea pipeline. Also, the pressure drop in pipelines will increase. Therefore, gentle seabed slope is preferred.

E) Seabed Features

- Seabed scars are caused by trawl or anchors. It indicates occurrence of fishing activities. The more seabed scars detected in the area, the more often fishing activities there are and hence, the chances of pipeline dragging by boats or hit by dropped objects from ships increase as well.
- Coral patches are not desirable along the pipeline route because these features increase the installation difficulty during anchoring planning and handling.

F) Construction Limitation

- At the shore approach, a pipeline will often deviate from a straight route as shown in **Figure 1.2**. The reason is perpendicular usually gives shortest beach pull since the length of pipe which must be pulled from ship to shore is minimized. Besides that, the environmental wave loading is also minimized.

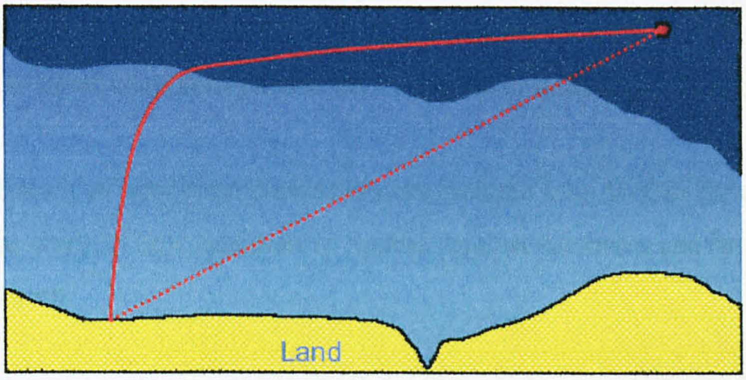


Figure 1.2: Deviation of pipeline route as it approaches shore
[Ranhill WorleyParsons, 2007]

1.2.2 SIGNIFICANCE OF THE PROJECT

Significance occurs during the analysis of pipeline routes using Spatial Analyst. Major criteria in subsea pipeline route selection for this research will be ranked according to their priority as follows:

- Rank 1: Cost of construction.
- Rank 2: Ease of constructability in terms design limitation and pipe length.
- Rank 3: Utility conflicts and frequency of human activities within the area.
- Rank 4: All necessary subsea pipeline routing criteria.

Ranking of routes based on least-cost-path shall be the first step in short listing the available alternatives. Then, the minimum length of pipeline as well as minimum complexity in the method of construction come into consideration. This is because these two factors have direct effects on the cost. Third and fourth rank are non-cost criteria where compliance to the standard of subsea pipeline design is compulsory. The area with minimum crossing over existing pipeline services and minimum human activities is best preferred.

1.3 OBJECTIVES

- To identify and input pipeline routing criteria's datasets into ArcGIS.
- To develop least-cost-path Cost-Weighted-Distance function.
- To compare existing route with GIS-developed route.

1.4 SCOPE OF STUDY

The scope of study is divided into four categories.

- First, the understanding and mastering of ArcGIS.
- Second, the identification of parameters or criteria to be considered in pipeline route selection.
- Third, the study of how these parameters can be input into ArcGIS for analysis.
- Fourth, the study of how functions in Spatial Analyst extension can be used to generate least-cost-path.

A) GIS

It consists of ArcGIS which has the functions of mapping and analyzing. The two main stages of the entire research analysis using GIS are mapping of the study area and analyzing the mapped proposed pipeline routes. First stage involves the study of how to map the research areas into digital format as well as input data into GIS as databases format. This stage must be carried out before second stage – analysis of pipeline route, can be performed. Second stage involves learning the steps of information integration using Spatial Analyst because it is crucial during the analysis of submarine pipeline routes selection where relevant data being input in the first stage need to be combined to produce results. Another alternative besides integration is setting criteria to obtain desirable result.

B) Criteria of Pipeline Route Selection

Second category involves theoretical study of submarine pipeline installation to transfer oil and gas from offshore production unit to onshore. Many factors can affect the efficiency of the pipeline during the its installation or laying process. The impacts of factors like environmental forces, seabed geographical features, and soil behavior as well as water depth on pipeline laying process have to be studied. This helps in identifying the necessary data need to be incorporated in route selection analysis using ArcGIS. From the two areas of studies, the most ideal pipeline routing plan can be produced.

C) Data input into ArcGIS

Third category involves methods to input data such as topographical features, 3-dimensional coordinates of seabed, 2-Dimensional coordinates of starting and ending point, as well as the area and location of no-go zones. Factors that need to be considered are the type of data obtained from the company and the conversion method needed to transform the original format to format that can be read and analyzed using ArcGIS. Therefore, it is crucial to know what are the other methods that can assist in the conversion process.

D) Generating Least-Cost-Path using Spatial Analyst

Fourth category involves the analysis of the route selection criteria to generate a least-cost-path using extension Spatial Analyst. There are certain functions in this extension that are necessary to perform the analysis. The studies of how to use these functions are crucial.

CHAPTER 2

LITERATURE REVIEW

2.1 PIPELINE ROUTE SELECTION

2.1.1 GENERAL

Optimal route selection at the outset of an offshore pipeline project has the potential to minimize installation difficulties, avoid geohazards, eliminate spanning and subsequently reduces construction costs. Selection should be based on safety of public, protection of the environment and the probability of damage to the pipe or other facilities. Factors to be taken into consideration are ship traffic, fishing activity, offshore installation, existing pipelines and cables, unstable seabed, subsidence, uneven seabed, turbidity flows, seismic activity, obstructions, dumping areas for waste, exposure to environmental damage and oyster beds. Table 2.1 shows the selection of pipeline route's (onshore or offshore) main considerations. (Ranhill WorleyParsons, 2007)

Table 2.1: Main Categories of Onshore and Offshore Pipeline Route Criteria

No	Category	Description
1.	Pipeline Location Class	Range from Class 1 – 4, specifying the number of buildings or area's feature that extends 200m on either sides of the centerline of any continuous 1.6km length of pipeline as shown in Figure 2.1.
2.	Availability of Survey Data	The seabed features and any other facilities along the pipeline routes within the study area should be identified through survey and utility investigation.
3.	Pipeline Easement	For offshore case, the ease of construction matters most. For example, construction in a sloping area or a valley is structurally more difficult than flat seabed.
4.	Available Pipeline Right of Way (ROW)	Describe the area around pipelines are properties of other parties. Hence, agreement to conduct any form of operation should be granted before any construction begins. For offshore case, minimum distance between

		pipelines for crossing of existing utility should be considered under this category.
5.	Costs of considerations	Usually the shortest route would be selected because it satisfies both constructability easement and cost criteria.

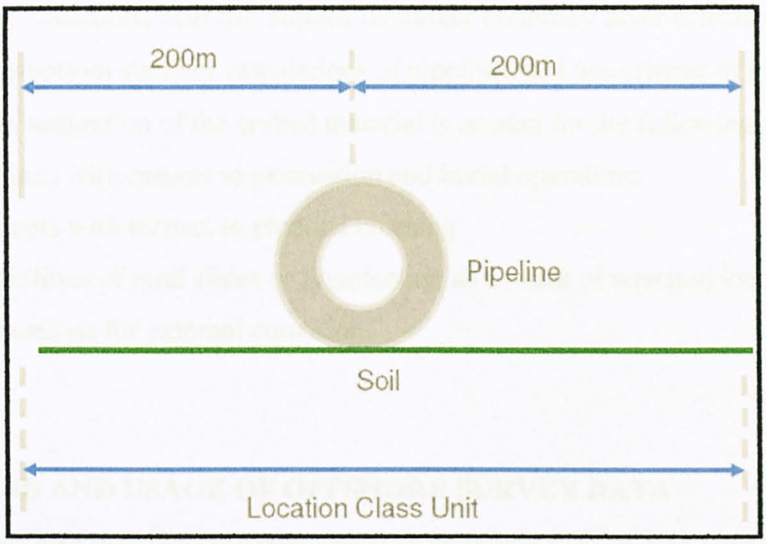


Figure 2.1: Pipeline Location Class [Ranhill WorleyParsons, 2007]

2.1.2 ROUTE SURVEY

- A survey should be carried out along the planned pipeline route to provide sufficient data for design and installation related activities.
- The survey corridor should have sufficient width to define a pipeline corridor which will ensure safe installation and operation of the pipeline.
- Utility investigation need to be carried out to identify possible conflicts with existing and planned installations as well as possible wrecks and obstructions. Examples of such installations include other subsea pipelines, power and communication cables.
- All topographical features which may influence the stability and installation of the pipeline should be covered by the route survey, including
  a) Obstructions in the form of rock outcrops, large boulders, pock marks
  b) Topographical features that contain potentially unstable slopes, sand waves, deep valleys and erosion in the form of scour patterns or material deposits.

2.1.3 SEABED PROPERTIES

- Geotechnical properties may be obtained from generally available geological information, results from seismic surveys, sea bottom topographical surveys, in-situ and laboratory test.
- In areas where the seabed material is subject to erosion, special studies of the current and wave conditions near the bottom including boundary layer effects may be required for the on-bottom stability calculations of pipelines and assessment of pipeline spans.
- Special investigation of the seabed material is needed for the following problems:
  a) Problems with respect to excavation and burial operations
  b) Problems with respect to pipeline crossing
  c) Possibilities of mud slides or liquefaction as a result of repeated loading and
  d) Implications for external corrosion.

2.1.4 REQUIRED AND USAGE OF OFFSHORE SURVEY DATA

A detailed survey data should be available prior to finalizing the pipeline route and carrying out detailed design. The required offshore survey data and corresponding usage are described in **Table 2.2**. (Ranhill WorleyParsons, 2007)

Table 2.2: Required and usage of offshore survey data

No.	Required Data	Usage of Data
1.	Soil geotechnical survey	• To assess the pipeline stability either on the seabed or buried.
2.	Seabed topographical features	• To be used in pipeline transient analysis and bottom roughness analysis. • To identify the areas to be avoided in pipeline route selection.
3.	Fishing and shipping activities	• To be used for trawl board impact assessment and pipeline route selection.
4.	Offshore environmental condition(current, waves etc)	• To be used in pipeline mechanical design.
5.	3rd party facilities (existing pipelines, cables etc)	• To be used in pipeline crossing analysis.

2.2 OFFSHORE PIPELINE ROUTE SELECTION CRITERIA

2.2.1 ECONOMICALLY

The following pipeline route considerations have an impact on the offshore pipeline costs:

- The shortest route between the two and points of the pipeline would be the cheapest. This is because the line pipe and other material cost is the lowest, and also the construction time is the fastest thus giving cost benefits.
- Valleys or sloping seabed and coral areas (which is restricted by environmental regulations) cause considerable difficulties in construction, which is reflected in the cost which can be up to approximately ten times greater than a similar distance on the easiest sections.
- All pipeline crossings should be avoided or reduced to a minimum because they are often time consuming and disruptive to progree and cost a significant lump sum of money in addition to the regular pipeline cost, normally based on length.

2.2.2 TECHNICALLY

- Spiderweb' arrangements, with the pipeline radiating in all directions from the platform should be avoided as shown in Figure 2.2.
- Platform landing/ loading zones should be avoided.
- Risers shouldn't be placed under flare/vent booms.
- Risers should be protected and not located near living quarters (except water and slurry lines).
- A 500m straight length is required near the platform as shown in Figure 2.3.
- Pipelines should be routed 200m away from vent platforms.
- Pipeline crossing angle > 30° as shown in Figure 2.4.
- Spacing between pipelines is 25 – 50m as shown in Figure 2.5.

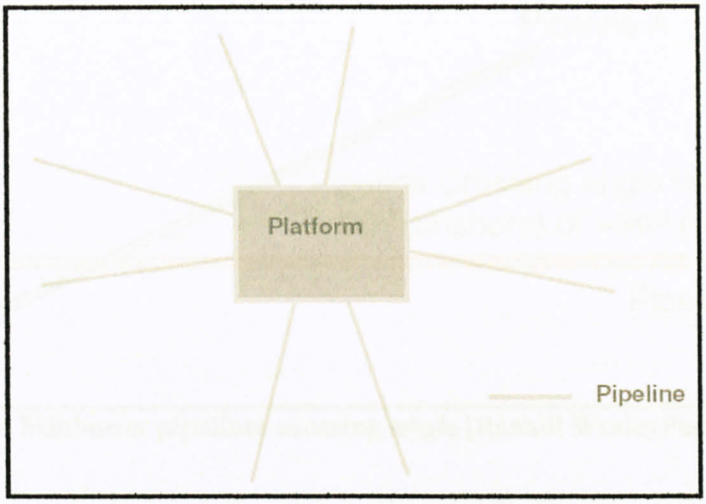


Figure 2.2: Spiderweb arrangement of pipelines from a platform

[Ranhill WorleyParsons, 2007]

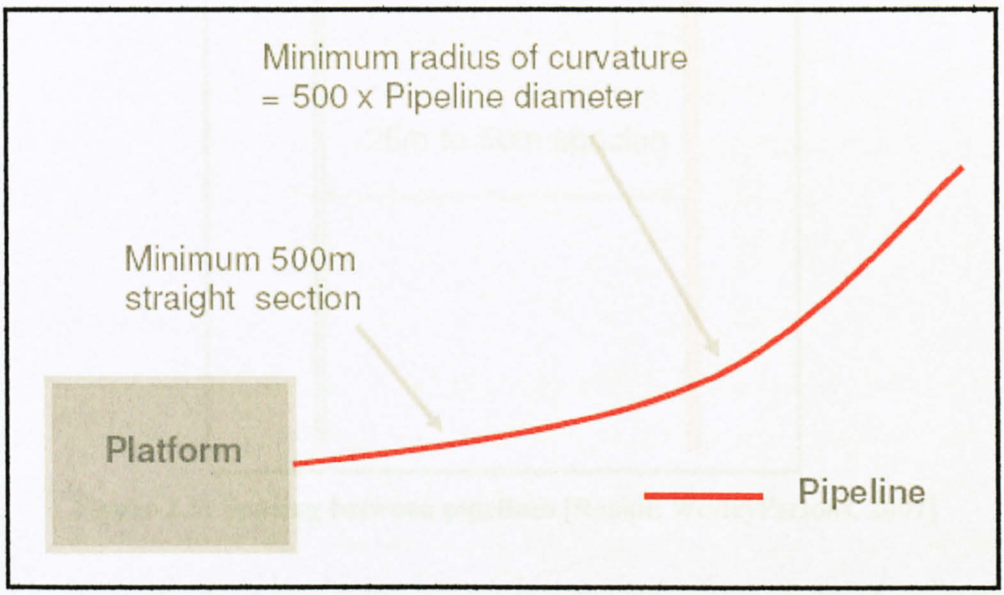


Figure 2.3: Minimum 500m straight section pipeline near platform

[Ranhill WorleyParsons, 2007]

