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A Spatial Decision Support Tool for Oil Palm Plantation Management

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ABSTRACT

Malaysia is in the process of modernizing its oil palm plantation management, by implementing geo-information technologies which include Remote Sensing (RS), Geographic Information System (GIS), and Spatial Decision Support System (DSS). Agencies with large oil palm plantations such as the Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA), Guthrie Sdn. Bhd., and Golden Hope Sdn. Bhd. have already incorporated GIS in their plantation management, with limited use of RS and DSS. In 2005, FELCRA, Universiti Putra Malaysia (UPM) and Espatial Resources Sdn. Bhd. (ESR) collaborated in a research project to explore the potentials of geo-informatics for oil palm plantation management. The research was conducted in FELCRA located in Seberang Perak Oil Palm Scheme. In that research, a tool integrating RS, GIS and Analytical Hierarchy Process (AHP) was developed to support decision making for replanting of the existing old palms. RS was used to extract productive stand per hectare; AHP was used to compute the criteria weights for the development of a suitable model; and GIS was used for spatial modelling so as to generate the decision support layer for replanting. This paper highlights the approach adopted in developing the tool with special emphasis on the AHP computation.

Keywords: Remote Sensing, Geographic Information System, Analytical Hierarchical Process, Spatial Modelling and Spatial Decision Support Tool

ABBREVIATIONS

Analytical Hierarchy Process	– AHP
Remote Sensing	– RS
Geographic Information System	– GIS
Spatial Decision Support Tool	– SDST
Federal Land Development Authority	– FELDA
Federal Land Consolidation and Rehabilitation Authority	– FELCRA
Universiti Putra Malaysia	– UPM

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INTRODUCTION

Malaysia is regarded as the world's largest exporter of palm oil and its production is increasing annually due to the potential world bio-fuel markets. The cultivation of oil palm in Malaysia is largely based on private plantation management such as Guthrie Sdn. Bhd. and Golden Hope Sdn. Bhd., or organized mini estates under the supervision of some government agencies like Federal Land Development Authority (FELDA), and Federal Land Consolidation and Rehabilitation Authority (FELCRA). This has enabled a better utilization of resources through the application of advanced management statistically based tools currently and widely accepted in the palm oil industry.

In the current digital era, there is a need to modernize the management of oil palm estates in Malaysia, i.e. using state-of-the-art spatial technologies, which include Remote Sensing (RS), Geographic Information System (GIS), Global Positioning System (GPS) and Spatial Decision Support Tool (SDST), to enable reliable, cost effective and timely data collection and analysis, thus supporting more accurate decision making.

In recent years, researchers in Malaysia have embarked into the use of RS technologies in extracting oil palm crop performance indicators such as tree inventorying (Loh *et al.*, 2005), oil palm phenology (Ibrahim *et al.*, 2002) and palm macro-nutrient assessment (Nor Azleen *et al.*, 2002). The RS, GIS and GPS tools have also been developed to generate spatial layers relevant for integrated oil palm plantation management (Tey and Chew, 1997; Mariamni *et al.*, 2002; Wahid *et al.*, 2002). However, no effort has been carried out in developing the SDST for the management of oil palm plantation, despite the fact that the tool has been made operational for land use planning in several other countries (Diamond and Wright, 1988; Loh, 1991; Parker *et al.*, 2003).

The widely accepted decision making process comprises three major phases (Simon, 1960; Malczewski, 1999). These include intelligence (problem surveillance), design (setting alternatives) and choice (choosing the most attractive/best alternative). RS provides a powerful capacity to capture data through a variety of earth observation satellites. These data are then organized in the GIS to provide selection, integration, manipulation, exploration, and confirmation and generate useful information for the analysis of various processes. However, given the present RS-GIS technology level, the information generated as such mostly does not fulfil the requirements of the different phases of the decision making process, particularly in the choice phase.

