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RESEARCH ARTICLE

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

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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.

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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.

Contreras & 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 & Crowcroft, 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 (Musliman *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; Naghdi & Mohammadi Limaei, 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-*

taneifolia and *Zelkova carpinifolia*. The mean of trees density per hectare was 214.92 and the canopy cover was 75-85% (Mohammadi *et al.,* 2014).

The roads in district I were constructed in 1989, but the roads of district II has not been built yet. The bedrock is lime and sand stone with altitude ranging from 100 to 1,935 m above sea level. The forest is mixed deciduous which has been established on brown forest soil with mostly sandstone as bedrock Clay-loam-silty texture and worn stones are spread around the region. The climate is moderate and moist. The mean annual precipitation is varying from 528 mm to 817 mm which the lowest is in July and August (Fig. 1).

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.

$$R_{density} = \frac{R_{Length}}{A} \quad (1)$$

$$R_{spacing} = \frac{10000}{R_{density}} \quad (2)$$

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.

$$S_{distance} = \frac{R_{spacing}}{2} \quad (3)$$

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.

$$E = \frac{S}{A} \times 100 \quad (4)$$

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).

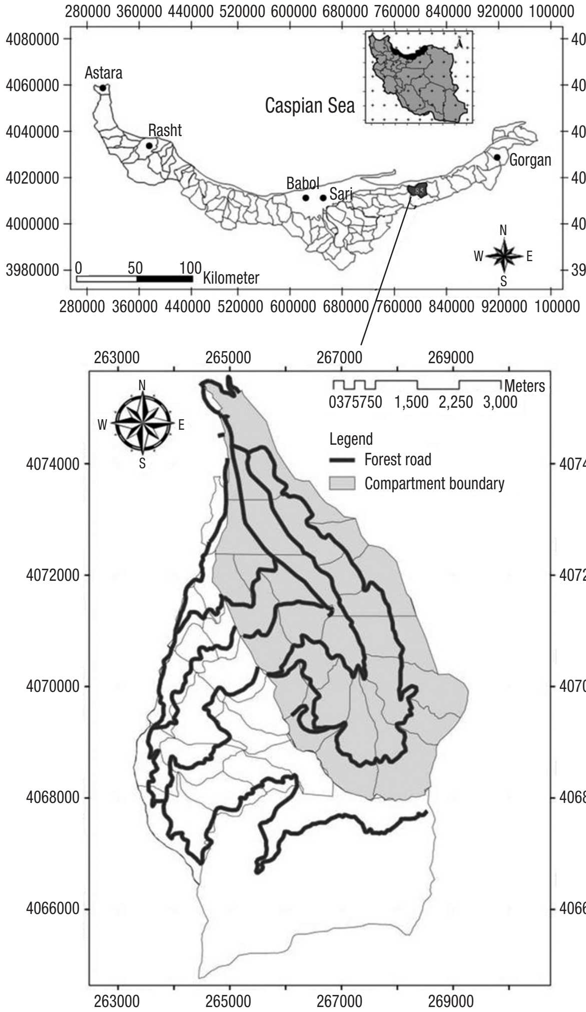

Figure 1. The geographical position of the study area.

Surface Distribution Algorithm (SDA)

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.

$$Y = \frac{\sum D_i}{n} \quad (5)$$

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).

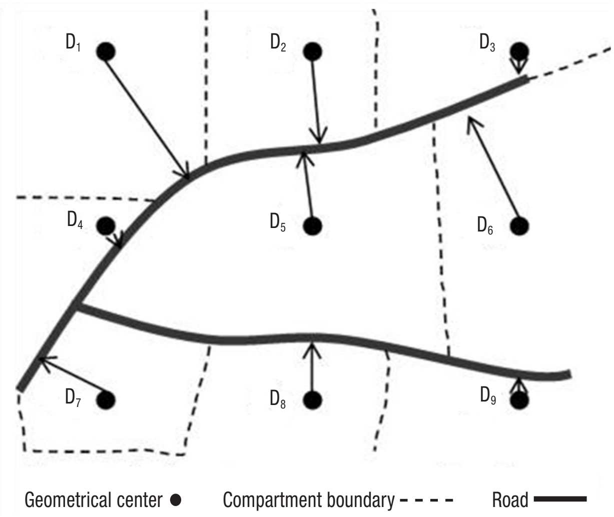

Figure 2. Schematic of surface distribution algorithm.