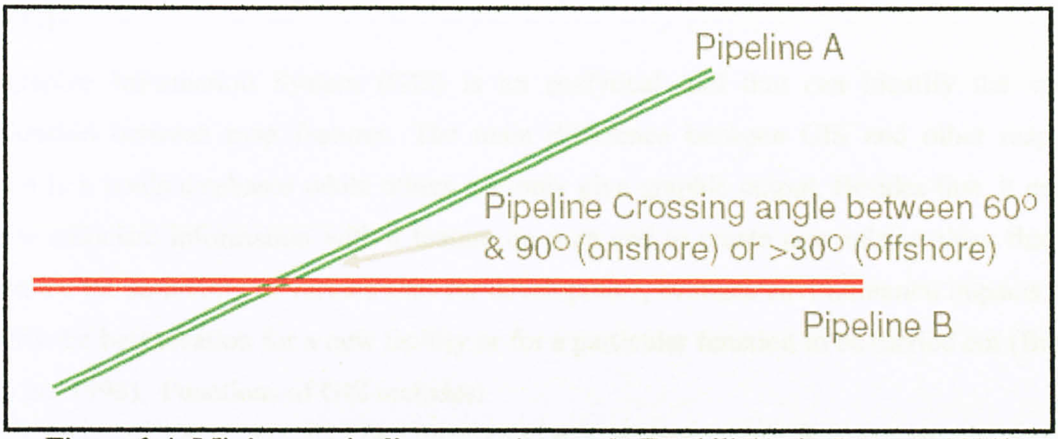


Figure 2.4: Minimum pipelines crossing angle [Ranhill WorleyParsons, 2007]

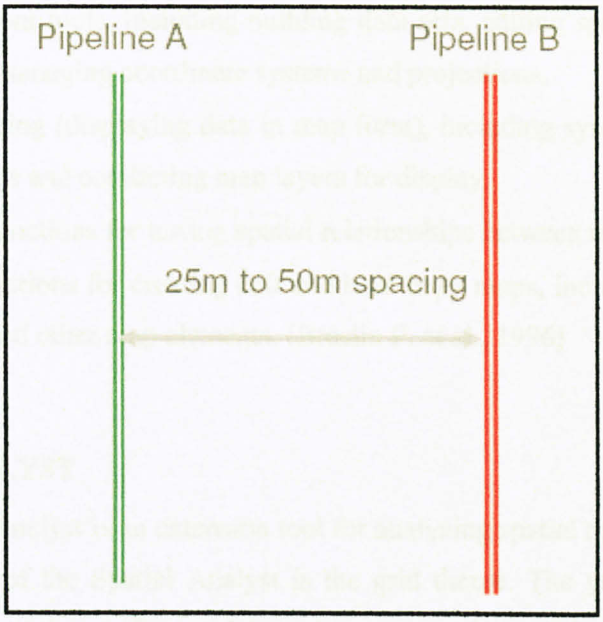


Figure 2.5: Spacing between pipelines [Ranhill WorleyParsons, 2007]

2.3 ARCGIS

2.3.1 FUNDAMENTAL KNOWLEDGE

A geographic information system is a system for capturing, storing, analyzing and managing data. It is capable of integrating, storing and displaying geographically-referenced information. Its applications vary from scientific investigation, criminology, history, to environmental impact assessment, urban planning and resource management. For example, GIS allow immediate calculation of emergency response times in the event of a natural disaster or best emergency exit route during a fire. Besides that, it can be used to find the best pipeline routing plan on land using Network Analyst and subsea using Spatial Analyst.

2.3.2 GIS

Geographic Information System (GIS) is an analytical tool that can identify the spatial relationship between map features. The main difference between GIS and other mapping system is it holds databases while others can only give graphic output. Besides that, it can be able to associate information with a feature on map and to create new relationships that can determine the suitability of various sites for development, evaluate environmental impacts, thus identify the best location for a new facility or for a particular function to be carried out (Breslin P. *et. al.*, 1996). Functions of GIS includes:

- Data entry from a variety of source, including digitizing, scanning, text files, and spatial data formats.
- Data management tools, including building data sets, editing spatial features and their attributes, and managing coordinate systems and projections.
- Thematic mapping (displaying data in map form), including symbolizing map features in different ways and combining map layers for display.
- Data analysis functions for testing spatial relationships between map layers.
- Map layout functions for creating soft and hard copy maps, including titles, scale bars, north arrows, and other map elements. (Breslin P. et al., 1996)

2.3.3 SPATIAL ANALYST

The ArcView Spatial Analyst is an extension tool for analyzing spatial relationships in the data. The main component of the Spatial Analyst is the grid theme. The grid theme is the raster equivalent of the feature theme. Raster dataset is a rectangular matrix of cells where there is only one value per cell. Using this cell-based modeling extension, the features affecting the pipeline routing will be processed to create a series of "resistance" raster grid. (Teng *et.al.*, 2004)

Cost-distance is a function in this extension that can generate the least-cost path of subsea pipeline route. Instead of calculating the actual distance from one point to another, it determines the shortest cost distance (or accumulated travel cost) from each cell to the nearest cell in the set of source cells. A second exception is that cost distance functions apply distance not in geographic units but in cost units. (Teng *et.al.*, 2004)

All cost distance functions require a source Grid and a cost Grid. A source Grid can contain single or multiple zones, which may or may not be connected. All cells that have a value (including 0) are processed as source cells. All non-source cells need to be assigned No Data on the source Grid. A cost Grid assigns impedance in some uniform-unit measurement system that depicts the cost involved in moving through any particular cell. The value of each cell in the cost Grid is assumed to represent the cost-per-unit distance of passing through the cell, where a unit distance corresponds to the cell width. These costs may be travel time, dollars, preference and so forth. (Teng *et.al.*, 2004)

2.3.4 ROUTING PROCEDURE

Developement of the least-cost-path (LCP) basically involves three major steps (ESRI, 2002):

- Develop discrete cost surface datasets in raster format that represent pipeline routing criteria .
- Generate an accumulated cost surface from the combination of discrete cost surfaces.
- Developement of least-cost-path using cost weighted distance function tool.

CHAPTER 3

METHODOLOGY

3.1 ROUTING PROCEDURE

Figure 3.1 shows the detail steps used in analysis of routing procedure.

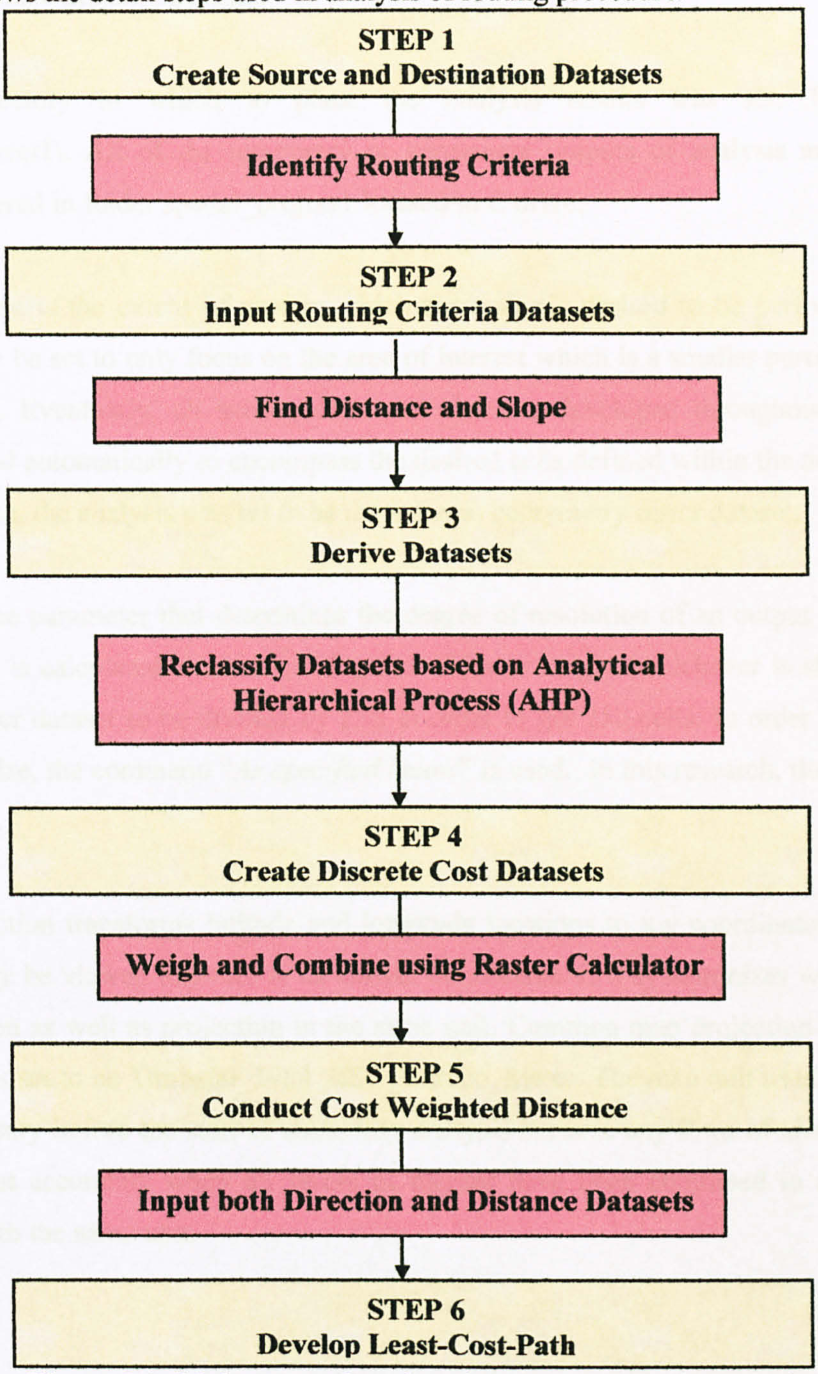


Figure 3.1: Main steps of performing least-cost-path analysis

3.2 SETTINDG-UP OF ANALYSIS PROPERTIES

Before commencing any spatial analysis, analysis properties or environment as shown in Figure 3.2 need to be specified in terms of:

- Working directory
- Analysis extent
- Cell size
- Coordinate system of results

Working directory in which to place the analysis results was set. For example, c:\spatial_project1\. All of the temporary or permanent outputs of analysis and files auto-created are stored in folder spatial_project1 located in C drive.

Analysis extent is the extent of area in which the analysis desired to be performed at. This parameter can be set to only focus on the area of interest which is a smaller portion of a larger raster dataset. Eventually, all subsequent raster datasets developed throughout the analysis would be sized automatically to encompass the desired cells defined within the analysis extent. In this research, the analysis was set to be the same as bathymetry raster dataset.

Cell size is the parameter that determines the degree of resolution of an output raster dataset. By default, it is calculated based on taking the width or height (whichever is shortest) of the extent of raster dataset to be divided by 250 in order to get 250 cells. In order to specify the desired cell size, the command "*As specified below*" is used. In this research, the cell size was set to be 30m.

A map projection transforms latitude and longitude locations to x,y coordinates. All datasets input can only be viewed together at its correct coordinates if it synchronizes with the correct map projection as well as projecting in the same unit. Common map projection for each layer of dataset was set to be Timbalai_1984_RSO_Borneo_Meter. The map unit used is meter. This step is necessary before the start of suitability analysis because any form of analysis can only be carried out accurately when all layers of themes have been combined in the same map projection with the same unit.

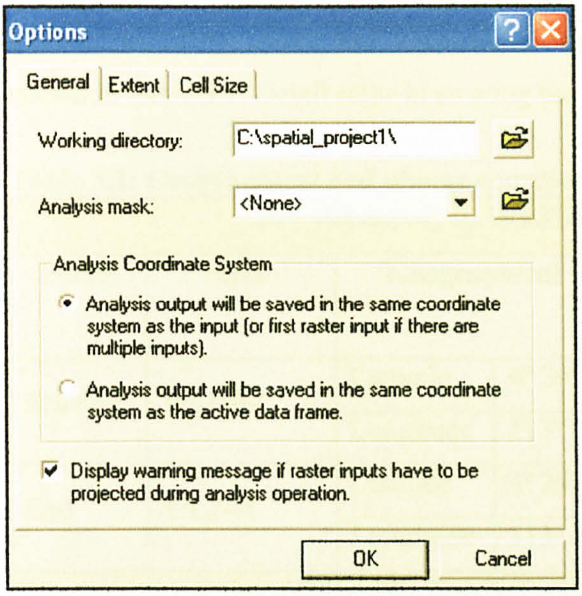


Figure 3.2.1: Working directory

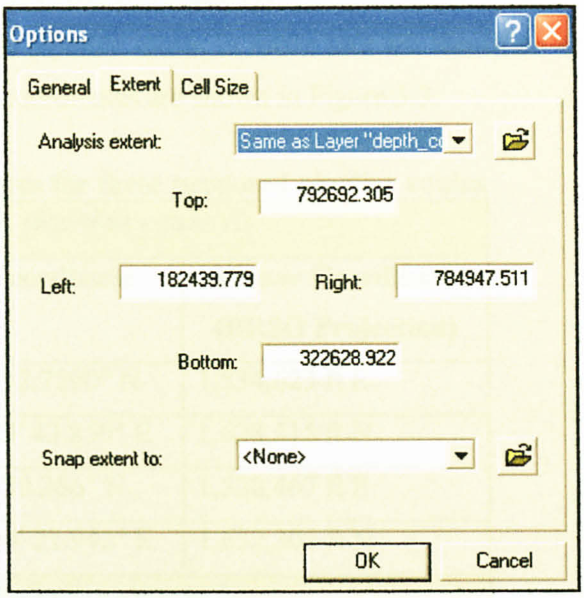


Figure 3.2.2: Analysis extent

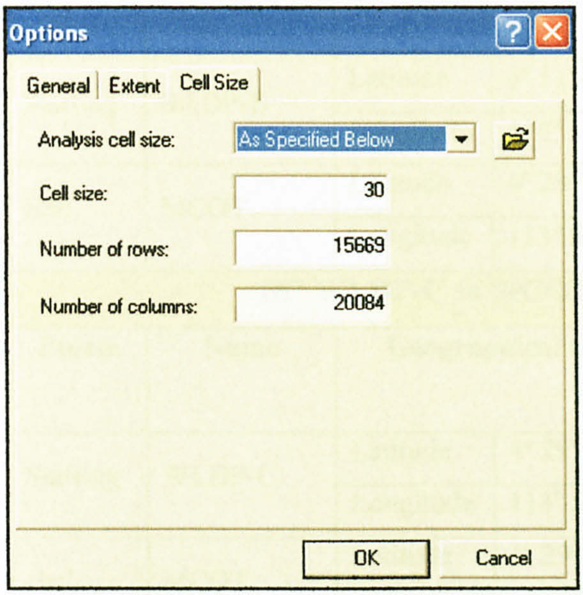


Figure 3.2.3: Cell size

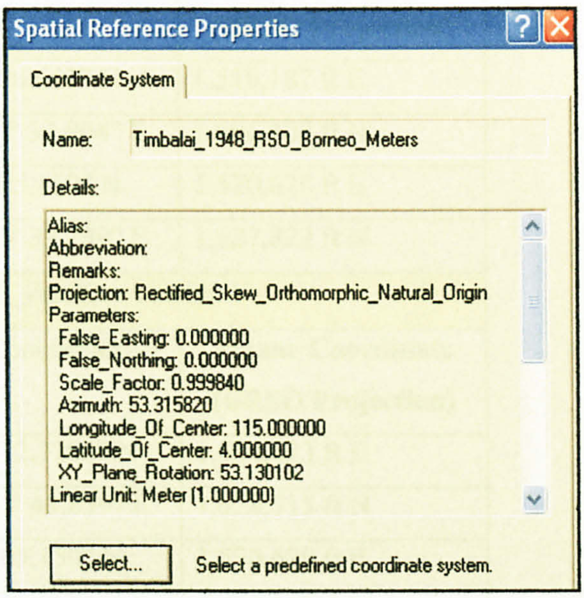


Figure 3.2.4: Map projection system

Figure 3.2 Spatial analysis properties

3.3 CREATION OF SOURCE AND DESTINATION DATASETS

Coordinates of the source and destination of the pipeline routes in meter unit are identified as shown in Table 3.1. Detail steps in creating the coordinates are shown in Figure 3.3.

