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Construction of New Forest Roads in Malaysia Using a GIS-Based Decision Support System

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Abstract

This paper describes how a Geographical Information System (GIS)-based Decision Support System (DSS) was applied in selecting the most compatible block or compartment to construct a new forest road for a sustainable timber harvesting purposes. The study area was located in Gunong Stong Permanent Forest Reserve, Kelantan, Malaysia between latitude 5°00' N and 5°25' N and longitude 101°20' E and 102°05' E. Four criteria have been considered in this paper which is timber volume (m^3), slope (degree), ground condition and distance from the primary and secondary forest road that previously exists (m). ArcView and ArcMap softwares were used to evaluate all the criteria using remote sensing and field data. Results indicated that the best block that fulfill all the criteria chosen for the new forest road construction is Block Nos. 9 and 11.

Keywords: Geogrpahic information system, Decision support system, Forest harvesting, Forest road, Road construction

1. Introduction

Virtually everyone makes hundreds of decisions each day. Good decision making means that the person are informed and have relevant and appropriate information on which to base the choice. Information has been referred as facts, numbers, historical data, graphics, pictures, and sounds (Sauter, 1997). Decision support system (DSS) technology and applications was built to support the decision making. DSS is being used in many fields including forestry. GIS is one of the decision support system tools that help the forest manager or silviculturist to do better decision making. GIS help the forester to do planning and preparation of a block or compartment based on their objectives or targets. GIS has the capability to map, record data, planning and involve in special projects.

Construction of new forest road is one of the main issues that arise in forestry management. Many criteria aspects have to be considered before a new road is constructed. In this study, four criteria have been identified which is timber volume (m^3), slope (degree), ground condition and distance from the road that previously exists (m). Scoring model is being used as a weighting for each classes of criteria (Williams, 2000) in this study. ArcMap and ArcCatalog is the GIS software that has been selected to decide the best block that fulfills all criteria.

2. Methodology

2.1 Study area

State of Kelantan, Malaysia at the northern part of Peninsular Malaysia, in a northern-east direction, between latitude 5°00' N and 5°25' N and longitude 101°20' E and 102°05' E had been selected as the study area (Figure 1). Compartment 1 until compartment 16 has been selected as the demonstrative area (Figure 2). The terrain of the study area was classified as very steep slope (greater than 10°). The climate in the study area is a hot humid tropical climate. Temperature and rainfall has been categorized by three distinct features: uniform temperature, high humidity and heavy rainfall. The temperature rarely fell below 20.5°C nor rose beyond 36°C. The mean annual rainfall was seldom less than 2000 mm. The heaviest rainfall occurred during the November, December and January. Dry season was been marked from February until April.

<Figure 1.>

<Figure 2>

2.2 Identification and evaluation of criteria

The determination of criteria is very important as guidance for collecting data that is needed to help the effectiveness of decision making process. Four criteria have been identified: timber volume (m^3), slope (degree), ground condition and distance from the road that had been exist (m). All the selected criteria were classified. Table 1 through Table 4 shows the classification of the criteria.

<Table 1: The volume of the harvest block classes>

<Table 2: Criteria for evaluating slope>

<Table 3: Criteria for evaluating ground conditions>

<Table 4: Criteria for evaluating distance from existing secondary roads>

Next, each classification of criteria was given a score. The maximum score given was one hundred and the minimum was zero (Table 5). This evaluation was very important for the calculation process in ArcMap software to decide the best compartment to construct the new forest road.

<Table 5: Evaluation criteria for the harvest block selection>

2.3 Data collection

Data collection process is very important for data validation and integration. Data that was used in this study are described in Cabral, 2000. Table 6 shows the data for demonstration area (Block No.1-16).

<Table 6: Information of demonstration area>

2.4 System implementation

ArcMap and ArcCatalog software had been chosen as decision support tools to find the best block or compartment to construct new logging roads. Both ArcMap and ArcCatalog software are integrated. In ArcMap, information concerning the demonstration area will be stored in a database (Figures 3 and 4). Next, scores will be given for each data that has been stored (Figure 5).

<Figure 3>

<Figure 4>

<Figure 5>

The calculation of score value was done to get the result of this study using Raster Calculator function that exists in ArcMap. The formula used for calculation is:

Calculation = [distance2 - distance2] + [ground_con2 - ground_con2] + [slope5 – slope5] + [volume2 - volume2]

ArcCatalog has been used to save all the layer files from ArcMap. Combination of all layers will also be saved in ArcCatalog (Figure 5).

3. Results and discussion

Figure 6 shows the classes of volume of harvest for the blocks. The highest score, 60 shows the highest volume that can be harvested in a block. Meanwhile, 40 the lowest score showed the lowest volume that can be harvested. The highest volume that can be harvested in the demonstration area ranges from 40 m^3/ha to 50 m^3/ha whereas 20 m^3/ha to 30 m^3/ha is the lowest volume. Table 7 showed results of a selected demonstration area for the estimation of timber volume.