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

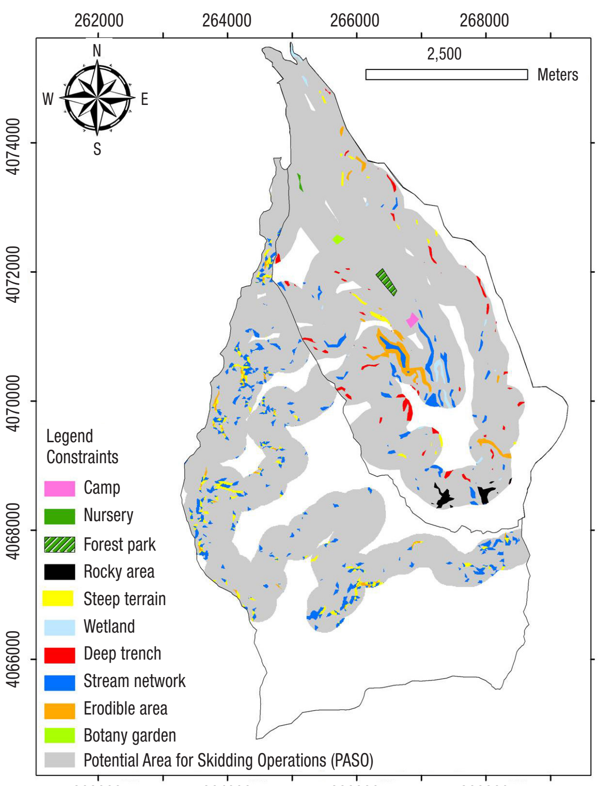

Figure 3. Distribution of the skidding constraints in both districts.

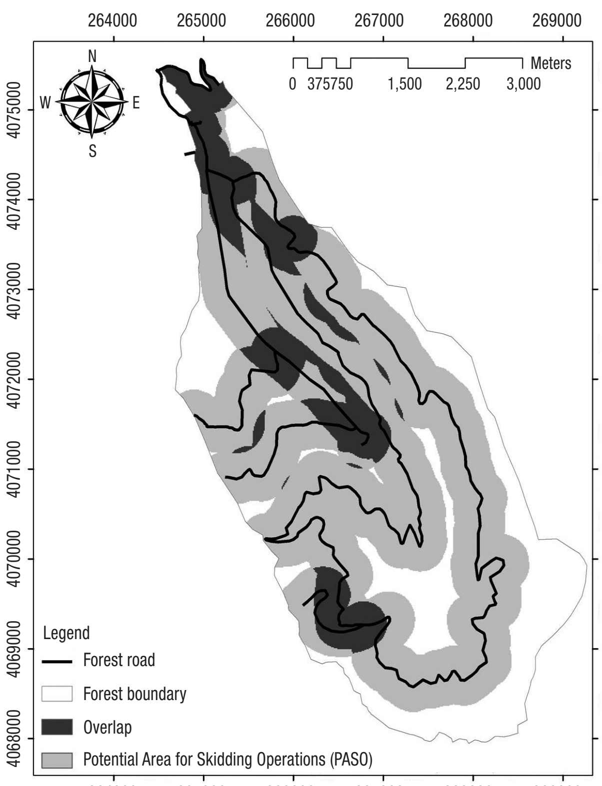

Figure 4. PASO using uncorrected Backmund algorithm in district I.

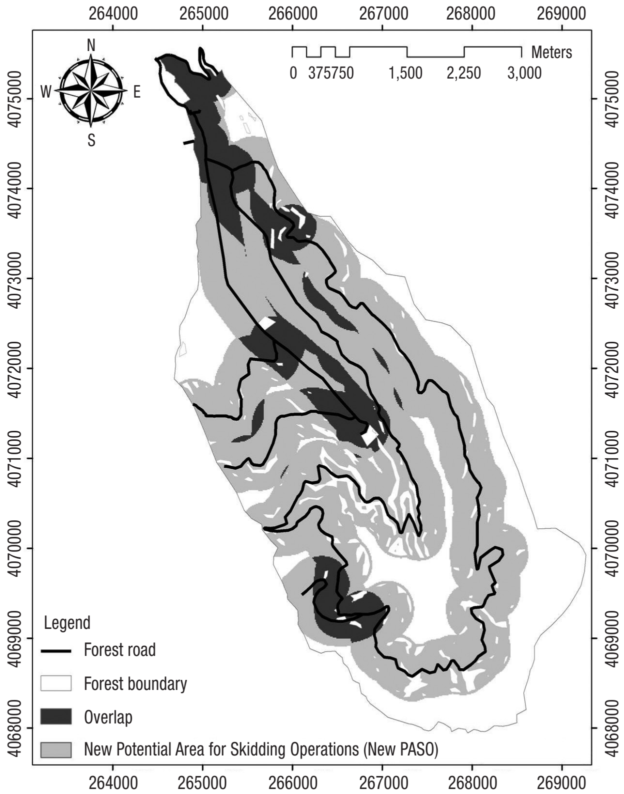

Figure 5. New PASO after removing skidding constraints from district I.