Table 3.1: Geographical and planar coordinates for three proposed pipeline routes

16" WLDP-C to WLP-A pipeline route A				
Points	**Name**	**Geographical Coordinate**		**Planar Coordinate (BRSO Projection)**
Starting	WLDP-C	Latitude	4° 29' 12.7290" N	1,534,623 ft E
		Longitude	113° 53' 43.859" E	1,628,515 ft N
End	WLP-A	Latitude	4° 29' 50.266" N	1,538,467 ft E
		Longitude	113° 54' 21.942" E	1,632,305 ft N
16" BADP-B to MCOT pipeline route B				
Points	**Name**	**Geographical Coordinate**		**Planar Coordinate (BRSO Projection)**
Starting	BADP-B	Latitude	4° 11' 04.641" N	1,519,187 ft E
		Longitude	114° 17' 33.004" E	1,696,407 ft N
End	MCOT	Latitude	4° 29' 05.150" N	1,570,620 ft E
		Longitude	113° 59' 39.799" E	1,627,822 ft N
16" WLDP-C to MCOT pipeline route C				
Points	**Name**	**Geographical Coordinate**		**Planar Coordinate (BRSO Projection)**
Starting	WLDP-C	Latitude	4° 29' 12.7290" N	1,534,623 ft E
		Longitude	113° 53' 43.859" E	1,628,515 ft N
End	MCOT	Latitude	4° 29' 05.150" N	1,570,620 ft E
		Longitude	113° 59' 39.799" E	1,627,822 ft N

Step 1: Establish data in Microsoft Excel

- The data is identified to be in BRSO Projection.
- The values in latitude and longitude need to be converted into numerical values as shown in X and Y-coor (Table 3.2).
- ArcView GIS can only read data in "numbers" instead of "string" in order to display their coordinates correctly.

Table 3.2: Establishment of data to be input into ArcView GIS

NAME	LATITUDE	X-coor	LONGITUDE	Y-coor
WLDP-C	113° 53' 43.859"E	113.8955	4° 29' 12.7290"N	4.4869
WLP-A	113° 54' 21.942"E	113.9061	4° 29' 50.266" N	4.4973
BADP-B	114° 17' 33.004"E	114.2925	4° 11' 04.641" N	4.1846
MCOT	113° 59' 39.799"E	113.9944	4° 29' 05.150" N	4.4848

Step 2: Save data in DBF format

The established data must be saved in type DBF (Dbase III) in order to be opened and read in ArcView GIS or ArcGIS 9.1

Step 3: Open the table in ArcView

- Spatial analyst tool used in this step is "Add Table"

Step 4: Create a theme from the data in the table

- A theme is to be created using the data from Table Geographical_coor.dbf.

  X and Y fields denote X- and Y-coordinates in ArcView GIS

Step 5: Convert the theme to shapefile

- Conversion of theme to shapefile (point feature) need to be made so that it can be analyzed

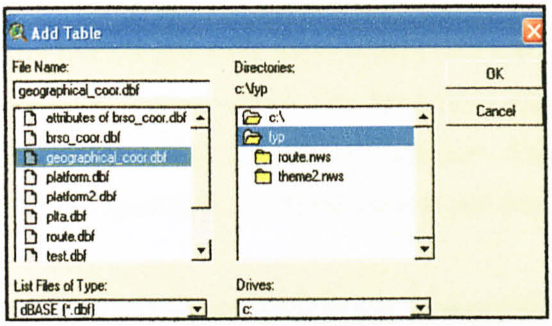
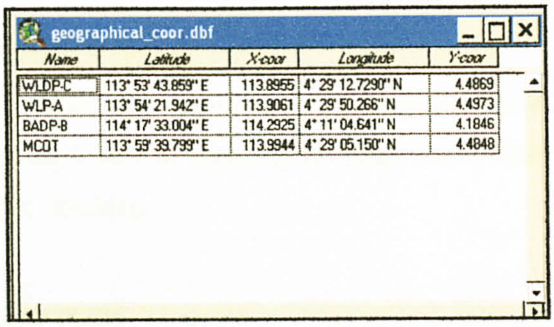


Figure 3.3.1: "Add Table" function



Name	Latitude	X-coor	Longitude	Y-coor
WLDP-C	113° 53' 43.859" E	113.8955	4° 29' 12.7290" N	4.4869
WLP-A	113° 54' 21.942" E	113.9061	4° 29' 50.266" N	4.4973
BADP-B	114° 17' 33.004" E	114.2925	4° 11' 04.641" N	4.1846
MCOT	113° 59' 39.799" E	113.9944	4° 29' 05.150" N	4.4848

Figure 3.3.2: DBF format table

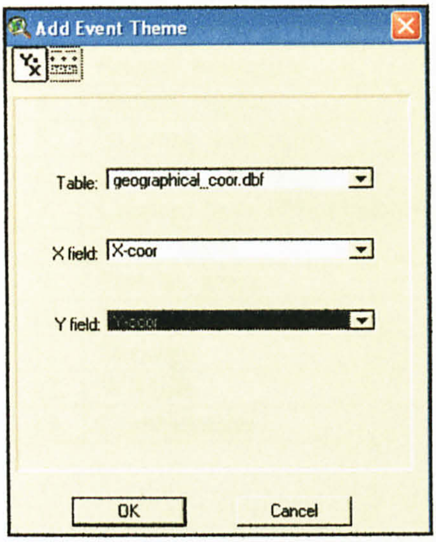


Figure 3.3.3: "Add Event Theme" function

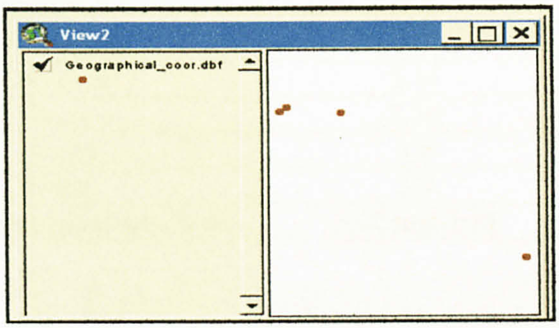


Figure 3.3.4: Theme in .dbf file

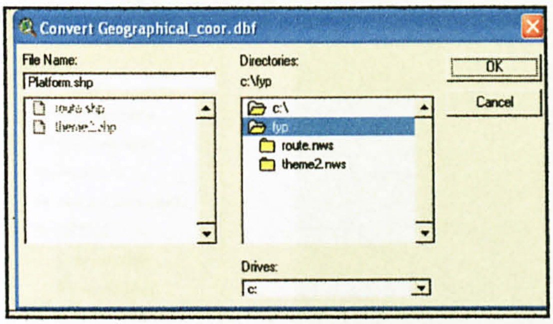


Figure 3.3.5: "Convert to Shapefile" function

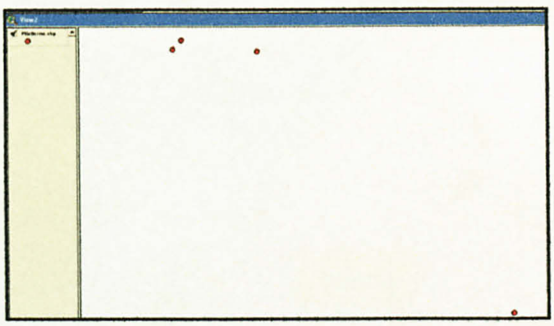


Figure 3.3.6: Platforms shapefile

Figure 3.3: Steps in creating coordinates of platforms in shapefile

3.4 INPUT OF ROUTING CRITERIA DATASETS

Pipeline routing criteria that have been identified earlier were input as topographic layers of shapefiles using "Add theme" function. The following layers of topographic shapefiles (Table 3.3 & Figure 3.4 – 3.13) are viewed and combined in ArcMap.

Table 3.3: Topographic layers of shapefiles as data input

No.	Shapefile Name	Shapefile Type	Figure
1.	Sabah_sarawak_boundary	Polylines	3.4
2.	Sabah_sarawak_region	Polygons	3.4
3.	Brunei_boundary	Polylines	3.4
4.	Brunei_region	Polygons	3.4
5.	Existing_platforms	Points	3.5
6.	Existing_pipelines	Polylines	3.6
7.	Contour lines of bathymetry	Polylines	3.4
8.	Coral_reefs	Polygons	3.7
9.	Prawns_areas	Polygons	3.11
10.	Turtle-nesting_areas	Polygons	3.10
11.	Shrimps	Points	3.8
12.	Wildlife	Points	3.9
13.	Combination	Polylines, Polygons and Points	3.12 and 3.13

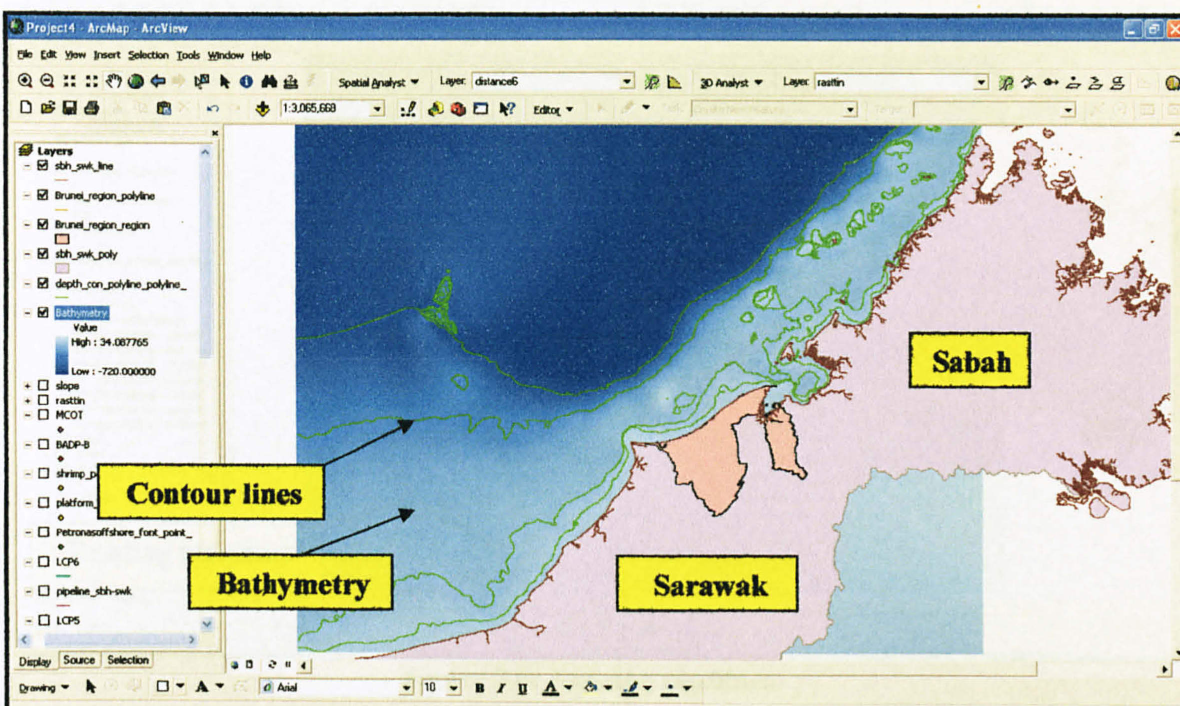


Figure 3.4: Bathymetry (Darker blue indicates deeper sea)

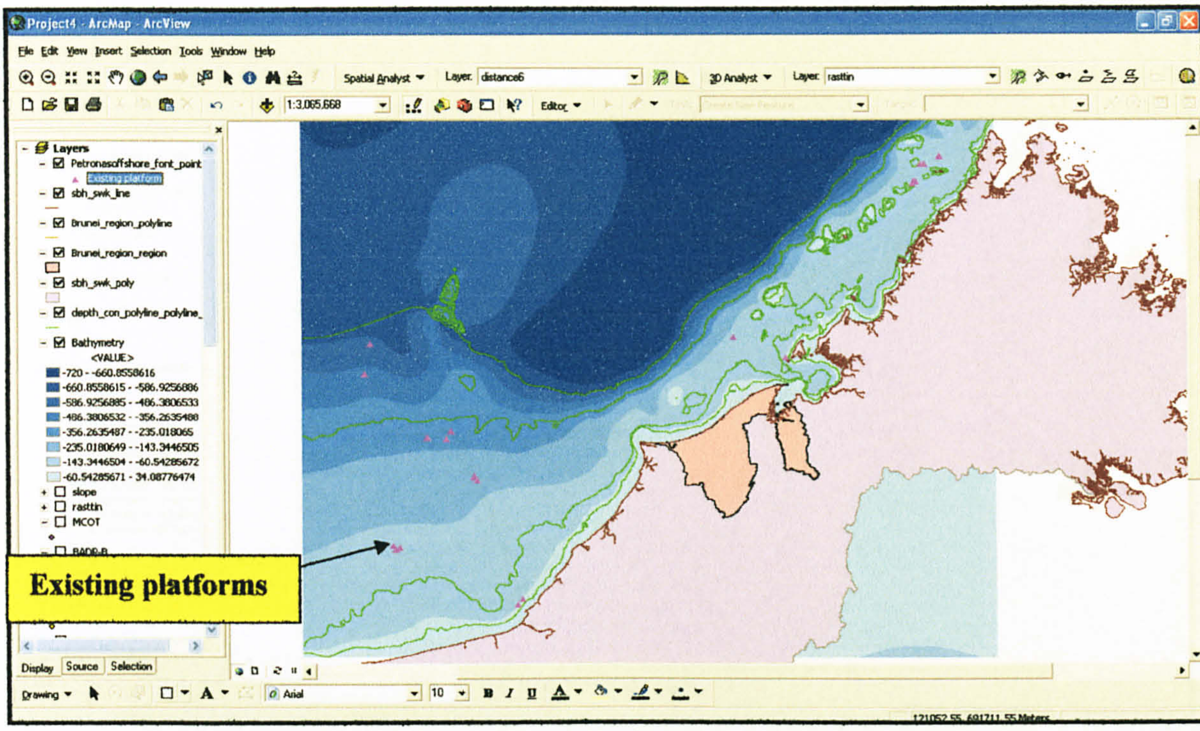


Figure 3.5: Existing platform (purple color triangles)

