

## Developing Priorities and Ranking for Suitable Forest Road Allocation using Analytic Hierarchy Process (AHP) in Peninsular Malaysia

(Membangunkan Keutamaan dan Taraf untuk Perancangan Jalan Hutan Berasaskan Proses Hierarki Analitik (AHP) di Semenanjung Malaysia)

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### ABSTRACT

*In hilly forest area, aligning forest roads is the key towards an effective and sustainable forest management. Constraints in forest road planning are mainly concern with environmental factors and topographical conditions. Selecting the criteria for planning forest road and setting the priorities, ranking them for environmental sustainability and reduce cost in road construction is important. Different criteria are required at different forest area since the quantifiable relationship between cause and effect to meet the goal are not comprehensively prioritized. In order to solve the problem, the relative importance factor from multi criteria basis, namely Analytic Hierarchy Process (AHP) was applied. Therefore, the objective of this study was to develop priorities and rank a selected criterion for planning forest road in hilly forest area using AHP approach. Four criteria had been identified to meet the goal of suitable forest road allocation namely slope, river crossing, elevation and existing forest road. The suitable criteria selected were sorted with weight in ranking order to minimize the impact of timber harvesting. Our results showed that the priorities and ranking were as follows; slope ( $w = 0.558$ ), followed by river crossing ( $w = 0.303$ ), elevation ( $w = 0.095$ ) and lastly existing forest road ( $w = 0.044$ ), respectively. Therefore, the relative preference factor developed in this study can be used by the Forestry Department for formulating suitable forest road allocation in hilly area simultaneously to be integrated with geographic information system technology.*

*Keywords: Analytical hierarchy process; forest road planning; harvest planning; priorities criteria*

### ABSTRAK

*Di kawasan hutan berbukit, penjajaran jalan hutan adalah faktor utama untuk mencapai pengurusan hutan yang berkesan. Masalah di dalam perancangan jalan hutan selalunya berkait dengan faktor alam sekitar dan keadaan topografi. Membuat pilihan bagi beberapa kriteria tertentu untuk mengurangkan kos perancangan adalah perlu. Kriteria yang berbeza diperlukan untuk kawasan hutan yang berlainan kerana hubungannya dikaitkan dengan sebab dan akibat tidak selalunya diberi keutamaan secara komprehensif untuk mencapai objektif pengurusan. Maka untuk menyelesaikan masalah ini, faktor-faktor relatif yang penting telah dinilai berasaskan kriteria iaitu Proses Hierarki Analitik (AHP). Objektif kajian ini ialah untuk membangunkan keutamaan dan taraf beberapa kriteria yang telah dipilih untuk perancangan jalan hutan di kawasan berbukit menggunakan pendekatan AHP. Empat kriteria telah dikenal pasti untuk mencapai objektif penjajaran jalan hutan yang bersesuaian iaitu cerun, lintasan sungai, ketinggian dan jalan hutan yang sedia ada. Kriteria yang bersesuaian telah disusun mengikut berat keutamaan dalam susunan yang teratur untuk meminimumkan kesan penuaian hutan. Daripada keputusan, keutamaan/pemberat dan susunan kriteria adalah seperti berikut: cerun ( $w = 0.558$ ), diikuti oleh sungai ( $w = 0.303$ ), ketinggian ( $w = 0.095$ ) dan seterusnya jalan hutan yang sedia ada ( $w = 0.044$ ). Faktor relatif yang telah dibangunkan dalam kajian ini boleh diguna pakai oleh Jabatan Perhutanan untuk membuat perancangan jalan hutan yang bersesuaian di kawasan hutan bukit seterusnya diguna pakai bersama dengan teknologi sistem maklumat geografi.*

*Kata kunci: Kriteria keutamaan; perancangan jalan hutan; perancangan penuaian; proses hierarki analitik*

### INTRODUCTION

Forest roads are essential element which need proper planning in order to ensure that the transportation of timber is economical. Road structure and network reflect the cost of road construction and profitability of the harvest operation. Allocating an access road in harvesting area is highly desirable by considering several factors such as environmental and topographical

conditions. In Peninsular Malaysia road plan is developed by engineers using contour and thematic maps. In the case of forest roads several criteria may need to be evaluated to make the best decision. It was suggested that forest manager need to design and plan as many alternative road network to meet the suitable criteria for environmental sustainability and less financial cost. According to Abdi et al. (2009), Johnson and Madison

(1994), Slotterback (2008) and Trussat et al. (2002) numerous preference factors or mitigation measure to prevent, reduce or compensate for the impact need to be judged and predicted in advance for suitable forest road allocation. Certainly, different preference factors were required at different forest areas since the quantifiable relationship between cause and effect to meet the goal was not comprehensively prioritized. To solve the problem of prioritizing the relative importance factor the Analytic Hierarchy Process (AHP) was used in this study. The AHP has the potential to provide a consistent approach in multiple criteria deciding making.