FELCRA, Universiti Putra Malaysia (UPM) and Espatial Resources Sdn. Bhd. (ESR) collaborated in conducting a research project to explore the potentials of geo-informatics for the management of oil palm plantation in 2005. The overriding objective of the project was to establish a software spatial-based tool to support decision making for the replanting which is already existing in the old oil palm plantations in FELCRA; to-date, there are some 180000 hectares of oil palm plantations in Malaysia. In phase 1 of the project, which was completed in 2006, the researchers developed and integrated a database for the oil palm plantation management using the RS and GIS technologies (Loh *et al.*, 2005). Phase 2, which was currently implemented, focused on the development of the SDST.

MATERIALS AND METHODS

The flowchart of the methodology used is depicted in *Fig. 1*; it comprises of essentially four components – base information collection through RS, spatial layers generation in GIS, model development using AHP and spatial modelling to generate the decision support layer in the GIS environment.

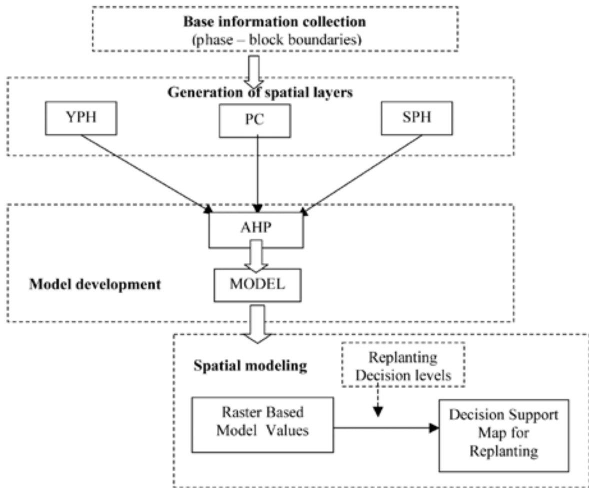

Fig. 1: The flowchart of the methodology used in the study

Study Area

Seberang Perak, comprising of some 7800 hectares of matured oil palms, was selected as the study area. It is located in the state of Perak, Malaysia, and located between the latitudes of 4.0735 and 4.2647 N, and the longitudes between 100.7983 and 100.9525 E (see *Fig. 2*). The area is situated on a gentle terrain, having basically peat soils and riverine alluvia. The mean monthly rainfall exceeds 120mm, except for July, which is regarded as a dry month, with the rainfall below 75mm. For the purpose of this study, Phase 15 covered about 1785 hectares of old oil palms, was selected for the development of the SDST, using the RS-GIS and Analytical Hierarchy Process (AHP).

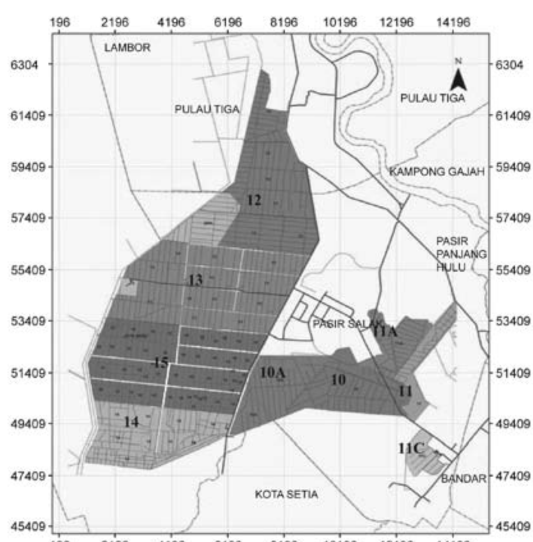

Fig. 2: The study area

Base Information Collection

IKONOS satellite imageries, dated July 21 2004, were acquired. The images were enhanced and geo-coded to conform to the Malaysian's Cassini Map Projection specifically designed for large scale map production, using 20 ground control points. An interactive linear contrast stretch was also applied to the image enhancement of the features of interest such as healthy and diseased palm trees, while the geo-coding process adopted the 1st polynomial transformation and the nearest neighbour re-sampling algorithm.