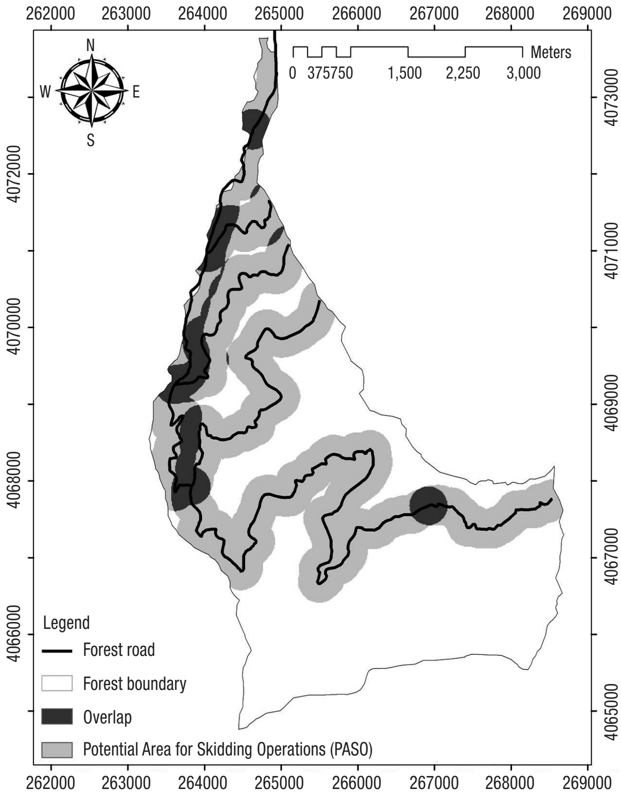

Figure 6. PASO using uncorrected Backmund algorithm in district II.

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

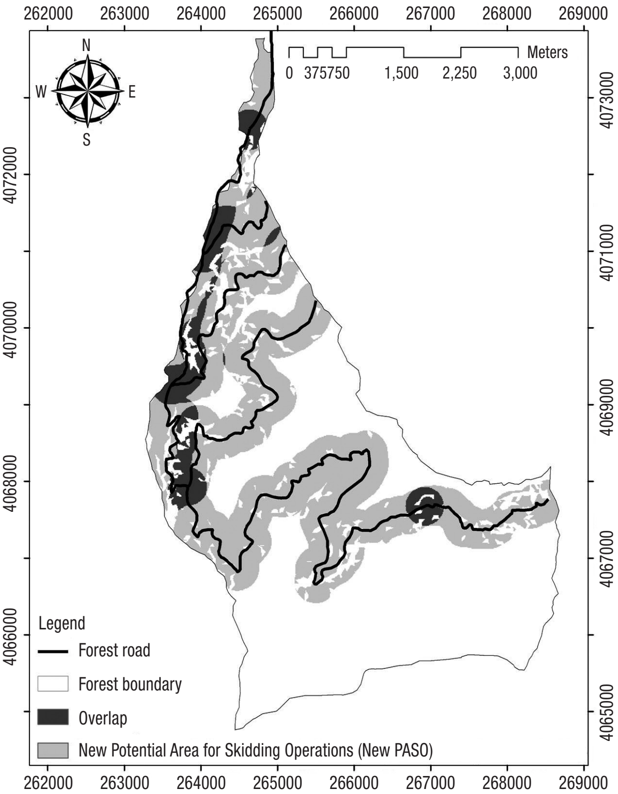

Figure 7. New PASO after removing skidding constraints area from district II.

