UNIVERSITI PUTRA MALAYSIA

OPTIMAL TIMBER TRANSPORTATION PLANNING IN TROPICAL HILL FOREST USING BEES ALGORITHM

JAMHURI BIN JAMALUDDIN

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the Degree of Doctor of Philosophy

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By

JAMHURI JAMALUDDIN

June 2022

Chairman : Associate Professor Norizah Kamarudin, PhD
Faculty : Forestry and Environment

The selection of timber extraction techniques is the most important in timber harvesting operations. In Malaysia, crawler tractor is limited to extracting timbers on gentle slopes ≤ 20°, while log fisher can extract timber at a steeper slope ≤ 40°. The selection of timbers to be extracted on undulate topography is the primary concern in timber transportation planning (TTP), especially those related to selecting the extraction technique with the least cost. Combining these two techniques allows TTP to be linked to timber harvesting area models. The planning depends on the legal restrictions, fixed and variable costs, landing locations, as well as the existing and proposed road network. This study proposed a multi-objective linear programming model with Bees algorithm (BA) to find an optimal cost TTP for extraction, forest road, and landing locations. The model uses grid cell-sized 10 m x 10 m characterised with timber locations, volume and fixed and variable costs to represent the study area. Cells with timbers were assigned as -from node, and the model finds the following cells simultaneously on the extraction technique selection and forest road network. To limit the searching space from timbers to the first exit; landing, a geographically weighted regression (GWR) was used to select the candidate landings. The model finds the final destination from the landings attributed to the cumulative timber volume with the same steps. This model was tested and found the log fisher as a preferable extraction technique with 1,351 timbers than the crawler tractor with only 206 timbers. The extraction costs for the log fisher and the crawler tractor were RM 85,236.73 and RM 5,523.03, respectively. The costs to prepare the extraction trail were RM 1,315.00 for the log fisher and RM 4,930.00 for the crawler tractor. The hauling cost from 14 landings to the final destination was RM 817.95, and the cost for preparing the feeder road was RM 60,948.00. The preparation cost for the feeder road calculated from the model was 25.18% less than the feeder road proposed by Forestry Department of Peninsular Malaysia (FDPM) (RM 81,454.32). Given the finding of this study, the

optimisation of the BA model has a better performance than the current practice of forest road planning in Malaysia. Although both practices have a similar objective to achieve sustainable timber harvesting with minimum impact on the environment and society, and low operational costs, the model developed in this study has shown better performance than the current practice. The sensitivity analysis conducted by changing the fixed and variable costs for crawler tractors, reducing the distance of log fisher trail and increasing the interval of landing locations shows the model capable of finding the least cost TTP solution. Overall, the model helps the forest engineer and the decision-makers to plan a suitable forest road networking for timber extraction and easily estimate the extraction costs, which the current practice is not able to.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan Ijazah Doktor Falsafah

PERANCANGAN PENGANGKUTAN BALAK YANG OPTIMAL DI HUTAN BUKIT TROPIKA MENGGUNAKAN ALGORITMA LEBAH

Oleh

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Pemilihan teknik pengekstrakan balak adalah penting dalam operasi penuaian balak. Di Malaysia, crawler tractor terhad untuk mengekstrak balak di lereng landai ≤ 20 °, sementara *log fisher* boleh mengekstrak balak pada lereng yang lebih curam ≤ 40 °. Pemilihan balak yang akan diekstraks di kawasan topografi berbukit adalah masalah utama dalam perancangan pengangkutan balak (TTP), terutama yang berkaitan dengan pemilihan teknik pengekstrakan balak dengan operasi kos yang paling rendah. Gabungan kedua teknik ini memerlukan TTP dikaitkan dengan model kawasan penuaian balak. Perancangan perlu dibuat berpandukan undang-undang dan garis panduan jalan hutan, kos tetap dan kos berubah, matau sementara, serta rangkaian jalan raya sedia ada dan yang akan dicadangkan. Kajian ini bertujuan mencadangkan model pengaturcaraan linear multi-objektif menggunakan *Bees Algorithm* (BA) bagi mendapatkan kos TTP paling rendah untuk pengekstrakan balak ke lokasi matau sementara. Model ini menggunakan sel grid berukuran 10 m x 10 m yang dicirikan dengan lokasi balak, jumlah kayu, serta kos tetap dan kos berubah untuk mewakili kawasan kajian. Sel yang mempunyai ciri lokasi balak ditetapkan sebagai lokasi grid permulaan. Model tersebut memilih sel yang seterusnya dengan menyelesaikan permasalahan pemilihan teknik pengekstrakan balak dan dalam masa yang sama merancang jaringan jalan hutan. Untuk menghadkan ruang pencarian dari lokasi balak ke matau sementara, analisa *geographically weighted regression* (GWR) digunakan untuk menentukan lokasi matau sementara. Model ini merancang jalan pengekstrakan dari lokasi balak hingga ke matau sementara, seterusnya jalan pengekstrakan bersambung dari matau sementara hingga ke jalan keluar utama menggunakan data kumulatif balak di matau sementara. Model ini mendapati *log fisher* adalah teknik pengekstrakan balak yang lebih baik dengan jumlah 1,351 balak dikeluarkan menggunakan jentera ini. Manakala, *crawler tractor* hanya dapat mengeluarkan 206 balak Kos pengekstrakan balak untuk *log fisher* dan *crawler tractor* masing-masing adalah

RM 85,236.73 dan RM 5,523.03. Kos untuk membina lorong *log fisher* adalah RM 1,315.00 bagi jentera *log fisher* dan RM 4,930.00 untuk lorong penarik bagi jentera *crawler tractor*. Kos pengangkutan balak dari 14 matau sementara ke destinasi akhir atau jalan keluar utama adalah sebanyak RM 817.95, dan kos untuk membina jalan tuju adalah RM 60,948.00. Kos penyediaan keseluruhan jalan tuju yang dikira dari model ini adalah 25.18.% lebih rendah dibandingkan dengan jalan tuju yang dicadangkan oleh Jabatan Perhutanan Semenanjung Malaysia (FDPM) (RM 81,454.32). Hasil dari kajian ini, pengoptimuman model BA dapat menghasilkan perancangan jalan yang lebih baik jika dibandingkan dengan amalan perancangan jalan hutan sedia ada di Malaysia. Walaupun kedua-dua amalan ini mempunyai objektif yang sama untuk mencapai penuaian balak secara lestari dengan impak minima terhadap alam sekitar dan masyarakat, model ini juga menghasilkan perancangan balak dengan kos operasi yang rendah. Kajian ini telah menunjukkan prestasi yang lebih baik daripada amalan semasa. Analisa sensitif telah dijalankan dengan mengubah kos tetap dan kos berubah bagi jentera *crawler tractor*, mengurangkan had jarak minima penarikan balak oleh jentera *log fisher* dan meningkatkan jarak diantara penempatan matau sementara. Hasilnya, model ini mampu mencari penyelesaian TTP dengan kos yang paling rendah. Secara keseluruhan, model ini dapat membantu jurutera hutan dan pembuat keputusan untuk merancang jajaran jalan hutan yang bersesuaian bagi tujuan pengekstrakan balak serta dapat menganggar kos pengekstrakan, yang mana ianya tidak dapat dilakukan oleh amalan sedia ada.

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LIST OF ABBREVIATIONS

ASL	above sea level
ALOS	Advanced Land Observing Satellite
AAC	annual allowable cut
ACO	ant colony optimisation
BA	Bees algorithm
CRF	commercial regeneration felling
CT	crawler tractor
CSA	cuckoo search algorithm
°	degree
DA	Dijkstra algorithm
DIF	department improvement felling
DEM	digital elevation model
DSM	Digital Surface Model
E	east
FRC	feeder road cost
FB	forager bees
FMU	Forest Management Unit
FDPM	Forestry Department of Peninsular Malaysia
GA	genetic algorithm
GIS	Geographic Information System
GWR	Geographically Weighted Regression
GPS	Global Positioning System

HC	hauling cost
ha	hectare
km	kilometer
LP	linear programming
LF	log fisher
LFTC	log fisher trail cost
MUS	Malayan Uniform System
m	meter
MC&I	multi criteria and indicator
NA	network algorithm
N	north
OLS	Ordinary Least Square
PSO	particle swarm optimisation
PDF	portable document format
%	percentage
PFR	Petuang Forest Reserve
Pre-F	pre felling
RIL	reduced impact logging
RIF	regeneration improvement felling
SB	scout bee
SMS	selective management system
SLE	shift level evaluation
SRTM	shuttle radar topography mission

SA	simulated annealing
SB	scout bees
Sp	species
SFM	sustainable forest management
TS	tabu search
TTP	timber transportation planning
TV	timber volume
VBA	visual basic for applications
WC	winching cost
VIF	value indicator factor

CHAPTER 1

INTRODUCTION

1.1 Background

Timber transportation is part of the wood supply chain (Frisk et al, 2010) and it is an essential component in the timber harvesting planning. Timber transportation planning includes a combination of road development and harvest equipment placement (Chung and Session, 2003; Contreras and Chung, 2007). Excessive forest road construction for timber harvesting in the tropics has been shown to cause considerable damages to the vegetation, residual tress, and excessive canopy opening (Razali et al, 2014; Kanazawa, 2017; Azian et al, 2019; Wagner et al, 2011; Yamada et al, 2016), as well as adverse effects on soil physical properties (Norizah et al, 2011; Cleophas et al, 2017; Vijith et al, 2018), and water quality (Ling et al, 2016; Knowler et al, 2017; Faizalhakim, 2017). Negative impacts on the forest ecosystem and environment can be minimised with proper road planning and suitable engineering designs to support timber harvesting operation, which will also reduce the road construction costs. Hence, careful planning for protecting these natural resources plays a crucial role in sustaining the productivity of the forest. As stated by Li-Guangda, (2007), in exploiting the forest for providing timbers as raw materials, proper forest engineering and sustainable operations must be considered in decision making. For more than a century, forestry practitioners and decision makers have given significant attention to timber transportation planning because moving logs from felling site to final destination (i.e., temporary landing, permanent landing, and mills) is one of the most expensive activities in the timber harvesting operation (Greulich, 2003; Norizah et al. 2012; Contreras et al, 2016; Mokhirev and Rukomojnikov, 2019). In Peninsular Malaysia, the traditional goal of transportation planning is to develop road networks that minimise road density with crawler tractors as the main skidding machine. As described in the forest road guidelines (FDPM: 2010, 2013), feeder roads, the roads constructed within the operation area to connect skid trails with the secondary roads should be at a maximum density of 40 m/ha.