According to Triantaphyllaou and Mann (1995), AHP method solve the complex decision making with pairwise comparison form a multilevel hierarchical structure through a set of pairwise comparisons to solve complex problems. Score weights were derived to meet the goal and sorted in ranking order. Nowadays, many forest road researches are carried out by using AHP method to solve forest road problems for the best single or alternative road networks with GIS integration. Each criterion was easily managed, combined and displayed with the integration of GIS technology as a map layer (Store & Kangas 2002). For example, Dahlin and Fredriksson (1995) used soil, moisture and elevation factors, Naghdi et al. (2008) used slope, altitude, aspect and soil texture factors and Rafiei et al. (2009) used slope, soil, geology, aspect, altitude and standing volume factors as the criteria set for the best suitability road network designs and plans. Meanwhile in Peninsular Malaysia, some studies have been done by combining the selected criterion layer with GIS application; however, score weight was derived according to the importance and ranking without a systematic prioritization using AHP method. For example, Kamaruzaman (2008) used timber volume, slope, ground condition and distance to existing road factors which those factors were combined without score weight derivation. Mohd Hasmadi and Kamaruzaman (2009) assigned the score weight of slope and distance to existing road factors based on personal experience and discussion with the forestry officer.

Indeed, the AHP method helps a decision maker to prioritize the goal and formulate a set of criteria. The method also assists systematically and logically in preparing evidence toward the selection of best suitable road network alternative from the multi-criteria analysis (Shiba 1995). Yet, AHP has not been widely used for forest road planning in Peninsular Malaysia. Therefore, the objective of this study was to develop and evaluate the relative preference factor using AHP method for formulation of suitable forest road allocation in Peninsular Malaysia.

## MATERIALS AND METHODS

### STUDY AREA AND DATA COLLECTION

The formulation of suitable forest road allocation was carried out at the Ulu Jelai Forest Reserve (FR), Kuala

Lipis, Pahang, Peninsular Malaysia. Four compartments were selected as a study area namely compartment 381, 382, 472, 473 and 484. These compartments range from latitude 101° 39' 31.735"E to 101° 36' 38.86"E and from longitude 4° 27' 51.85"N to 4° 18' 56.79" N. The forest area is composed of mixed virgin hill forest, high in species diversity with predominance of *Shorea* species such as Meranti seraya (*Shorea curtisii*) and Meranti rambai daun (*Shorea acuminat*). The study compartments were characterised with elevation between 140 m and 1,180 m. There was approximately 30 km of existing road network in the study compartment which was constructed in 2003 and the secondary road was continuously maintained for future timber harvesting operation. Likewise, the feeder roads were maintained for the purpose of post-harvest inventory and silviculture treatment of the regenerated forest. The location of the study area is presented in Figure 1.

Selection of appropriate criteria for suitable forest road allocation had been done by the decision maker. The group consisted of professional foresters, forest manager, forest engineer and forest concessionaire of forest operation at Ulu Jelai FR. The decision making was guided by the forest road guidelines and scientific literature. Suitability forest road allocation was encouraged to mitigate environmental constraint and fit the topography with minimum alterations of cut and fill works to the natural features (Judibal 2000; Tan 1999). These mitigating measures would prevent slope failure and sedimentation in streams. There was recommendation to avoid stream crossing if possible (FDPM 1999; Mohd Hasmadi 2005). From several factors, only four criteria were identified to be used as relative factor to achieve suitable forest road allocation: slope, elevation, river and existing road.

### ANALYTICAL HIERARCHY PROCESS (AHP)

Generally, four steps were involved in formulating the relative preference factor for suitable forest road allocation (Coutler 2004; Coutler et al. 2006; Islam & Abdullah 2006). Development of the formula consisted of structuring the problem in a hierarchy: completion of pairwise comparison between attributes to determine decision maker preferences, scaling of attributes and ranking of alternatives.

Initially, AHP gradually broke down the criteria or objectives with possible sub-objectives with respect to the goal (Malczewski 1999; Roh et al. 2008; Saaty 1980). A sub-objective presented the attribute of criterion and stored in map layer database (Malczewski 1999). Figure 2 shows the hierarchy of criterion for suitable forest road allocation with respect to the goal.

These formulations divided the suitable forest road allocation into four factors to be considered; suitability associated with slope, river, elevation and existing road. The selected factors were then judged by several alternatives and the hierarchy structure of the goal was compared with the objectives and alternatives.