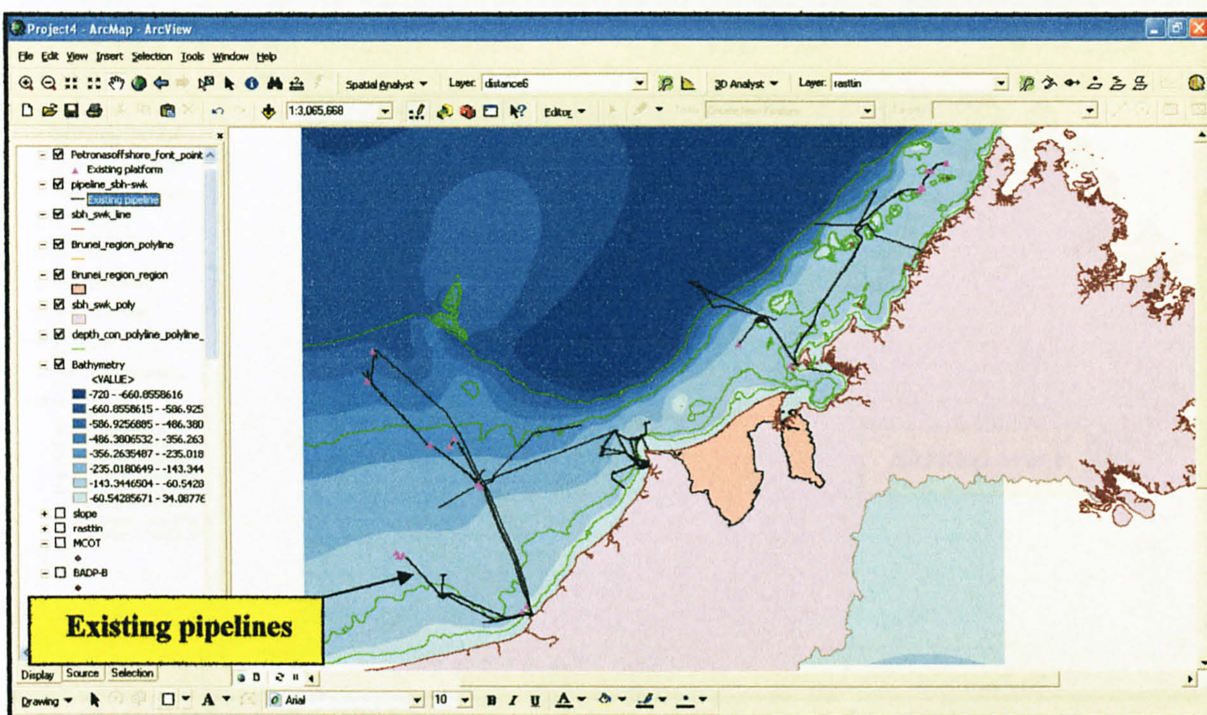


Figure 3.6: Existing pipelines

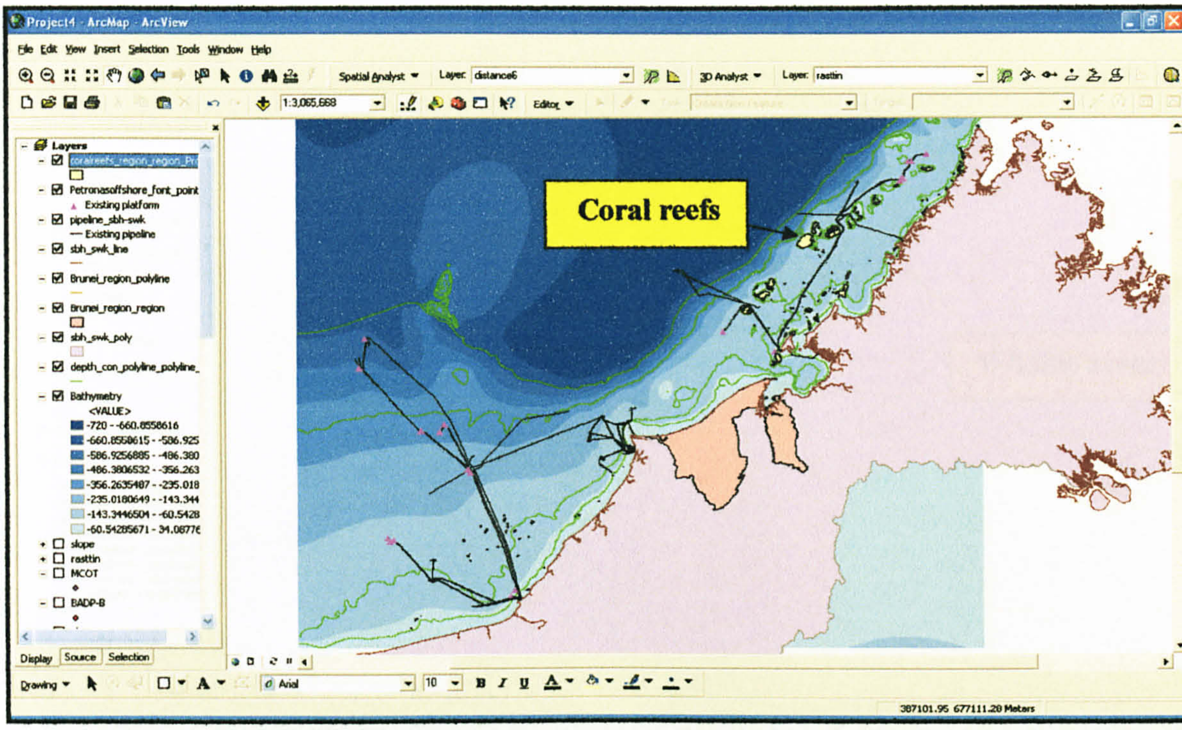


Figure 3.7: Coral reefs regions with hyperlink of picture

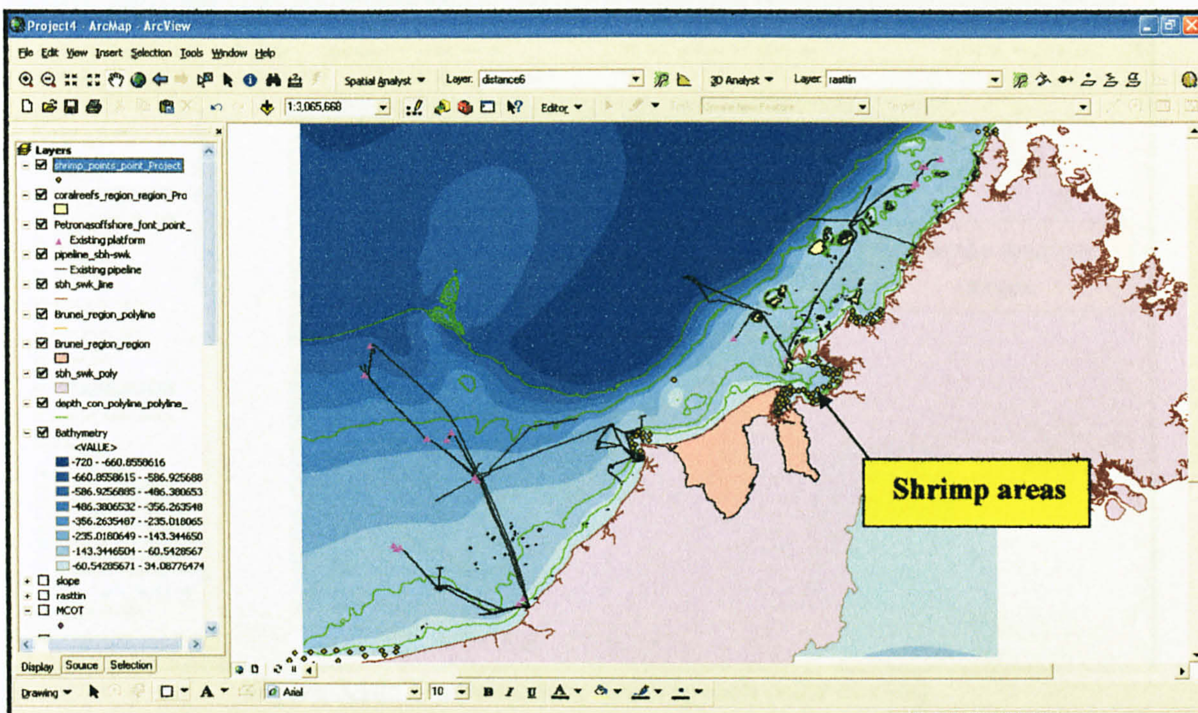


Figure 3.8: Shrimp areas or fishing areas (green color points)

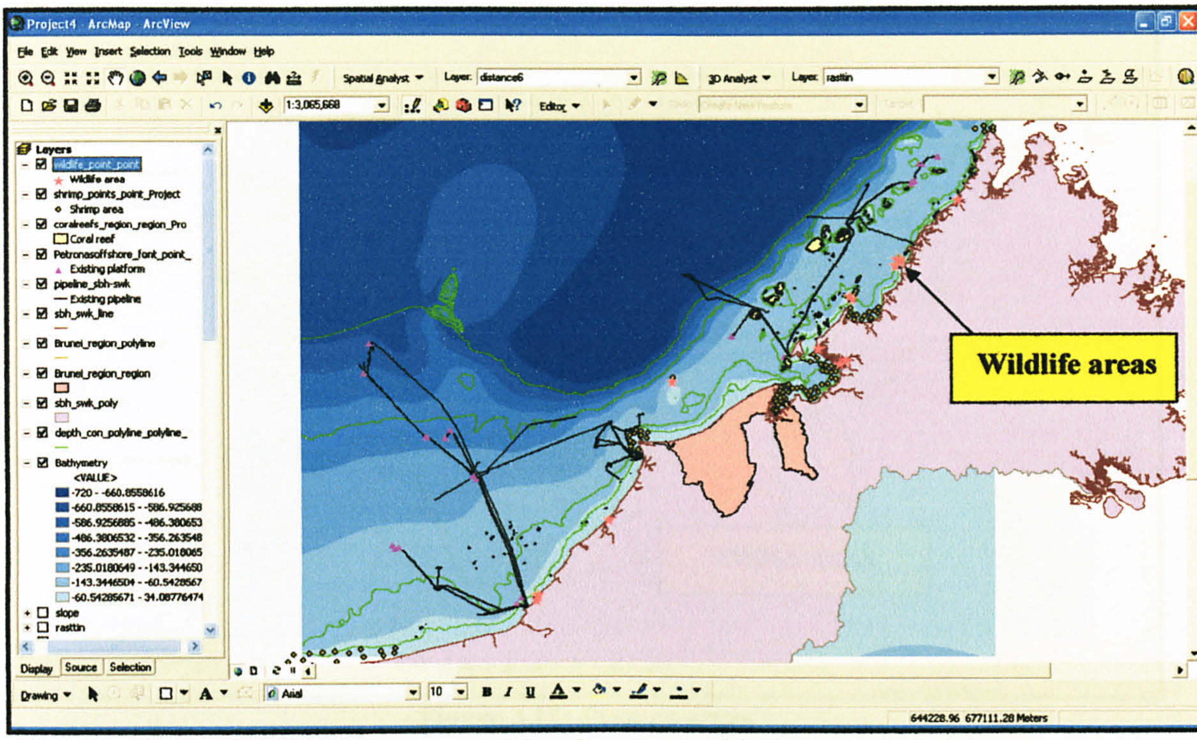


Figure 3.9: Wildlife areas (pink color stars) with hyperlink of pictures

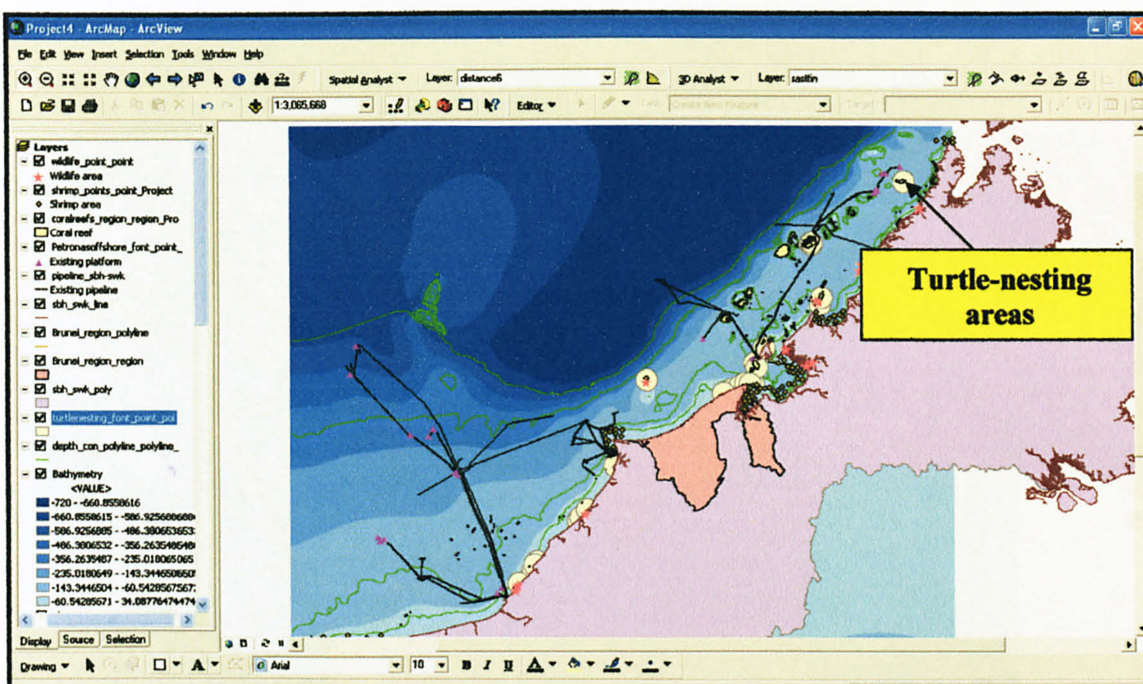


Figure 3.10: Turtle-nesting areas (peach color circles)

