Technical assessment of forest road network using Backmund and surface distribution algorithm in a hardwood forest of Hyrcanian zone

Aidin Parsakhoo
Assistant Professor, Department of Forestry, Faculty of Forest Sciences, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran

Abstract

Aim of study: Corrected Backmund and Surface Distribution Algorithms (SDA) for analysis of forest road network are introduced and presented in this study. Research was carried out to compare road network performance between two districts in a hardwood forest.

Area of study: Shast Kalateh forests, Iran.

Materials and methods: In uncorrected Backmund algorithm, skidding distance was determined by calculating road density and spacing and then it was designed as Potential Area for Skidding Operations (PASO) in ArcGIS software. To correct this procedure, the skidding constraint areas were taken using GPS and then removed from PASO. In SDA, shortest perpendicular distance from geometrical center of timber compartments to road was measured at both districts.

Main results: In corrected Backmund, forest openness in district I and II were 70.3% and 69.5%, respectively. Therefore, there was little difference in forest openness in the districts based on the uncorrected Backmund. In SDA, the mean distance from geometrical center of timber compartments to the roads of districts I and II were 199.45 and 149.31 meters, respectively. Forest road network distribution in district II was better than that of district I relating to SDA.

Research highlights: It was concluded that uncorrected Backmund was not precise enough to assess forest road network, while corrected Backmund could exhibit a real PASO by removing skidding constraints. According to presented algorithms, forest road network performance in district II was better than district I.

Keywords: technical assessment; forest road network; corrected Backmund; skidding distance; surface distribution algorithm.

Introduction

Forest road networks are designed in forest for a variety of reasons, including harvesting, forest conservation and recreational programs (Ismail, 2009). The analysis of different alternatives of forest road network especially in hard mountainous condition has received great attention as an appropriate tool to select the best alternative (Eastaugh & Molina, 2012). Assessment of road network is a key step to provide appropriate transportation planning (Heralt, 2002; Aruga et al., 2006). By technical assessment of forest road network, analyzers will generate maps and data that show management opportunities for changing current road network to address future needs, budgets, and harvesting concerns in a better way (Dean, 1997; Gumus et al., 2008). There are many algorithms to assess the performances of road alternatives based on environmental, economic and traffic safety point of views (Klassen, 2006; Ismail, 2009). The advantages and potential limitations of using this algorithm are different (Aruga et al., 2005; Sessions, 2007).

Backmund algorithm is the traditional theoretical technique in Iranian forestry which can determine the degree of forest openness through forest roads. The openness of a commercial forest area had to be calculated for determining the skidding distance and accessible area. The size of openness is an indicator of forest transport network performance (Pentek et al., 2005).
Road density, road spacing and skidding distance parameters are used to calculate Backmund algorithm. In this technique, maximum distances of skidding so-called Potential Area for Skidding Operations (PASO) is calculated around the road network and then overlaps is determined. One of the most important limitations of Backmund algorithm is that the constraints of ground-based skidding are not considered in all the PASO (Puya et al. 2009). Ground-based skidding is a system of moving wood on the ground to the depot (temporary timber storage areas). Severe constraints on the skidding operations and resources harvesting lead to decreased forest accessibility. Puya et al. (2009) recorded using GPS and mapped the position of stream network, soil condition and steep terrain as skidding constraints.

Contras & Chung (2007) used grid cells and shortest path algorithm in raster-based GIS data to show constraints and obstacles of ground-based timber harvesting. This information was suitable for locating log depot. The existence of these constraints forces the shortest skid trails to be re-routed, which lead to increase skidding distances (Jaafari et al., 2015). Another limitation of Backmund algorithm is that it is often ineffective in comparing road network alternatives with different density (Pentek et al., 2005; Sessions & Boston, 2006). Hayati et al. (2012) showed that despite a very good forest openness (90%), the efficiency coefficient of the studied road networks were not satisfactory (32% only) due to overlapping or falling outside the district area. Overlap areas are created when PASO contact together. These areas are opened twice so overlapping is unsuitable for forest openness (Pentek et al., 2005).

Surface Distribution Algorithm (SDA) is another method for analyzing road network. In this algorithm the distribution of road network on forest land is assessed and the proximity of roads to the center of timber compartments is determined (Wang & Crockett, 1992; Rogers, 2005; Xie & Levinson, 2006). The network with lower distance to the centers is better due to skidding distance can be shorter (Anderson & Nelson, 2004). Skidding distance can be determined by SDA, but forest openness and overlaps cannot be measured by this algorithm (Muslaman et al., 2008).

