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Decision support system to find a skid trail network for extracting marked trees

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Abstract

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Careful planning of skid trails as wood extraction routes in forests is an ongoing task and necessary for minimizing the environmental damage. The main objective of this study is to find skid trails to extract marked trees from stand sites to landing sites using a GIS-based decision support system (DSS) and network analysis techniques, where environmental information is incorporated into the objective. The techniques were applied in a stand where single trees are felled in near-to-nature conditions. This system is called a single tree selection cutting method. Parameters considered for mapping the terrain stability include slope, soil and stream network. The analytical hierarchy process was used to estimate the weights of these parameters. Routing between marked trees and log landing was done using a GPS-tracking survey and then the analysis was done using new route and service area tools in GIS. The service area tool shows accessibility of marked trees by skid trails. Results showed that on average the length of the route decreased by 6.65 and 19.22% with the use of a new route tool in compartments 29 and 4, respectively. In conclusion, DSS techniques increased accessibility of marked trees and decreased the length of the route.

Keywords: routing; slope stability; log landing; skidding; timber harvesting

The routing of a skid trail network has a tradition of being a manual process performed by forest engineers. Skid trail planning in forestry involves many decisions to avoid sensitive areas and increase access to marked trees. Better decisions can be made using advanced computer approaches (Kooshki et al. 2012). Skid trails are the wood extraction routes that complete the road network and are used to move logs or trees by skidders from a stump to a log landing at the edge of the road (Krueger 2004; Lubello 2008; Philippart et al. 2012). Nowadays, some researchers believe that skid trails should be regarded as a permanent component of forest land and they will be used for later entries into the forest after one 10-year period of selective harvesting (Dean 1997; Sterenczak, Moskalik 2014). This lead to decrease damage to forest stands and soil structure and therefore damage is concentrated in a minimum area. Therefore, careful planning and analysis of route performances are an ongoing task and necessary for minimizing the environmental impact (Wang et al. 2014).

The ArcGIS Network Analyst extension includes routing, service area, closest facility, travel directions and new location-allocation analysis (Keshkamat et al. 2009; Babapour et al. 2013) which

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enable users to determine the optimum route from different scenarios (Rees 2004; Akay et al. 2012). In recent years, these approaches as a decision support system have been developed to optimize the skid trail network (Inada et al. 2014). For example, Cheng and Chang (2001) developed a GIS-based network analysis system to automate the process of routing and design of an underground power supply system. In a hardwood mountainous temperate forest, GIS models can be effective, efficient, and practical to find the skid trail alignment and connectivity analysis (Xiang 1996; Cervero, Kockelman 1997; Grushecky et al. 2009).

Least time and energy cost information based on both trail length and slope was used to identify travel routes on forest trail networks in Central Taiwan (Chiou et al. 2010). Devlin et al. (2008) applied the ArcInfo Network Analyst tool to compare timber truck routes from forest harvesting site to mill in Ireland. It was found that the GPS routes were over 90% similar to what was generated by Dijkstra's routing algorithm within the GIS. Sterenczak and Moskalik (2014) used the airborne laser scanner and GIS to find the locations and routes of forest skid trails in a Scots pine stand in central Poland. They found that the use of existing stand gaps for skid trail designing can decrease the number of trees to be felled in the construction of the skid trail network.

In Hyrcanian forests of Iran, construction of forest roads and skid trails is the most costly and environmentally damaging operation for the forest ecosystem. In Iranian forestry, the development of new tools for planning skid trails is considered an important issue (Najafi et al. 2008; Mohammadi Samani et al. 2010; Akbarimehr, Naghdi 2012; Ezzati et al. 2016; Solgi et al. 2016). In Hyrcanian forests, the numbers of skid trails are not enough and in some regions they are extremely long and steep. So, more researches can still be done to find easy and accurate computer approaches to facilitate routing with addressing environmental concerns. In this study a new approach to skid trail planning in logging operations was determined. With the assistance of a decision support system in GIS, it is possible to search extensive area for locating path between marked trees for felling and log landing. The main objective of this study is to facilitate log collecting by skid trails.