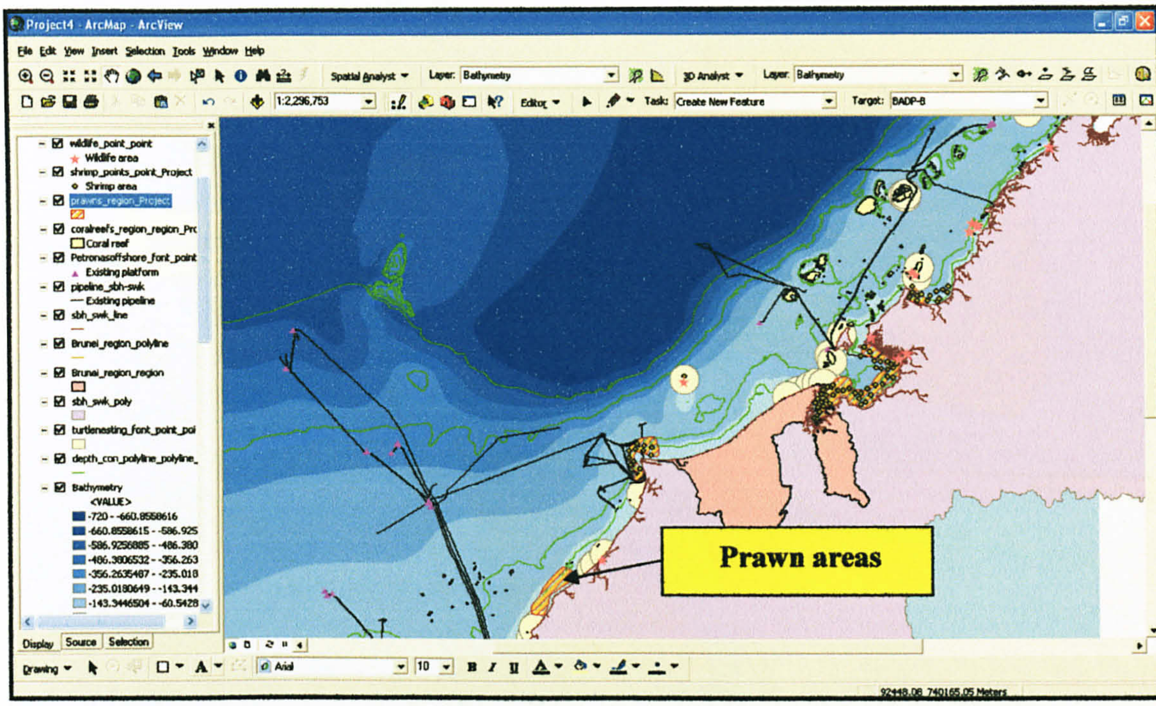


Figure 3.11: Prawns areas

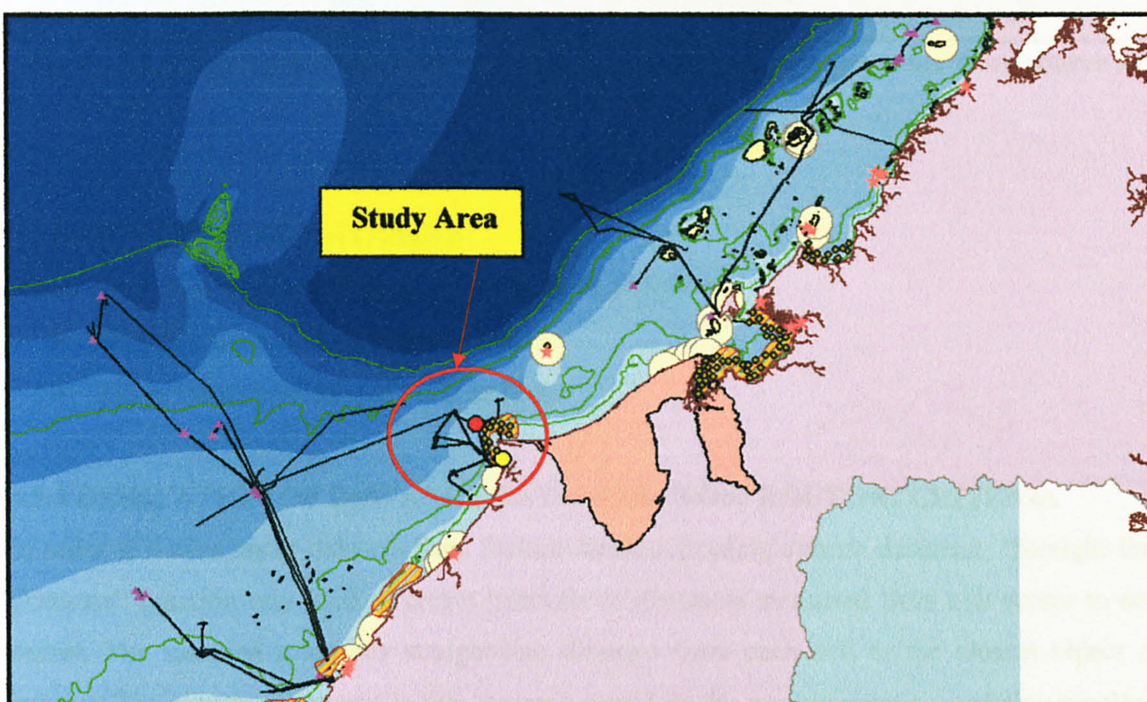


Figure 3.12: Combination of all layers at the scale of 1: 3,050,000 in Timbalai_1984_RSO_Borneo_Meter map projection

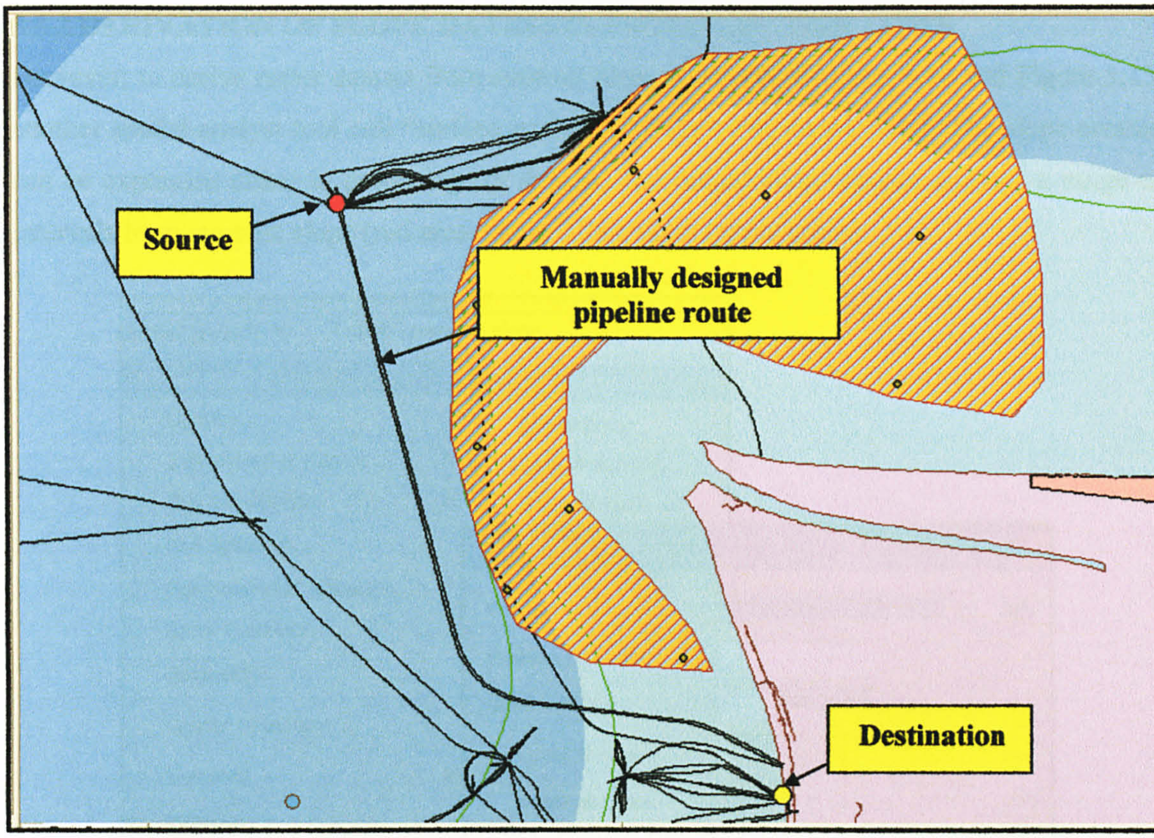


Figure 3.13: Enlarged study area with manually designed pipeline route from source to destination

3.5 DERIVATION OF DATASETS

Raster datasets were derived from vector datasets as follows:

- Distance from routing criteria datasets
- Slope from elevations of contour lines

3.5.1 DERIVATION OF DISTANCE DATASETS FROM ROUTING CRITERIA

In order to derive raster datasets from feature datasets (routing criteria datasets), "Straight-line Distance" function was used to create intervals of distances measured from cell center to cell center. The function measures straight-line distance from each cell to the closest object of interest. The objects of interest in this research would be the routing criteria – existing pipeline, prawn areas, turtle-nesting etc. The distance increases as it moves further away from the feature datasets. It originates from the object of interest and moves further away until it reaches to the extent of analysis as specified in analysis properties earlier.

3.5.2 DERIVATION OF SLOPE DATASETS FROM CONTOUR LINES

However, to derive raster dataset from contour lines as shown in Figure 3.14 and Figure 3.15, another spatial analyst tool call "surface analysis – slope" was used instead. The slope created can be expressed either in percentage or degree. The output slope dataset displays a range of intervals from steepest slope (red areas) to smallest slope (green areas).

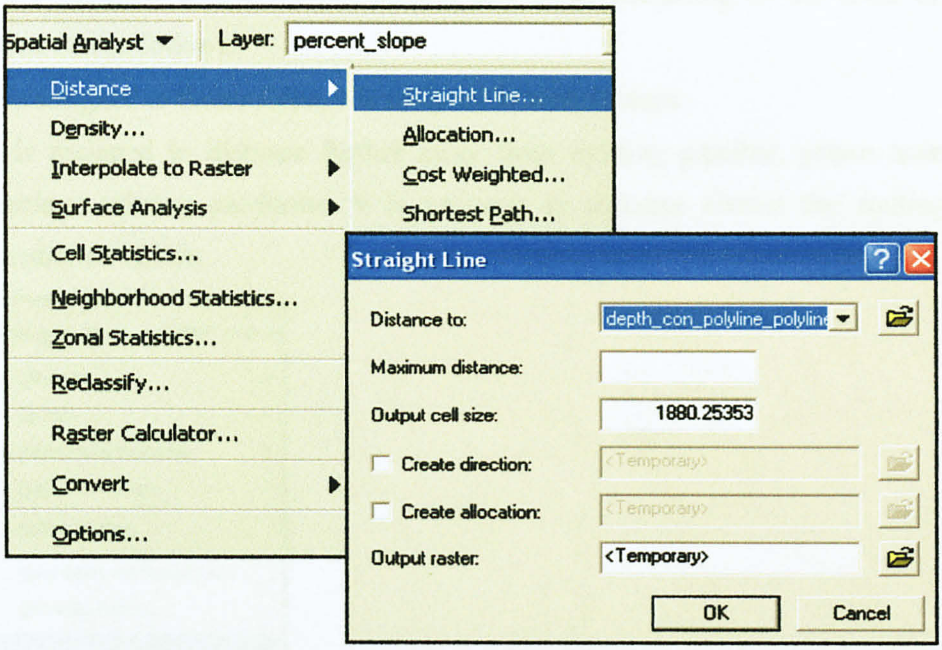


Figure 3.14: Derivation of distance dataset from routing criteria

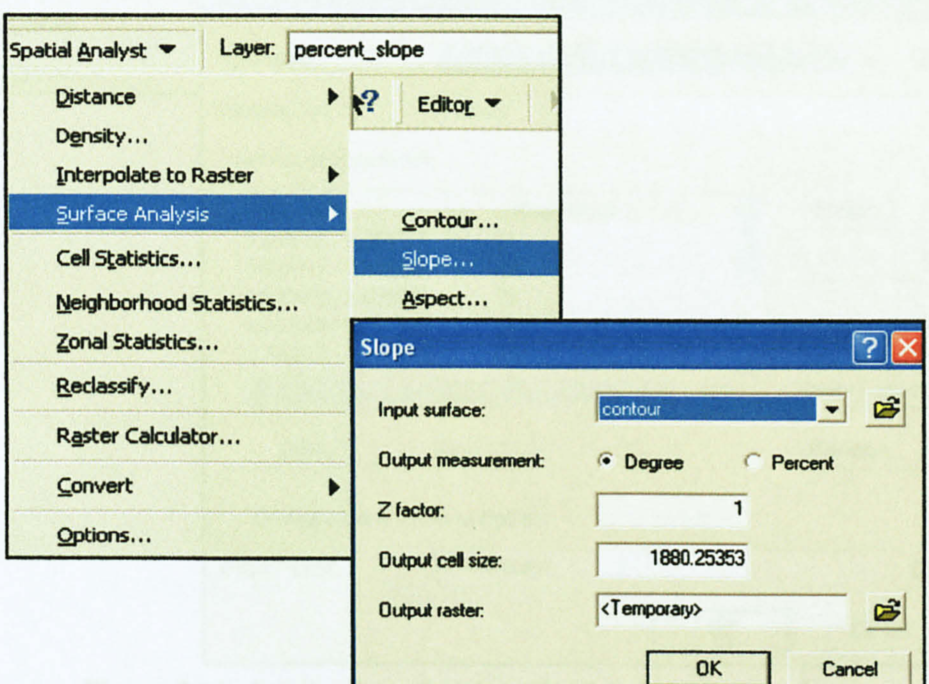


Figure 3.15: Derivation of slope dataset from contour lines

3.6 CREATION OF COST DATASETS

Reclassification changes a range of values in intervals or statistical values into specific range of integers. It establishes a common scale from 1 (most preferred) to 9 (least preferred) for rating each intervals within a dataset as shown in Figure 3.16. Higher integer values indicate higher cost of construction and lower integer values indicate lower cost of construction. Therefore, the integers are assigned to the routing criteria and slope according to the level of favored construction cost as follows:

- 1 is assigned to flatter slope, 9 is assigned to steeper slope
- 1 is assigned to distance further away from existing pipeline, prawn areas, turtle-nesting, existing platforms, 9 is assigned to distance closest the routing criteria mentioned earlier.