<Figure 6>

<Table 7: Attributes of volume for harvest block classes>

The second criteria that had been considered in this study are slope. The demonstration area has all classes of slope from 0^o until more than 45^o. From the illustration in Figure 7, Block Nos. 8, 9 and 10 has the lowest slope. Block Nos. 3, 4 and 16 have the highest slope. If the slope is high, the location is considered not suitable to construct new forest roads. Table 8 shows the attributes of slope for each block.

<Figure 7>

<Table 8: Attributes of slope>

The next criterion is the ground condition. The best ground condition is in block number 3, 4 and 16 (score = 100). The soil texture of these three blocks is sandy loam and fresh for soil moisture. The worst ground condition is in Block Nos.

8, 9 and 10 (score = 10) in which the soil texture is silty clay loam and the soil moisture is very wet. A good ground condition will make the construction of the road much better. Figure 8 shows the score of ground condition and Table 9 shows the attributes.

<Figure 8>

<Table 9: Attributes of ground condition>

The last criterion taken into consideration is the distance of the block from an existing forest road. Distance is considered because it affects the cost for construction of the road. Block No. 13, 14, 15 and 16 has the highest score because those blocks have existing forest roads. Block No. 7 has the highest potential to construct new forest roads. This is followed by Block No. 8, 10 and 12 (score = 80). The lowest score is in Block Nos. 1, 3, 6 and 9 (score = 20) where the distance is very high from the existing forest road. Scores of distance from existing forest roads are shown in Figure 9 and the attributes shown in Table 10.

<Figure 9>

<Table 10: Attributes of distance from existing forest road>

Figure 10 shows the result of this study which is the combination of all criteria (timber volume, slope, ground condition and distance from the road that previously existed) that had been considered. Block Nos. 13, 14, 15 and 16 have existing forest road. The block that has the highest total score is block number 9 and 11. Block Nos. 7 and 8 have total score equal to 250. This is followed by Block No. 5 (total score = 240), 10 (total score = 230), 6 (total score = 220), 4 (total score = 200), 3 (total score = 180) and 1 (total score = 160). The worst block to construct a new forest road is Block No. 2 (total score = 150).

<Figure 10>

4. Conclusion

GIS has a lot advantages in supporting the decision making process in sustainable forestry management especially for construction of new forest roads in minimal impact timber harvesting. The forester can achieve their objectives by using any combination layers in ArcMap and save the result using ArcCatalog for future reference and implementation.

References

Cabral, J. C. (2000). *GIS-Based Support System for Tactical Timber Harvest Planning: Design and Development.* Ph.D. Thesis, Universiti Putra Malaysia.

Sauter, V. (1997). *Decision Support Systems*. John Wiley & Sons, Inc., United States of America.

William, A. S. (2000). *An Introduction to Management Science, Quantitative Approaches to Decision Making*. South-Western College Publishing / ITP.

Table 1. The volume of the harvest block classes

Class	**Criteria**
I	>50m^3/ha
II	40m^3/ha – 50m^3/ha
III	30m^3/ha – 40m^3/ha
IV	20m^3/ha -30 m^3/ha
V	<20m^3/ha

Table 2. Criteria for evaluating slope

Slope Class	**Range (degree)**	**Description**
1	0^o – 15^o	**Level**
2	15^o – 25^o	**Gentle**
3	25^o – 35^o	**Moderate**
4	25^o – 45^o	**Steep**
5	>45^o	**Very Steep**

Table 3. Criteria for evaluating ground conditions

	1 **Good**	**2** **Moderate**	**3** **Poor**	**4** **Very Poor**
Sandy Moisture	Fresh (10-20%)	Moist (20-30%)	Wet (30-40%)	Very Wet (>40%)
Soil Texture	Sandy Loam	Sandy Clay Loam	Clay	Silty Clay Loam

Table 4. Criteria for evaluating distance from existing secondary roads

Class	**Distance from secondary roads (m)**
1	0 – 750
2	75 – 1500
3	1500 – 2250
4	2250 – 3000
5	>3000

Table 5. Evaluation criteria for the harvest block selection

Criteria	**Classification**	**Score**
Timber Volume	I	100
	II	80
	III	60
	IV	40
	V	20
Slope	0^o – 15^o	100
	15^o – 25^o	70
	25^o – 35^o	40
	25^o – 45^o	10
	>45^o	0
Ground Conditions	Good	100
	Moderate	70
	Poor	40
	Very poor	10
Distance from the existing road (m)	0 – 750	100
	75 – 1500	80
	1500 – 2250	60
	2250 – 3000	40
	>3000	20