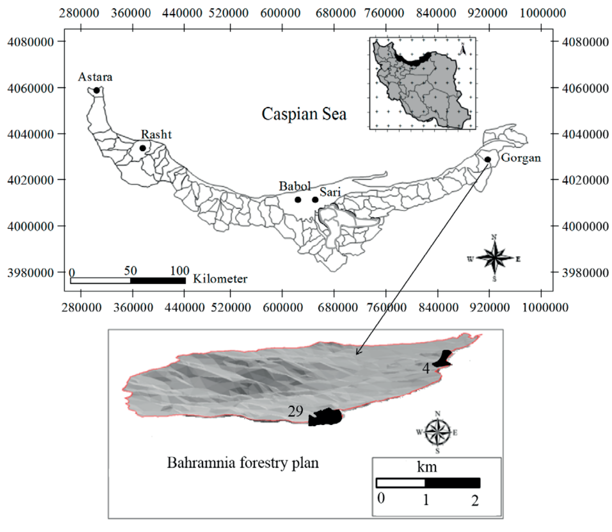


Fig. 1. Location map of compartments 4 and 29 in Bahramnia forestry plan, watershed 85 in Hyrcanian forests

MATERIAL AND METHODS

Study area. District one in Bahramnia's forestry plan with an area of 1,713 ha is located in Golestan province (36°43'27''N to 36°48'6''N and 54°21'26''E to 54°24'57''E). The total length of studied roads was 31 km. These roads were constructed in 1989. The forest is a mixed deciduous stand which was established on brown forest soil with mostly sandstone as bedrock. Clay-loam-silty texture and worn stones are spread around the region. The elevation ranges between 100 and 1,000 m a.s.l. The mean tree volume per hectare in the study area was estimated to be 247 $m^3 \cdot ha^{-1}$. Road density was 17.68 $m \cdot ha^{-1}$ and skidding routes were covered for the area of 1,204 ha. Tree species of the case study include Ironwood, Hornbeam, Beech, Oak and Elm. The mean of tree density per hectare was 214.92 and the canopy cover was 75–85% (Mohammadi et al. 2014; Parsakhoo 2016). The forest is harvested with a single tree selection cutting system according to an annual harvesting table. The climate of the region is Mediterranean warm and moist, with mean annual precipitation of about 562 mm and the lowest amount in July and August (Mohammadi et al. 2014) (Fig. 1). The length and density of roads are 31 km and 18.13 $m \cdot ha^{-1}$, respectively. The properties of the forest road network in district one are described in Table 1.

Determination of start and target nodes. This study was carried out to find a suitable network for ground-based skidding operations across a managed hardwood forest. In this study the potential areas suitable for log landings were located as start nodes along forest roads. The potential landings have an area of more than 100 m^2 and slope below 15% (sideslope). These nodes were recorded by GPS in a field survey as start nodes. The positions of marked trees were also taken by GPS as target nodes.

Table 1. Technical parameters of forest road network in Bahramnia forest

Road length (km)	Forest area (ha)	Road density (m·ha^{-1})	Road spacing (m)	Skidding distance (m)	Effective openness (%)
31	1,713	18.13	551.18	276.1	75.02

Mapping the slope stability for skid trail designing. The main criteria of mapping the slope stability in the case study were as follows: slope stability maps are useful for route designing (Nevečerel et al. 2007). The map of slope gradient was extracted from a digital elevation model with a pixel size of 10 m. The classification of slope was done according to restrictions for skid trail operations. Slope class of 0 to 20% is where the skidding operation is feasible, but not safe for rubber-tire skidders. Class of 21 to 30% has moderate gradient and skidders can move on a skid trail along the slope (perpendicularly to the contour lines). Class of 31–55% is steep and the skid trail should be excavated and skidders can move only on diagonal routes. Slope class of more than 56% is very steep and is not suitable for ground-based skidding by rubber-tire skidders (Fig. 2a). During skidding operations on a steep terrain, the given load is subjected to an uneven weight balance on the rear axle, which can further increase soil disturbance (Najafi et al. 2010).