The maximum skid trail density permitted to be constructed is 300 m/ha with no earthworks. Skid trails are constructed to facilitate skidding logs by crawler tractors from felling sites to temporary landing places located along the feeder roads. Subsequently, all logs will be transported to a permanent landing place via feeder and secondary roads by log trucks. All the construction works must meet the necessary official specifications so that a forest management unit (FMU) can be certified with a Sustainable Forest Management (SFM) status under the Multi Criteria and Indicator (MC&I) guideline (Norizah et al, 2011). Although good planning and proper constructions have been practised for building forest roads, changes to the forest landscape are sometimes unavoidable. Wide canopy openings are expected as a result of feeder road and skid trail constructions (Wyatt-Smith, 1954; FDPM, 2001; Hrůza et al, 2018; Mercier and Dengler, 2019). Thus, according to Negishi et al, (2006), natural revegetation on the surface of logging roads will not take place until the severely eroded and compacted surface conditions are ameliorated, and time is needed for the badly affected areas to recover. Razali et al, (2014) suggested there would be low regeneration rates of seedlings and saplings under forest gaps created during the skidding operations. Since the Japanese era of 1941, timber harvesting activities in Malaysia have been mechanised. Common machineries used are truck tractors or commonly known as San Tai Wong truck and crawler tractors machine. A San Tai Wong or truck tractor is used to transport timbers from the temporary landing within a timber harvesting operation area to a permanent landing via secondary roads (Norizah et al, 2016). On the other hand, a crawler tractor is used to skid timbers from a felling site to a landing through skid trails, and at the same time, it is used to level forest ground to create skid trails. Also, this machine can be used in excavating earth for road construction and road maintenance (Norizah et al, 2011; Norizah et al, 2012). Due to the enormous size of the physical engineering structure and heavy weight, which are necessary for these machineries to work in rugged forest areas (i.e., uneven terrains and slopes, dense tree distribution and root systems), there will be high adverse impacts on the environments, as well indirect harmful effects on the forest ecosystem (Kamaruzaman and Nik Mohamad Shah, 1996; FDPM, 2003a: Norizah et al, 2011; Norizah, 2012), including faunas (Jamhuri et al, 2018; Tee et al, 2018).

The ability of crawler tractors to work at slopes ranging from 16° to 25° (FDPM, 1999) has restricted logs at a slope higher than that to be extracted. According to Wan Mohd Suhaimi and Borhan (2010), insufficient annual allowable cut (AAC) for the second timber harvesting rotation in low dipterocarp forest forces timber harvesting to be implemented in hill mixed dipterocarp forest with elevation down to between 1000 m and 350 m. The hill dipterocarp timber harvesting has been going on since the early 1980 (Kasran, 1988); and Lee (1981) reported that hill dipterocarp timber harvesting had started since the early mid-1960s in the Sarawak state and was licensed in the year 1979. From the slope characteristics observed in the Shuttle Radar Topography Mission (SRTM) images of Peninsular Malaysia (http://srtm.csi.cgiar.org), most of the areas with elevation 350 m and above are characterised with a slope of more than 20°- 30°. These gradients limit the ability of crawler tractors to do skidding activities in the hill forest. These additional topographic characteristics and the operational requirements have thus restricted the proper planning of forest roads for attaining a high productivity of timber extraction volume in a forested area unreachable by a crawler tractor.

Since the timber harvesting has shifted to hill areas and extraction activities are mechanised with reduced impact logging (RIL) practices (Kamaruzaman and Nik Mohamad Shah, 1994; FDPM 2003a; FDPM 2011; Norizah et al, 2011), the goal of transportation planning changes to give minimum impact to the environment, other than minimising the road density. In impassable areas due to slope limitations, alternative roads or different types of machineries are necessary. Thus, to overcome these limitations of the crawler tractors (later known as conventional machines), a Reduce Impact Logging (RIL) machinery, known as cable winch system or popularly referred to as log fisher was introduced for hill timber harvesting operation in the late 2000s (FDPM, 2010). The advent of a long hauling skidding machine to extract logs in an area characterised with slope of ≥ 20° and not more than 40° in 2000 (Alastair, 2001; Norizah 2011) gives licensees or forest concessionaires new hope of increasing their volume productivity when given a timber operation area in the hill forest. A log fisher is an excavator-based cable winching system that can winch logs in a distance of up to 300 metres, regardless of slope conditions, and it requires no skid trails. A comparative study by Norizah et al. (2012) depicts the following log skidding efficiencies: the rate of log fisher is 46.39 m^3/hour and that of crawler tractor 45.98 m^3/hour, and hence the former has a higher marginal efficiency of about 0.41 m^3/hour. However, log fisher operation will incur an average higher cost of about 26.8% (Norizah et al, 2012) compared with crawler tractor; this cost disadvantage has limited the log fisher utilisation by most of the forest concessionaires. Approximately RM 4.38/m^3 is required for skidding activities with crawler tractor, and RM 8.80/m^3 with log fisher. Although timber extraction with a log fisher requires a higher operational cost, studies by Abdul Rahim et al. (2009); and Norizah et al. (2012); Noraishah et al. (2015) suggest that the log fisher could produce less impact on the forest environment, and any additional costs for harvesting activities can be resolved by resorting to proper forest transportation planning. Noraishah et al., (2015) examined the changes of carbon stock in timber areas extracted with the crawler tractor and log fisher techniques; they found that timber extraction with the log fisher method reduced the logging damages and improved stand conditions. Carbon loss for areas with the log fisher extraction examined in their study is 6.77%, while that of the crawler tractor is 22.45%. They also revealed the growth of the residual stands, especially the new seedlings, improved in areas extracted with the log fisher as compared with the crawler tractor. Forest degradation was also reduced in terms of carbon stocks, in addition to other ecological benefits.

Because of these differences in costs, productivity, regulations, as well the benefits and environmental liability addressed in the previous studies, Norizah et al. (2012) suggested that the two logging systems, namely the crawler tractor and log fisher, could be complementary to each other, and applying a combination of the two systems might reduce the overall costs of timber harvesting. Determining the timber transportation planning design for a timber harvesting area is a difficult task because many considerations need to be taken into account: timber volume and timber distribution (Quintero-Méndez and Jerez-Rico, 2017; Yahya & Ismail, 2017; Noraida et al, 2018; Saadun et al, 2019; Gülci et al, 2020); terrain and environmental conditions (Kooshki et al, 2012; Cleophas et al, 2017; Kassim et al, 2018; Mokhirev and Rukomojnikov, 2019; Asad et al, 2020); costs including fixed cost and variable cost as well as productivity of timber extraction (Norizah and Chung, 2014; Lin et al, 2016; Han et al, 2018). In addition, different timber extraction techniques require different road specifications and designs. Specifications of road characteristics for the crawler tractor and log fisher in Peninsular Malaysia forest are shown in Table 1.1.

Table 1.1. Road characteristics for crawler tractor and log fisher machines

	Crawler Tractor Machine	Log Fisher Machine
Density	≤300 m/ha	≤50 m/ha
Length of the lane	≤300 m new; ≤500 m old	≤50 m
Slope	≤ 11°-17° (San Tai Wong), ≤14°-22° (Crawler tractor), ≤17°-24° (Bulldozer and truck tractor)	≤ 40°
Road width	≤4.0 m	≤4.0 m

(FDPM, 2013; 2016)

Hence, combining these two types of machineries in timber transportation planning could be a tricky decision and might result in a higher cost and expenditure if the wrong decision were made. Thus, using the trade-off analysis and optimisation methods between these two machines can solve the transportation problem and suggest the suitable machines to be used in a particular area. The optimisation with different heuristic approaches of selected algorithms has been the focus of research for decades (Zahraee et al, 2020). Mathew (1942) introduced the forest road planning with cost estimation for construction; fixed cost, and cost of transportation activity; as well as variable costs. A number of studies have been conducted using cost as the influencing factor for forest road planning in terms of distance and alignment, such as Chung and Session (2003), Chung et al, (2003), Aruga et al, (2005), Session (2007), Contreras and Chung (2011), Norizah and Chung (2014), Kizha & Han (2016), Akay & Süslü (2017) and Aguiar et al. (2021). All of these studies had resulted in construction of the least forest road network and minimum environmental damage. In this study, in order to design the timber transportation network with the least cost, appropriate timber extraction machines to be used in accordance with the forest road guidelines and specifications need to be identified, the costs of which are the variables in estimating the cost of the forest road network.

Solving a timber transportation network problem remains a daunting optimisation task and is a challenge to the researchers. Heuristic approaches have been tested continually to find the optimality of solutions. One of the promising algorithms not yet applied to the timber transportation network problem is the Bees Algorithm (BA), an optimisation technique introduced in 2005 by Pham and colleague (Pham et al, 2005). To date, researchers have explored numerous applications of BA in an attempt to solve several different optimisation problems. Although previous researchers of BA focused on the road network problems in urban areas, the concepts of solutions they tried to elucidate are similar to the forest transportation problem in the Malaysian forest. For example, the extraction of logs from a stump site to landing can be represented by the concepts of serving the communities to reach their targeted location within a minimum travel time and finding the shortest routes (Gomez *et al,* 2013; Long *et al,* 2014; Alzaqebah *et al,* 2018); wise use of an existing road in a timber harvesting area is quite similar to upgrading an existing road network to reduce construction costs (Szeto *et al,* 2015); and the trade-off analysis between the two timber transport activities, namely the crawler tractor and log fisher is similar to the concept of trade-off analysis between traffic efficiency and vehicle passes with less pollution impact on the environment (Long *et al,* 2014).

Hence, based on the concept of BA and the performance shown from previous work using BA as an algorithm to find the optimisation of transportation problem, this study addresses the following research questions and all the problems listed are solved with BA:

1. Where to build the least cost road network for the crawler tractor and log fisher in order to extract timber efficiently?

2. What is the viable cost for building a forest road network such that timber extraction can be carried out profitably using the crawler tractor and log fisher technique?

3. How do we initiate a timber harvesting operation with the RIL practice?

1.2 Problem Statement

Timber transportation is one of the most expensive activities in the timber harvesting operation. By formulating proper transportation planning, the cost of the entire timber harvesting operation can be reduced (Contreras and Chung, 2007; Mohd Hasmadi, 2009; Frisk et al, 2010; Norizah and Chung, 2014). While the crawler tractor needs feeder roads and skid trails to haul timber from the felling site, the log fisher only uses feeder roads with some modifications as trails to haul the timber. The log fisher trail has no infrastructure as prescribed for the feeder road and is permitted to be constructed at a maximum rate of 50 m/ha, if necessary (FDPM, 2016). The skid trail for the crawler tractor is permitted to be constructed at a maximum rate of 300 m/ha (FDPM, 2010) and it is mandatory so that the crawler tractor can reach the stump site in order to move the logs to the landings. Timber extraction with the crawler tractor requires additional canopy opening for the skid trail construction that is limited to slopes of ≤ 20°; in contrast, the log fisher machine can operate on steep slopes of as high as 20° and limited to below 40°. Since most of the timber harvesting operations have been carried out in hilly areas (350 m to 1000 m), the ability of the crawler tractor to extract timber is limited, as some areas are characterised with steep slopes. Due to the limitation of the crawler tractor to work on steep slopes, the cost of timber transportation may escalate, as the machinery takes a longer alternative road to avoid steep slopes in order to reach the stump site for log extraction. Safari et al. (2016) stressed that high soil disturbance would occur if a crawler tractor were used in an area with steeper slopes, because alterations of the slope gradient is necessary to prepare efficient passable routes (Bergua et al. 2019; Wong et al. 2020; Imaizumi & Sidle, 2021). Currently, the TTP practices in Malaysia are either by using a crawler tractor or log fisher with a manually plan on the topographic map. This practice require detail measurement and drawing by considering the environmental factor according to forest road guideline (FDPM, 2011, 2013, 2016). Hence, this study intends to analyse the optimum cost of timber transportation planning by using the heuristic approach of BA to combine the two timber extraction methods, namely the crawler tractor and log fisher. The BA capable to minimise travel time, shortest path of road network and optimum cost. (Szeto et al, 2015; Alzaqebah et al. 2018, Beed et al. 2020). The benefit of using this optimisation technique for transportation planning is the ability of it to ascertain a suitable access route so that the timber can be extracted profitably – by the crawler tractor or log fisher, or a combination of both; the respective transportation costs of both extraction methods are estimated and an optimal cost model of timber harvesting planning in the hill forest area is designed.