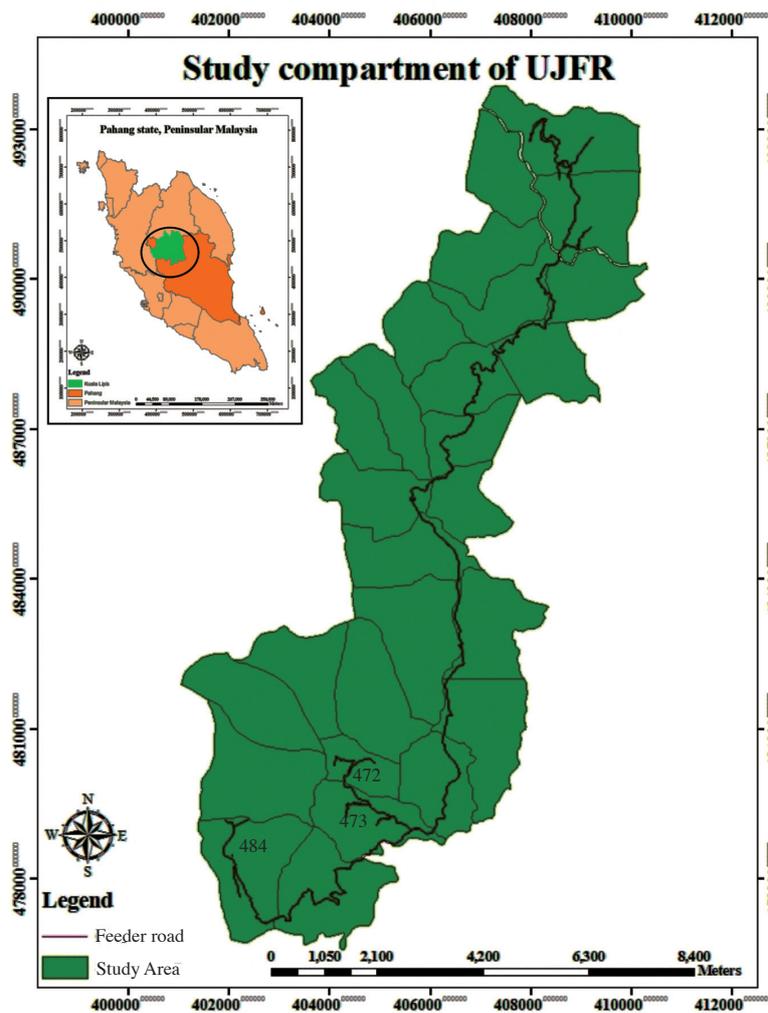


FIGURE 1. The location of study compartment at Ulu Jelai FR, Peninsular Malaysia

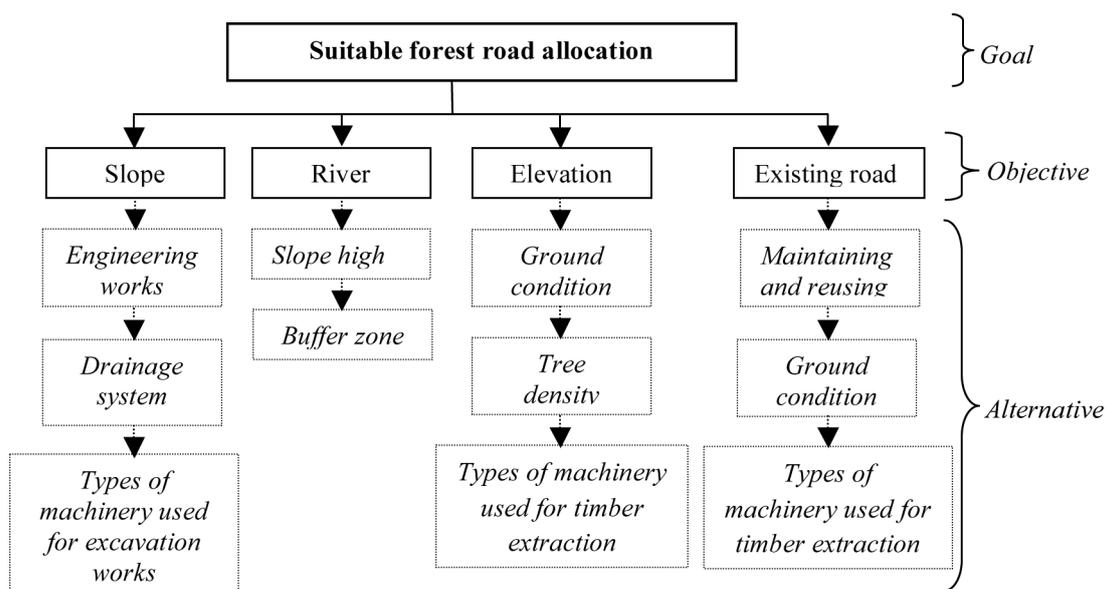


FIGURE 2. Hierarchy of the formulation structure for suitable forest road allocation