Plantation phase-block boundaries were extracted from the IKONOS imageries through a manual digitization and input into the GIS as arcs and polygon files with topology built.

Spatial Layer Generation

Three spatial layers were generated in the GIS – yield per hectare (YPH), production cost per fresh fruit bunch (PC) and stand per hectare (SPH). The data for YPH and PC were provided by FELCRA, while the SPH was extracted from the IKONOS datasets through a manual digitization of individual trees, as shown in *Fig. 3*.

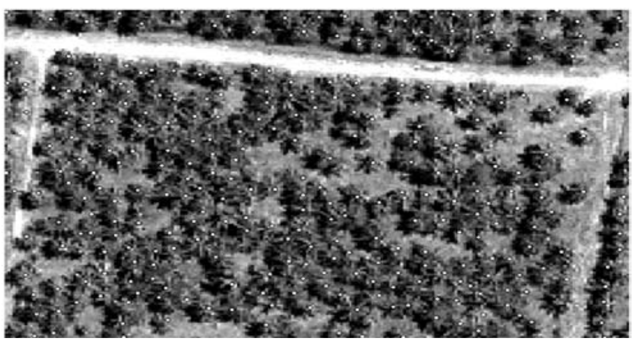

Fig. 3: Manually digitized trees from IKONOS data

Model Development Using the AHP

The AHP approach (Saaty, 1977; Saaty, 1980; Saaty, 1982) was adopted to determine the criteria priorities (weight) for the development of a model to support the decision making in replanting the existing old oil palm stand. The AHP incorporated both the qualitative and quantitative aspects of human thinking. It particularly involves (i) hierarchical structuring of the issue at hand, breaking it into separated and related structural elements or criteria; (ii) prioritizing criteria through a mathematical means; and (iii) ensuring consistency in criteria prioritization mathematically.

Spatial Modelling

A spatial weighted linear model was adopted for the generation of the decision support map for replanting, as given in equation 1. It represents the summation value of the products of criteria weights and sub-criteria scores to be assigned to each pixel of the composite spatial layer to support replanting. Weighted linear combination analysis is a common procedure in the GIS-based multi-criteria analysis. It has been adopted in the resource and disaster management studies (Chuvieco and Congalton, 1989; Graeme, 1996; Hall *et al.*, 1997; Feick and Hall, 1999).

$$R = \sum WiXi \tag{1}$$

Where, *R* represents the composite value for replanting; Wi is the criteria weight, and Xi is a sub-criteria score.

RESULTS AND DISCUSSION

AHP Computations

In this study, a 3-level hierarchy structure was designed to support the decision making for replanting. The alternatives for decision making in replanting, including (i) replant, (ii) under observation and (iii) status quo, were placed at the 3rd or bottom level of the hierarchical structure, as shown in *Fig. 4*. The next level consisted of the criteria selected for judging the alternatives; these were (i) yield per ha (YPH), (ii) production cost per ton of fresh fruit bunch (PC), and (iii) stand per ha (SPH). The top level was a single element – the decision support for replanting.

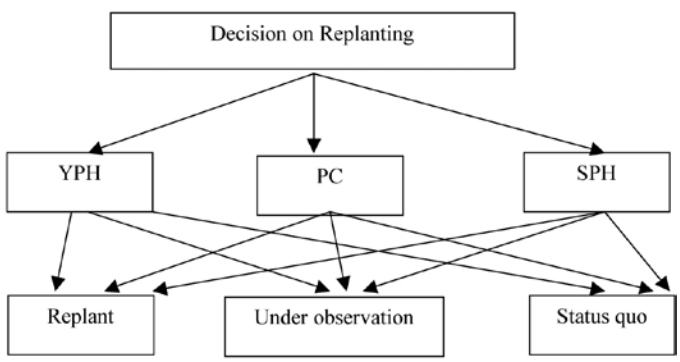

Fig. 4: Hierarchical structure for replanting decision

Although the three criteria selected influences one another, their respective impacts on decision making for replanting differ in importance. The justifications for the selection of these criteria are given in Table 1. Terrain, which is important in determining whether replanting an area with oil palm is an acceptable choice, was not selected as a criterion as the entire study area was flat, and therefore, suitable for the oil palm cultivation.