1.3 Objectives

This study aims to optimise the timber transportation planning and the detailed objectives are as below:

1. To identify suitable access routes for timber extraction activity

2. To estimate the transportation costs of timber extraction activities by using the crawler tractor and log fisher

3. To model an optimal cost timber harvesting plan in the hill forest

1.4 Research Design

The concept of research design is outlined to meet the aims and objectives of the study. This section explains the details of the overall concept, methodology and connection of each chapter presented in this thesis. There are several processes taken in complying with the algorithm to optimise the timber transportation planning. Figure 1.1 show a conceptual workflow of the entire project, from start to finish. These figures explain the general workflow and steps in solving the timber transportation planning problem in the hill forest of Peninsular Malaysia.

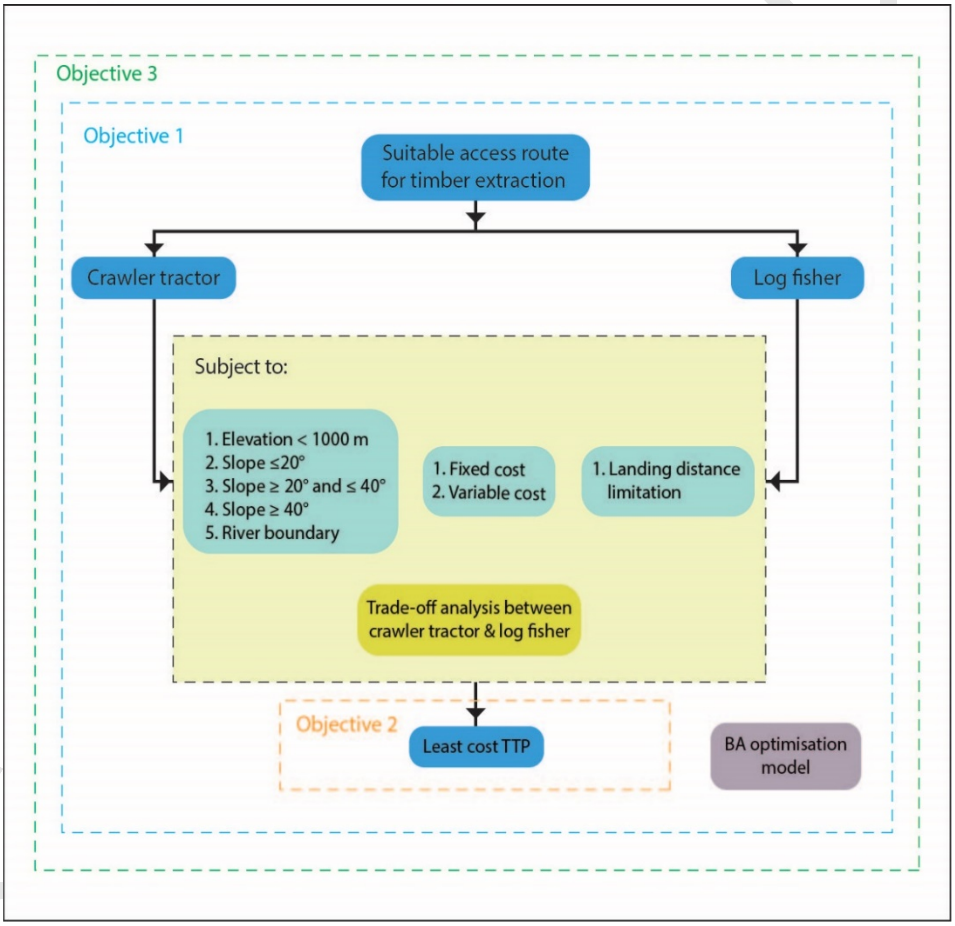

Figure 1.1: Conceptual workflow for the research methodology

1.5 Scope and Limitation

The scope of the study is design TTP in timber harvest area using the heuristic approach of BA to combine the two timber extraction methods, namely the crawler tractor and log fisher specifically in hill tropical forest. However, this study has limitations in acquired the latest cost data. Thus, this study using previous cost data from previous study. The cost studies were not covered in this thesis and no latest studies from the previous article were found in the literature. The cost data used in this study is secondary data from previous study. Additionally, the determination of the landing area in the model selection was not performed in the model selection due to complex problem formulation to meet especially on the regulations. Details explanation and description were covered in Chapter 3.

1.6 Thesis Outline

This study focuses on the timber transportation planning problem. This thesis includes a brief historical description of the timber harvesting machineries, the main types of machines used in Peninsular Malaysia. Various methods and techniques of timber transportation planning are discussed with their respective strengths and limitations in solving the timber transportation planning problem. Previous studies of applying the algorithm techniques in solving the timber transportation planning problems are also discussed. Moreover, a review of the algorithm techniques application is further dealt with in this thesis with the benefits and capabilities of each technique in solving the timber transportation planning problem; besides, their respective limitations are also elaborated on. The thesis is organised in the following manner:

Chapter 1 presents the general background of the study, justification of the study, problem statement, aim and objectives, and research designs. Other topics discussed in this section include transportation planning with heuristic approach for cost and environmental damage minimisation.

Chapter 2 reviews and discusses relevant issues about the concepts, practices, historical developments of timber harvesting transportation planning, methods and systems used, and previous studies related to algorithm applications in solving the timber transportation planning problems.

Chapter 3 describes the methodology and materials used in this study. The explanation of problem formulation of the BA is detailed. The method is structured based on the study objective.

Chapter 4 contains the results and discussions on solving the TTP problem. The chapter describes these issues or items: formulation of grid cells results obtained; timber distribution within the timber harvesting area; the proposed landing selection area; and the BA model application for TTP in the Compartment 62A. In addition, two other matters are dealt with in this section: first, a comparison of timber extraction techniques between the log fisher and crawler tractor as generated by the BA algorithm; and second, the sensitivity analysis to evaluate the effects of the cost changes. The BA model results for TTP in the Compartment 62A are briefly described in this chapter.

Chapter 5 states the overall conclusion on solving the TTP problem in the Peninsular Malaysian context. This chapter also includes the limitations of the study and constraints encountered in this study. Suggestions and recommendations of the study are also included in this chapter. However, this study has limitations, using previous cost data of the previous study. The cost studies were not covered in this thesis and no latest studies from the previous article were found in the literature. The cost data used in this study is secondary data from previous study. Additionally, the determination of the landing area in the model selection was not performed in the model selection due to complex problem formulation to meet especially on the regulations. Details explanation and description were covered in Chapter 3.

REFERENCES

Abdul Rahim, A., Ho, M. S., & Zariyawati, M. A. (2009). A comparison analysis of logging cost between conventional and reduce impact logging practices. *International Journal of Economics and Management*, 3(1): 354-366.

Achenbach, H., Wenker, J. L., & Rüter, S. (2018). Life cycle assessment of product-and construction stage of prefabricated timber houses: a sector representative approach for Germany according to EN 15804, EN 15978 and EN 16485. European *Journal of Wood and Wood Products*, 76(2): 711-729.

Acuna, M. (2017). Timber and biomass transport optimisation: A review of planning issues, solution techniques and decision support tools. Croatian Journal of Forest Engineering: *Journal for Theory and Application of Forestry Engineering*, 38(2): 279-290.

Adamovsky, M. G., Styranivsky, O. A., & Borys, M. M. (2017). Spatial modeling of transport development of forest area and their potential environmental risks. *Науковий вісник НЛТУ України*, 27(8): 92-96.

Aguiar, M. O., da Silva, G. F., Mauri, G. R., de Mendonça, A. R., de Oliveira Santana, C. J., Marcatti, G. E., ... & Leite, C. C. C. (2021). Optimizing forest road planning in a sustainable forest management area in the Brazilian Amazon. *Journal of Environmental Management*, 288(1): 1-11.

Akay, A. E., & Süslü, H. E. (2017). Developing GIS based decision support system for planning transportation of forest products. *Journal of Innovative Science and Engineering*, 10(1): 6-16.

Akay, Abdullah E., Hasan Serin, John Sessions, Ebru Bilici, &Mehmet Pak. (2021). Evaluating the Effects of Improving Forest Road Standards on Economic Value of Forest Products. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering,* 42(2): 245-258.

Alastair, S. (2001). A locally developed log-extraction technique is reducing damage to the peat swamp forests of Peninsular Malaysia. *ITTO Tropical Forest Update*, 11(2): 1-12.

Alkhanak, E. N., & Lee, S. P. (2018). A hyper-heuristic cost optimisation approach for Scientific Workflow Scheduling in cloud computing. *Future Generation Computer Systems*, 86: 480-506.

Altunel, A. O., Genç, Ç. Ö., & Torun, P. (2016). Can Operational Planning Help Cut the Cost of Logging: A Case Study of Ihsangazi Forest Directorate. *Forest Engineering and Technologies*, 1(1): 71-84.

Alves, R. T., Fiedler, N. C., Silva, E. N. D., Lopes, E. D. S., & Carmo, F. C. D. A. D. (2013). *Technical analysis and transportation costs of wood with different types of vehicles.* 37(5): 897-904.

Alzaqebah, M., Jawarneh, S., Sarim, H. M., & Abdullah, S., (2018). Bees Algorithm for Vehicle Routing Problems with Time Windows. *International Journal of Machine Learning and Computing*, 8(3): 236-240.

Amaliah, B., Fatichah, C., & Suryani, E. (2020). A new heuristic method of finding the initial basic feasible solution to solve the transportation problem. *Journal of King Saud University-Computer and Information Sciences,* 21(1): 1319-1578.

Amir Huni, M.S., & Abd-Rahman, J.M. (1993). Forest management practice and conservation measures in upland forest logging. *Forest Research Institute of Malaysia.* 2(1): 1-15.

Anderson, A. E., & Nelson, J. (2004). Projecting vector-based road networks with a shortest path algorithm. *Canadian Journal of Forest Research*, 34(7): 1444-1457.

Angilella, S., Giarlotta, A., & Lamantia, F. (2010). A linear implementation of PACMAN. *European journal of Operational Research*, 205(2): 401-411.

Appanah, S., Krishnapillay, B., & Dahlan, M. (2000). Sustainable production of forest products in the humid tropics of Southeast Asia: latest developments. *In XXI IUFRO World Congress. Kuala Lumpur, Malaysia* 1(1): 201-210.

Applegate, G., Putz, F. E., & Snook, L. K. (2004). Who pays for and who benefits from improved timber harvesting practices in the tropics? lessons learned and information gaps. *Center for International Forestry Research* 2(1): 1-35.