Secondly, the selected criteria identified as qualitative data were converted into quantitative data for the purpose of deriving the eigenvector or cost weight ( $w_i$ ) to achieve the suitability forest road allocation through pairwise comparison. The pairwise matrix was described as;

$$A = \begin{pmatrix} & a_1 & a_2 & \dots & a_n \\ a_1 & a_{11} & a_{12} & \dots & a_{1n} \\ a_2 & a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_n & a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix}$$

where  $a_{ij} = w_i / w_j$  (for  $i, j = 1, 2, \dots, n$ ) represents the strength of importance of the factor (criterion/alternative). As described  $a_i$  was preferably important than  $a_j$  with respect to the objective. Conversely, the reciprocal value was allocated for the comparison of those criteria such  $a_{ji} = (1/a_{ij}) * w_j$ , where  $i = 1, 2, \dots, n$  were the priority weights (to be determined) of the factors. For example, criterion A was judged more moderately important than criterion B and the scale was assigned as 3; certainly, criterion B was 1/3 times as important as criterion A.

Qualitative data was determined by the decision makers through verbal judgements with preference score by Saaty (1990) as a reference (Table 1).

In order to compare the criteria of objectives within the second level of hierarchy, the following questions were asked to the decision maker to get the quantitative scale for the selected factors.

How important was slope as compared to river in allocating the suitable forest road network? How important was slope as compared to elevation in allocating the suitable forest road network? How important was slope as compared to existing road in allocating the suitable forest road network? How important was river as compared to elevation in allocating the suitable forest road network? How important was river as compared to existing road in allocating the suitable forest road network? How important was elevation as compared to existing road in allocating the suitable forest road network?

Later, the pairwise comparison matrix were constructed in response to those questions and presented in Table 2. The matrix of scale given by decision maker was normalised to sum to one to determine the weight for the relative important of each criterion for suitable forest road allocation. The pairwise comparison matrix was solved by:

$$w_i = \frac{1}{\lambda_{max}} \sum_{j=1}^n a_{ij} w_j \quad i = 1, 2, \dots, n$$

where  $\lambda_{max}$  was the largest eigenvalue of the pairwise comparison matrix A. The main diagonal was normalized and always equal to unity such that

$$\sum_{i=1}^n w_i = 1.$$

TABLE 1. The scale used in the AHP to convert qualitative data of verbal response to numeric values of quantitative data as adapted from Saaty (1977)

Intensity of importance	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Moderately importance	Experience and judgement slightly favour one activity over another
5	Strongly important	Experience and judgements strongly favour one activity over another
7	Very strongly important	An activity is favoured very strongly over another, dominance is demonstrated in practice
9	Absolutely important	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above nonzero numbers	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 $i$ .	

TABLE 2. Pairwise comparison for the objective with respect to the goal

Sub-objective	Slope	River	Elevation	Existing road
Slope	1	Moderate important	Strong important	Extreme important
River	1/3	1	Strong important	Very strong important
Elevation	1/5	1/5	1	Moderate important
Existing road	1/7	1/9	1/3	1

The consistency of judgement was then verified by consistency ratio (CR). Consistency ratio was conducted by five steps below;

1. Pairwise comparison matrix was multiplied by relative priorities
2. Weighted sum vector elements were divided by associated relative priorities
3. Average (denoted  $\lambda_{\max}$ ) of the value from step 2 was computed
4. Consistency index (CI) was computed by

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

5. Consistency ratio (CR) was computed by

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

The random index value can change between different numbers of criterion ( $n$ ). Based on 500 simulation runs by Saaty (1980), number of criterion from 3 to 11 have been experimented. The results confirmed that number of criteria 3 received 0.58 of random index and for the next number of criteria 4, 5, 6, 7, 8, 9, 10 and 11, the random indexes are 0.90, 1.12, 1.24, 1.32, 1.41, 1.45, 1.49 and 1.51, respectively. By having CR value below 0.1, the pairwise comparison is acceptable and score weight can be useful in decision making (Saaty 1977).

Last but not least, the overall score derived were ranked by their importance with respect to the suitable forest road allocation. The overall score ( $S$ ) with respect to goal was the sum weight of objective ( $x_1, x_2, \dots, x_3$ ) and the corresponding attribute value ( $y_1, y_2, \dots, y_3$ ) to be  $S = x_1y_1 + x_2y_2 + x_3y_3$ . The factors with a higher total weight derived were the more suitable factors to achieve the main objective.