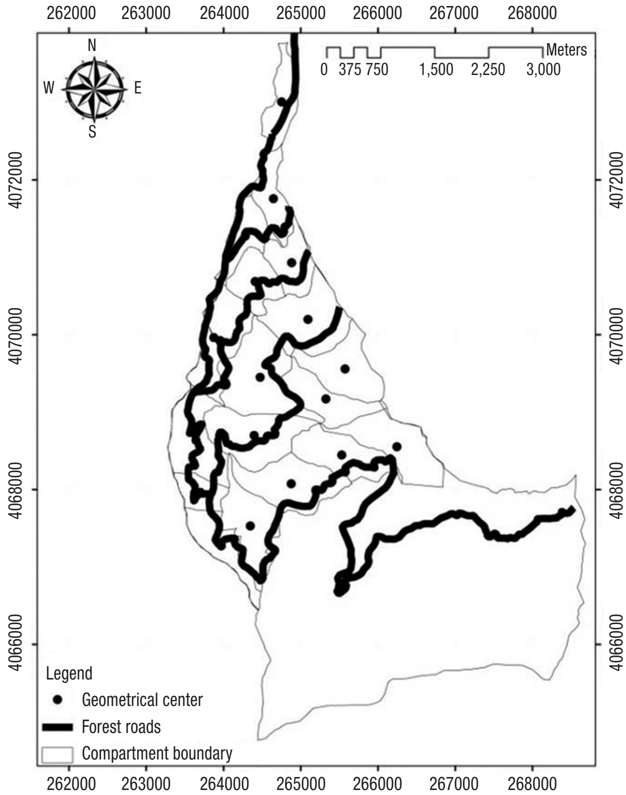

Figure 9. Geometrical center of timber compartments in district II of Shast Kalate forests.

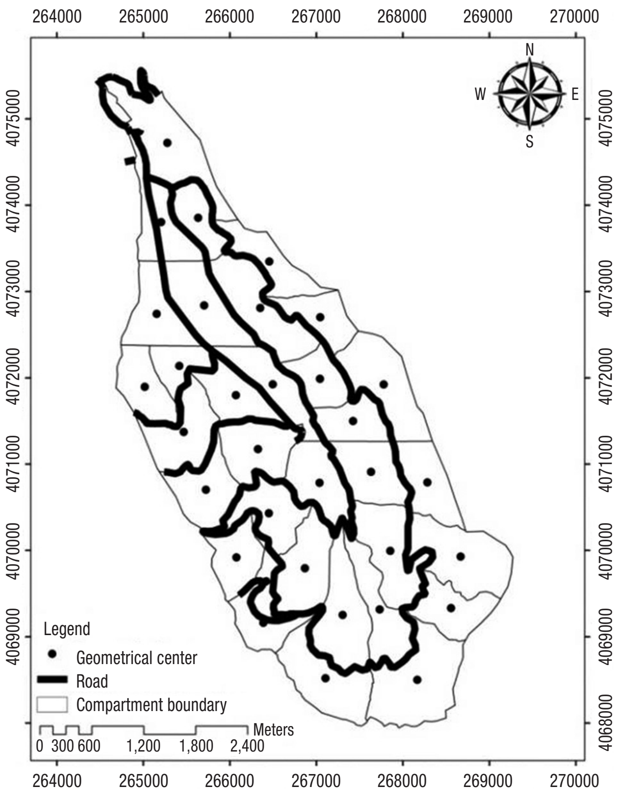

Figure 8. Geometrical center of timber compartments in district I of Shast Kalate forests.

Table 5. Mean shortest distance from geometrical center of timber compartments to road.

District	Number of timber compartment	Mean	Std. Deviation
I	33	199.45	84.103
II	19	149.31	132.421

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

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 & Parsakhoo, 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.

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References

Anderson AE, Nelson J, 2004. Projecting vector-based road networks with a shortest path algorithm. Canadian J For Res 34: 1444-1457. http://dx.doi.org/10.1139/x04-030.

Aruga K, Sessions J, Akay AE, 2005. Heuristic planning techniques applied to forest road profiles. J For Res 10: 83-92. http://dx.doi.org/10.1007/s10310-004-0100-4.

Aruga K, Tasaka T, Sessions J, Miyata ES, 2006. Tabu search optimization of forest road alignments combined with shortest paths and cubic splines. Croatian J For Eng 27: 37-47.

Abdi E, Majnounian B, Darvishsefat A, Mashayekhi Z, Sessions J, 2009. A GIS-MCE based model for forest road planning. Journal of Forest Science 55(4): 171–176.

Backmund F, 1968. Indices for the degree of accessibility of forest districts via roads. Schweizerishe, Zeitschrift Fuer Forstwesen (SZF) 119: 445-452.

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 J For Res 37: 276-292. http://dx.doi.org/10.1139/x06-219.

Dean JD, 1997. Finding optimal routes for networks of harvest diet access roads using GIS-based techniques. Canadian J For Res 27: 11-22. http://dx.doi.org/10.1139/x96-144.

Eastaugh CS, Molina DM, 2012. Forest road and fuelbreak siting with respect to reference fire intensities. Forest Systems 21: 153-161. http://dx.doi.org/10.5424/fs/2112211-12232.

Eshaghi Rad J, Seyyedi N, 2012. Effects of strip and single-tree selection methods on woody species diversity in Caspian forests (Iran). Int J For Soil Erosion 2: 171-174.