Armir, N. A. Z., Zakaria, S., Begum, R. A., Chamhuri, N., Ariff, N. M., Harun, J., ... & Kadir, M. A. (2020). The Readiness of Peninsular Malaysia Wood-based Industries for Achieving Sustainability. *BioResources*, 15(2): 2971-2993.

Aruga, K. (2005). Tabu search optimization of horizontal and vertical alignments of forest roads. *Journal of Forest Research*, 10(4): 275-284.

Aruga, K., Ishida, Y., & Uemura, R. (2016). Operational efficiency and cost of strip road construction in Tochigi prefecture, Japan. *From Theory to Practice: Challenges for Forest Engineering*, 1(1): 1-27.

Aruga, K., Murakami, A., Nakahata, C., Yamaguchi, R., Saito, M., & Kanetsuki, K. (2013). A model to estimate available timber and forest biomass and reforestation expenses in a mountainous region in Japan. *Journal of Forestry Research*, 24(2): 345-356.

Asad, S., Abrams, J. F., Guharajan, R., Sikui, J., Wilting, A., & Rödel, M. O. (2020). Stream Amphibian Detectability and Habitat Associations in a Reduced Impact Logging Concession in Malaysian Borneo. *Journal of Herpetology*, 54(4): 385-392.

Atiqah, A., Rhyma, P., Jamhuri, J., Zulfa, A., Samsinar, M., & Norizah, K. (2020). Using Google Earth Imagery to Detect Distribution of Forest Cover Change-Is the Technique Practical for Malaysian Forests? *The Malaysian Forester*, 83(1): 1-15.

Avellan, K. C., Belopotocanova, E., & Ghobakhlou, M. (2018). Massive wood elements and modular housing technology as innovative building concept of sustainable urban planning. In Paper presented at *IABSE Conference–Engineering the Developing World,* Kuala Lumpur, Malaysia.

Azian, M., Ismail, P., Abd. Rahman, K., Samsudin, M., Mohd Nizam, M.S., Nur Hajar, Z.S., Azmer, M., Lim, K.L. & Yusoff, M (2017). Comparative study of carbon emission changes from different logging techniques in inland production forest in Pahang. *The Malaysian Forester*, 80(1): 111-124.

Azian, M., Nizam, M. S., Samsudin, M., Ismail, P., Nur-Hajar, Z. S., Lim, K. L., & Yusoff, M. (2019). Carbon Emission Assessment from Different Logging Activities in Production Forest of Pahang, Malaysia. *Journal of Tropical Forest Science*, 31(3): 304-311.

Bager, A., Roman, M., Algedih, M., & Mohammed, B. (2017). Addressing multicollinearity in regression models: a ridge regression application. *Journal of Economic and Finance Research,* 30(4): 597-600.

Baharuddin, K., Mokhtaruddin, A. M., & Muhamad, M. N. (1995). Surface runoff and soil loss from a skid trail and a logging road in a tropical forest. *Journal of Tropical Forest Science*, 1(1): 558-569.

Beed, R., Roy, A., & Bhattacharya, D. (2020). A hybrid multi-objective tour route optimization algorithm based on particle swarm optimization and artificial bee colony optimization. *Journal of Computational Intelligence,* 37(1): 1-26.

Bergua, S. B., Piedrabuena, M. Á. P., & Alfonso, J. L. M. (2019). Snow avalanches, land use changes, and atmospheric warming in landscape dynamics of the Atlantic mid-mountains. *Applied Geography*, 107(1): 38-50.

Berry, M. D., & Sessions, J. (2018). A forest-to-product biomass supply chain in the Pacific Northwest, USA: A multi-product approach. *Applied Engineering in Agriculture*, 34(1): 109-124.

Bettinger, P., Boston, K., Kim, Y. H., & Zhu, J. (2007). Landscape-level optimization using tabu search and stand density-related forest management prescriptions. *European Journal of Operational Research*, 176(2): 1265-1282.

Bittencourt, L. F., & Madeira, E. R. M. (2011). HCOC: a cost optimization algorithm for workflow scheduling in hybrid clouds. *Journal of Internet Services and Applications*, 2(3): 207-227.

Biyanto, T. R., Irawan, S., Febrianto, H. Y., Afdanny, N., Rahman, A. H., Gunawan, K. S., ... & Bethiana, T. N. (2017). Killer whale algorithm: an algorithm inspired by the life of killer whale. *Procedia Computer Science*, 124(1): 151-157.

Bratu, I. A. (2019, October). Digitizing maps procedure for scientific forestry administration by GIS database. Case study: Rasinari forestry administration. In 2019 *International Conference on Energy & Environment,* 1(1): 95-98.

Britto, P. C., Jaeger, D., Hoffmann, S., Robert, R. C. G., Fantini, A. C., & Vibrans, A. C. (2017). Productivity assessment of timber harvesting techniques for supporting sustainable forest management of secondary Atlantic Forests in southern Brazil. *Annals of Forest Research*, 60(2): 203-215.

Brown, K., & Visser, R. (2017). *Erosion sources and sediment pathways to streams associated with forest harvesting activities in New Zealand.* University of Canterbury, New Zealand.

Brunsdon, C., McClatchey, J., & Unwin, D. J. (2001). Spatial variations in the average rainfall-altitude relationship in Great Britain: an approach using geographically weighted regression. *International Journal of Climatology: A Journal of the Royal Meteorological Society*, 21(4): 455-466.

Bucci, V., Corigliano, P., Crupi, V., Epasto, G., Guglielmino, E., & Marinò, A. (2017). Experimental investigation on Iroko wood used in shipbuilding. Proceedings of the Institution of Mechanical Engineers.*Journal of Mechanical Engineering Science*, 231(1): 128-139.

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

Caliskan, E. (2013). Environmental impacts of forest road construction on mountainous terrain. *Iranian Journal of Environmental Health Science & Engineering*, 10(1): 1-8.

Cassiano, C. C., Salemi, L. F., Garcia, L. G., & de Barros Ferraz, S. F. (2021). Harvesting strategies to reduce suspended sediments in streams in fast-growing forest plantations. *Ecohydrology & Hydrobiology*, 21(1): 96-105.

Chang, Y. K., & Chen, H. C. (2011, March). Layered cutting scheme for packet classification. In 2011 IEEE: *International Conference on Advanced Information Networking and Applications,* 675-681.

Charlton, M., Fotheringham, S., & Brunsdon, C. (2009). Geographically weighted regression. White paper. *National Centre for Geocomputation. National University of Ireland Maynooth*, 2.

Chung, W., & Contreras, M. (2011). Forest Transportation Planning Under Multiple Goals Using Ant Colony Optimization. *Ant Colony Optimization - Methods and Applications,* 15: 221-236.

Chung, W., & Sessions, J. (2001, December). NETWORK 2001—transportation planning under multiple objectives. In Proceedings of the *International Mountain Logging and 11th Pacific Northwest Skyline Symposium,* 194-200.

Chung, W., & Sessions, J. (2003). NETWORK 2000, a program for optimizing large fixed and variable cost transportation problems. *In Systems Analysis in Forest Resources* (pp. 109-120). Springer, Dordrecht.

Cleophas, F., Musta, B., How, P. M., & Bidin, K. (2017). Runoff and Soil Erosion in Selectively-logged Over Forest, Danum Valley Sabah, Malaysia. *Transactions on Science and Technology,* 4(4): 449-459.

Cleuren, H. (2001). Paving the road for forest destruction: key actors and driving forces of tropical deforestation in Brazil, Ecuador and Cameroon. *LUCC Report,* (4).

Conrad IV, J. L. (2019). Analysis of timber transportation accident frequency, location, and contributing factors in Georgia, USA 2006-2016. *International Journal of Forest Engineering*, 30(2): 109-120.

Contreras, M. A., Parrott, D. L., & Chung, W. (2016). Designing skid-trail networks to reduce skidding cost and soil disturbance for ground-based timber harvesting operations. *Journal of Forest Science*, 62(1): 48-58.

Contreras, M., & Chung, W. (2007). A computer approach to finding an optimal log landing location and analyzing influencing factors for ground-based timber harvesting. *Journal of Natural Resources Canada,* 292: 276-292.

Contreras, M., & Chung, W. (2007). A computer approach to finding an optimal log landing location and analyzing influencing factors for ground-based timber harvesting. *Canadian Journal of Forest Research*, 37(2): 276-292.

Daminov, I., Prokhorov, A., Caire, R., & Alvarez-Herault, M. C. (2021). Assessment of dynamic transformer rating, considering current and temperature limitations. *International Journal of Electrical Power & Energy Systems*, 129: 106886.

Danilović, M., Kosovski, M., Gačić, D., Stojnić, D., & Antonić, S. (2015). Damage to residual trees and regeneration during felling and timber extraction in mixed and pure beech stands. *Šumarski list*, 139(5-6): 253-262.

Davidovits, P. (2008). *Physics in Biology and Medicine, Third edition. Academic Press.* p. 10. ISBN 978-0-12-369411-9. Archived from the original on 2014-01-03. Retrieved 2016-02-23.

Davis, L. K., Norman, J. K., Pete B., Theodore E. H. (2015). Forest Management, To Sustain Ecological, Economic, and Social Values, Fourth Edition. *CBS Publishers & Distributors.* ISBN 978-81-239-2659-9. Retrieved 10-11-2020.

de Mello, K., Randhir, T. O., Valente, R. A., & Vettorazzi, C. A. (2017). Riparian restoration for protecting water quality in tropical agricultural watersheds. *Ecological Engineering*, 108: 514-524.

Deane, P. M., & Deane, P. M. (1979). *The first industrial revolution.* Cambridge University Press, Cambridge.

Demir, M. (2007). Impacts, management and functional planning criterion of forest road network system in Turkey. *Transportation Research Part A: Policy and Practice,* 41(1): 56-68.

Elias., Grahame, A., Kuswata, K., Machfudh., Art, K. (2001). Reduce Impact Logging Guideline for Indonesia. *Center for International Forestry Research.*

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., ... & Sullivan, C. A. (2017). Trees, forests and water: Cool insights for a hot world. *Global Environmental Change,* 43: 51-61.

Epstein, R., Weintraub, A., Sessions, J., Sessions, B., Sapunar, P., Nieto, E., ... & Musante, H. (2001, December). PLANEX: A system to identify landing locations and access. *In Proceedings of the International Mountain Logging and 11th Pacific Northwest Skyline Symposium,* 10-12.

Ezzati, S., Najafi, A., & Bettinger, P. (2016). Finding feasible harvest zones in mountainous areas using integrated spatial multi-criteria decision analysis. *Land Use Policy,* 59: 478-491.

Faizalhakim, M., A., S. (2017). *Climate and land use changes in relation to runoff variability in the Kelantan River Basin using SCS-CN and geospatial technology.* (Unpublished master dissertation) Universiti Putra Malaysia, Malaysia.

Farrelly, J. S., Clemons, C., Witkins, S., Hall, W., Christison-Lagay, E. R., Ozgediz, D. E., ... & Caty, M. G. (2017). Surgical tray optimization as a simple means to decrease perioperative costs. *Journal of Surgical Research,* 220: 320-326.