Table 6. Information of demonstration area

Block	**Hectare**	**Volume (m^3)**	**Slope (degree)**	**Ground Condition**	**Access to Existing Road (m)**
1	303	9136	35 – 45	moderate	3160
2	280	10104	35 – 45	poor	2500
3	378	12572	>45	good	3350
4	390	11722	>45	good	2760
5	344	11356	15 – 25	moderate	3090
6	416	15563	15 – 25	moderate	3340
7	374	12692	25 – 35	moderate	2360
8	390	12345	0 – 15	very poor	1000
9	385	13157	0 – 15	very poor	1100
10	426	16057	0 – 15	very poor	2425
11	330	9274	25 – 35	moderate	1160
12	349	9651	15 – 25	moderate	50
13	340	9262	15 – 25	moderate	100
14	365	13265	25 – 35	moderate	180
15	411	15613	35 – 45	poor	190
16	342	14322	>45	good	50

Table 7. Attributes of volume for harvest block classes

Harvest block	**Volume/hectare (m^3/ha)**	**Class of volume**	**Score of volume**
1	30.15	3	60
2	36.09	3	60
3	33.26	3	60
4	30.06	3	60
5	33.01	3	60
6	33.01	3	60
7	26.54	4	40
8	33.74	3	60
9	30.51	3	60
10	29.45	4	40
11	21.77	4	40
12	41.7	2	80
13	39.01	3	60
14	42.78	2	80
15	37.99	3	60
16	41.88	2	80

Table 8. Attributes of slope

Harvest block	**Slope (^{o})**	**Class of slope**	**Description of slope**	**Score of slope**
1	35-45	4	Steep	10
2	35-45	4	Steep	10
3	>45	5	Very steep	0
4	>45	5	Very steep	0
5	15-25	2	Gentle	70
6	15-25	2	Gentle	70
7	25-35	3	Moderate	40
8	0-15	1	Level	100
9	0-15	1	Level	100
10	0-15	1	Level	100
11	25-35	3	Moderate	40
12	15-25	2	Gentle	70
13	15-25	2	Gentle	70
14	25-35	3	Moderate	40
15	35-45	4	Steep	10
16	>45	5	Very steep	0

Table 9. Attributes of ground condition

Harvest block	**Soil moisture**	**Soil texture**	**Description of ground condition**	**Class of ground condition**	**Score of ground condition**
1	Moist	Sandy clay loam	Moderate	2	70
2	Wet	Clay	Poor	3	40
3	Fresh	Sandy loam	Good	1	100
4	Fresh	Sandy loam	Good	1	100
5	Moist	Sandy clay loam	Moderate	2	70
6	Moist	Sandy clay loam	Moderate	2	70
7	Moist	Sandy clay loam	Moderate	2	70
8	Very wet	Silty clay loam	Very poor	4	10
9	Very wet	Silty clay loam	Very poor	4	10
10	Very wet	Silty clay loam	Very poor	4	10
11	Moist	Sandy clay loam	Moderate	2	70
12	Moist	Sandy clay loam	Moderate	2	70
13	Moist	Sandy clay loam	Moderate	2	70
14	Moist	Sandy clay loam	Moderate	2	70
15	Wet	Clay	Poor	3	40
16	fresh	Sandy loam	Good	1	100

Table 10. Attributes of distance from existing forest road

Harvest block	**Access from existing forest road (m)**	**Class of access**	**Score of access**
1	3160	5	20
2	2500	4	40
3	3350	5	20
4	2760	4	40
5	2360	4	40
6	3090	5	20
7	50	1	100
8	1000	2	80
9	3340	5	20
10	1160	2	80
11	2425	4	40
12	1100	2	80
13	100	1	100
14	180	1	100
15	190	1	100
16	50	1	100