Prioritizing the criteria was done using the pair-wise comparison ratings developed by Saaty (1980), as presented in Table 2. The method employs an underlying scale, with ratings from 1 to 9, to rate the relative importance or preference for two criteria to be compared. The matrix depicted in Table 3 shows the ratings assigned to YPH, PC and SPH, by oil palm agronomists from FELCRA. The comparison was based on the relative preference of the two elements in a pair to the decision on replanting. The YPH was equal to moderately preferred over PC, and therefore, was given a rating of 2. Further YPH was moderately preferred over the SPH, and was assigned a rating of 3. Finally, PC was equal to moderately preferred over SPH, and given a rating of 2. If the same element was compared to itself, it was considered to be of equal importance and therefore, a value of 1 was assigned. The reciprocal comparisons of the paired criteria were also assigned ratings accordingly.

TABLE 1
Criteria justification

No.	Criteria	Justification
1	Yield per hectare (YPH)	Yield per unit area is very important because it determines whether return to management is economical, given the existing price of palm oil.
2	Production cost per ton fresh fruit bunch (PC)	Production cost is important as it is influenced by prices of variables such as input prices and labour cost. It is also influenced by YPH.
3	Productive stand per hectare (SPH)	Productive stand per hectare (SPH) is moderately important as it reflects the number of healthy trees uninfected by Ganoderma disease and bagworms, which are common in the study area. It also influences YPH and PC.

TABLE 2
Scale for the pair-wise comparison

Intensity of Importance	Definitions
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Source: Saaty (1980)

TABLE 3
Pair-wise comparison matrix to assess the importance of criteria

Criteria	YPH	PC	SPH
YPH	1	2	3
PC	0.5	1	2
SPH	0.333	0.5	1
Total	1.833	3.5	6

The summarized field records for the SPH, YPH and PC, from an adjacent phase (Phase 13) of similar soil and climatic conditions, are presented in Table 4 below. The table shows that a 32 % drop in the YPH had caused a 15% increase in the PC. However, the drop in the SPH was insignificant, and had a slight influence on the drop in the YPH; this was mainly attributed to the occurrence of a pronounced dry period in Jun, Jul and Aug, 2005. This greatly affected bunch formation and flower initiation. Based on this argument, agronomists at FELCRA have rated YPH >PC>SPH in terms of their importance in decision making for replanting the existing matured oil palm areas.

To synthesize these values for more meaningful comparisons, the matrix values given in Table 3 were first normalized as given in Table 5, followed by the computation of the average normalized values for each criterion provided in Columns 4 of Table 6. These average normalized values are essentially the more meaningful weights to be used in comparing the level of importance assigned for the YPH, PC and SPH, which are respectively 0.539, 0.297 and 0.164.

TABLE 4
Field records for the SPH, YPH and PC of Phase 13 - 2006 and 2007

Criteria	Jan.-Jun. 2006	Jan-Jun. 2007	Percent change
YPH (tonne per hectare)	9.79	6.65	- 32.07
PC (RM per tonne FFB)	127.67	146.25	+ 14.55
SPH (trees per hectare)	123	117	- 4.88

Source: FELCRA Seberang Perak Report for June 2006 and June 2007

TABLE 5
Normalised pair-wise comparison matrix

Criterion	YPH	PC	SPH
YPH	0.545	0.571	0.500
PC	0.273	0.286	0.333
SPH	0.182	0.143	0.167
Total	1.000	1.000	1.000

TABLE 6
Relative weights assigned to the criteria

Criterion	YPH	PC	SPH	Weights
YPH	0.545	0.571	0.500	0.539
PC	0.273	0.286	0.333	0.297
SPH	0.182	0.143	0.167	0.164
Total	1.000	1.000	1.000	1.000

The AHP measures the consistency of the judgments, in setting up priorities for the elements, with respect to a criterion by means of a consistency ratio (CR). If the ratio is < 0.1, the judgments are considered as consistent. However, if the ratio is >0.1, the judgments are considered to be inconsistent and somewhat random and it should therefore be reviewed (Saaty, 1982; Malczewski, 1999).