Single-tree selection cutting which is a closes-to-nature silviculture system is planned for harvesting hardwood forests of Hyrcanian zone. The aim is to achieve an uneven-aged and mixed forest. Tree marking in this method needs to precise statistical data about tree distribution in diameter classes (Eshaghi Rad & Seyyedi, 2012). This work is difficult because of the government regulations on skid trail construction and maximum skidding distance limit (Hayati et al., 2012). There are many constraints (for example steep terrain, wetlands, erodible area, rocky area, deep trench, instable and marshy soil, and etc) in forest that a harvesting planner should consider with regards to skidding operations and machine selection. Another important harvesting challenge is the density and distribution of forest road. Road with higher density and better distribution make harvesting cost lower. Skidding distance for rubber-tire skidders may reach 3 kilometers and maximum allowable longitudinal slope on skid trails is 25%. Nowadays, many studies are conducted in hardwood forests of Hyrcanian zone to determine optimal road density as well as analysis of road performance (Ghaffariyan & Sobhani, 2008; Najafi et al., 2008; Naghd & Mohammadi Limei, 2009). Previously applied methodology in the literature review has mostly failed to assess accurate PASO and forest road network distribution because the constraints and obstacles of ground-based skidding were not located and measured and this is a research gap to be solved. The novelty of our proposed methodology is correction of Backmund algorithm by considering these areas to plan skidding operations in a better way. The main objectives of this work were to:

A) determine constraints and obstacles of ground-based skidding in PASO of study area.
B) correct Backmund algorithm to better design new routes in unopened areas
C) use corrected Backmund and SDA to compare the performance of existing forest road network in two districts of Shast Kalate Educational and Research Forests, northern Iran.

Material and methods

Study area

Shast Kalateh forest is located in Golestan province and in watershed number of 85. This forest has been divided in two districts. District I with an area of 1,713.3 ha in extended from 36° 43’ 27” to 36° 45’ 6” N and 54° 21’ 26” to 54° 24’ 57” E. District II with an area of 1,992 ha is located from 36° 42’ 30” to 36° 43’ 30” N and 54° 21’ 6” to 54° 23’ 30” E. The total length of forest roads in districts I and II were 30.3 and 28 km (21 km is located in timber compartments with area of 995 ha), respectively. Stream network, deep trench, erodible area, rocky area, nursery, steep terrain, botany garden, wetland, forest park and camp are the main skidding constraints in our study area. In our study area, single-tree selection method is done in timber compartments at 10-year intervals. Two cycles of operations has already been done in district I. District II has not been harvested yet. The trees species of a case study are Parrotia persica, Carpinus betulus, Fagus orientalis, Quercus cas-
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In SDA, the model builds a network consisting of a set of points and links. Points represent geometrical center of timber compartments and depots, and links represent the skid trails. The geometrical center of timber compartments was determined using the data management features tool and then the shortest perpendicular distance of the center of timber compartments to roads was measured using the distance shortest path tool. Equation 5 is used to analyze different alternatives of forest roads and determine the best distribution of road network in the field.

\[ Y = \frac{\sum D_i}{n} \]  

Where \( Y \) is mean distances from the center of timber compartments to road (m), \( D_i \) is shortest perpendicular distance from geometrical center of timber compartment \( i \) to road (m) and \( n \) is the number of compartments (Fig. 2).

Backmund algorithm

In this study the density of forest roads in harvestable area and the distances among roads were calculated using Equation 1 and 2, respectively.

\[ R_{density} = \frac{R_{Length}}{A} \]  \hspace{1cm} (1)

\[ R_{spacing} = \frac{10000}{R_{density}} \]  \hspace{1cm} (2)

Where \( R_{density} \) is road network density (m ha\(^{-1}\)), \( R_{Length} \) is total length of forest roads (m), \( A \) is total harvestable area (ha) and \( R_{spacing} \) is distance among roads (m). \( S_{distance} \) is maximum skidding distance (m), which was calculated using Equation 3.

\[ S_{distance} = \frac{R_{spacing}}{2} \]  \hspace{1cm} (3)

Then PASO with a width of maximum skidding distance for rubber-tire skidder or mean distance among road was designed at both sides of the road in ArcMap software using the proximity buffer tool. In uncorrected Backmund algorithm, total area of PASO was calculated to determine openness degree of forest by forest road network (Equation 4). Overlaps among roads were detected using the overlay intersect tool. In another algorithm it can be possible to calculate unopened areas in forest and consequently the forest openness areas.