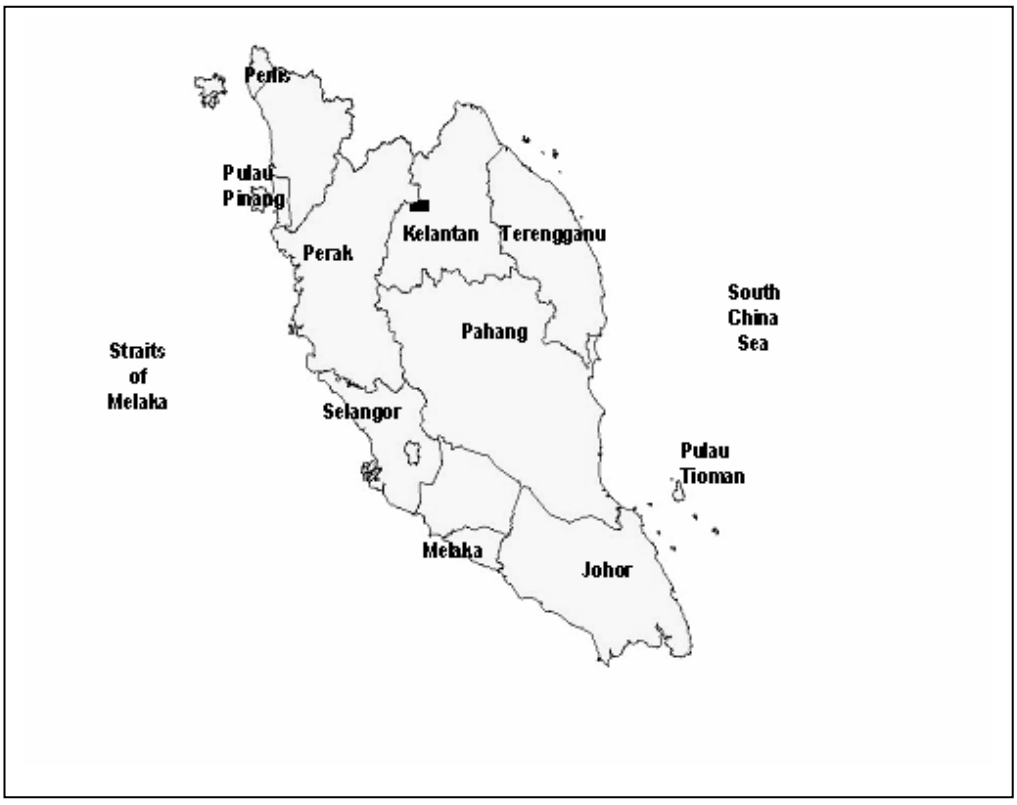


Figure 1. Study area and location

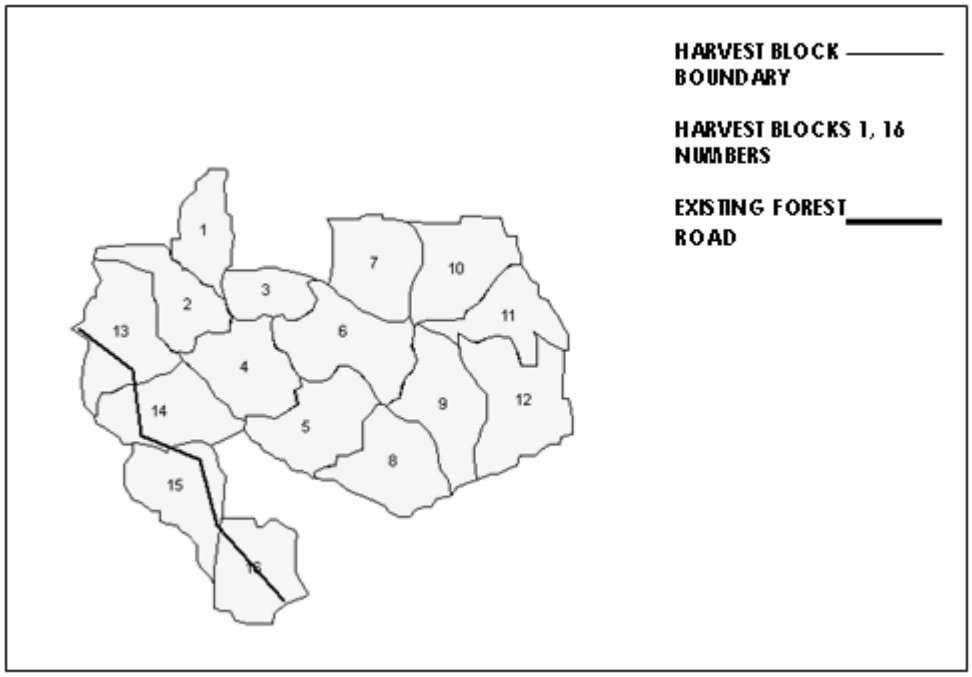