Ferreira da Silva, E., Da Silva, G. F., Orfanó Figueiredo, E., Breda Binoti, D. H., Ribeiro de Mendonça, A., Moreira Miquelino Eleto Torres, C., & Macedo Pezzopane, J. E. (2018). Allocation of storage yards in management plans in the Amazon by means of mathematical programming. *Forests,* 9(3): 127.

Finér, L., Čiuldienė, D., Lībieté, Z., Lode, E., Nieminen, M., Pierzgalski, E., ... & Sikström, U. (2018). WAMBAF–Good Practices for Ditch Network Maintenance to Protect Water Quality in the Baltic Sea Region*. Journal of Natural Resources Institute Finland.*

Fisher, P. F. (1991). First experiments in viewshed uncertainty: the accuracy of the viewshed area. *Photogrammetric engineering and remote sensing,* 57(10): 1321-1327.

Forestry Depatment Peninsular Malaysia (FDPM). (1999). *Forest road specification for Peninsular Malaysia.* Kuala Lumpur: Forest Department Headquarters Peninsular Malaysia.

Forestry Depatment Peninsular Malaysia (FDPM). (2001). Manual Perhutanan 2001. Jilid I. Kuala Lumpur: Forest Department Headquarters Peninsular Malaysia.

Forestry Depatment Peninsular Malaysia (FDPM). (2003). Manual Perhutanan 2003. Jilid III. *Forestry Department Peninsular Malaysia,* Kuala Lumpur.

Forestry Department Peninsular Malaysia (FDPM), 2010. *Garis Panduan Jalan Hutan 2010.* Kuala Lumpur: Forest Department Headquarters Peninsular Malaysia.

Forestry Depatment Peninsular Malaysia (FDPM). (2011). *Manual Perhutanan 2011*. Kuala Lumpur: Forest Department Headquarters Peninsular Malaysia.

Forestry Depatment Peninsular Malaysia (FDPM). (2013). Enhancing Forest biodiversity conservation through Central Forest Spine (CFS) programme: future challenges. *In Proceedings of the Conference on Perak's Central Forest Spine, Ipoh.* Kuala Lumpur, 13.

Forestry Department Peninsular Malaysia (FDPM). 2016. *Garis Panduan Penggunaan Jentera Log Fisher Dalam Pengusahasilan Hutan Darat Asli Dalam Hutan Simpanan Kekal.* Kuala Lumpur: Forest Department Headquarters Peninsular Malaysia.

Fotheringham, A. S., Brunsdon, C., & Charlton, M. (2003). Geographically weighted regression: the analysis of spatially varying relationships. *John Wiley & Sons.*

Fotheringham, A. S., Charlton, M., & Brunsdon, C. (1997). Two techniques for exploring non-stationarity in geographical data. *Geographical Systems,* 4(1): 59-82.

Frisk, M., Göthe-Lundgren, M., Jörnsten, K., & Rönnqvist, M. (2010). Cost allocation in collaborative forest transportation. *European Journal of Operational Research,* 205: (2),

Gan, K. S., Zairul, A. R., Geetha, R., & Khairul, M. (2021). Life Cycle Assessment on Log Harvesting from Natural Forest in Peninsular Malaysia. *Journal of Tropical Forest Science,* 33(2): 213-223.

George, S., & Binu, S. (2018). Vehicle Route Optimisation Using Artificial Bees Colony Algorithm and Cuckoo Search Algorithm-A Comparative Study. *International Journal of Applied Engineering Research,* 13(2): 953-959.

Getis, A. (2010). Spatial autocorrelation. In Handbook of applied spatial analysis (pp. 255-278). *Springer,* Berlin, Heidelberg.

Gomez, A., Imran, A., & Salhi, S. (2013). Solution of classical transport problems with bee algorithms. *International Journal of Logistics Systems and Management,* 15(2-3): 160-170.

Görgens, E. B., Mund, J. P., Cremer, T., de Conto, T., Krause, S., Valbuena, R., & Rodriguez, L. C. E. (2020). Automated operational logging plan considering multi-criteria optimization. *Computers and Electronics in Agriculture,* 170: 105253.

Greulich, F. E. (1997). Optimal Economic Selection of Road Design Standards for Timber Harvesting Operations—A Corrected Analytical Model. *Forest science,* 43(4): 589-594.

Guangda, L., (2007). Development of Forest Engineering in China—Looking Ahead Ten Years. *Journal of Forest Engineering,* 10(1), 13-20.

Guedes Pinto, L. F., Stanley, P., Gomes, P. C., & Robinson, D. (2008). Experience with NTFP certification in Brazil. *Forests, Trees and Livelihoods,* 18(1): 37-54.

Gülci, N., Akay, A. E., & Erdaş, O. (2020). Optimal planning of timber extraction methods using analytic hierarchy process. *European Journal of Forest Research,* 139(4): 647-654.

Hacisalihoğlu, S., Gümüş, S., Kezik, U., & Karadağ, H. 2018. Impact of forest road construction on topsoil erosion and hydro-physical soil properties in a semi-arid mountainous ecosystem in Turkey. *Polish Journal of Environmental Studies,* 28(1): 113-121.

Han, H., Chung, W., She, J., Anderson, N., & Wells, L. (2018). Productivity and costs of two beetle-kill salvage harvesting methods in northern Colorado. *Forests,* 9(9): 572.

Han, H., Chung, W., Wells, L., & Anderson, N. (2018). Optimizing biomass feedstock logistics for forest residue processing and transportation on a tree-shaped road network. *Forests,* 9(3), 121.

Hasan, E., Tarhule, A., Kirstetter, P. E., Clark III, R., & Hong, Y. (2018). Runoff sensitivity to climate change in the Nile River Basin. *Journal of hydrology,* 561: 312-321.

Hernina, R., Rosyidy, M. K., Ashilah, Q. P., Bassayev, M. H., Huda, D. N., Pratama, A. A., & Putra, T. A. (2021, March). Unmanned aerial vehicle (UAV) application for supporting climate change readiness program in depok municipality, Indonesia. *In IOP Conference Series: Earth and Environmental Science,* 683(1), 012106.

Higuchi, N., 1994. Utilization and management of forest resources of the tropical moist forests. *Acta Amaz,* 24: 275-288.

Hobiger, T., & Jakowski, N. (2017). Atmospheric signal propagation. In Springer handbook of global navigation satellite systems. *Springer*, *Cham,* 165-193.

Höhle, J., & Höhle, M. (2009). Accuracy assessment of digital elevation models by means of robust statistical methods. *Journal of Photogrammetry and Remote Sensing,* 64(4): 398-406.

Hosseini, E. (2017). Three new methods to find initial basic feasible solution of transportation problems. *Applied Mathematical Sciences,* 11(37): 1803-1814.

Hosseini, S. A., Mazrae, M. R., Lotfalian, M., & Parsakhoo, A. (2012). Designing an optimal forest road network by consideration of environmental impacts in GIS. *Journal of Environmental Engineering and Landscape Management,* 20(1): 58-66.

Howell, R., Aust, W. M., & Bolding, M. C. (2019). Forestry best management practices and modeled erosion on planned and logger-selected bladed skid trails in the Ridge and Valley region, Virginia, USA. *International Journal of Forest Engineering,* 30(2): 68-75.

Hrůza, P., Mikita, T., Tyagur, N., Krejza, Z., Cibulka, M., Procházková, A., & Patočka, Z. (2018). Detecting forest road wearing course damage using different methods of remote sensing. *Remote Sensing,* 10(4): 492.

Imaizumi, F., & Sidle, R. C. (2021). Effects of terrain on the occurrence of debris flows after forest harvesting. *Geografiska Annaler: Series A, Physical Geography,* 1-14.

Irawanti, S., Race, D., Stewart, H., Parlinah, N., & Suka, A. P. (2017). Understanding the timber value chain in community-based forestry in Indonesia: Analysis of sengon in central Java. *Journal of Sustainable Forestry,* 36(8): 847-862.

Ismail, A. H., Aziz, N. S., Zainal, Z. F., Abdullahi, Z. H., Haziqah, M. T. F., & Maznah, W. W. (2021, March). Zooplankton study in Bukit Merah Reservoir, Malaysia: a preliminary biodiversity assessment. *In IOP Conference Series: Earth and Environmental Science,* 711(1):012003.

Jamhuri J. (2017). *Assessing Relationship Between Mammal Occurrence and Forest Vegetation Structure by Using GWR.* (Unpublished master dissertation) Universiti Putra Malaysia, Malaysia.

.

Jamhuri, J., Samantha, L. D., Ling, S., & Norizah, K. (2018). Selective logging causes the decline of large-sized mammals including those in unlogged patches surrounded by logged and agricultural areas. *Biological Conservation,* 227: 40-47.

Jegatheswaran, R., Ramasamy, G., Ioras, F., & Senin, A. L. (2017). Environmental and Economic Impact of Using Logging Residues as Bioenergy: The Case of Malaysia. *BioResources,* 12(4): 7268-7282.

Jin, Y., Sun, Y., & Ma, H. (2018). A developed artificial bee colony algorithm based on cloud model. *Mathematics,* 6(4): 61.

Joost-Gaugier, Christiane L. (2006), *Measuring Heaven: Pythagoras and his Influence on Thought and Art in Antiquity and the Middle Ages, Ithaca.* New York: Cornell University Press, ISBN 978-0-8014-7409-5

Jude, O., Ifeanyichukwu, O., Ihuoma, I., & Akpos, E. (2017). A new and efficient proposed approach to find initial basic feasible solution of a transportation problem. *American Journal of Applied Mathematics and Statistics,* 5(2): 54-61.

Kamaruzaman J (1988). Soil compaction from off-road transportation machine on tropical hill forest land. *Pertanika,* 11(1): 31-37.

Kamaruzaman J (1991). Effects of tracked and rubber-tyred logging machines on soil physical properties of the Berkelah Forest Reserve, Malaysia. *Pertanika,* 14(3): 265-276.

Kamaruzaman J, Nik Muhamad M, Desa A (1986). Effects of logging roads on erosion and sedimentation. In Proceeding of Workshop on Roading and Development Activities in Relation to Soil Erosion and Sedimentation Control in Watersheds, *ed. Saplaco, S.R., Baltazar, E.M.* Jakarta, Indonesia. 20 – 26 July.

Kamaruzaman, J. (2008). Construction of New Forest Roads in Malaysia Using a GIS-Based Decision Support System. *Computer and Information Science,* 1(3): 48-59.

Kamaruzaman, J., & Dahlan, H. (2008). Sustainable forest management practices and environmental protection in Malaysia. *Transactions on Environment and Development,* 4(3): 191-199.

Kamaruzaman, J., & Shah Nik Mustafa, N. M. (1996). Guidelines on logging practices for the hill forest of Peninsular Malaysia. *Food Agriculture Organization - Forestry Paper,* 89-100.

Kamaruzaman, J., & Taha, D. H. D. H. (2008). Sustainable forest management practices and environmental protection in Malaysia. *Transactions on Environment and Development,* 4(3): 191-199.

Kamil, E. A., Takaijudin, H., & Hashim, A. M. (2020, August). Distribution of Mangroves in Kedah, Malaysia: A Remote Sensing and Ground-Truth Based Assessment. *In IOP Conference Series: Earth and Environmental Science*, 549(1): 012005.