## RESULTS AND DISCUSSION

Matrices for pairwise comparison of the hierarchy structure for suitable forest road allocation were completed using decision maker judgement and scientific literature found in previous study of tropical forest hill and forest road guidelines by Forestry Department. The multi-objectives for suitable forest road allocation were described as minimising the excavation works in slope area, minimising stream crossing, optimising the timber production within the eligible harvestable block and minimising the distance to existing forest road particularly the secondary road which

are periodically maintained for the purpose of future timber harvest operation. Hence, according to multi-objectives judgement, slope was moderately preferred over river, strongly preferred over elevation and extremely preferred over existing road. River was strongly preferred over elevation and very strongly preferred over existing road, while elevation was moderately preferred over existing road. The qualitative judgement had been converted to quantitative scale in order to construct the weight score and subsequently sorting the criterion in a ranking order to meet the goal of suitable forest road allocation. The consistency ratio derived from the pairwise comparison showed the judgement was acceptable below the 0.1 value.

Table 3 shows that slopes have had a high weight score with 0.558 and it was the main factor to be considered by forest manager and forest engineer in forest road planning and design. Study by Samani et al. (2010) for forest road planning in mountainous area showed that slope was one of the main factors as well to be considered among the four factors listed.

To have a minimum excavation works in slope area, several factors were formulated. It was attributed to consideration over the topographical features and geographical condition for engineering work to comply with the guidelines and specifications by forestry department (FDPM 1999, 2010). In addition types of machinery used such as wide grader or excavator blade to keep the road width within 5 m (Wan Mohd & Moh Paiz 2003) was also considered. A drainage system facilities to avoid excessive water flow from the upper slope and damaging the road segment particularly at cut and fill slope area which will eliminate the stagnant water surface and subsequently fasten the water evaporation process or road surface (Mohd Hasmadi et al. 2008) was also considered. The preferences given to the attributes in the formulation of the minimum excavation works with respect to the goal are presented in Table 4. It was the engineering work as the main factor to be considered in allocating the forest road network at slope area that have had high weight score with 65% which was moderately important over drainage system (28%) and very strongly important over machinery used for excavation works (7%).

The second factor considered in allocating the suitable forest road network was river (0.303). This criterion was selected based on the Forest Department guideline in order to protect the river from sedimentation occurrence and to keep the water quality in good condition for water supply used by local residents and wild life. The minimum stream

TABLE 3. The pairwise comparison matrix for the objective (second level of hierarchy) with respect to the goal (CR = 0.042)

Sub-objective	Slope	River	Elevation	Existing road	Weight
Slope	1	3	5	7	0.558
River	1/3	1	5	9	0.303
Elevation	1/5	1/5	1	3	0.095
Existing road	1/7	1/9	1/3	1	0.044

TABLE 4. The pairwise comparison matrix for the alternative (third level of hierarchy) with respect to the 'slope' (CR = 0.06)

Alternative	Engineering work	Drainage system	Machineries used	Weight
Engineering work	1	3	7	0.649
Drainage system	1/3	1	6	0.279
Machineries used	1/7	1/6	1	0.072

crossing for suitable forest road allocation was determined by buffer zone and slope high. The buffer zone was judged as moderately important over slope high condition. It can be described as at high slope condition, cut and fill slope failure frequently occurred and more attention need to be taken during the planning stages for suitable forest road allocation. Nevertheless, the width of buffer zone was one of the alternative practices to eliminate the soil erosion from entering the river. Thus, buffer zone had been 75% favoured for minimizing the stream crossing over 25% for slope high in allocating the suitable forest road as shown in Table 5.

From the pairwise comparison matrix with respect to the goal, elevation was the third factor to be considered with 9.5% had been addressed for suitable forest road allocation. Before an area was permitted to be harvested, an eligible harvest block should be decided in advance by area demarcation process. Forestry department has outlined several characteristics of demarcation limit for timber harvesting operation concerning the fragile ground condition area towards a realization of SFM practices and environmentally acceptable timber harvesting. Besides that, consideration on the type of machinery for timber extraction had also been taken into account for its accessibility to the harvesting site and reachability to the log to be extracted. According to Forest Harvest Plan 2006 – 2015 of Pahang state, the topographical features and geographical condition below 750 m generally consists of slope of 20° or less was suitable for forest harvest operation. Meanwhile, Muziol (1999) stated that timber harvesting operation can occur below the elevation of 1,000 m which was within the production forest area. Whether the tree

density was abundant at the elevation above the 1,000 m, timber harvesting operation was not permitted since this area had been gazetted as a protection forest. Therefore, forest road should be aligned at the elevation below 1,000 m as outlined by forestry department. Henceforth, decision maker had attributed the elevation with ground condition, types of machinery to be used for timber extraction and tree density. Table 6 shows the weight derived from the AHP formulation and ground condition was the main factor influencing the elevation criterion in achieving the suitable forest road allocation with 57% had been assigned. Meanwhile, the machinery for timber extraction was the second criterion (37%) and last but not least important criterion with respect to the elevation was the tree density (6%). Figure 3 illustrates the topographical features and ground condition of the study compartment at elevation above 750 m.