A stream map was prepared from topographic map and field surveys by portable GPS – Garmin map 60s (Version 2.5, 2005). Forests that are close to streams are susceptible to instability (Fig. 2b). The soil map was prepared in a geological organization and classified into three codes 1.14, 2.17 and 4.15 (Fig. 2c).

Weights of criteria were calculated through questionnaires which were completed by 10 forest engineering experts and then an overlay process was done. The analytic hierarchy process (AHP) is a more general form of the multi-criteria decision system which is used in this study and in Expert Choice software (Version 11, 1992) to determine factor weights and instability degrees (Saaty 2003). Each questionnaire contained the questions about the importance of each factor influencing the slope stability for skid trail planning (Table 2). All the thematic layers were then integrated in a raster calculator tool, and using the overlay process of GIS a slope stability map was produced.

Skid trail designing. Possible routes between start and target nodes on a stable terrain were registered in a field survey by GPS, then they were analysed using the following methods in the ArcGIS Network Analyst tool (Version 10.1, 2012).

Route network analysis. Service area is a systematic tool in GIS to run a buffer around skid trails

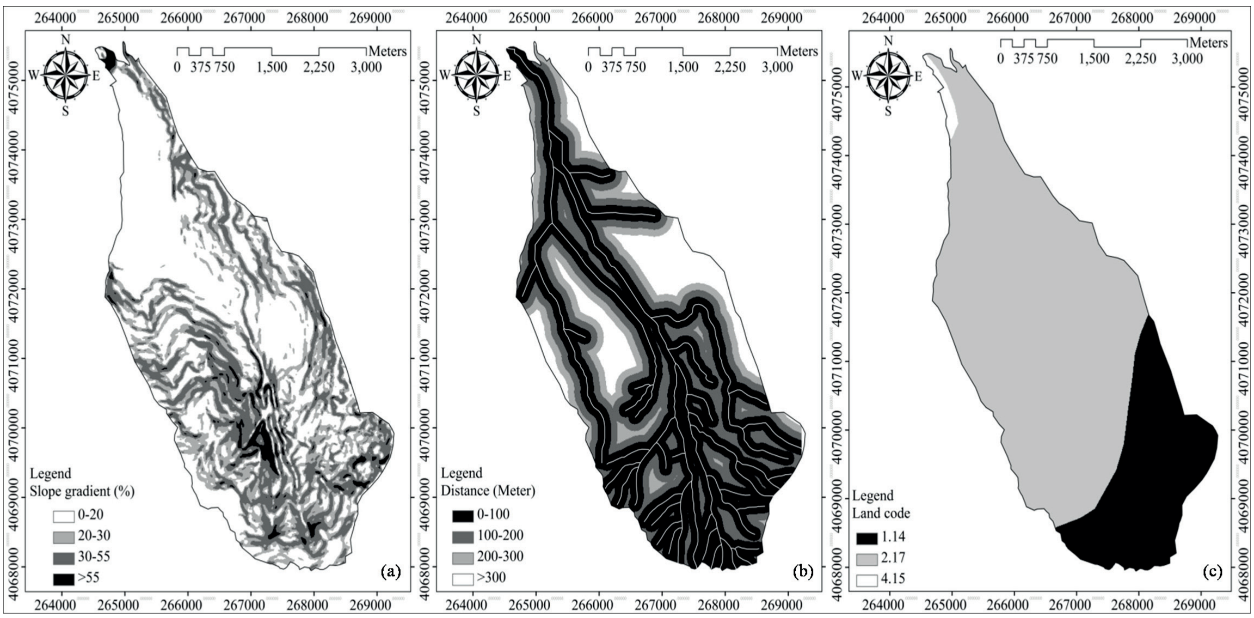


Fig. 2. Slope map (a), map of stream buffer (b), soil map (code 1.14 includes lime stone and metamorphic igneous stone. The soil is shallow and heavy in texture; code 2.17 includes conglomerate and sandstone as well as loess formations. The soil is deep and heavy in texture and code 4.15 includes hillside plains with the flat alluvium of stream. The soil is deep with clay and loam-clay texture and clay-sandy-loam is in the alluvial part) (c)