Figure 2. Study and demonstration area

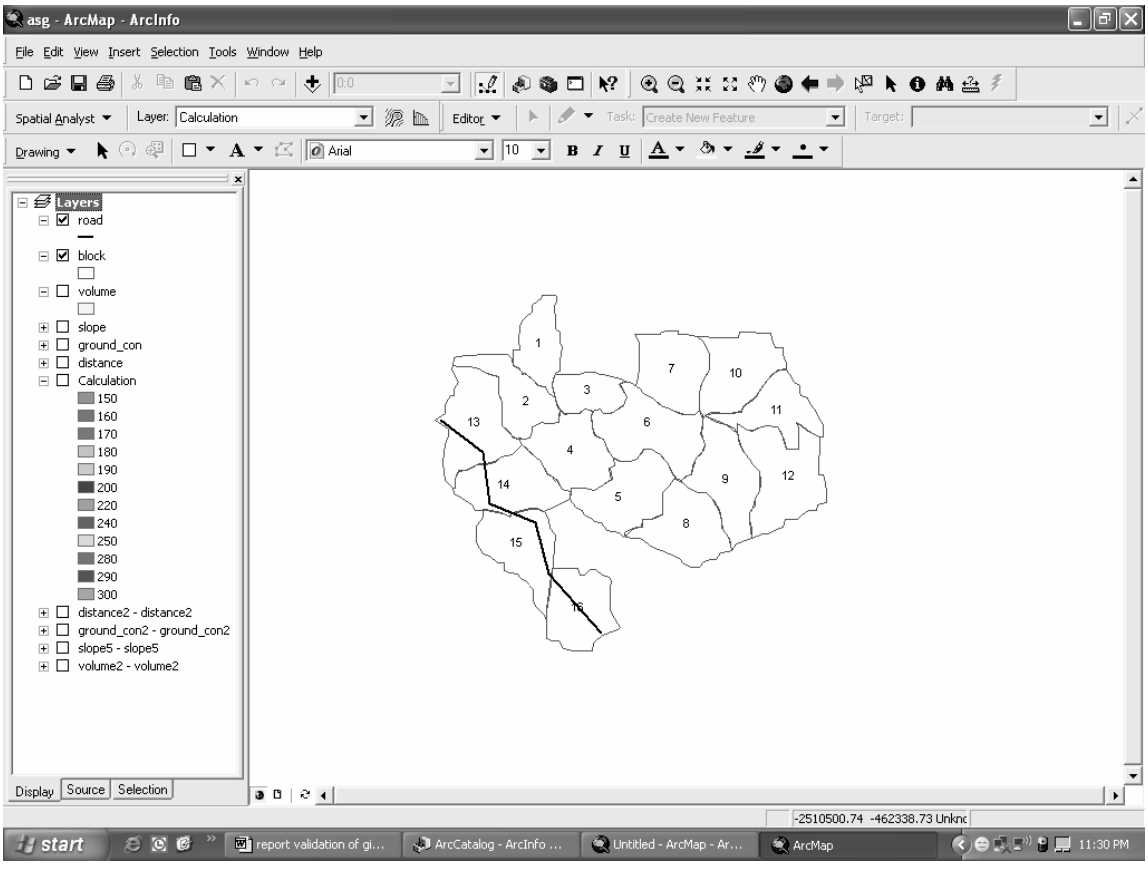
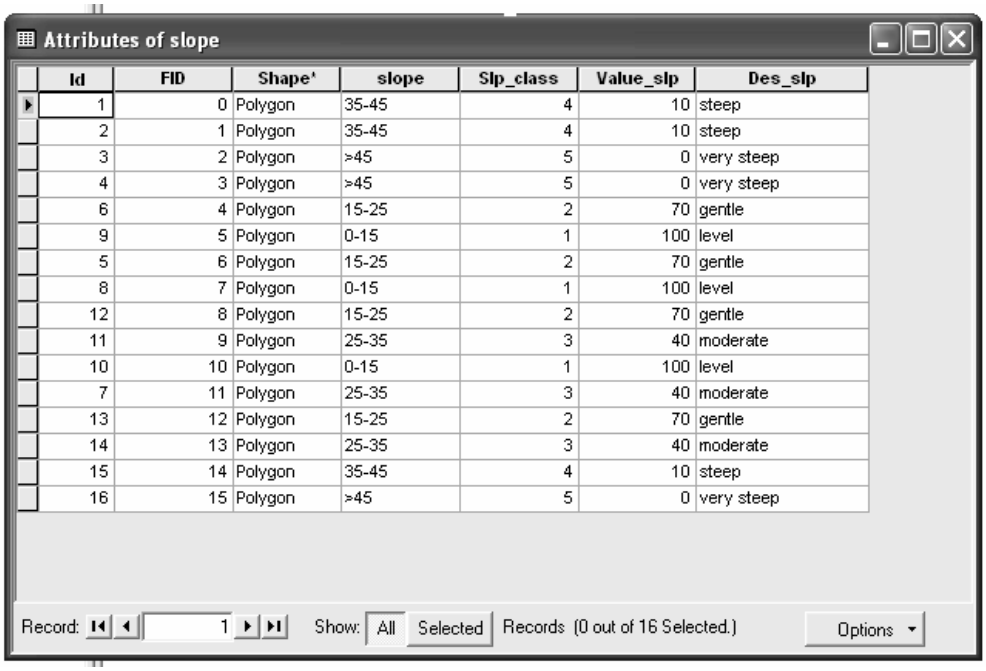