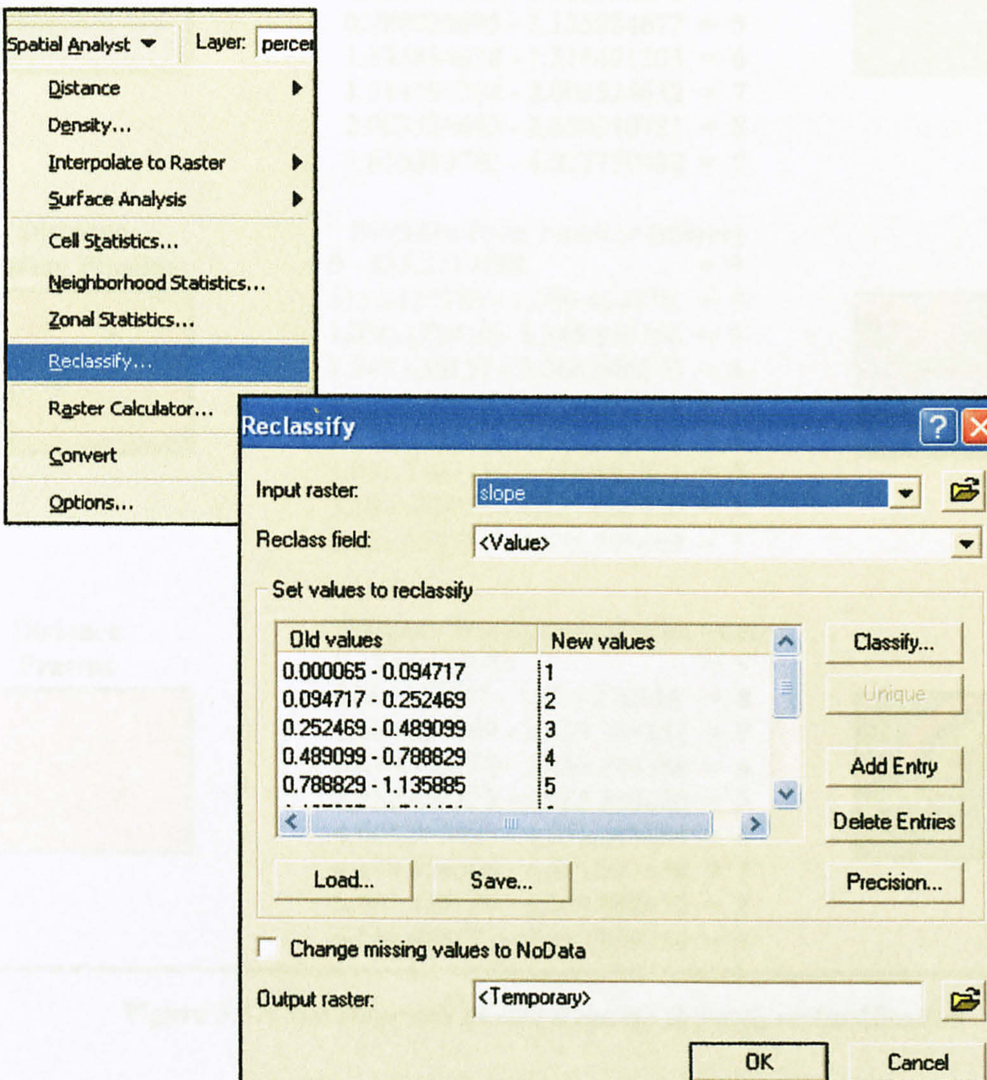


Figure 3.16: Application of reclassification function on slope

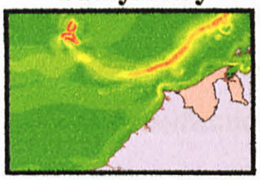
Figure 3.17 shows the weightage assigned to each of the different intervals of parameters for bathymetry, existing pipelines and prawns datasets

<u>Development of Discreet Cost Surfaces using Reclassification</u>

Common scale of rating: 1(Most prefered/ least cost) to 9(Least prefered/ maximum cost)

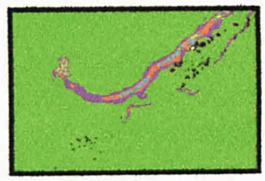
Derived Maps	**Weightage Assigned**	**Preference Maps**

Slope Bathymetry



Slope (Degree)

0.000065099 - 0.094716731	= 1
0.094716731 - 0.252469450	= 2
0.252469450 - 0.489098529	= 3
0.489098529 - 0.788828695	= 4
0.788828695 - 1.135884677	= 5
1.135884678 - 1.514491203	= 6
1.514491204 - 2.003524632	= 7
2.003524633 - 2.650310781	= 8
2.650310782 - 4.022759438	= 9



Distance Existing Pipeline

Distance from pipeline (meter)

0 - 515.2117188	= 9
515.2117189 - 1,030.423438	= 8
1,030.423439 - 1,545.635156	= 7
1,545.635157 - 2,060.846875	= 6
2,060.846876 - 2,576.058594	= 5
2,576.058595 - 3,091.270312	= 4
3,091.270313 - 3,606.482031	= 3
3,606.482032 - 4,121.693750	= 2
4,121.693751 - 4,636.905469	= 1

Distance Prawns

Distance from prawns' area (meter)

0 - 813.111084	= 9
813.1110841 - 1,626.222168	= 8
1,626.222169 - 2,439.333252	= 7
2,439.333253 - 3,252.444336	= 6
3,252.444337 - 4,065.555420	= 5
4,065.555421 - 4,878.666504	= 4
4,878.666505 - 5,691.777588	= 3
5,691.777589 - 6,504.888672	= 2
6,504.888673 - 7,317.999756	= 1

Figure 3.17: Development of cost datasets through reclassification

3.7 COST WEIGHTED DISTANCE ANALYSIS

After application of a common scale to the raster datasets through reclassification to create cost datasets, the cost datasets were combined and weighed to form an accumulated cost surface. Weighting of the datasets was carried according to the importance or influence on the routing process. The higher the percentage assigned to a particular dataset, the more influence it would have in the analysis result. The percentages given to all datasets must amount to 100%. "Raster calculator" spatial analyst tool was used to create accumulated cost surface as shown in Figure 3.18. The routing criteria that are considered in the study area of Baram Field have been given weightage accordingly:

- Reclassification of distance to existing pipeline : 0.5 (50%)
- Reclassification of slope : 0.4 (40%)
- Reclassification of distance to prawn areas : 0.1 (10%)

After creating accumulated cost surface, the function called "Cost-weighted Distance" was used to create a distance surface and a direction surface as shown in Figure 3.19. A direction surface guides the route to the destination.

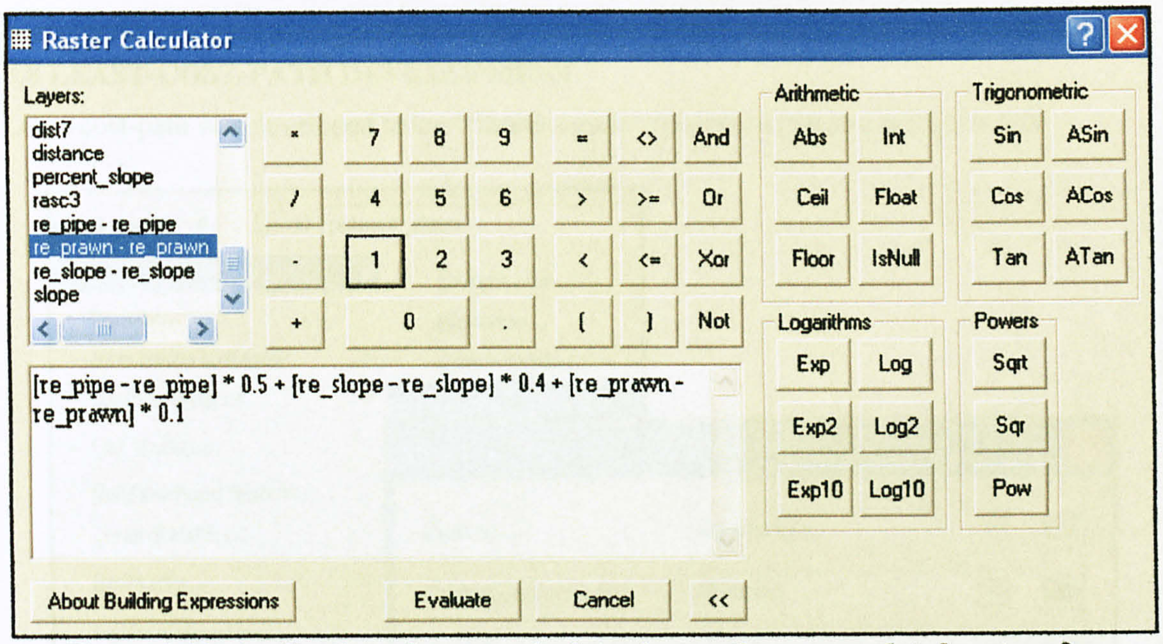


Figure 3.18: Application of raster calculator in creating accumulated cost surface

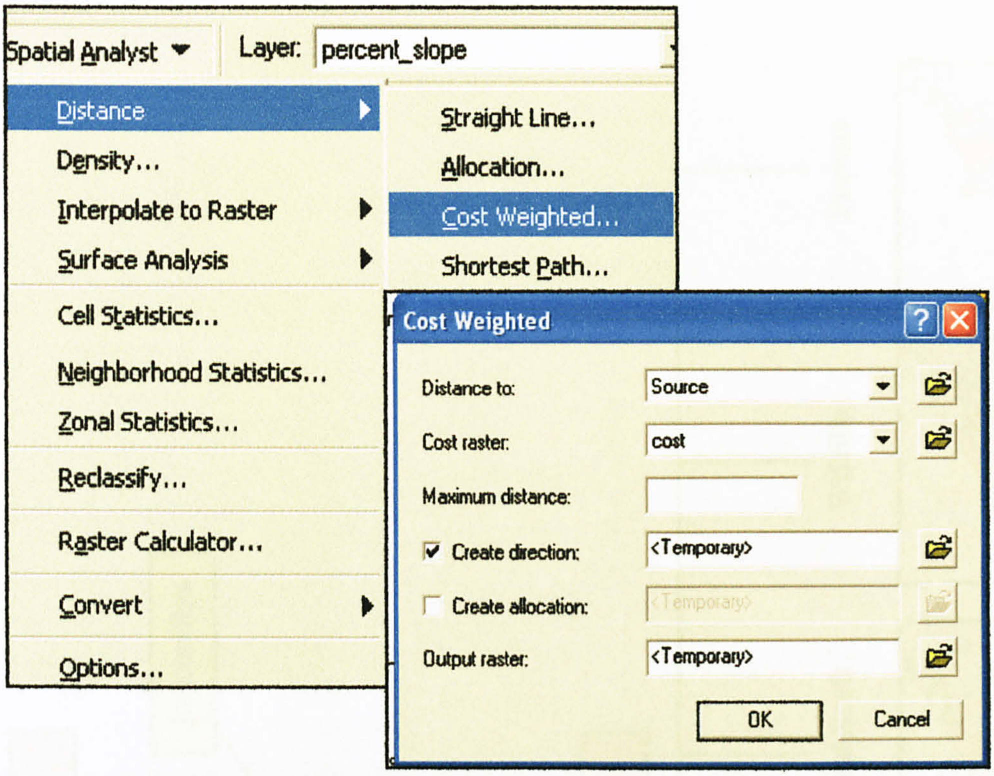


Figure 3.19: Application of cost-weighted function

3.8 LEAST-COST-PATH DEVELOPMENT

Least-cost-path was developed using "Shortest-path" function as shown in Figure 3.20.