Table 2. Importance of criteria influencing the slope stability and rating different classes of criteria for modelling the slope stability in an analytical hierarchy process

Criterion	Importance value	Class	Stability rating	Stability class
Slope (%)	0.63	0–20	1	very high
		21–30	2	high
		31–55	3	moderate
		> 56	4	low
Soil (land code)	0.29	1.14	1	high
		2.17	2	moderate
		4.15	3	low
Stream (m)	0.08	0–100	4	low
		101–200	3	moderate
		201–300	2	high
		> 301	1	very high

inconsistency index – 0.0904

and evaluate accessibility and position of marked trees. Using this tool, the number of marked trees within *X*-kilometre of a skid trail can be counted. In GIS, the distance was measured on a straight length and then the slope of the terrain was added for slope correction using Eq. 1:

$$L' = L\cos\alpha \quad (1)$$

where:
L' – corrected distance (m),
L – uncorrected distance on the slope (m),
α – slope degree.

Table 3. Physiographical properties of stability classes

Code	Stability level	Slope (%)	Soil (land code)	Distance from stream (m)
1	very high	0–20	4.15	> 301
2	high	21–30	2.17	201–300
3	moderate	31–55	2.17	101–200
4	low	> 56	1.14	0–100

A new route tool can find the best route to get from a log landing to marked trees based on the length of the route. The routes can be specified interactively by placing nodes on the screen and entering an address. The optimal route can be the quickest, shortest and most scenic route. This approach was used for intermediated marked trees.

RESULTS

Weights of effective factors on slope stability

Results showed that the criteria affecting the slope stability were slope, soil and stream with the relative weights of 0.63, 0.29 and 0.08, respectively. Stability degree decreased with increasing slope gradient. Moreover, the slope stability was increased by increasing a distance from the stream. Physiographical properties of stability classes are shown in Table 3. The slope stability zonation map was classified into four categories: very high stability (code 1: 40.62%), high (code 2: 24.53%), moderate (code 3: 23.84%) and low stability (code 4: 11.01%) (Fig. 3).