\[ E = \frac{S}{A} \times 100 \]  \hspace{1cm} (4)

Where \( S \) is PASO (ha) and \( E \) is forest openness (%). The coordinates and polygons of skidding constraints were taken in field survey using GPS. In the next stage the data was transmitted from GPS to ArcMap and these areas were removed from PASO map. The new PASO shows the openness percentage of forest after application of corrected Backmund algorithm (Backmund, 1968).
Results

Network analysis using corrected Backmund

Skidding constraints and obstacles fragmented PASO of two districts (Fig. 3). PASO map exhibit the extent of permissible areas which the ground-based skidding can be done for rubber-tire skidders. It was produced on the basis of uncorrected Backmund and road spacing value 565.6 m (Fig. 4). 75.5% of district I had potential areas for skidding operations. 6.94% of these areas (PASO) were unsuitable for skid trail construction due to skidding constraints and so were removed from PASO (Table 1). New PASO was prepared based on corrected Backmund algorithm (Fig. 5). In our case study forest openness with an area of 1,713.3 ha decreased to 70.3% after use of corrected Backmund (Table 2).

According to uncorrected Backmund, 75.9% of district II had potential areas for skidding operations (Fig. 6). But, 8.48% of this area were unsuitable for skid trail construction and so were removed from PASO (Table 3).

In district II with an area of 995 ha, forest openness decreased to 69.5% after the use of corrected Backmund algorithm (Fig. 7). Table 4 shows the technical parameters of forest road network according to corrected and uncorrected Backmund algorithms.

Network analysis using SDA

In SDA, the mean distance from the geometrical center of the timber compartments of district I to the road was 199.45 m (Fig. 8). The mean distance from the geometrical center of the timber compartments of
Table 1. Relative percentage of skidding constraint areas to the whole area of PASO in district I.

| Constraints         | Area (%) | Constraints         | Area (%) | Constraints  | Area (%) |
|---------------------|----------|---------------------|----------|--------------|----------|
| Stream network      | 3.23     | Nursery             | 0.0005   | Forest park  | 0.36     |
| Deep trench         | 0.98     | Steep terrain       | 0.29     | Camp         | 0.17     |
| Erodible area       | 0.76     | Botany garden       | 0.09     | Total        | 6.94     |
| Rocky area          | 0.33     | Wetland             | 0.71     |              |          |

Table 2. Technical parameters of forest road network in district I.

| Algorithms           | Road density (m ha⁻¹) | Road spacing (m) | PASO & New PASO (ha) | Forest openness (%) |
|----------------------|-----------------------|------------------|---------------------|---------------------|
| Uncorrected Backmund | 17.68                 | 565.6            | 1,294.19            | 75.5                |
| Corrected Backmund   | 17.68                 | 565.6            | 1,204.41            | 70.3                |

Table 3. Relative percentage of skidding constraint areas to the whole area of PASO in district II.

| Constraints         | Area (%) | Constraints         | Area (%) | Constraints  | Area (%) |
|---------------------|----------|---------------------|----------|--------------|----------|
| Stream network      | 3.84     | Wetland             | 0.07     | Deep trench  | 0.41     |
| Steep terrain       | 3.44     | Rocky area          | 0.06     | Erodible area| 0.66     |
| Total               | 8.48     |                     |          |              |          |

Table 4. Technical parameters of forest road network in district II.

| Algorithms           | Road density (m ha⁻¹) | Road spacing (m) | PASO & New PASO (ha) | Forest openness (%) |
|----------------------|-----------------------|------------------|---------------------|---------------------|
| Uncorrected Backmund | 21.1                  | 473.8            | 755.25              | 75.9                |
| Corrected Backmund   | 21.1                  | 473.8            | 691.17              | 69.5                |
district II to the road was 149.31 m (Fig. 9). Therefore, according to SDA the forest road network distribution in district II was better than that of district I. Means shortest distance presented differences between districts, with the maximum and the minimum path ranging between 199.45 and 149.31 m for district I and II, respectively (Table 5).

**Discussion**

The overall large investment for road network construction in the case study area reflects the importance of precise network analysis in the forest area, which suggests that the traditional algorithms such as uncorrected Backmund in this area has not accurately resulted in roads being located in mountainous areas. This paper has presented two metrics (Corrected
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Backmund and SDA) to analysis forest road networks in a way meaningful to road network managers. It was concluded that uncorrected Backmund was not precise enough to evaluate forest road network (Fig. 4 and 6).