Kanazawa, K. (2017). Sustainable harvesting and conservation of agarwood: A case study from the Upper Baram River in Sarawak, Malaysia. *Tropics,* 25(4): 139-146.

Kasran, B. (1988). Effect of logging on sediment yield in a hill dipterocarp forest in Peninsular Malaysia. *Journal of Tropical Forest Science,* 56-66.

Kassim, S., Ismail, R., Ismail, S., & Ismail, F. (2018, January). Timber Harvesting Damage Prediction for Sustainable Forest Management*. In Proceedings of the 12th International Conference on Ubiquitous Information Management and Communication,* 1-5.

Kaya, A., Bettinger, P., Boston, K., Akbulut, R., Ucar, Z., Siry, J., ... & Cieszewski, C. (2016). Optimisation in forest management. *Current Forestry Reports,* 2(1): 1-17.

Kennard, D. K., Gould, K., Putz, F. E., Fredericksen, T. S., & Morales, F. (2002). Effect of disturbance intensity on regeneration mechanisms in a tropical dry forest. *Forest ecology and management,* 162(2-3): 197-208.

Khalit, S. I., Lion, M., Nik, A. R., Mamat, H., OmarHusaini, M. T., Rodzi, M. A., & Ghiasi, V. (2011). Pre-Harvesting Modeling of Soil Erosion Using Modified

Soil Loss Equation (MSLE) In Tropical Catchment Forest. *Electronic Journal of Geotechnical Engineering,* 16.

Kirillova, S. S., Borisov, A. N., & Bezrukov, B. A. (2019, November). Transformation of the structure of the timber industry complex on the path to new industrialization. *In IOP Conference Series: Earth and Environmental Science*,392(1): 012061.

Kizha, A. R., & Han, H. S. (2016). Processing and sorting forest residues: Cost, productivity and managerial impacts. *Biomass and Bioenergy,* 93: 97-106.

Knowler, D., Page, A., Cooper, A., & Araujo, H. A. (2017). Valuing a Logging Externality: Loss of the Water Purification Service of Temperate Coastal Rainforests. *Water Economics and Policy,* 03(02): 1650032.

Kooshki, M., Hayati, E., Rafatnia, N., & Ahmadi, M. T. (2012). Using GIS to evaluate and design skid trails for forest products. *Taiwan Journal of Forest Science,* 27(1): 117-124.

Kramer, O. (2017). *Genetic algorithm essentials (Vol. 679)*. Springer.

Kufre, O. K. O. N. (2018). Sustainability of wood harvesting in tropical rainforest of Nigeria. *Eurasian Journal of Forest Science,* 6(2): 44-55.

Kukulska, A., Salata, T., Cegielska, K., & Szylar, M. (2018). Methodology of evaluation and correction of geometric data topology in QGIS software. *Acta Scientiarum Polonorum. Formatio Circumiectus,* 17(1): 137-150.

Lassausaie, J., Bret, A., Bouapao, X., Chanthavong, V., Castonguay-Vanier, J., Quet, F., ... & Bouchard, B. (2015). Tuberculosis in Laos, who is at risk: the mahouts or their elephants?. *Epidemiology & Infection,* 143(5): 922-931.

Lastra, F., Meneses, N., Altamirano, E., Raymundo, C., & Moguerza, J. M. (2019, July). *Production management model based on lean manufacturing for cost reduction in the timber sector in Peru. In International Conference on Applied Human Factors and Ergonomics* (pp. 467-476). Springer.

Le, Q. H., Van Nguyen, T. H., Do, M. D., Le, T. C. H., Nguyen, H. K., & Luu, T. B. (2018). *TXT-tool 1.084-3.1: landslide susceptibility mapping at a regional scale in Vietnam. In Landslide dynamics: ISDR-ICL landslide interactive teaching tools* (pp. 161-174). Springer.

Lee, H. S. (1981). *Silvicultural management options in the mixed dipterocarp forests of Sarawak.* (Unpublished master dissertation) Australian National University, Australia.

Lestari, B. D., Hanafiah, D. S., Sahar, A., & Zaitunah, A. (2021, March). Timber transportation using two types of trucks in industrial plantation forests, North Sumatra, Indonesia. *In IOP Conference Series: Materials Science and Engineering*, 1122(1):012005.

Lijewski, P., Merkisz, J., Fuć, P., Ziółkowski, A., Rymaniak, Ł., & Kusiak, W. (2017). Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport. *European Journal of Forest Research,* 136(1): 153-160.

Lim, K., & Yusoff, M. (2017). Comparative study of carbon emission changes from different logging techniques in inland production forest in Pahang. *The Malaysian Forester,* 80(1): 111-124.

Lopez, J., De La Torre, R., & Cubbage, F. (2010). Effect of land prices, transportation costs, and site productivity on timber investment returns for pine plantations in Colombia. *New Forests,* 39(3), 313-328.

López-Locés, M. C., Ríos-Mercado, R. Z., Aguirre-Calderón, O. A., & González-Velarde, J. L. (2020). Towards sustainable timber harvesting of homogeneous stands: dynamic programming in synergy with forest growth simulation. *Springer,* 28: 575–598.

Loukes, D. K., & McLaughlin, J. (1991). GIS and transportation: Canadian perspective*. Journal of Surveying Engineering*, 117(3): 123-133.

Luostarinen, K., & Verkasalo, E. (2000). Birch as sawn timber and in mechanical further processing in Finland. A literature study. *Journal of The Finnish Forest Research Institute,* 1-40.

Malladi, K. T., & Sowlati, T. (2017). Optimization of operational level transportation planning in forestry: a review. *International Journal of Forest Engineering,* 28(3): 198-210.

Mar, K. U. (2002). *The demography and life history strategies of timber elephants in Myanmar* (Unpublished doctoral dissertation), University of London, London.

Mashor, M.J., Jupiri, T., Nizam, M.S. & Ismail, P. (2017). Impact of Harvesting Methods on Biomass and Carbon Stock in Production Forest of Sabah, Malaysia. *Journal of Advance Management Research,* 5(4): 2393-9664.

Masumian, A., Naghdi, R., & Zenner, E. K. (2017). Effectiveness of water diversion and erosion control structures on skid trails following timber harvesting. *Ecological Engineering,* 105: 370-378.

McCracken, S. D., Brondizio, E. S., Nelson, D., Moran, E. F., Siqueira, A. D., & Rodriguez-Pedraza, C. (1999). Remote sensing and GIS at farm property level: Demography and deforestation in the Brazilian

Amazon. *Photogrammetric Engineering and Remote Sensing,* 65: 1311-1320.

McEwan, A., Brink, M., & van Zyl, S. (2013). Produced by Forest Engineering Southern Africa (FESA) and The Institute for Commercial Forestry Research (ICFR). *Institute for Commercial Forestry Research Bulletin,* (2): 1-149.

McFero Grace III, J., Skaggs, R. W., & Cassel, D. K. (2006). Soil physical changes associated with forest harvesting operations on an organic soil. *Soil Science Society of America Journal,* 70(2): 503-509.

Meena, M., & Jaipal, A. K. (2020). A perspective study on seasonal threats of blackbuck, Antilope cervicapra in Marwar region of Rajasthan, India. *Journal of Experimental Zoology India,* India, 23(2), 1957-1963.

Melander, L., & Ritala, R. (2020). Separating the impact of work environment and machine operation on harvester performance. *European Journal of Forest Research,* 139(6): 1029-1043.

Melemez, K. (2015). Risk factor analysis of fatal forest harvesting accidents: A case study in Turkey. *Safety science,* 79: 369-378.

Mercier, P., Aas, G., & Dengler, J. (2019). Effects of skid trails on understory vegetation in forests: a case study from Northern Bavaria (Germany). *Forest Ecology and Management,* 453: 117579.

Mohd Hasmadi, I., Kamaruzaman, J., & Muhamad Azizon, J. (2008). Forest Road Assessment in Ulu Muda Forest Reserve, Kedah, Malaysia. *Modern Applied Science,* 2(4), 100-108.

Mohd Hasmadi. I., & Norizah, K. (2010). Soil disturbance from different mechanised harvesting in hill tropical forest, Peninsular Malaysia. *Journal of Environmental Science and Engineering,* 4(1): 34.

Mohd. Hasmadi, I, Kamaruzaman, J and 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. H. (2009). Planning of Access Road Using Satellite Technology and Best Path Modeling. *Modern Applied Science*, 3(3): 83-176.

Mohd Hasmadi, M., & Taylor, J. C. (2008). Sensitivity analysis of an optimal access road location in hilly forest area: A GIS approach. *Am. J. Appl. Sci*, 5(12), 1686-1692.

Mokhirev, A., & Rukomojnikov, K. (2019, August). Grapho-analytical modelling of technological chain of logging operations in dynamic natural and production conditions. *In IOP Conference Series: Earth and Environmental Science*, 316(1):012039.

Monti, C. A., Gomide, L. R., Oliveira, R. M., & FranÇa, L. C. (2020). Optimization of Wood Supply: The Forestry Routing Optimization Model. *Anais da Academia Brasileira de Ciências,* 92(3): 1-17.

Müller, F., & Hanewinkel, M. (2018). Challenging the assumptions of a standard model: How historical triggers in terms of technical innovations, labor costs and timber price change the land expectation value. *Forest Policy and Economics,* 95: 46-56.

Murmura, F., & Bravi, L. (2018). Additive manufacturing in the wood-furniture sector. *Journal of Manufacturing Technology Management,* 29(2): 350-371

Mutati, K., Kitheka, J. U., & Otieno, H. (2018). Sand gradation in seasonal rivers and their suitability for construction of sand dams in Kitui South, Kenya. *Journal of Environment and Earth Science*, 8(6): 97-109.

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 Shafaroud Watershed-Guilan. *In Proceeding of 7th Annual Asian Conference and Exhibition on Geospatial Information, Technology and Applications,* 9.

Najafi, A., & Richards, E. W. (2013). Designing a forest road network using mixed integer programming. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering,* 34(1): 17-30.

Nawaz, M. F., Bourrie, G., & Trolard, F. (2013). Soil compaction impact and modelling. A review. *Agronomy for Sustainable Development,* 33(2): 291-309.

Negishi, J. N., Sidle, R. C., Noguchi, S., Nik, A. R., & Stanforth, R. (2006). Ecological roles of roadside fern (Dicranopteris curranii) on logging road recovery in Peninsular Malaysia: Preliminary results. *Forest Ecology and Management,* 224(1-2): 176-186.

Nitanan, K. M., Shuib, A., Sridar, R., Kunjuraman, V., Zaiton, S., & Herman, M. A. (2020). The total economic value of forest ecosystem services in the tropical forests of Malaysia. *International Forestry Review,* 22(4): 485-503.

Noraida, A. W., Abdul-Rahim, A. S., & Mohd-Shahwahid, H. O. (2018). Sawn Timber Market and The Impact of Sustainable Forest Management Practices in Peninsular Malaysia. *Journal of Tropical Forest Science,* 9-24.

Noraishah, S., Azian, M., Samsudin, M., Ismail, P., K, A. R., S, N. H. Z., & Rahim, A. O. (2015). A Comparative Study of Carbon Stock Changes from Different Logging Techniques in Ulu Jelai Forest Reserve , Kuala Lipis , Pahang, *Universiti Malaysia Kelantan (UMK),* 3: 98-102.