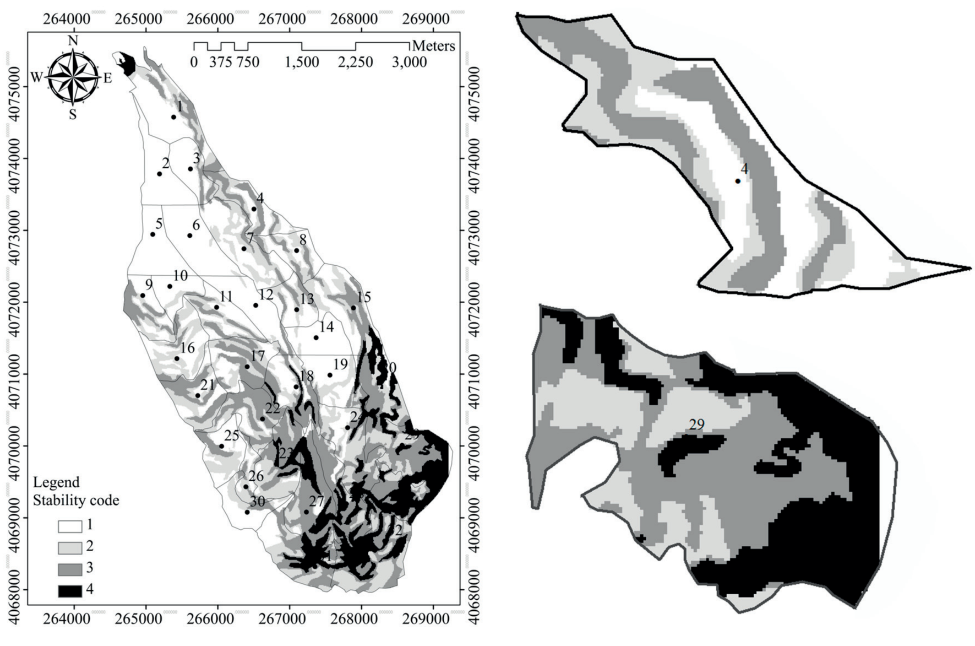


Fig. 3. Stability map of the study area and compartments 4 and 29

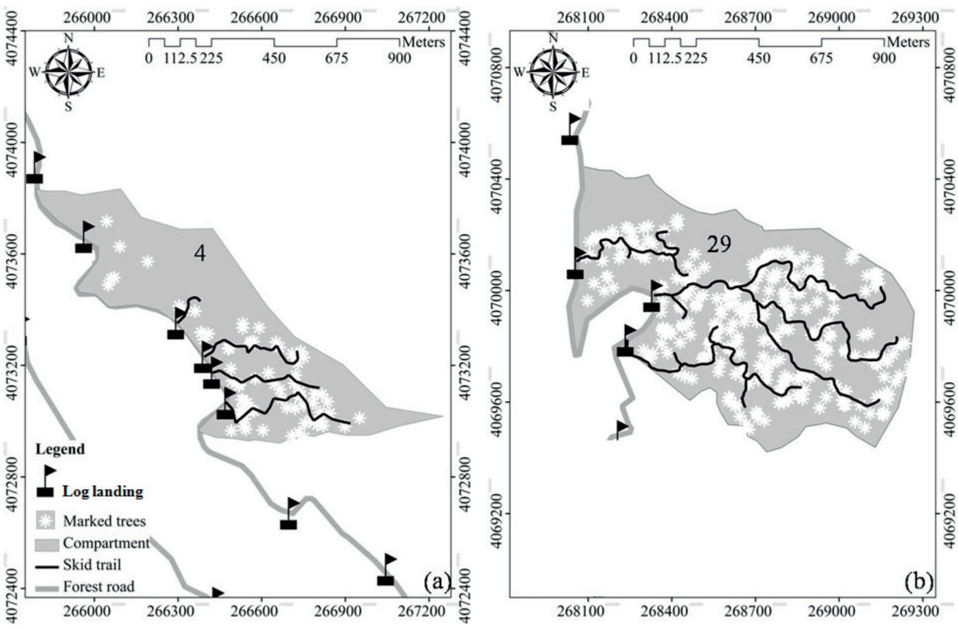


Fig. 4. Distribution of skid trails in compartment 4 (a) and 29 (b)

Designed skid trails according to slope stability

It was attempted to design routes among all marked trees. Approximately 73% of the skid trail length in compartment 29 passed through the area with moderate to high stability. More than 90% of the length of skid trails in compartment 4 passed across the ground with moderate to very high stability (Table 4). The length and density of designed skid trails in compartments are shown in Table 5. Skid trails covered 56.34 ha (73.32%) and 20.89 ha (48.14%) of compartment 29 and 4, respectively. Skid trails were almost all located in areas with higher density of marked trees (Fig. 4).

Table 4. Passage of skid trails from different classes of stability level

Stability level	Length of skid trail			
	compartment 29		compartment 4	
	(km)	(%)	(km)	(%)
Very high	0.0	0.00	0.6	34.48
High	1.5	30.34	0.5	29.08
Moderate	2.1	42.52	0.6	36.05
Low	1.3	27.14	0.007	0.39

Table 5. Technical parameters of designed skid trails

Compartment	Area (ha)	Length (km)	Density ($m \cdot ha^{-1}$)	Skidding coverage (%)
29	76.84	4.8	62.80	73.32
4	43.39	1.7	39.57	48.14