Ghaffariyan MR, Sobhani H, 2008. Optimum road spacing of ground-based skidding operations in Nowshahr, Iran. Caspian J Env Sci 6: 105-112.

Gumus S, Acar HH, Toksoy D, 2008. Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. Environ Monit Assess 142: 109–116. http://dx.doi.org/10.1007/s10661-007-9912-y.

Hayati E, Majnounian B, Abdi E, 2012. Qualitative evaluation and optimization of forest road network to minimize total costs and environmental impacts. Italian Soc Silv For Ecol 5: 121-125. http://dx.doi.org/10.3832/ifor0610-009.

Heinimann HR, 1998. A computer model to differentiate skidder and cable-yarder based road network concepts on steep slopes. J Forest Res 3: 1-9. http://dx.doi.org/10.1007/BF02760286.

Heralt L, 2002. Using the ROADENG system to design an optimum forest road variant aimed at the minimization of negative impacts on the natural environment. J For Sci 48: 361-365.

Ismail MH, 2009. Planning of access road using satellite technology and best path modeling. Modern Applied Science 3: 83-95. http://dx.doi.org/10.5539/mas.v3n3p83.

Jaafari A, Najafi A, Rezaeian J, Sattarian A, Ghajar I, 2015. Planning road networks in landslide-prone areas: A case study from the northern forests of Iran. Land Use Policy 47: 198-208. http://dx.doi.org/10.1016/j.landusepol.2015.04.010.

Klassen A, 2006. Planning, location, survey, construction and maintenance for low-impact forest roads. Fourth Technical Procedures Manual, pp: 63-74.

Lotfalian M, Parsakhoo A, 2012. Forest roads network planning. Ayiizh Press, Tehran, Iran. 155 pp.

Mohammadi J, Shataei Sh, Namiranian M, 2014. Comparison of quantitative and qualitative characteristics of forests structure and composition in natural and managed forest stands (Case study: Shast Kalate forests of Gorgan). J Wood & For Sci Tech 21: 65-83. (In persian).

Musliman IA, Abdul Rahman A, Coors V, 2008. Implementing 3D network analysis in 3D-GIS. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B2. Beijing, pp: 913-918.

Najafi A, Sobhani H, Saeed A, Makhdom M, Marvi Mohajer M, 2008. Planning and assessment of alternative forest road and skidding networks. Croatian J For Eng 29: 63-73.

Naghdi R, Mohammadi Limaei S, 2009. Optimal forest road density based on skidding and road construction costs in Iranian Caspian Forests. Caspian J Env Sci 7: 79-86.

Naghdi R, Babapour R, 2009. Planning and evaluating of forest roads network with respect to environmental aspects via GIS application (Case study: Shafaroud forest, northern Iran). Proceeding of Second International Conference on Environmental and Computer Science, Dubai, UAE, pp: 424-427.

Pentek T, Pičman D, Potočnik I, Dvorščak P, Nevečerel H, 2005. Analysis of an existing forest road network. Croatian J For Eng 26: 39-50.

Pentek T, Nevečerel H, Dasović T, Poršinsky M, Šušnjar I, Potočnik I, 2010. Analysis of secondary relative openness in hilly area as a basis for selection of winch rope length. Šumarski list 134: 241-248.

Puya K, Majnounian B, Feghhi J, Lotfalian M, Abdi E, 2009. The efficiency of Backmund method for evaluation of forest road networks with regard to capabilities of wheeled skidders in ground skidding method. Iranian J For 1: 35-42.

Rogers LW, 2005. Automating contour-based route projection for preliminary forest road designs using GIS. A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science. University of Washington, Management and Engineering Division, College of Forest Resources, pp: 78.

Sessions J, Boston K, 2006. Optimization of road spacing for log length shovels logging on gentle terrain. Int J Forest Eng 17: 53-60.

Sessions J, 2007. Forest road operations in the Tropics. ISBN-10 3-540-46392-5 Springer-Verlag Berlin Heidelberg New York. pp: 170.

Tucek J, Pacola E, 1999. Algorithms for skidding distance modelling on a raster digital terrain model. Int J Forest Eng 10: 67-79.

Wang Z, Crowcroft J, 1992. Analysis of shortest-path routing algorithms in a dynamic network environment. ACM Computer Communication Review 22: 63-71. http://dx.doi.org/10.1145/141800.141805.

Xie F, Levinson DM, 2006. Measuring the structure of road networks. Geographical Analysis 39: 336-356. http://dx.doi.org/10.1111/j.1538-4632.2007.00707.x