Norizah, K., & Chung, W. (2014). Timber harvest area planning in Malaysia using a network algorithm. In Proceedings of the 37th Council on Forest Engineering Annual Meeting. Moline, Illinois (pp. 1-7).

Norizah, K., Mohd Hasmadi, I. M., Kamaruzaman, J., & Alias, M. S. (2012). Operational efficiency of Rimbaka timber harvester in hilly tropical forest. *Journal of Tropical Forest Science,* 368-378.

Norizah, K., Mohd. Hasmadi, I, Kamaruzaman, J., & Alias, M., S. (2011). Evolution and development of forest harvesting in Peninsular Malaysia. *The Malaysian Forester,* 74(2): 79-102.

Norizah, K., Mohd-Hasmadi, I., Husna, S., & Chung, W. (2016). Log Hauling Productivity in Timber Harvesting Operation in Peninsular Malaysia Forest. *Journal of Tropical Forest Science,* 207-216.

Norizah, K., Mohd Hasmadi, I., & Zaki, P. H. (2011). Forest Land Use Development and its Benefits toIndigenous Peoples*. Perspektif: Jurnal Sains Sosial dan Kemanusiaan,* 3(1): 24-38.

Nüchel, J., Bøcher, P. K., & Svenning, J. C. (2019). Topographic slope steepness and anthropogenic pressure interact to shape the distribution of tree cover in China. *Applied Geography,* 103: 40-55.

Olofsson, P., Foody, G. M., Stehman, S. V., & Woodcock, C. E. (2013). Making better use of accuracy data in land change studies: Estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment,* 129: 122-131.

Ong, C., Deprés, G., Hollebecq, J. E., Shaiffudin Hishamudin, M. O., Kamaruddin, N., Anugerah, A. R., ... & Roda, J. M. (2020). Quantifying the effect of landscape structure on transport costs for biorefinery of agricultural and forestry wastes in Malaysia. *GCB Bioenergy,* 12(11): 910-922.

Özbakir, L., Baykasoğlu, A., & Tapkan, P. (2010). Bees algorithm for generalized assignment problem*. Applied Mathematics and Computation,* 215(11), 3782-3795.

Pakhriazad, H. Z., Shinohara, T., Nakama, Y., & Yukutake, K. (2004). A Selective Management System (SMS): A case study in the implementation of SMS in managing the dipterocarp forests of Peninsular Malaysia. *Kyushu Journal of Forest Research,* 57(3): 39-44.

Parker, R., & Bowers, S. (2006). *Timber harvesting options for woodland owners.* Oregon State University, United State of America. Retrieved 27 May 2021.

Parsakhoo, A., & Jajouzadeh, M. (2016). Determining an optimal path for forest road construction using Dijkstra's algorithm. *Journal of Forest Science,* 62(6): 264-268.

Parsakhoo, A., & Mostafa, M. (2015). Road network analysis for timber transportation from a harvesting site to mills (Case study : Gorgan county - Iran), 2015(12): 520-525.

Pearce, A. J., & Hodgkiss, P. D. (1987). Erosion and sediment yield from a landing failure after a moderate rainstorm, Tairua Forest. *New Zealand Forestry,* 32(3): 19-22.

Petković, V., & Potočnik, I. (2018). Planning forest road network in natural forest areas: a case study in northern Bosnia and Herzegovina. *Croatian Journal of Forest Engineering: Journal for Theory and Application of Forestry Engineering,* 39(1): 45-56.

Peyrov, S., Najafi, A., & Nourodini, A. R. (2016). Predicting the earthwork width and determining the annual growth loss due to forest road construction using artificial neural network and ArcGIS. *Journal of Forest Science,* 62(7): 337-344.

Pham, D. T., & Ghanbarzadeh, A. (2007, July). Multi-objective optimisation using the bees algorithm. *In 3rd International Virtual Conference on Intelligent Production Machines and Systems,* 6.

Pham, D. T., Ghanbarzadeh, A., Koc, E., Otri, S., Rahim, S., & Zaidi, M., (2005). The bees algorithm. *Technical Note, Manufacturing Engineering Centre,* Cardiff University, UK.

Pinard, M. A., Putz, F. E., Tay, J., & Sullivan, T. E. (1995). Creating timber harvest guidelines for a reduced-impact logging project in Malaysia. *Journal of Forestry,* 93(10): 41-45.

Piragnolo, M., Grigolato, S., & Pirotti, F. (2019). Planning Harvesting Operations in Forest Environment: Remote Sensing for Decision Support. ISPRS Annals of Photogrammetry, *Remote Sensing & Spatial Information Sciences,* 4.

Pirasteh, S., Shamsipour, G., Liu, G., Zhu, Q., & Chengming, Y. E. (2020). A new algorithm for landslide geometric and deformation analysis supported by digital elevation models. *Earth Science Informatics,* 13(2): 361-375.

Pokharel, R., Grala, R. K., Grebner, D. L., & Cooke, W. H. (2019). Mill willingness to use logging residues to produce electricity: A spatial logistic regression approach. *Forest Science,* 65(3): 277-288.

Potocnik, I. (2003). Forest Road Formation Width as an Indicator of Human Impact on Forest Environment. *Ekologia(Bratislava) / Ecology(Bratislava)*, 22(3): 298-304.

Prandi, F., Magliocchetti, D., Poveda, A., De Amicis, R., Andreolli, M., & Devigili, F. (2016). New Approach for forest inventory estimation and timber harvesting planning in mountain areas: the SLOPE project. International Archives of the Photogrammetry, *Remote Sensing & Spatial Information Sciences,* 41.

Putz, F. E., Sist, P., Fredericksen, T., & Dykstra, D. (2008). Reduced-impact logging: challenges and opportunities. *Forest ecology and management,* 256(7): 1427-1433.

Quintero-Méndez, M. A., & Jerez-Rico, M. (2017). Heuristic forest planning model for optimizing timber production and carbon sequestration in teak plantations. *iForest-Biogeosciences and Forestry,* 10(2): 430.

Rand, J., Castro Rodriguez, P., Tarp, F., & Trifkovic, N. (2019). The governance of global value chains, the state, and small businesses: The case of timber in Myanmar (No. 2019/78). *WIDER Working Paper.*

Ratnasingam, J., Ark, C. K., Mohamed, S., Liat, L. C., Ramasamy, G., & Senin, A. L. (2017). An analysis of labor and capital productivity in the Malaysian timber sector. *BioResources,* 12(1): 1430-1446.

Razali, A., Syed Ismail, S. N., Awang, S., Praveena, S. M., & Zainal Abidin, E. (2020). The impact of seasonal change on river water quality and dissolved metals in mountainous agricultural areas and risk to human health. *Environmental Forensics,* 21(2): 195-211.

Razali, N., Kamarudin, N., & Mohd. Hasmadi, I. (2014). Examining the rate of vegetation diversity under abandoned skid trails in peninsular Malaysia forest. *Journal of Agricultural and Crop Research,* 2(8): 165-172.

Rhyma, P. P., Norizah, K., Hamdan, O., Faridah-Hanum, I., & Zulfa, A. W. (2020). Integration of normalised different vegetation index and soil-adjusted vegetation index for mangrove vegetation delineation. *Remote Sensing Applications: Society and Environment,* 17: 100280.

Riggert, R., Fleige, H., Kietz, B., Gaertig, T., & Horn, R. (2017). Dynamic stress measurements and the impact of timber harvesting on physical soil properties. *Australian Forestry,* 80(4): 255-263.

Rominiyi, O. L., Adaramola, B. A., Ikumapayi, O. M., Oginni, O. T., & Akinola, S. A. (2017). Potential utilization of sawdust in energy, manufacturing and agricultural industry; waste to wealth. *World Journal of Engineering and Technology,* 5(03): 526.

Saad, N., Norizah, K., Zulfa, A. W., & Mohdhafizal, I. (2018). Mobile phone and tablet assisted positioning device for trekkers: The case for sultan Idris shah forestry education centre (SISFEC). *The Malaysian Forester,* 81(2): 175-183.

Saadun, N., Khamurudin, M. N., Azhar, B., Omar, H., & Hariz, M. H. (2019). Export Performance of Tropical Timber Products Certified by The Malaysian Timber Certification Scheme. *Journal of Sustainability Science and Management,* 14(5): 115-127.

Safa, M. S., Ibrahim, Z., & Abdu, A. (2004). Potentialities of new line planting technique of Enrichment planting in Peninsular Malaysia: A review of resource sustainability and economic feasibility.

Safari, A., Kavian, A., Parsakhoo, A., Saleh, I., & Jordán, A. (2016). Impact of different parts of skid trails on runoff and soil erosion in the Hyrcanian forest (northern Iran). *Geoderma,* 263: 161-167.

Safiah, Y. M. Y., & Rodziah, H. (2010, August). Optimization of the route of the forest logging road. *In 2010 International Conference on Chemistry and Chemical Engineering*, 249-252.

Saharudin, A., Azmi, H. and Mohd-Zamri, R. (2004). Kajian mengenai kos dan produktiviti sistem pengusahasilan hutan bukit di Semenanjung Malaysia, *Jabatan Perhutanan Semenanjung Malaysia:* Kuala Lumpur.

Saifullah, M. K., Kari, F. B., & Othman, A. (2018). Income dependency on non-timber forest products: an empirical evidence of the indigenous people in Peninsular Malaysia. *Social Indicators Research,* 135(1): 215-231.

Sales, A., Gonzáles, D. G. E., Martins, T. G. V., Silva, G. C. C., Spletozer, A. G., Telles, L. A. D. A., ... & Lorenzon, A. S. (2019). Optimization of Skid Trails and Log Yards on the Amazon Forest. *Forests,* 10(3): 252.

Samsudin, M. F., Amin, M. F. M., Omar, S. A. S., Rasat, M. S. M., & Salam, M. A. (2020, August). Analysis of Water Stress Index (WSI) for District Surrounding Ulu Sat Forest Reserve, Kelantan, Malaysia. *In IOP Conference Series: Earth and Environmental Science,* 549(1):012015.

Santos de Freitas, R. L. (2019). *Multi-camera Surveillance System for Time and Motion Studies of Timber Harvesting Operations*. (Unpublished master dissertation). University of Kentucky, United State of America.

Santosh K. & Suresh, N. (2019). Optimisation of Vehicle Routing Problem for School Buses Using Honey Bee Algorithm. International *Journal of Mechanical Engineering and Technology,* 10 (8): 345-355.

Savenkova, N., Zashihina, I., Savenkov, D., Derbin, M., & Chelysheva, T. (2019). Studying the impact of heavy vehicles for timber transportation on the road with the use of thetotal load equivalency factor*. International Multidisciplinary Scientific GeoConference: SGEM,* 19(3.2): 843-851.

Schulz, H. (1993). The development of wood utilization in the 19th, 20th and 21st centuries. *The Forestry Chronicle,* 69(4): 413-418.

Sessions, J. (2007). Forest road operations in the tropics. Berlin, Heidelberg, New York: *Springer.*

Shabaev, A., Sokolov, A., Urban, A., & Pyatin, D. (2020). Optimal Planning of Wood Harvesting and Timber Supply in Russian Conditions. *Forests,* 11(6): 662.