Skid trails in service area tool

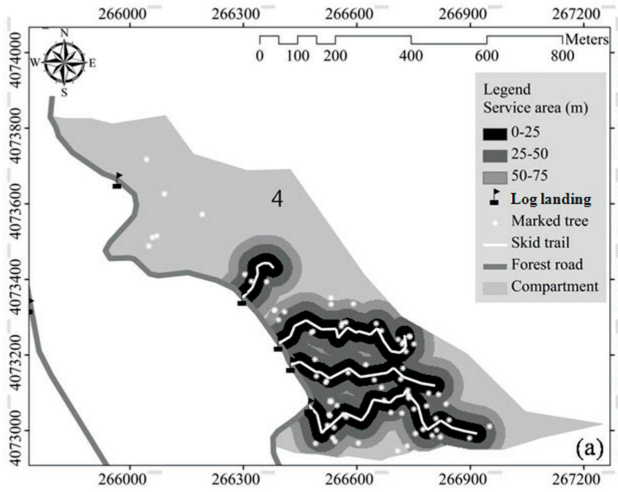
The multi-ring service area around any skid trail encompassed marked trees that can be reached within 25, 50 and 75 m within the allowed skid trail coverage (Fig. 5). On average 50.25, 27.31 and 10.79% of marked trees are located within 0–20, 21–50 and 51–75 m of service areas. 1.3% of trees in compartment 29 and 3.95% in compartment 4 are located at intermediate position on overlaps, so they should be routed by a new route technique. In some cases, the marked trees are situated far away from the service area of designed skid trails. These trees are called inaccessible (Table 6).

Skid trails in new route tool

The skid trail pattern to access intermediate marked trees is shown in Fig. 6. On average the length of the route decreased by 6.65 and 19.22% with the use of a new route algorithm in compartments 29 and 4, respectively (Table 7). Totally, the new route algorithm decreased the route length by 12.03% in the study area.

DISCUSSION

Finding skid trails for a forest area which are feasible for harvesting is important especially in a single tree selection cutting system (Kősir, Krč 2000). New route and service area tools in GIS can



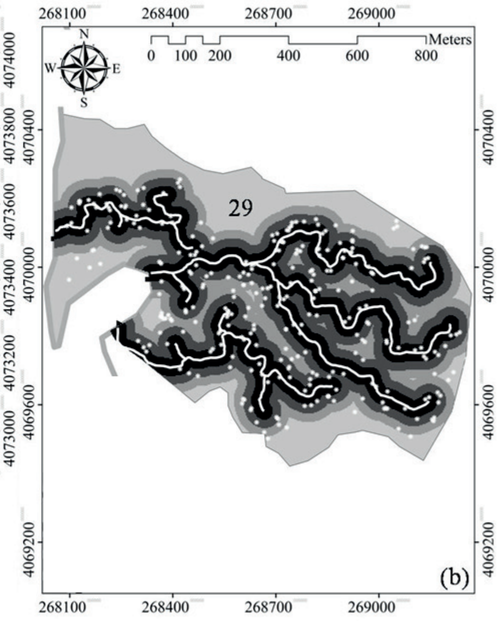


Fig. 5. Marked trees accessible by skid trails according to service area categories: compartment 4 (a), 29 (b)

Table 6. Number of accessible marked trees in different service area categories

Service area (m)	Marked trees	
	number	(%)
	Compartment 29	
0–25	147	47.88
25–50	95	30.94
50–75	38	12.38
Inaccessible*	23	7.49
Intermediated**	4	1.30
	Compartment 4	
0–25	40	52.63
26–50	18	23.68
51–75	7	9.21
Inaccessible	8	10.53
Intermediated	3	3.95

*trees are situated far away from the service area of designed skid trails, **trees are located in an area where two service areas overlap

Table 7. Length of routes to extract intermediated marked trees from compartments

Route	Route length (m)	
	new	previous
	Compartment 29	
a	676.39	709.48
b	569.00	602.00
c	812.00	945.00
d	1,274.00	1,305.00
	Compartment 4	
e	180.50	214.00
f	281.90	372.28
g	483.00	587.00

support decisions on locating routes among marked trees (Lihai et al. 1996; Girvetz, Shilling 2003). Suitable route spacing can be influenced by logging method, price of products, log landing costs, machine costs, road and skidding pattern, topography and soil condition (Devlin, McDonnell 2009; Sterenczak, Moskalik 2014). Indeed, the Network Analyst model is a practical tool to help the forest engineer to analyse and develop skid trails for a forest area with little access to the marked trees.