The decision made on multi criteria of suitable forest road allocation had identified existing road as the fourth criterion to be considered with 4.4%. The existing road served as a junction connecting the feeder road segment for the access to the adjacent compartment for future timber harvesting operation in the eligible harvest block. Minimising the distance of existing road network to the eligible harvest block will lessen the cost (Holmes et al. 2002) and minimum impact to the residual forest (Abdul Rahim et al. 2009; Holmes et al. 2002). The formulation of existing road with respect to the goal had been judged with three attributes: condition of the existing road to serve as a connecting junction with various topographical features and geographical condition, maintaining and reusing the

TABLE 5. The pairwise comparison matrix for the alternative (third level of hierarchy) with respect to the 'river' (CR = 0.000)

Alternative	Buffer zone	Slope high	Weight
Buffer zone	1	3	0.75
Slope high	1/3	1	0.25

TABLE 6. The pairwise comparison matrix for the alternative (third level of hierarchy) with respect to the 'elevation' (CR = 0.01)

Alternative	Ground condition	Machineries used	Tree density	Weight
Ground condition	1	7	9	0.570
Machineries used	1/7	1	7	0.370
Tree density	1/9	1/7	1	0.060



FIGURE 3. Poor ground condition with rock gradient and sandy soil which was caused by the cut and fill slope failure at forest road side and timber extraction was difficult to be conducted in this situation-elevation is 800 m. (Picture (a) and (b) were taken at compartment 381, while picture (c) was taken at compartment 484)

TABLE 7. The pairwise comparison matrix for the alternative (third level of hierarchy) with respect to the 'existing forest road' (CR = 0.06)

Alternative	Ground condition	Machineries used	Maintaining and reusing	Weight
Ground condition	1	5	7	0.731
Machineries used	1/5	1	3	0.188
Maintaining and reusing	1/7	1/3	1	0.081

existing road if appropriate to be used and the decision on the machinery used were suitable to pass the existing road for timber extraction purposes. Consequently, the relative preference factors from the verbal judgement among the decision maker were derived as ground condition was strongly important over types of machinery used, very strongly important over maintain and reusing the existing road and types of machinery used for timber extraction was moderately important over maintaining and reusing the existing road. The matrices presented in Table 7 and ground condition were identified as the main criterion to minimise the distance of planned road from the existing one for suitable forest road allocation with 0.731 weight assigned. This is followed by type of machinery used in extraction process (0.188). Maintaining and reusing the existing road was another alternative to minimising the distance with weightage score 0.081. The summary of the results of the relative preferences for each criterion with attributes are shown in Figure 4.

#### CONCLUSION

Several options can be listed to minimize the impact of timber harvesting operation for sustainable forest management practices. A multi criteria of mitigation measure related to suitable forest road allocation was designed in the context of Ulu Jelai Forest Reserve. Recommendation of the best alternatives as listed by decision maker which coupled with scientific literature with respect to the objective has been recommended for application in the suitable forest road allocation as the consistency ratio is below 0.1 values. Accordingly, the matrices of pairwise comparison indicated that slope ( $w = 0.558$ ) was the main factor for a suitable forest road allocation. This was followed by river

crossing ( $w = 0.303$ ), elevation ( $w = 0.095$ ) and last was the distance from existing road ( $w = 0.044$ ). The analytic hierarchy process has the potential for prioritizing and ranking criteria for forest road planning where a set of data must rely in part on professional judgement. AHP provides decision makers with a structured means of incorporating both scientific data and professional judgements. On the other hand, the overall score for each criterion can be used as a measure of the relative worth of a given criterion (in relation to the goal). The flexibility provided by AHP requires decision makers to make decisions concerning a particular situation and therefore, it is necessary for the decision maker to have a clear understanding of the consequences of these decisions.

#### REFERENCES

- Abdi, E., Majnounian, B., Darvishefat, A., Mashayekhi, Z. & Session, J. 2009. A GIS-MCE based model for forest road planning. *Journal of Forest Science* 55(4): 171-176.
- Abdul Rahim, A.S., Mohd Shawahid, O. & Zariyawati, M.A. 2009. A comparison analysis of logging cost between conventional and reduced impact logging practices. *International Journal of Economic and Management* 3(3): 354-366.
- Coutler, E.D. 2004. Setting forest road maintenance and upgrade priorities based on environmental factor and expert judgement. Ph.D (Thesis), Oregon State University, United States, 218 p. (Unpublished).
- Coutler, E.D., Session, J. & Wing, M.G. 2006. Scheduling forest road maintenance using the analytical hierarchy process and heuristic. *Silva Fennica* 40(1): 143-160.
- Dahlin, B. & Fredriksson, J. 1995. Computer-assisted forest road planning- A proposed interactive model with special emphasis on private forest land. *International Journal of Forest Engineering* 6(2): 35-39.
- Forestry Department Peninsular Malaysia (FDPM). 1999. *Spesifikasi Jalan Hutan (Jalan Tuju dan Lorong Penarik)*