She, J., Chung, W., & Kim, D. (2018). Discrete-event simulation of ground-based timber harvesting operations. *Forests,* 9(11): 683.

Shi, W. (1998). A generic statistical approach for modelling error of geometric features in GIS. *International Journal of Geographical Information Science,* 12(2): 131-143.

Shuhaimi-Othman, M., Mushrifah, I., Lim, E. C., & Ahmad, A. (2008). Trend in metals variation in tasik Chini, Pahang, Peninsular Malaysia. *Environmental Monitoring and Assessment,* 143(1): 345-354.

Solgi, A., Naghdi, R., Tsioras, P. A., Ilstedt, U., Salehi, A., & Nikooy, M. (2017). Combined effects of skidding direction, skid trail slope and traffic frequency on soil disturbance in north mountainous forest of Iran. Croatian Journal of Forest Engineering: *Journal for Theory and Application of Forestry Engineering,* 38(1): 97-106.

Soman, H., Kizha, A. R., & Roth, B. E. (2019). Impacts of silvicultural prescriptions and implementation of best management practices on timber harvesting costs. *International Journal of Forest Engineering,* 30(1): 14-25.

Sun, B., Chen, X., & Zhou, Q. (2017*). Analyzing the uncertainties of ground validation for remote sensing land cover mapping in the era of big geographic data. In Spatial Data Handling in Big Data Era* (pp. 31-38). Springer, Singapore.

Susilawati, D., Kanowski, P., Setyowati, A. B., Resosudarmo, I. A. P., & Race, D. (2019). Compliance of smallholder timber value chains in East Java with Indonesia's timber legality verification system. *Forest Policy and Economics,* 102: 41-50.

Švajlenka, J., Kozlovská, M., & Spišáková, M. (2017). The benefits of modern method of construction based on wood in the context of sustainability. *International Journal of Environmental Science and Technology,* 14(8): 1591-1602.

Szeto, W. Y., Jiang, Y., Wang, D. Z. W., & Sumalee, A., (2015). A Sustainable Road Network Design Problem with Land Use Transportation Interaction over Time. *Networks and Spatial Economics,* 15(3), 791-822. https://doi.org/10.1007/s11067-013-9191-9

Tang, J., Gao, F., Liu, F., Zhang, W., & Qi, Y. (2019). Understanding spatio-temporal characteristics of urban travel demand based on the combination of GWR and GLM. *Sustainability,* 11(19): 5525.

Tavankar, F., Bonyad, A. E., & Majnounian, B. (2015). Affective factors on residual tree damage during selection cutting and cable-skidder logging in the Caspian forests, Northern Iran. *Ecological Engineering,* 83: 505-512.

Tavankar, F., Picchio, R., Nikooy, M., Jourgholami, M., Latterini, F., & Venanzi, R. (2021). Effect of soil moisture on soil compaction during skidding operations in poplar plantation. *International Journal of Forest Engineering,* 1-12.

Tee, S. L., Samantha, L. D., Kamarudin, N., Akbar, Z., Lechner, A. M., Ashton-Butt, A., & Azhar, B. (2018). Urban forest fragmentation impoverishes native mammalian biodiversity in the tropics. *Ecology and Evolution,* 8(24): 12506-12521.

Thang, H. C. (1987). Forest management systems for tropical high forest, with special reference to Peninsular Malaysia. *Forest Ecology and Management,* 21(1-2): 3-20.

Thang, H. C., & Chappell, N. A. (2005). Minimising the hydrological impact of forest harvesting in Malaysia's rainforests. *Cambridge University Press*, 36(1): 852-866.

Tian, S., Liu, Q., Xu, W., & Yan, J. (2013, October). *A discrete hybrid bees algorithm for service aggregation optimal selection in cloud manufacturing.* In International conference on intelligent data engineering and automated learning (pp. 110-117). Springer, Berlin, Heidelberg.

Väätäinen, K., Laitila, J., Anttila, P., Kilpeläinen, A., & Asikainen, A. (2020). The influence of gross vehicle weight (GVW) and transport distance on timber trucking performance indicators-Discrete event simulation case study in Central Finland. *International Journal of Forest Engineering,* 1-15.

Varol, T., Ertuğrul, M., Özel, H. B., Emir, T., & Çetin, M. (2019). The effects of rill erosion on unpaved forest road. *Applied Ecology and Environmental Research,* 17(1): 825-839.

Vasiliev, I. R. (2020). Visualization of spatial dependence: an elementary view of spatial autocorrelation. *In Practical handbook of spatial statistics,* 17-30.

Venn, T. J., & Whittaker, K. (2003). Potential specialty timber markets for hardwoods of western Queensland, Australia. Small-scale Forest Economics*, Management and Policy,* 2(3): 377-395.

Verhulst, M. (1958). Joint optimization of long-range planning and short-range programming. *Operations Research,* 6(4): 580-590.

Vijith, H., Hurmain, A., & Dodge-Wan, D. (2018). Impacts of land use changes and land cover alteration on soil erosion rates and vulnerability of tropical mountain ranges in Borneo. *Remote Sensing Applications: Society and Environment,* 12: 57-69.

Wagner, S., Fischer, H., & Huth, F. (2011). Canopy effects on vegetation caused by harvesting and regeneration treatments. *European Journal of Forest Research,* 130(1): 17-40.

Wan, M., & Borhan, M. (2010). Managing second rotation natural tropical rain forests under the selective management system: the case of Dungun Timber Complex, Terengganu, *Malaysia. Malaysian Forester,* 73(2): 227-238.

Wang, L. (1997). Assessment of animal skidding and ground machine skidding under mountain conditions. *Journal of Forest Engineering,* 8(2): 57-64.

Wang, L. (2000). Environmentally sound timber extracting techniques for small tree harvesting. *Journal of Forestry Research,* 11(4): 269-272.

Wang, Y., Zhu, Y., Wang, M., Jin, S., & Rao, Q. (2020). Atmospheric Refraction Calibration of Geometric Positioning for Optical Remote Sensing Satellite. *Geoscience and Remote Sensing Letters,* 17(12): 2130-2134.

Webb, A. A., Dragovich, D., & Jamshidi, R. (2012). Temporary increases in suspended sediment yields following selective eucalypt forest harvesting. *Forest ecology and management,* 283: 96-105.

Widayani, P., Wibowo, T. W., Pramono, B. A. S., Nur'aini'Afifah, Z., Meikasari, A. D., & Firdaus, M. R. (2019, December). Determination of evacuation routes based on spatial characteristic and least cost path for landslide in Bruno, Purworejo, Central Java. In Sixth International Symposium on LAPAN-IPB Satellite. *International Society for Optics and Photonics,* 11: 11372.

Wikipedia. (2020). Harga minyak Malaysia. Wikipedia. https://ms.wikipedia.org/wiki/Harga_minyak_Malaysia. Retrieved 4 June 2021.

Wong, M. K., Selliah, P., Ng, T. F., Amir Hassan, M. H., Van Ranst, E., & Inubushi, K. (2020). Impact of agricultural land use on physicochemical properties of soils derived from sedimentary rocks in Malaysia. *Soil Science and Plant Nutrition,* 66(1): 214-224.

Wu, R., Mavromatidis, G., Orehounig, K., & Carmeliet, J. (2017). Multiobjective optimisation of energy systems and building envelope retrofit in a residential community. *Applied Energy,* 190: 634-649.

Wyatt-Smith, D. M. (1954). A manual of Malayan silviculture for inland lowland forest. *Malayan Forest Record,* (16): 1-12.

Yahya, Y., & Ismail, R. (2017, January). Computer simulation of tree mapping approach to project the future growth of forest. In Proceedings of the 11th *International Conference on Ubiquitous Information Management and Communication,* 1-7.

Yamada, T., Moriwaki, Y., Okuda, T., & Kassim, A. R. (2016). Long-term effects of selective logging on dipterocarp populations in the Pasoh Forest Reserve, Malaysia. *Plant Ecology & Diversity,* 9(5-6): 615-626.

Yeh, W. C. (2008). A fast algorithm for searching all multi-state minimal cuts. *Transactions on Reliability,* 57(4): 581-588.

Yoshida, M., Son, J., & Sakai, H. (2017). Biomass transportation costs by activating upgraded forest roads and intermediate landings*. Bulletin of the Transilvania University of Braşov, Special Issue Series II: Forestry, Wood Industry, Agricultural Food Engineering,* 10(59): 1.

Yoshida, T., Hasegawa, M., Ito, M. T., Kawaguchi, T., Seino, T., Chung, A. Y. C., & Kitayama, K. (2019). Litter Decomposition on Forest Roads Versus Inside Tropical Rainforests in Sabah, Malaysia. *Journal of Tropical Forest Science,* 31(1): 108-113.

Yusmah, M. Y. S. (2007). *Development of a geographic information system (GIS)-based tool for timber harvesting planning for a Malaysian tropical forest.* Swansea University (United Kingdom).

Zahraee, S. M., Shiwakoti, N., & Stasinopoulos, P. (2020). Biomass supply chain environmental and socio-economic analysis: 40-Years comprehensive review of methods, decision issues, sustainability challenges, and the way forward. *Biomass and Bioenergy*, 142: 105777.

Zanuncio, A. J. V., Carvalho, A. G., Silva, M. G. D., & Lima, J. T. (2017). Importance of Wood Drying to the Forest Transport and Pulp Mill Supply. *Cerne*, 23(2): 147-152.

Zhang, D., Cai, S., Ye, F., Si, Y. W., & Nguyen, T. T. (2017). A hybrid algorithm for a vehicle routing problem with realistic constraints. *Information Sciences,* 394: 167-182.

Zhang, S., Xu, S., Huang, X., Zhang, W., & Chen, M. (2019). Networked correlation-aware manufacturing service supply chain optimization using an extended artificial bee colony algorithm. *Applied Soft Computing,* 76: 121-139.

Zhang, X., Wang, C., Cheng, L., Jiang, S., & Qi, J. (2019, December). Timber Transportation Vehicle Detection Based on SSD-GIoU. *In 2019 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Big Data & Cloud Computing, Sustainable Computing & Communications, Social Computing & Networking*,1410-1415.

Zheng, J., & Zhang, Z. (2018). An Optimized Artificial Bee Colony Algorithm for the Shortest Path Planning Problem. *In CICTP 2018: Intelligence, Connectivity, and Mobility*,2639-2648.

Zhou, R., & Hansen, E. A. (2006, July). Domain-independent structured duplicate detection. *In Proceedings of The National Conference on Artificial Intelligence*, 21(2): 1082.

Zulfa, A. W., Norizah, K., Hamdan, O., Zulkifly, S., Faridah-Hanum, I., & Rhyma, P. P. (2020). Discriminating trees species from the relationship between spectral reflectance and chlorophyll contents of mangrove forest in Malaysia. *Ecological Indicators,* 111: 106024.

Zuo, K., Potangaroa, R., Wilkinson, S., & Rotimi, J. O. (2009). A project management prospective in achieving a sustainable supply chain for timber procurement in Banda Aceh, Indonesia. *International Journal of Managing Projects in Business,* 2(3):386-400.