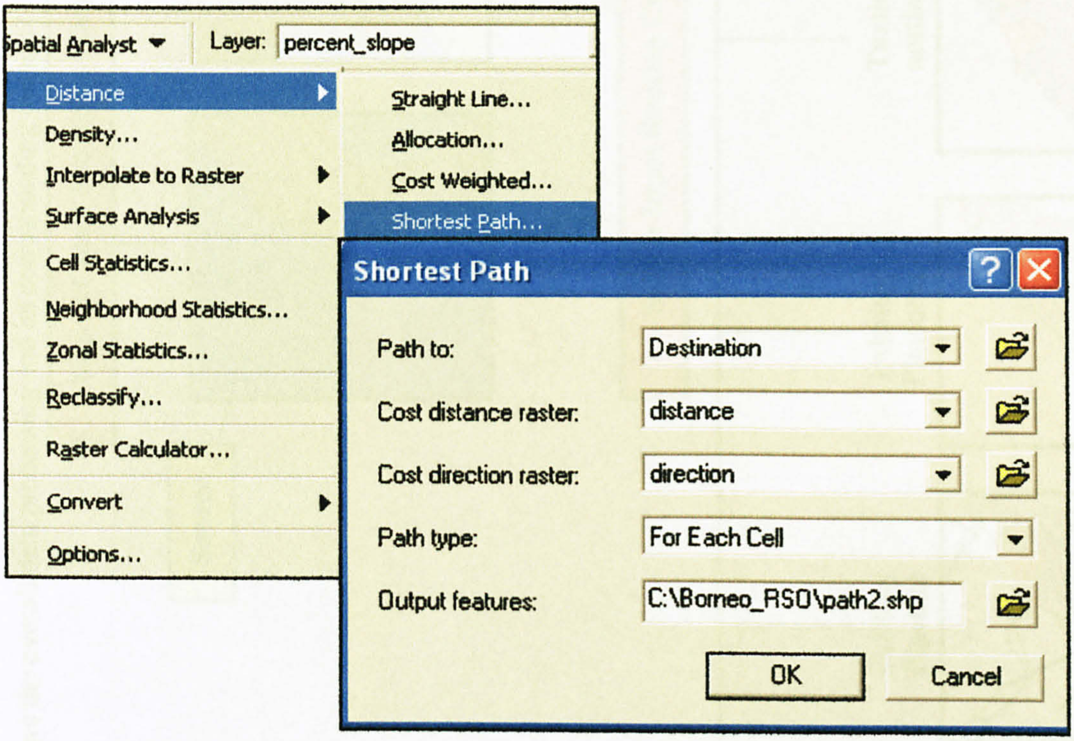
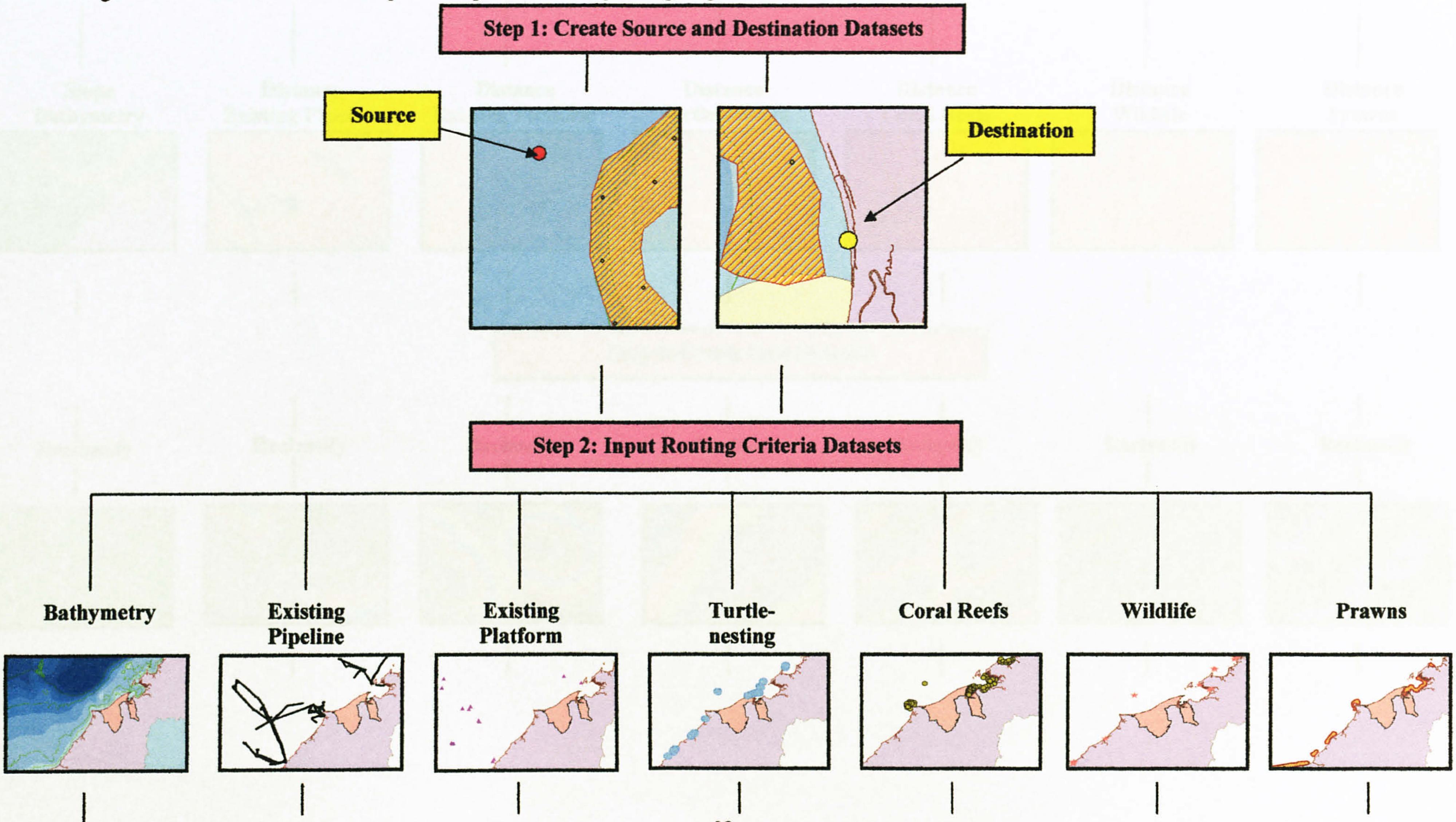
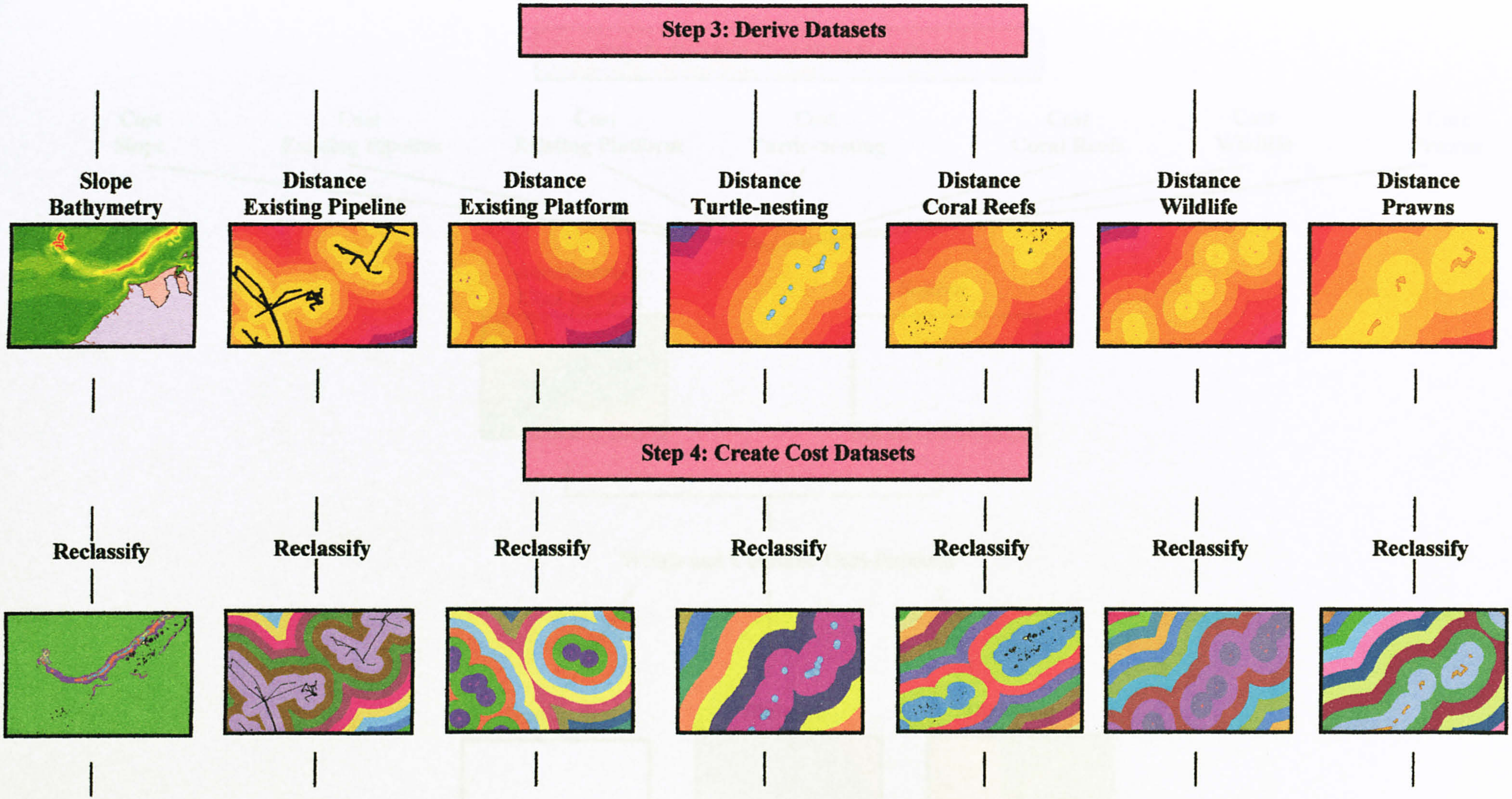


Figure 3.20: Application of Shortest path function

3.9 OVERALL DATA PROCESSING

Figure 3.21 shows the overall data processing and its corresponding outputs.




Step 3: Derive Datasets
Slope
Bathymetry
Distance
Existing Pipeline
Distance
Existing Platform
Distance
Turtle-nesting
Distance
Coral Reefs
Distance
Wildlife
Distance
Prawns
Step 4: Create Cost Datasets
Reclassify
Reclassify
Reclassify
Reclassify
Reclassify
Reclassify
Reclassify

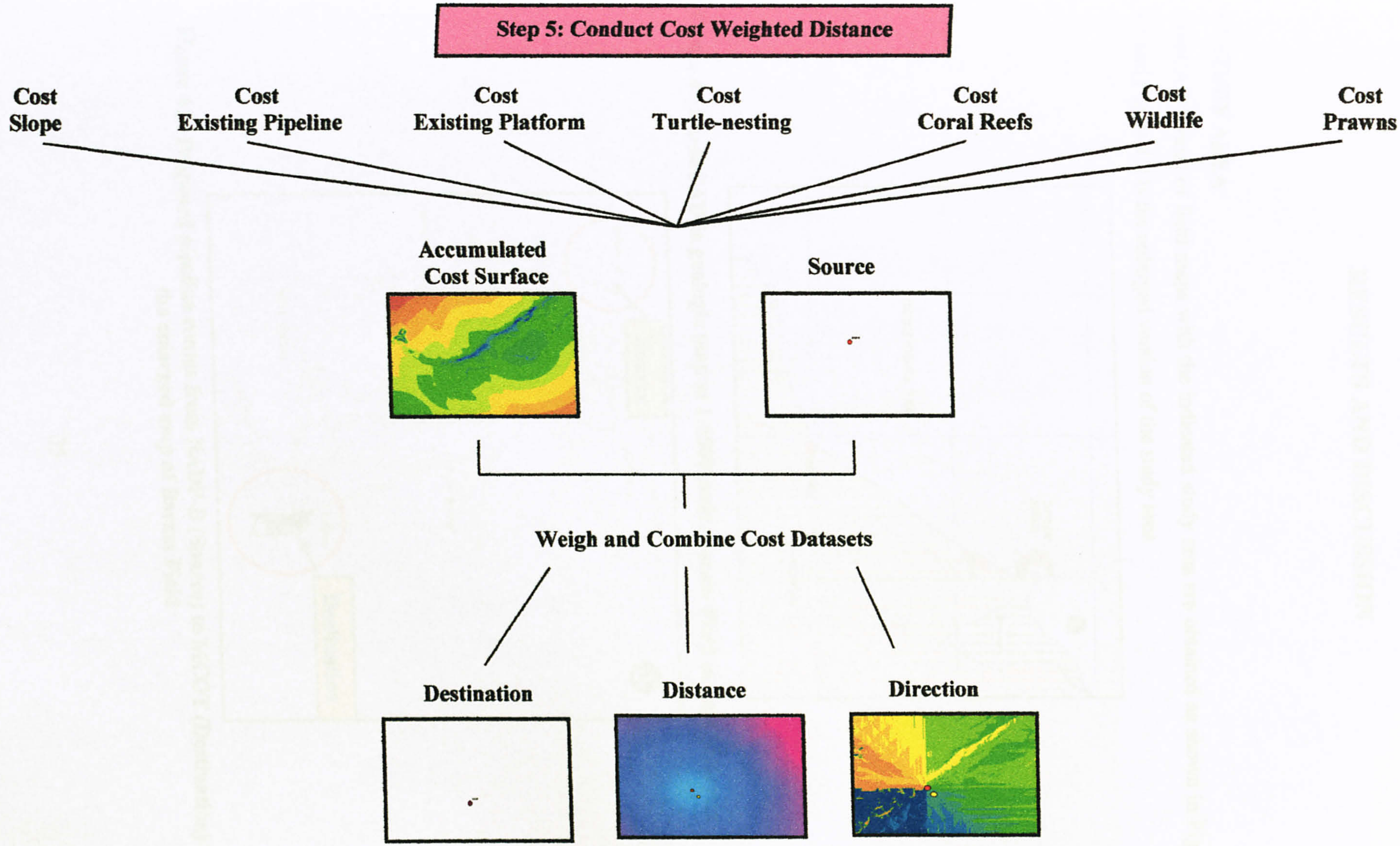


Figure 3.21: Data processing of routing analysis

CHAPTER 4

RESULTS AND DISCUSSION

4.1 STUDY AREA

AutoCAD format of field maps with the indicated study area are obtained as shown in Figure 4.1 and Figure 4.2 is the enlarged version of the study area

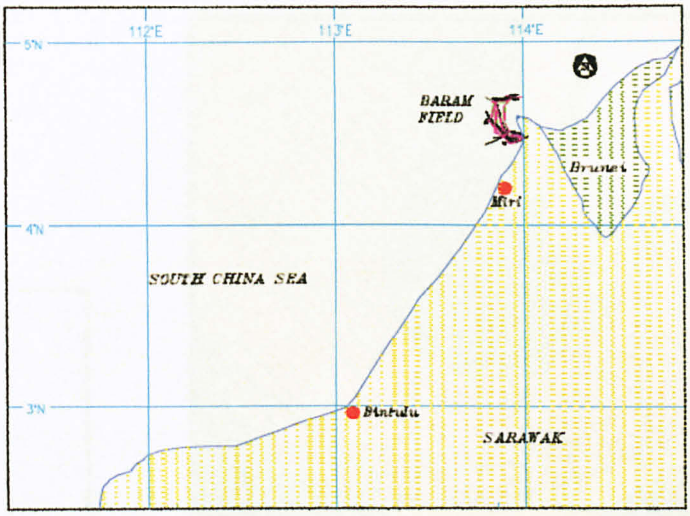


Figure 4.1: AutoCAD in geologic map at 1:5000 scale, Baram Field in East Malaysia

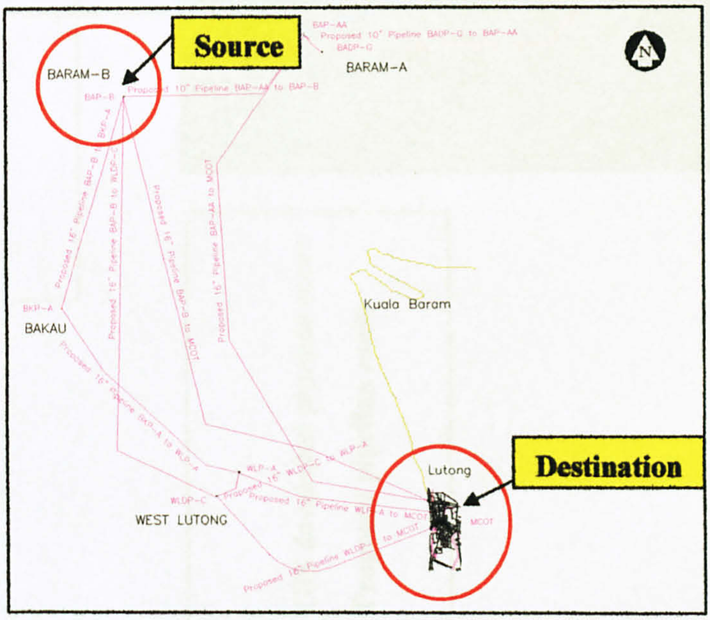


Figure 4.2: Proposed pipeline routes from BADP-B (Source) to MCOT (Destination) in the enlarged map of Baram Field

4.2 GIS-GENERATED LEAST-COST-PATH

Figure 4.3 shows the result of GIS-generated pipeline route and the proposed pipeline route.

