Timber transportation planning using bees algorithm

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Abstract. Timber transportation planning is among the costliest activities in forest operation. Traditionally, the goal of timber transportation planning adopted to determine feasible way to extract high timber volume from the stump site to the final destination. However, modern transportation problems are not driven by the productivity of timber itself, but also by the efficiency of forest operation. This efficiency considerations and requirements introduce a new technique in timber extraction called log fisher as a complement to common technique, cable skidder. Nevertheless, side constraints within timber transportation planning may arise when two timber extraction techniques applied, complicates to and from several problems more extensive and more complex. While cable skidders affixed only on gentle slopes, log fishers possibly applicable regardless of slope conditions. Proper evaluation required to justify decisions since the use of these two techniques in the right places will result in efficient timber transportation planning. In the present study, a new problem-solving approach using Bees Algorithm (BA) was developed. BA can provide transportation planner with a large and complex transportation planning problem solving while complying with the forest road guidelines as required by the Forestry Department of Peninsular Malaysia. Herein, timber extraction technique is considered the least-cost in the main objective function for an efficient timber transportation planning and limitation of machinery to extract timber as constraints. Preliminary results show that this problem solving is promising for timber transportation planning problems with side constraints. A description of the algorithm development and its search process presented within this study.

Keywords: Network analysis, Transportation planning, Optimisation, Bee Algorithm.

1. Introduction
Designing timber transportation planning remained as a challenging part in forest operation, especially in hilly areas. An in-depth and detailed plan is necessary to ensure a whole forest road network sustained for a long-term use with minimum construction and maintenance cost [20] [16] while ensuring timber operation conducted with Reduce Impact Logging (RIL) practices.
Timber extraction is the main activity in forest operation. Felled timber will be transported from stump site to collection point called landing depicts for timber extraction activity. Heavy machinery such as cable skidder and log fisher are among the types of machinery used in this activity in Peninsular Malaysia [14,15,16]. Different types of machinery used in timber extraction need to comply respective road guidelines. Forest transportation in Peninsular Malaysia ruled under several policies namely Forest Road Guidelines 2010, Forest Road Guidelines 2013 and Guidelines for the Use of Log Fisher Machinery in Natural Forest Harvesting in Permanent Forest Reserves 2016.

According to the guidelines, construction of forest road for cable skidder require skid trails for timber to be extracted from stump site to landing. The maximum allowable length and density for skid trail is not more than 300m for each and entire skid trail network within a hectare of forest operated [1]. Skid trail construction alters the physical condition of timber operation area with the amount of vegetation pushed by the cable skidder along the path to reach the stump site. In contrast, log fisher can winch felled timber and placed it in landing without disturbing vegetation since it was equipped with a heavy-duty cable with a length of 300m. Due to this less impact to the plant, [2] permitted a log fisher trail constructed with a maximum length of 50m for each trail with the maximum density of 50m/ha. At the end of this trail, a platform sized 25m x 25m established to ease the movement of log fisher while winching timber with the heavy load. Slope limits for operation also differs between these two types of machinery; cable skidder is restricted to lift timber at areas more than 20 degrees, log fisher is not permitted to haul timber at areas more than 40 degrees. Through this slope limitation, operators able to identify location suitable for cable skidder and log fisher in harvest area. A Study by [3,4] revealed log fisher productivity (46.39m³/hour) was slightly higher than cable skidder (45.98m³/hour). This was due to the ability of log fisher to take timber at steeper slope exceeding 20 degrees unreachable by cable skidder. Another unique difference between these two machines is that the operational cost of cable skidder is RM4.38/m³, whereas log fisher requires RM8.80/m³ to extract timber from felling site to the landing [4].

Movement of timber operation from the inland forest (elevation up to 300m) to the hilly forest with the maximum limit of forest operation permitted below 1000m of elevation and some areas undergone second rotational harvesting [12, 1] have brought new challenges to timber transportation system management. Multiple goals and additional side constraints on planning a efficient forest road network with multiple objectives require new problem solving-techniques and decision-making support tool. In this study, we present the computerised method, geographic information system (GIS) and optimisation technique to find a least-cost forest road network with log fisher is the primary extraction machine used in timber operation area. In this study, two different road standards; log fisher trail and feeder road (both roads connected at landing) are considered in the forest road network. For this purpose, the optimisation technique of Bees Algorithm (BA) is used with graph theory [13]. The graph theory is a mathematical structure used to model pairwise relations between objects. A graph in this context made up of vertices known as nodes that connected by edges in the form of links or lines.