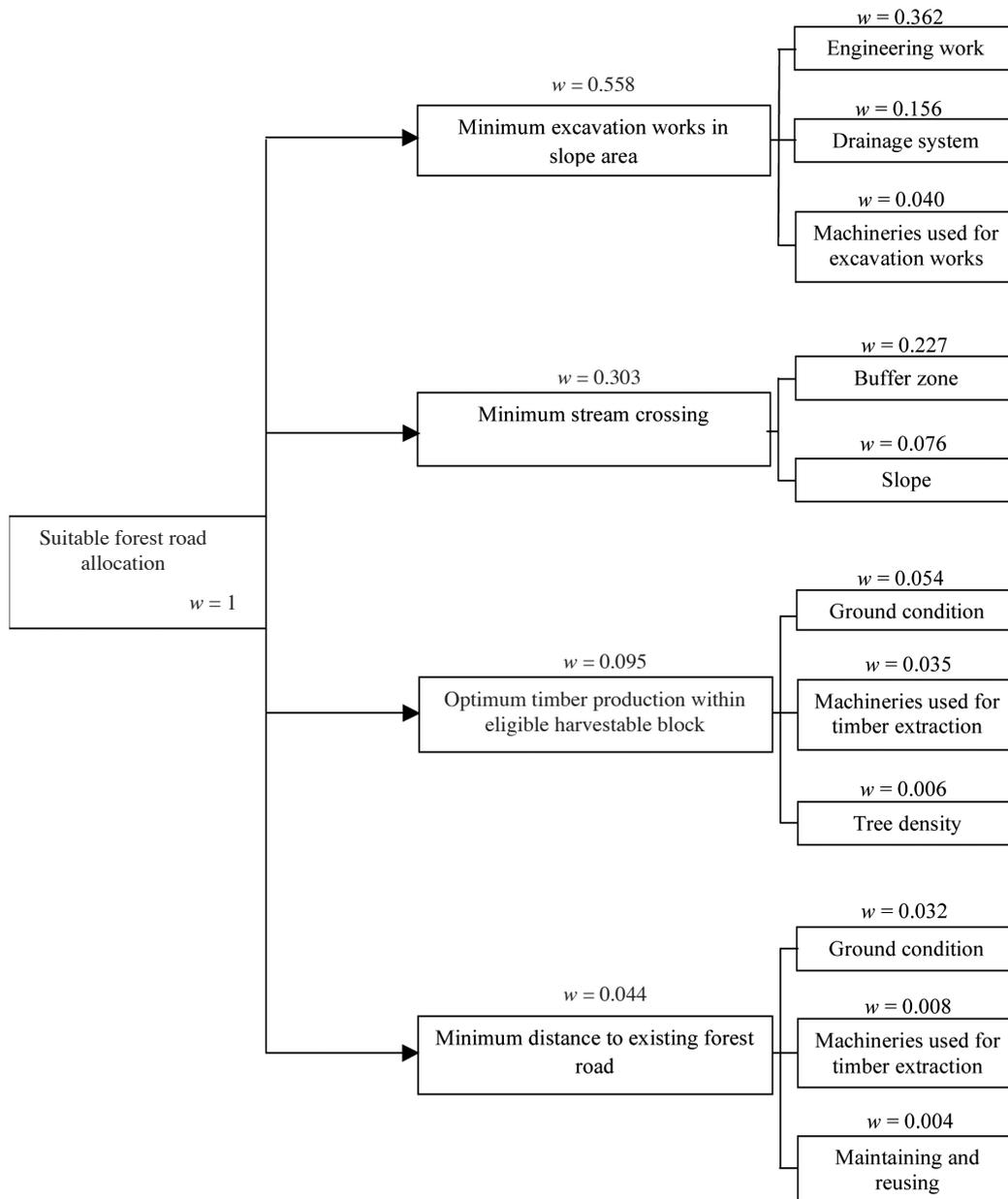


FIGURE 4. Hierarchy of the criterion for suitability forest road allocation by AHP decision making