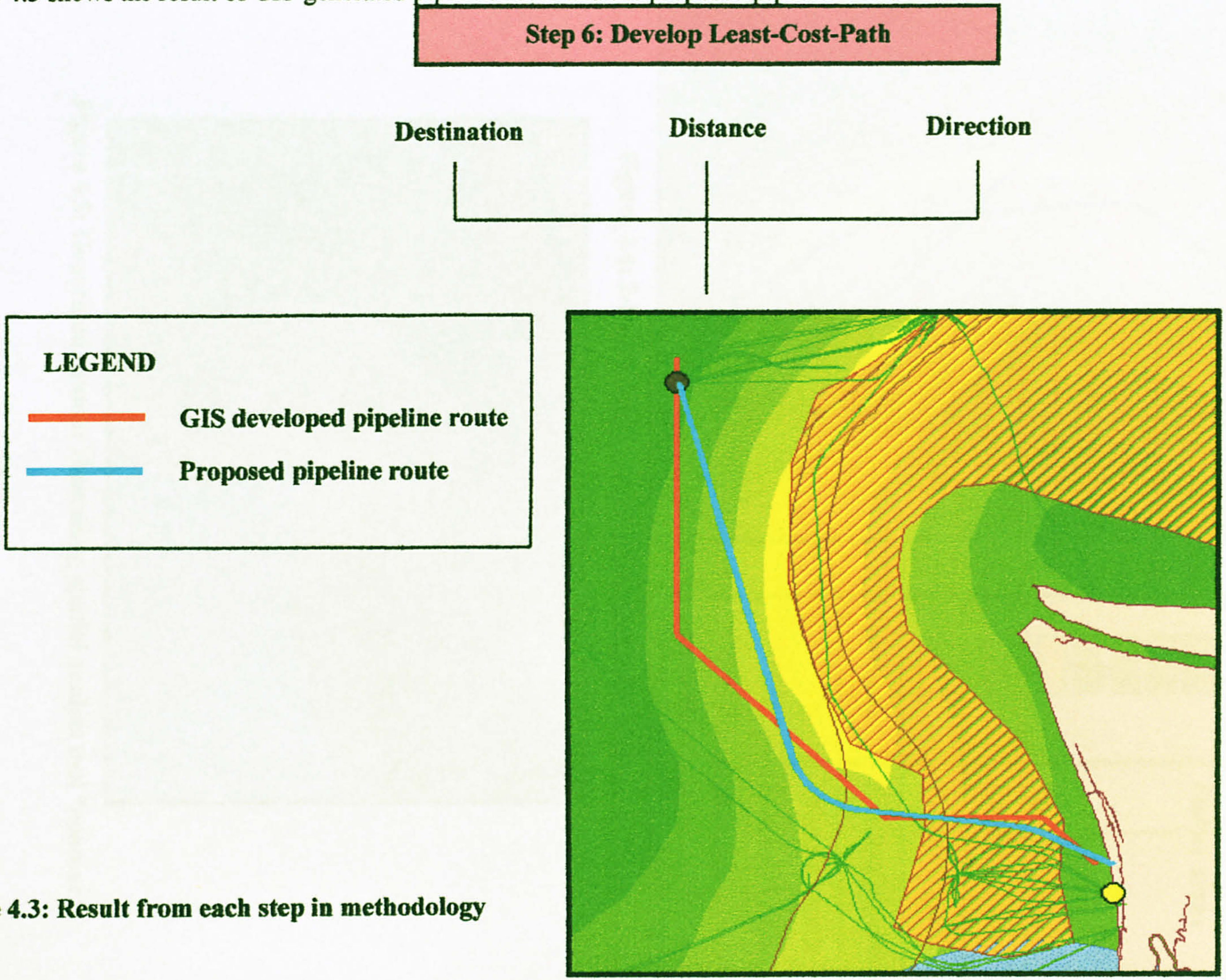


Figure 4.3: Result from each step in methodology

4.3 GENERATION OF 2 AND 3-DIMENSIONAL PROFILES

Four pipeline routes in 2-dimensional profile are shown in Figure 4.4. The contour lines of the study area are generated using the "contour" function in Spatial Analyst tool based on the elevation of bathymetry as shown in Figure 4.5. It is then opened in ArcView and by using 3D Analyst, the 3-Dimensional profile of subsea topography can be generated as shown in Figure 4.6. A 3-dimensional profile of the pipeline routes which can be viewed in 360 degree angle through navigation in GIS can create a better visualization of the analysis results.

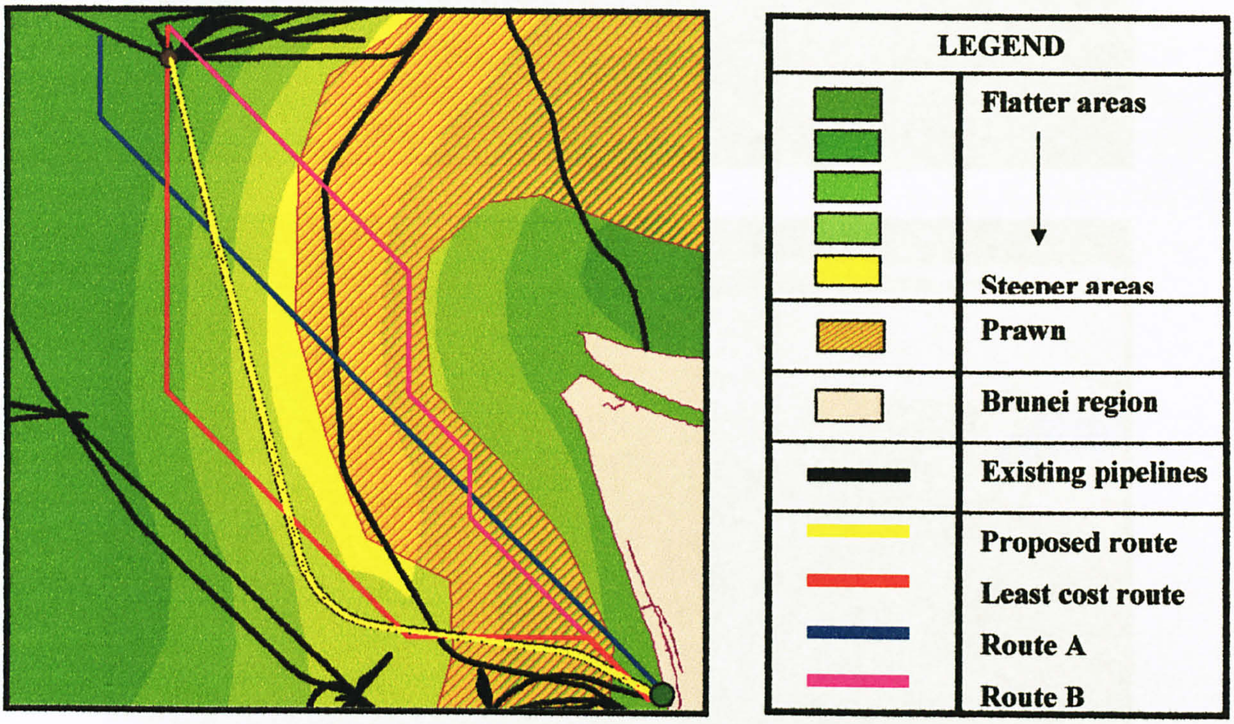


Figure 4.4: 2-Dimensional profile of the analysis results

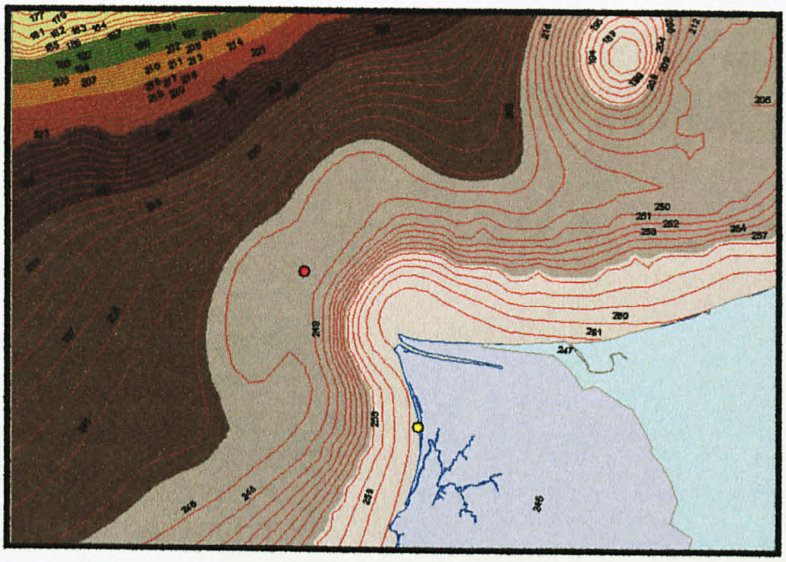


Figure 4.5: Generated contour lines using spatial analyst tool "contour"

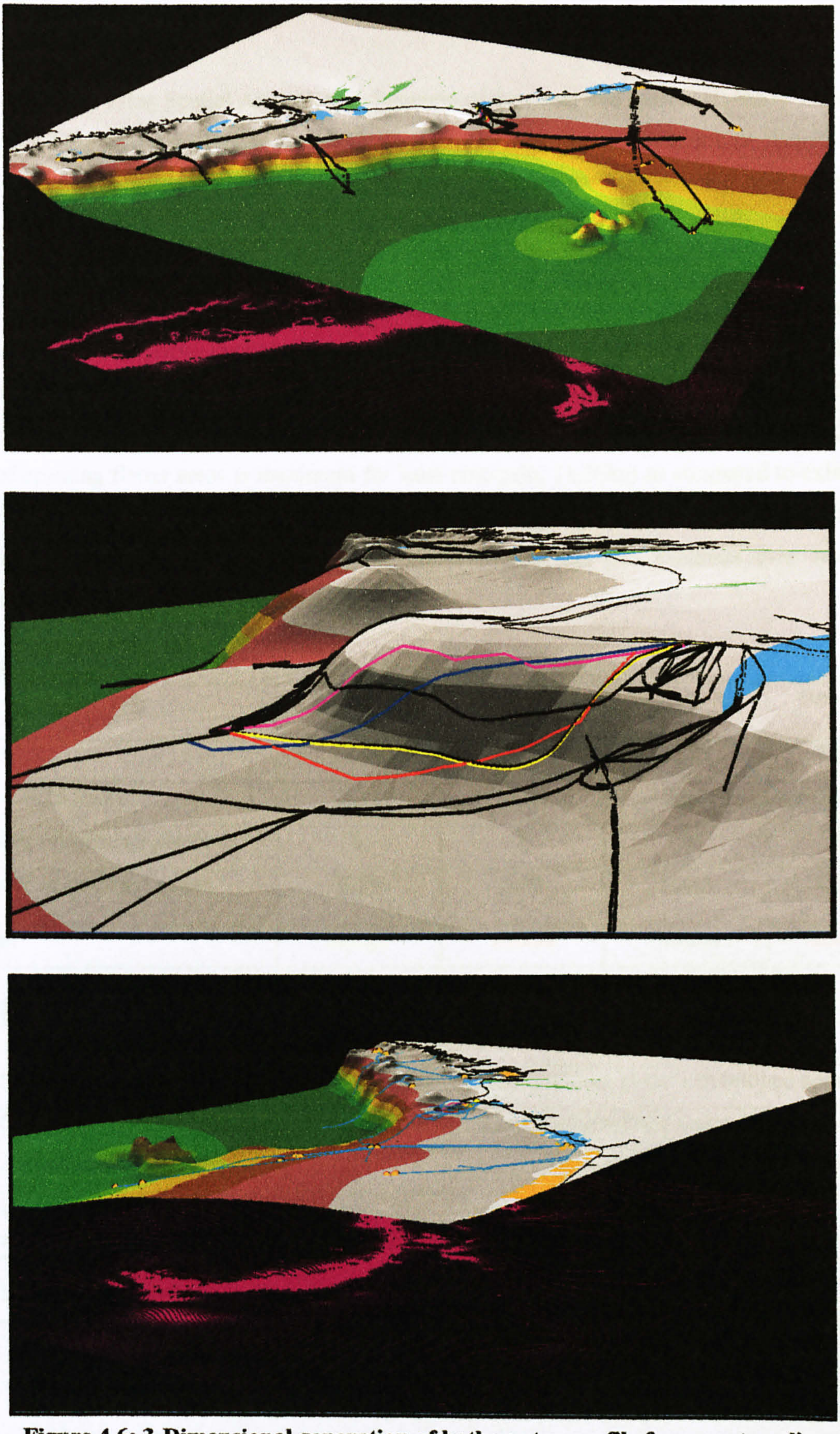


Figure 4.6: 3-Dimensional generation of bathymetry profile from contour lines

4.4 DISCUSSION

From the analysis using Spatial Analyst, the alignment of the generated least cost path is found to be similar to the existing pipeline route. However, when it is judged in terms of factors that determine the cost of construction, the least-cost-path is better than the existing route since it crosses less steep areas despite of its length is only 0.09km longer than the existing route. The comparison of the important factors in determining pipeline construction cost is summarized in Table 4.1. Route A served as the default route where no consideration is given to the avoidance of existing pipelines, prawn areas and steep slopes. Instead, it only finds the shortest path from source to destination. Route B is generated by giving importance to avoiding existing pipelines and less consideration to the prawn areas and slope factors. From the results in Table 4.1, the length of crossing flatter areas is maximum for least-cost-path, 11.56km as compared to existing route which is only 3.77km. Therefore, it fulfills the top priorities which are the safety and cost in route design process. Table 4.2 describes the improvements that GIS enhances over manual engineering method in pipeline route design.

Table 4.1: Comparison of cost-determining factors between pipeline routes

Feature	Existing Route	Least Cost Path	Route A	Route B
Length (km)	**28.64**	**28.73**	**27.21**	**26.24**
Slope < 0.25 (km)	**3.77**	**11.56**	**3.88**	**3.29**
Crossing of existing pipeline	**1**	**1**	**1**	**1**
Crossing of prawns' areas (km)	**5.20**	**5.00**	**19.46**	**13.94**
Legend				

Table 4.2: Comparison between the manual and GIS method in pipeline route design

No.	Manual Engineering Method	GIS Method
1.	Slower optimum route's developed approach	Faster optimum route's developed approach
2.	Complex engineering computations needed	Complex engineering computations omitted
3.	Actual unit costs are needed	Actual unit costs are replaced by weightage
4.	Delayed of pre-cost estimate	Earlier pre-cost estimate
5.	2-Dimensional profile generation	3-Dimensional profile generation
6.	Individual professional experience required	Comprehensive GIS skills required

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

All the objectives in this research have been achieved. The pipeline routing criteria are identified and input into GIS. Spatial Analyst is used in the least cost path analysis. The GIS-developed route is 0.09km longer than the existing pipeline route but it crosses most of the flatter slope areas which contributes to reduction in pipeline construction cost. The use of cost weighted distance function in performing the three basic steps of GIS-based routing, hence 1) establish discrete cost surfaces, 2) combine and weigh cost surfaces to produce accumulated cost surface and 3) develop of least cost path, has been a fast, accurate and easy-to-use approach as compared to contemporary routing method. However, this method is still not as accurate as the manual method because there are other factors such as environmental forces that affects the routing criteria in which GIS is not able to take into consideration. In conclusion, the GIS approach is no doubt a more structured and consistent method than contemporary routing method because all the routing criteria and corresponding level of importance in affecting pipeline construction cost are not only specified and documented clearly, but can also be monitored to generate more routes according to different sets of weightage desired.

5.2 RECOMMENDATIONS

- In order to improve the accuracy of the analysis results, it is suggested that the projection system of all the datasets must be same.
- The number of data should be increased in order to increase the level of accuracy.
- The scale of map should be adjusted so that the deviation of results after integration of various datasets can be minimized.

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Naghibi, F. & Delavar, M.R., 2002. "Pipeline Routing Using Geospatial Information System Analysis". M.Sc. Research Seminar, Department of Surveying and Geomatic Engineering, Engineering Faculty, University of Tehran.

Ranhill WorleyParsons, 2007. Pipeline Training Module: Fundamental of Pipeline Engineering, Module 1.