BA applied to elucidate an optimum solution for timber transportation planning (TTPP) of the forest road network in Peninsular Malaysia due to the accuracy lesser processing time to formulate problem and the ability to solve complex real-world optimisation tasks. BA is an optimisation algorithm introduced by [8]. From the previous study by [11], they used BA to solve the vehicle routing problem. Their study was able to minimize overall travelling distance for a number of vehicles when serving a set of customers and in return decrease the overall transportation cost. [10] used BA to solve vehicle routing problem from the effects of road network design on land-owner and intergenerational inequity in an urban area. Included in their model was information on land-use transportation interaction over time to define network design solutions and overcome the trade-off dimension of sustainability objectives between social, economic, and environment.
2. Problem Formulation in Timber Transportation Planning Problem using BA

2.1 Datasets and problem formulation

Two types of data used; (1) primary data comprising distribution of trees to be harvested and digital raster image of Advanced Land Observing Satellite (ALOS) Digital Elevation Model (DEM) (https://asf.alaska.edu/data-sets/sar-data-sets/alos-palsar/), and (2) secondary data comprising digital vector layer of river networks and existing forest road, with fixed cost (log fisher trail: MYR 14.4/m; feeder road: MYR 18/m) and variable cost (winching: MYR 0.13/m; hauling: MYR 0.002/m) acquired from previous study [20, 4, 16]. Fixed cost derived from construction cost for log fisher trail and feeder road. During the time this paper was written, accurate and reliable information about the construction cost of log fisher trail was unavailable. Thus, we assumed log fisher trail would contribute to 80% of fixed costs for feeder road since both roads characterised with similar specification except the requirement to build side drain for log fisher trail was unnecessary [2].

Raster image with 12.5 m resolution of ALOS DEM used to create elevation and slope in digital vector layer under ArcMap software version 10.5 of GIS. All data integrated with BA formulated via computer language under Visual Basic for Applications (VBA) in Microsoft Excel to determine the least-cost timber transportation planning (Figure 1) (description and steps given in section 3.2). Prior to that, grid cells (later known as a node) of GIS vector layer sized 10m x 10m created representing the region of interest for timber harvest operation. Cells characterised with a distribution of trees to be harvested; will be the starting point (later known as timber node) and each cell potentially characterised with log fisher trail or feeder road, platform, landing and existing road; will be the final destination. Fixed and variable costs linked the timber node to an adjacent node of potential log fisher trail or forest road (later known as a link) to find the least-cost forest road network. Node represents the centre of grid cell. Distance from one node to adjacent node will be 10m if the direction is straight line while 14.142m if the direction is in diagonal direction following Pythagorean theorem formula; \( C = \sqrt{a^2 + b^2} \).

Figure 2 shows an example of how the node and link work to represent winching activity in a timber harvest area. The red line represents the link with the cost associated from timber node, in this example is T5. This T5 will have timber volume used as a constant factor multiplied with variable cost only since no trail needed at this stage. Timber volume brought to eight adjacent to-node (i.e., 1,2,3,4,5,6,7,8 or 9) within proximity 300m [2, 21]. Adjacent node to be selected will be the node that yields the least cost for winching activity. Adjacent node (to-node) selected then become a platform. Since trail for log fisher are permitted to be constructed at a maximum of 50m, the link for log fisher trail built to landing within 50m proximity of the platform; platform become from-node. This link will be attributed to fixed and variable cost. For hauling activity, cumulative volume at landing assessed to find the feeder road. The concept is similar to Figure 2. This step repeated until T5 (from node) linked with the final destination. Fixed and variable cost is attributed at each link connecting from-node to to-node. The landing was determined manually in the grid cell. Candidate landings used as the destination node for log fisher trail and starting node for feeder road with cumulative timber volume within the selected landing node. A landing might have more than one timber as it becomes the destination for winching activity. Fifteen candidate landings selected by using Geographically Weighted Regression (GWR) technique, and the selection based on a suitability map over the planning area with ArcMap software version 10.5. The suitability map created based on raster layer of slope (<40 degrees), elevation (timber operation maximum limit <1000m ASL) and river buffer (depending on a riverbank with minimum buffer zone of 20 m) as shown in Figure 3. All variables; slope, elevation and river combined with linear weight combination (LWC). Entire variables were treated to have similar weight; thus, the weightage value calculated with arithmetic operation of raster data was 33.33%. The output of LWC was then reclassified using Natural Break (Jenks) reclassification method into four classes of suitability. There are 1) highly suitable, 2) moderately suitable, 3) marginally suitable, and 4) not suitable. Finally, landing was selected by using GWR. [18] and [19] describes GWR as a regression that considered location area as a weightage to measure the significant between variables.
Figure 1. The optimised algorithm for a least-cost forest road network in Peninsular Malaysia using Bees Algorithm (BA).