Figure 3. Interface of ArcMap



Attributes of slope

Id	FID	Shape*	slope	Slp_class	Value_slp	Des_slp
1	0	Polygon	35-45	4	10	steep
2	1	Polygon	35-45	4	10	steep
3	2	Polygon	>45	5	0	very steep
4	3	Polygon	>45	5	0	very steep
6	4	Polygon	15-25	2	70	gentle
9	5	Polygon	0-15	1	100	level
5	6	Polygon	15-25	2	70	gentle
8	7	Polygon	0-15	1	100	level
12	8	Polygon	15-25	2	70	gentle
11	9	Polygon	25-35	3	40	moderate
10	10	Polygon	0-15	1	100	level
7	11	Polygon	25-35	3	40	moderate
13	12	Polygon	15-25	2	70	gentle
14	13	Polygon	25-35	3	40	moderate
15	14	Polygon	35-45	4	10	steep
16	15	Polygon	>45	5	0	very steep

Record: 1 Show: All Selected Records (0 out of 16 Selected.) Options

Figure 4. Example of database for slope

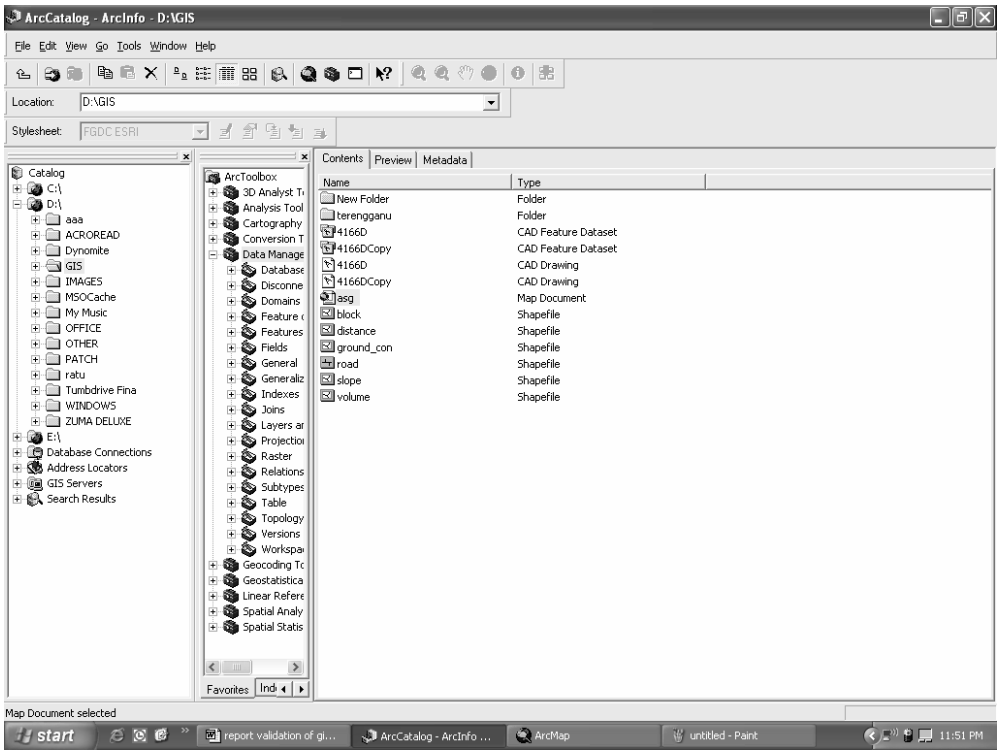


Figure 5. Interface of ArcCatalog

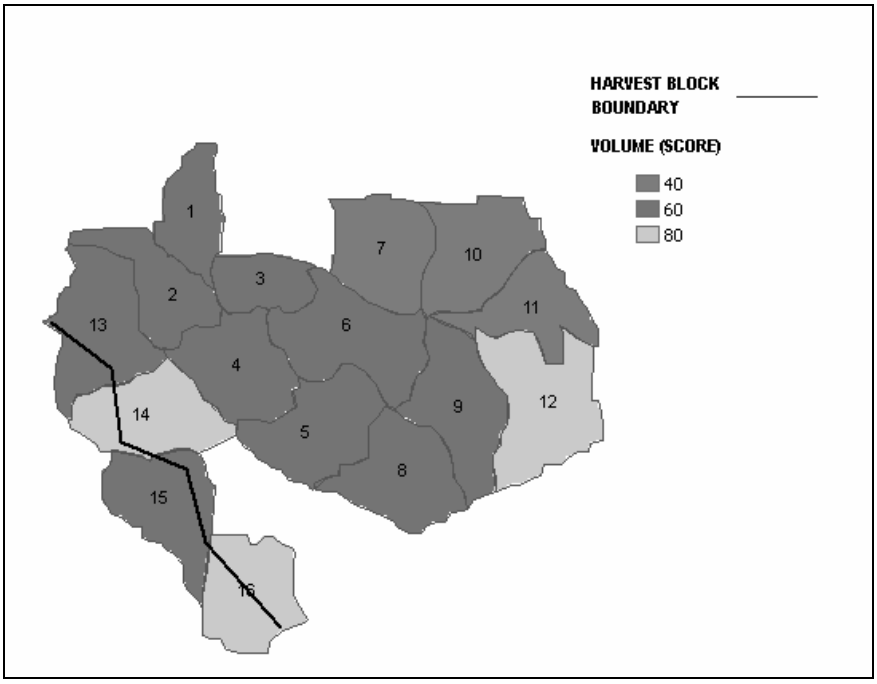