In a forestry program a specific skidding system can be used based on technical capabilities and forest area conditions where that system should work to reduce operational costs and increase the value of wood (Filippo et al. 2007; Lubello 2008). The first step to find skid trails is determining stability classes of forest land using soil and slope and distance to stream as inputs (Lihai 2000). The output file is called stability map. Designing trails on instable land zones may lead to choose the routes with high skidding cost and environmental risk (Mahini, Abedian 2014). Several skid trails with the total length of 6.5 km were designed and tracked in a field survey by GPS on the stable area.

We have described the skid trail planning situation in Bahramnia forestry plan using the new decision support system in detail. An important part of the system is the access to marked trees. There are several options how to register skid trails among trees. However, since choosing among options the solution is difficult, a multi-criteria analysis based on AHP was used (Vreeker et al. 2002; Karlsson et al. 2006). Service area and new route tools were applied to evaluate accessibility of trees according

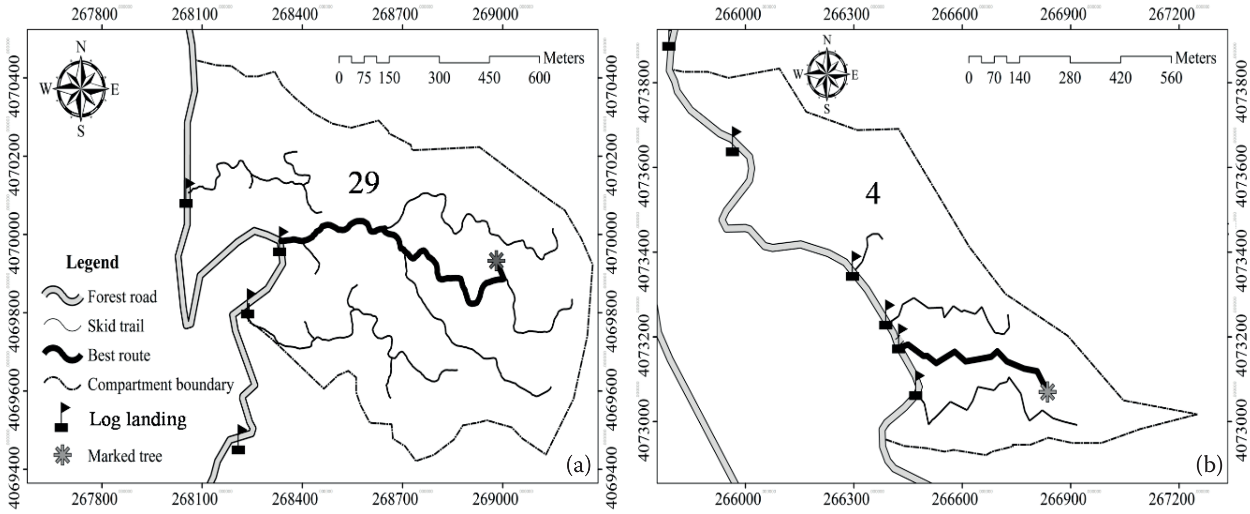


Fig. 6. The routes for extracted marked trees to a log landing in compartments 29 (a) and 4 (b)

to the length of the skid trail. In this study, with the use of a new route tool the length of the route decreased. To improve this method, it is necessary to add skidding cost and time values on route links. We showed that these models can lead to the best solutions in very short computing times. The effectiveness of the presented method has been proved using data from real problems in mountain areas.

CONCLUSIONS

The following results have been drawn from the network analysis of skid trails using decision support system and technical parameters for the selection. Network Analyst extensions provided the best route from the marked trees to log landings. The results confirm that a considerable amount of data is needed to ensure that skid trails be effectively designed in the forest. Such data includes data relating to slope, stream, soil in terms of slope stability, position of marked trees and log landings. The findings relating to the application of network analysis tools showed that the new route algorithm decreased the route length by 12.03% in our study area. Future work with network analysis tool involves the development of faster solution techniques to limit the size of the skid trail network. It is recommended to increase the accuracy of routing by a continual field survey and investigating the terrain topography.

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