In this algorithm it is assumed that all the forest areas around the road network are opened by skid trails and/or has potential for skidding operations up to maximum skidding distances, while it is not possible due to the existence of constraints and obstacles. Therefore, it is necessary to determine the forest openness based on the constraints of depot and skid trail construction. The position of constraints and obstacles should be located and then removed from potential area for skidding operations to achieve corrected Backmund. South of study area with high slope and sensitive geological and hydrographic situations was not an appropriate location to design forest roads. In the current study, geographical position of skidding constraints was the important information layer for analyzing road performance. Naghdi & Babapour (2009) stated that the slope, soil texture, bed rock and hydrographic layers were most important layers that determine skidding constraints and possibility of road construction. Their results are similar to those of the current study.

The existing forest road network analysis showed that the road density and spacing is acceptable but it is possible to carry on with the opening of unopened areas. Calculating average skidding distance is an important parameter for the determination of the optimum road density and spacing. Skidding distances in districts I and II were 282.8 m and 236.9 m, respectively. Therefore, the width of areas surrounding of roads in two districts I and II were equal to 565.6 m and 473.8 m, respectively. It is possible for road networks with different density and spatial distribution to achieve the same potential area for skidding operations (Rogers, 2005). Where forest access is needed, it would be necessary to determine a minimum required road network with maximum potential area for skidding operations (Sessions & Boston, 2006; Xie & Levinson, 2006).

In surface distribution algorithm the mean distances of geometrical centers to road in district I was 199.45 m, whereas in district II the mean distances was 149.31 m. Therefore forest road network distribution in district II was better than that of district I. Indeed, the skidding distances and consequently the skidding cost in district II was lower than that of district I. For achieving a high-quality and efficient management of forest, it is necessary to provide an optimal distributed network of forest road (Pentek et al., 2010). Nowadays, different skidding distance models were programmed to help the road planners judge the efficiency of existing or planned road networks while considering the real skidding distance and the proposed technology of skidding (Heinimann, 1998; Tucek & Pacola, 1999).

Each algorithm has its own limitations and advantages that will be further investigated in our ongoing research.

It has been recommended by many authors that depending on terrain and forest conditions the optimum density of forest road network should be between 17 and 30 m ha⁻¹ for the needs of timber harvesting (Pentek et al., 2005; Sessions, 2007). In agreement with the mentioned report, road density in forest district I and II were 17.68 and 21.1 m ha⁻¹, respectively. Abdi et al. (2009) used geographical information system and multi-criteria evaluation to design a forest road network with the lowest construction cost. This algorithm is useful to evaluate and select optimum road from different alternatives. The value of 250 m has been chosen by Pentek et al. (2005) for skidding distance on slope less than 55%. In addition, they emphasized that on slope more than 55% another system of forest opening should be selected instead of ground-based skidding. Skidding distances in districts I and II were 283 and 237 m, respectively. In evaluating the forest openness by road systems which has been accepted by Iranian foresters till 60% is insufficient openness, from 60 to 70% is hardly good openness, from 70 to 85% is very good openness and over 85% the overlap increases and so it cannot be suitable (Lotfalian & Parsakho, 2012).

Values of forest openness are above 70% in district I (Table 2) and II (Table 4) in Shast Kalate forest and these values have been given the adequate road density and distribution in our study area. Numeric data of forest openness by road says the actual state of forest road infrastructure and defines the need for future opening of forests.

Conclusions

The analysis of forest road network using corrected Backmund algorithm is necessary to design new routes in unopened areas. In addition, to identify the unopened area, PASO estimating under constraints and obstacle conditions may also be provided by corrected Backmund. It was concluded that uncorrected Backmund was not precise enough to assess forest road network, while corrected Backmund could exhibit a real PASO by removing skidding constraints. In recent study we found that forest openness in two districts were in range of 69.5-70.3% and Therefore, according to standards of foresters the studied road networks can be classified as very good openness. Beside, SDA can investigate...
the surface distribution of road network in area. It was detected that forest road network distribution in district II was better than that of district I. Totally, forest road network performance in district II was better than district I. Integrating these two algorithms help us to reach optimum PASO with lowest overlaps. By constructing roads and skid trails with suitable density the costs can be reduced.

Acknowledgements

The authors wish to thank the helpful comments from anonymous reviewers, whose remarks and indications significantly improved the original manuscript. Thanks also to Dr. Negar Rasouli for editing and improving the English quality of manuscript.

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