Figure 6. Score of volume for harvest block classes

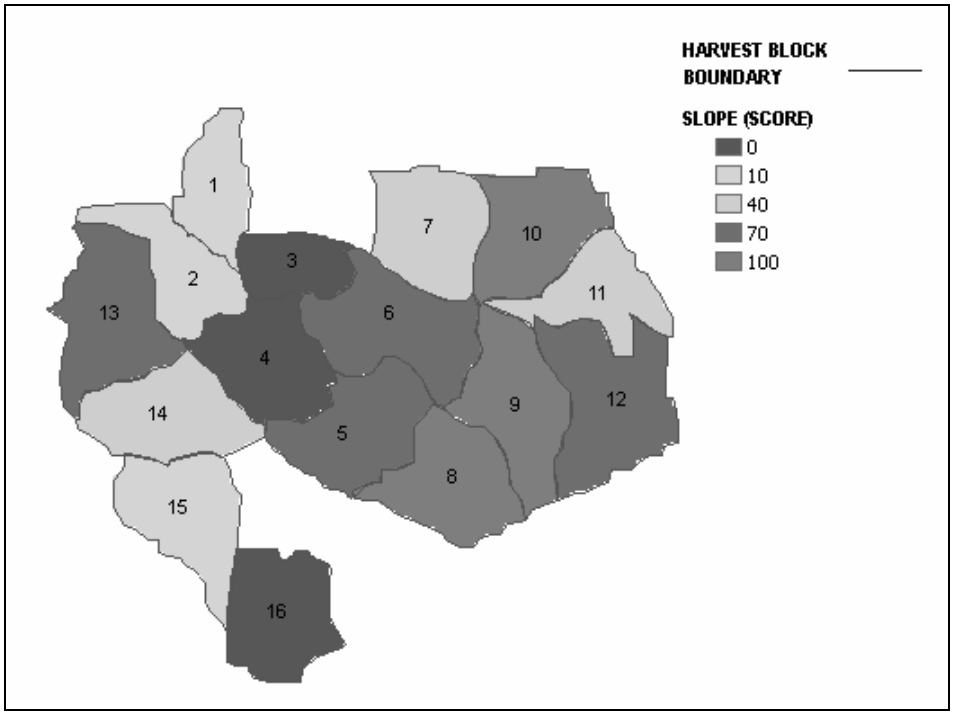


Figure 7. Score of slope

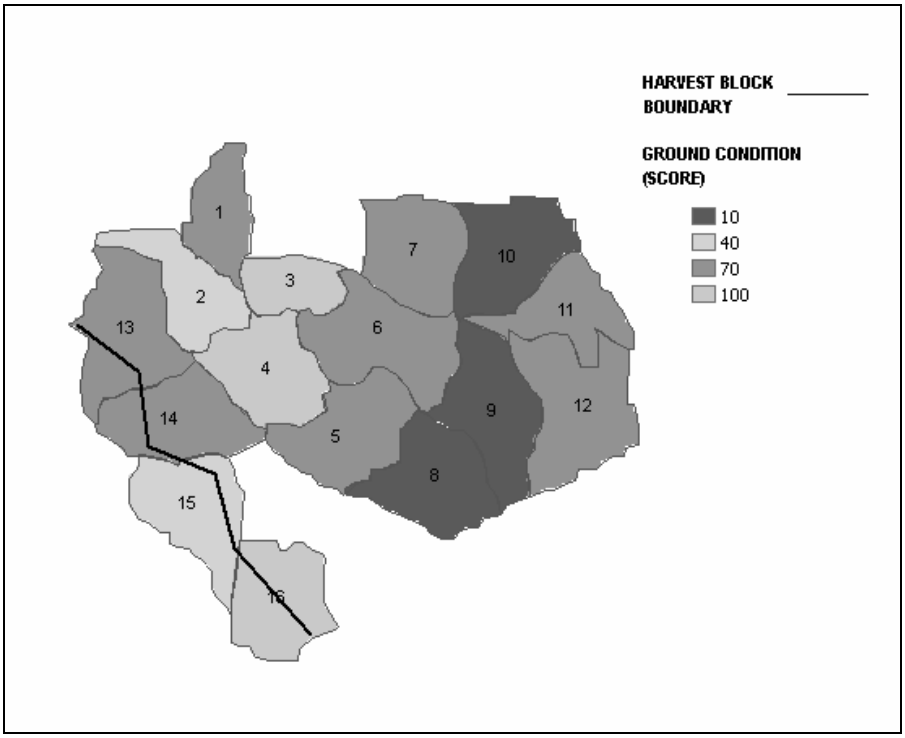


Figure 8. Score of ground condition

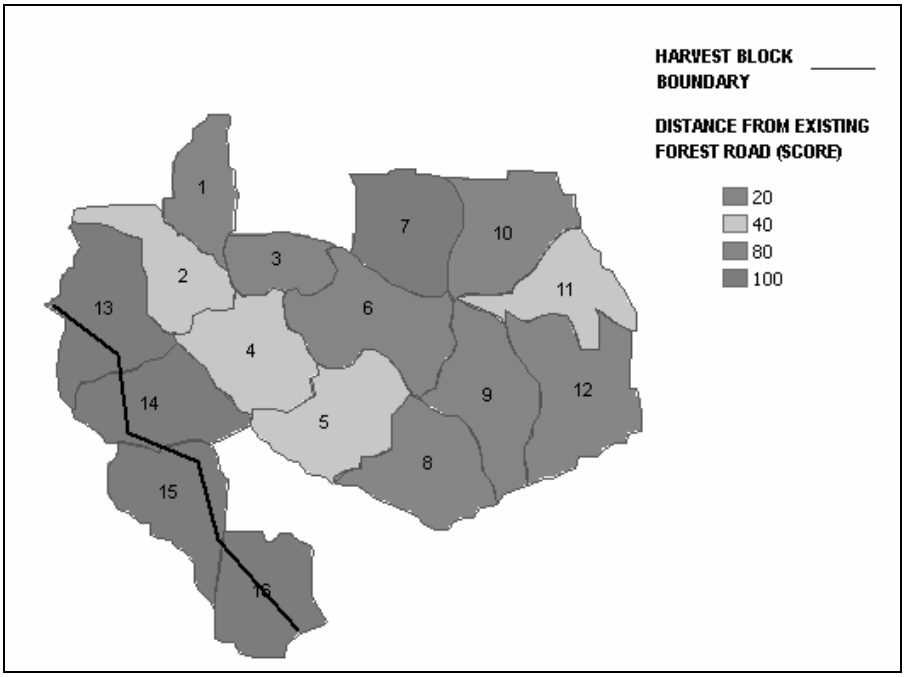


Figure 9. Score of distance from existing forest road

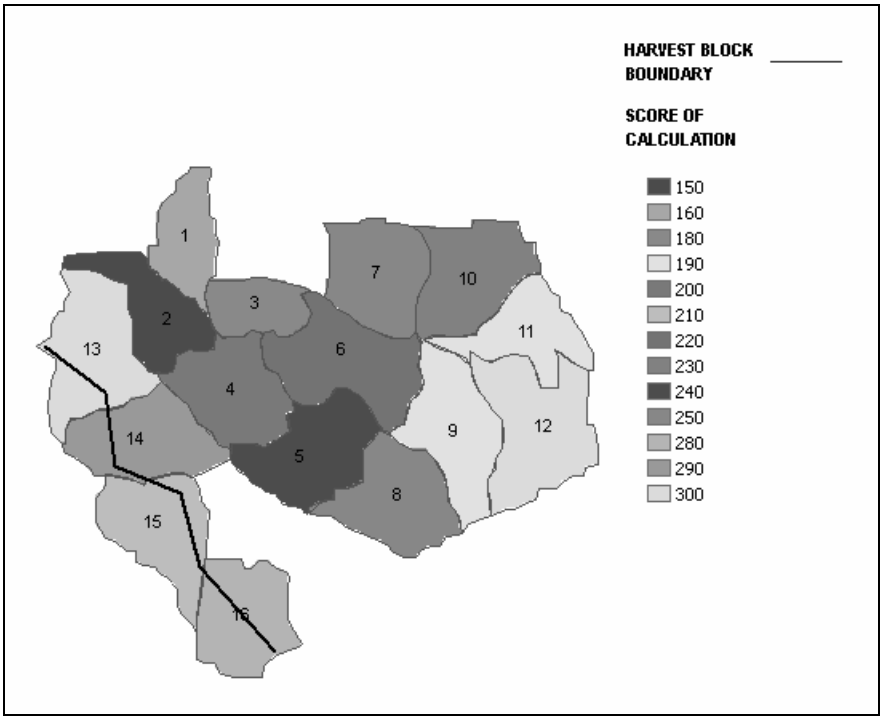


Figure 10. Calculation of results using ArcMap