The step by step procedure adopted by both Saaty (1982) and Malczewski (1999) to compute the CR is as follows:

(i) The weighted sum vectors were computed by multiplying the pair-wise comparison matrix with the criteria weights;

$$\begin{pmatrix} 1 & 2 & 3 \\ 0.5 & 1 & 2 \\ 0.333 & 0.5 & 1 \end{pmatrix} \times \begin{pmatrix} 0.539 \\ 0.297 \\ 0.164 \end{pmatrix} = \begin{pmatrix} 0.539 & 0.504 & 0.492 \\ 0.269 & 0.297 & 0.328 \\ 0.179 & 0.149 & 0.164 \end{pmatrix} = \begin{pmatrix} 1.625 \\ 1.894 \\ 0.492 \end{pmatrix}$$

(ii) The consistency vector (λ_{max}) was calculated by averaging the weighted sum vectors, as shown below:

$$\begin{pmatrix} 1.625 \\ 0.894 \\ 0.492 \end{pmatrix} \div \begin{pmatrix} 0.539 \\ 0.297 \\ 0.164 \end{pmatrix} = \begin{pmatrix} 3.015 \\ 3.010 \\ 3.000 \end{pmatrix}$$

Next, the average value for the consistency vector (λ_{max}) was calculated as: λ_{max} = (3.015+3.010+ 3.000) ÷ 3 = 3.008

(iii) The consistency index (CI) was calculated according to equation 2 below:

$$CI = (\lambda_{max} - n) / n - 1 \quad (2)$$

Where, λ_{max} is the principle eigenvalue of the matrix, and n is the order of the pair-wise comparison matrix. The CI was computed as:

$$CI = (3.008 - 3)/2 = 0.004$$

(iv) The consistency ratio was then computed using equation 3.

$$CR \quad = CI/RI \quad (3)$$

Where, CI is the consistency index and RI is the random index value, which is dependent on the matrix order provided by Saaty (1980), as given in Table 7. The CI provides a measure of departure from consistency, while the RI is the CI of a randomly generated pair-wise comparison matrix.

Therefore, the CR determines the level of consistency and it should be < 0.10, so as to permit a reasonable level of consistency in the pair-wise comparison judgments (Saaty, 1982; Malczewski, 1999).

The CR in this study was computed as (0.004 ÷ 0.58) = 0.069, which is significantly below the threshold value of 0.1, and this indicates a high level of consistency. Hence, the criteria weights were accepted.

Spatial Modelling

The digital layers for the YPH, PC and SPH were generated in a GIS environment, as depicted in *Figs. 5, 6* and *7*, respectively.

TABLE 7
Random index values (Saaty, 1980)

N (matrix order)	RI
2	0.00
3	0.58a
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41a