- Untuk Semenanjung Malaysia, Kuala Lumpur: Forestry Department Peninsular Malaysia.
- Forestry Department Peninsular Malaysia (FDPM). 2010. *Garis Panduan Jalan Hutan*. Kuala Lumpur: Forestry Department Peninsular Malaysia.
- Holmes, T.P., Blate, D.M., Zweede, J.C., Pereira, R., Barreto, P., Boltz, F. & Bauch, R. 2002. Financial and ecological indicators of reduced impact logging performance in the eastern Amazon. *Forest Ecological Management* 163: 93-110.
- Islam, R. & Abdullah, N.A. 2006. Management decision making by the analytic hierarchy process: A proposed modification for large scale problems. *Journal of International Business and Entrepreneurship Development* 3(1/2): 18-40.
- Johnson, R.A. & Madison, M.E. 1994. Tying impact mitigation requirements to local general plans, *Journal of Environmental Impact Assessment* 14: 61-74.
- Judibal, C.C. 2000. GIS-based support system for tactical timber harvesting planning; designing and development. Ph.D (Thesis), Universiti Putra Malaysia, Serdang, Selangor, Malaysia. 174 p. (unpublished).
- Kamaruzaman, J. 2008. Construction of new forest road in Malaysia using a GIS-based decision support system. *Journal of Computer and Information Science* 1(3): 48- 59.
- Malczewski, J. 1999. *GIS and Multicriteria Decision Analysis*. New York: John Wiley and Sons.
- Mohd Hasmadi, I. 2005. Application of geoinformatics technology to forest harvesting in Malaysia. PhD (Thesis), Cranfield University, United Kingdom. 330p. (unpublished).
- Mohd Hasmadi, I., Kamaruzaman, J. & Muhamad Azizon, J. 2008. Forest road assessment in Ulu Muda Forest Reserve of Peninsular Malaysia. *Journal of Modern Applied Science* 2(3): 101-108.

- Mohd Hasmadi, I. & Kamaruzaman, J. 2009. Planning of access road using satellite technology and best path modeling. *Journal of Modern Applied Science* 3(3): 83- 89.
- Muziol, C. 1999. The zonation of production forest into timber production restricted timber production and protection forest areas: An important tool for mitigating the impact of timber harvesting. (ed.) Shamsudin, I., Nur Hajar, Z.S. & Choon, K.K. *Proceeding of the Tropical Forest Harvesting: New Technologies Examined*. pp. 136-165.
- Naghdi, R., Bagheri, I., Ghajar, E., Taheri, K. & Hasanzad, I. 2008. Planning the most appropriate forest road network considering soil drainage and stability using GIS in Shararoud Watershed-Guilan. [http://www.gisdevelopment.net/application/utility/transport/ma08\\_79.html](http://www.gisdevelopment.net/application/utility/transport/ma08_79.html). Retrieved 1 July 2010.
- Rafiei, A.A., Lotfalian, M., Hosseini, S.A. & Parsakhoo, A. 2009. Determining the optimum road density for ground skidding system in Dalak Kheyl Forest hyrcanian zone. *World Applied Science Journal* 7(3): 263-270.
- Roh, T.H., Lee, J.C., Kim, H.G., Kim, J.J. & Jung, Y.H. 2008. Construction on decision support system for route location based on GIS. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVII (B2)*: 555-566.
- Saaty, T.L. 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology* 15: 234-281.
- Saaty, T.L. 1980. *The Analytic Hierarchy Process*. New York: McGraw Hill.
- Saaty, T.L. 1990. How to make a decision: The analytic hierarchy process. *European Journal of Operational Research* 48: 9-26.
- Samani, K.M., Hosseini, S.A., Lotfalian, M. & Najafi, A. 2010. Planning road network in mountain forests using GIS and Analytical Hierarchical Process (AHP). *Caspian Journal Environmental Science* 8(2): 151-162.
- Shiba, M. 1995. Analytic hierarchy process (AHP) based multi attribute benefit structure analysis of road network system in mountainous rural areas of Japan. *Journal of Forest Engineering* 7: 14-50.
- Slotterback, C.S. 2008. Evaluating the implementation of environmental review mitigation in local planning and development processes. *Environmental Impact Assessment Review* 28: 546-561.
- Store, R. & Kangas, J. 2002. Integrating spatial multi-criteria evaluation and expert knowledge for GIS-based habitat suitability modelling. *Landscape and Urban Planning* 55: 79-93.
- Tan, J. 1999. Locating forest roads by a spatial and heuristic procedure using microcomputers. *International Journal of Forest Engineering* 10(2): 1-10.
- Triantaphyllaou, E. & Mann, S.H. 1995. Using the analytic hierarchy process for decision making in engineering applications: Some challenges. *International Journal of Industrial Engineering: Applications and Practices* 2(1): 35-44.
- Trussat, S., Messier, D., Roquet, V. & Aki, S. 2002. Hydropower projects: A review of most effective mitigation measures. *Journal of Energy Policy* 30: 1251-1259.
- Wan Mohd, S.W.A. & Mohd Paiz, K. 2003. Alternatives reduced impact logging techniques in Peninsular Malaysia. In: *Proceedings of International Expert Meeting on the Development and Implementation of National Codes of Practices for Forest Harvesting- Issues and Options*. Kisazaru City, Chiba prefecture, Japan, 17-20 November 2003. 13 p.

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