Figure 2. Example of a link pattern represent; timber node (T5) and adjacent nodes (1, 2, 3, 4, 6, 7, 8, 9) potentially selected as log fisher trail or feeder road. Link attributed with the cost; fixed and/or variable.
2.2 BA optimisation in TTPP

Forager bees searching for the least-cost forest road network by using BA formula (eq. 1). In this formula, \( k \) and \( j \) are determined randomly \( \in \{1,2,\ldots,SN\} \) which \( k \) is randomly selected for neighbour nodes selection from timber point, while \( j \) is randomly selected from all nodes within the searching area. The values of \( k \) and \( j \) must be different from \( i \), and \( \theta_{ij} \) is a random number between (-1, 1) and \( V \) represents the fitness. Then, after completed search for neighbour node with BA formula; least cost of timber transportation planning is generated.

\[
V_{ij} = X_{ij} + \theta_{ij} (X_{ij}-X_{kj})
\]  

(1)

Three main steps involved in this optimisation;

Step 1. Group of scout bees going out to search for food sources, return to the hive and do a waggle dance to share information with forager bees. In TTPP, scout bees searching for the final destination from timber node. Once the final destination identified, scout bees convey the information to a group of forager bee. Forager bees received the information and started the local search to find adjacent nodes to be linked with the final destination that manifest the least cost following Eq. 2. This equation considered the total cost of fixed and variable costs at each node with timber volume as the weightage.

Step 2. Scout bees continuously searching for a final destination via all adjacent node at a global scale and repeatedly share the information to forager bees using waggle dance until there is no least-cost node is found. This process is known as iteration. The iteration that has been set for this model is 500 times, with ten scout bees. The more iterations process occurred, the more accurate the results gathered from this process. During the iteration, the cost for each link from the timber node to the final destination was recalculated. In addition, three criteria were taken into consideration as constraints to find least-cost forest road network, in this case, two types of forest road were generated; 1) log fisher trail, and 2) feeder road. Three criteria for consideration are 1) elevation below 1000m, (2) slope \( \leq 40\% \), and (3) boundary of river depending on the slope of the river itself following equation; \([7.6 + (0.6 \times \% \text{ slope})]\) (FDPM, 1999). Forager bees will avoid searching on the nodes that contained all these constraints.

Step 3. Forager bees started searching for the least-cost by using equation 2 consists of costs derived from Log Fisher Trail Cost (LFTC), Feeder Road Cost (FRC), Winching Cost (WC), Hauling Cost (HC) and Timber Volume (TV) are calculated with distances nodes. The least-cost from this calculation was chosen as road network for timber transportation planning.
Step 4. If entire nodes completed with all matched criteria, forager bees stop foraging, and the process is terminated. Otherwise, if the criterion did not match; remaining bees are assigned for global search and new population of scout bees are created and step 1 to 2 will be repeated until all requirement is matched.

Then, the result of least cost forest road network generated in text file (*.txt) and later converted to shapefile (*.shp) GIS layers using conversion process in ArcMap software version 10.5.

3. Application
To demonstrate the optimisation of BA for a least-cost forest road, we applied it to a 113ha forest operation area of compartment 62A in Petuang Forest Reserve (PFR), Kuala Berang, Terengganu (Figure 4). Forest roads construction required for timber extraction, and log fisher operations. Timber volume ranging from 50m$^3$ to 125m$^3$ was unevenly distributed over the entire compartment. Currently, no road exists within compartment except for an existing road located in the eastern part of the area. The area characterised with an elevation between 300m to 750m above sea level (ASL), slope ranging from 1 degree to 55 degrees and 5.98 km major river spread out over the area.

![Figure 4. Study Area located in Petuang Forest, Kuala Terengganu.](image)

TTPP with BA found the total cost for least-cost forest road networks valued at RM 17.89/m with total road length of 0.88m/ha for log fisher trail and 27.40m/ha for feeder road. Figure 5 illustrated the network of least-cost forest road developed via optimisation technique of BA. As a comparison, the forest road plan developed by FDPM were also presented in Figure 5 with the total cost and road length assessed at RM 18/m with 40m/ha respectively. No specific log fisher trail routes identified within forest road network plan by FDPM. Fifteen (15) landings selected to link log fisher trail to feeder road. This number...
of landings should reduce the overall costs of TTPP compared to 24 landings observed to be built under the forest road network plan by FDPM. It is not within the scope of this paper to compare this method with other possible optimisation techniques. The ultimate goal of this TTPP solution with BA is to assist forest planners in designing forest road networks for log fisher trails by providing feasible and good plans while optimising timber volume with multiple objectives.

Figure 5. A solution of least-cost forest road network with BA (orange and green solid line) and forest road network proposed by FDPM (red line)

4. Conclusion
Optimisation techniques of BA for least-cost TTPP generated for hill timber harvesting operation in Peninsular Malaysia. Considering the multiple objective functions, this technique improved the mechanism to design timber transportation planning accurately with lesser processing time. Technology and the computerised model developed in this study are expected to provide an efficient analytic tool for both concessionaire and forest department in practising log fisher for timber extraction. Our attempt to formulate and analyse the exact TTPP for a combination of cable skidder and log fisher activity, making the problems larger and complex using a network algorithm is still in progress. Yet, TTPP in Peninsular Malaysia, especially in the hill forest, will remain an important challenge for forest engineer in the future to lessen impact on the environment.

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