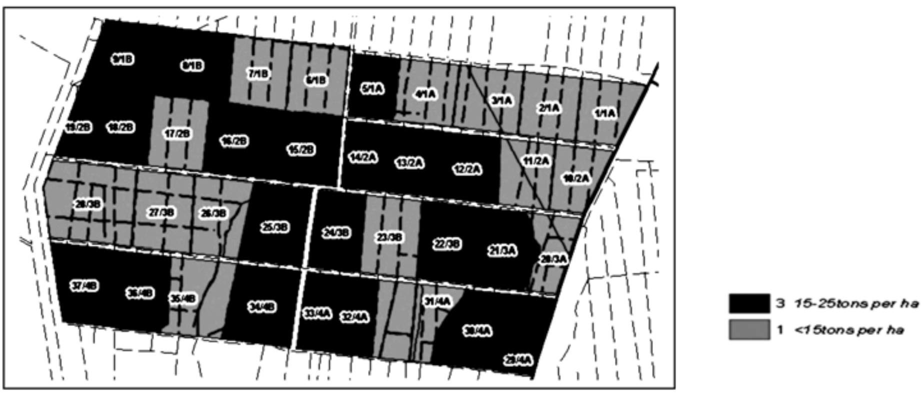

Fig. 5: Yield per hectare map of phase 15

Fig. 6: Production cost map of phase 15

Fig. 7: Stand per hectare map of phase 15

The sub-criteria scores for the YPH, PC and SPH determined by the agronomists at FELCRA are shown in Table 8.

Equation 1 was rewritten as equation 4, considering the criteria weights, which were computed using the AHP.

$$R = 0.539 \text{ YPH} + 0.297 \text{ PC} + 0.164 \text{ SPH} \tag{4}$$

In this study, the setting of the R limits for the three alternative classes of decision making for replanting (Table 9) was done after the consultation with the local oil palm agronomists and plantation managers.

Through the map calculator tool in the GIS, the final replanting decision support map was then generated using equation 4 and the associated sub-criteria scores for the YPH, PC and STP. This map is depicted in *Fig. 8*.

TABLE 8
Sub-criteria scores

Criteria	Sub-criteria scores
Yield per hectare	3 for 15-25 tons per ha
	1 for < 15 tons per ha
Production cost	5 for < RM 115 per ton FFB
	3 for RM 115 – 150 per ton FFB
	1 for > RM 150 per ton FFB
Stand per hectare	5 for > 125 palm trees per ha
	3 for 100 – 125 palm trees per ha
	1 for < 100 palm trees per ha

TABLE 9
Replanting decision classes

No.	Replanting Decision Classes	R Values
1	Replant	< 1.9
2	Under Observation	>1.9 – 3.8
3	No Replant	> 3.8

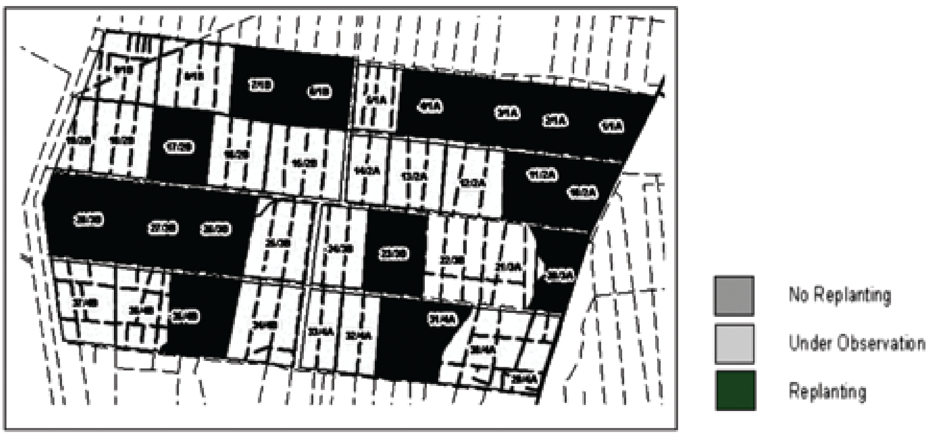

Fig. 8: Decision support map of Phase 15

CONCLUSIONS

In this study, a decision support tool for replanting of the existing old palms was developed using the integration of the RS, GIS and AHP technologies. The tool has been made operational to support the decision making for replanting in FELCRA.

For future research works in the study area, the automatic RS based algorithms will be developed to estimate yield of oil palm, stand per hectare, age of palm trees and height of palm trees. The criteria–age of the palm tree and the height of palm tree will also be considered in the AHP analysis and the spatial modelling to refine the SDST tool for replanting.

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