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Calculation of average skidding distance on sloping terrain with GIS tools

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Abstract: To determine skidding productivity and costs for skidding operation, it is necessary to estimate real skidding route and to calculate average skidding distance. This study was intended to expose how the real average skidding distance was to be calculated and which operation process was to be followed up for harvesting units/blocks having irregular shapes as three dimensions. Compartments, harvesting stands, were divided into sub-compartment polygons called harvesting blocks with respect to transport borders determined according to road location, stream flow, and topographic structure of mountainous terrain. To calculate average skidding distance based on surface length between the most suitable existing road segments and centroids of the polygons, a selective process was followed. In this study, vector and raster Geographic Information System (GIS) tools were used. To compare with other approaches and evaluate of the calculus algorithm, various skidding distance determination strategy were improved and applied on the same test area. In this study, spatial analyses have been made for 17 compartments selected from Pamucak Forest Planning Unit of Isparta Forest Region, in Southern of Turkey. According to the results the mean difference between real average skidding distance (ASD_R) and shortest average skidding distance (ASD_S) was found amount 24 meters for the test area. It has been considered that the ASD_R amount calculated in this study is too close to real skidding distance used for harvesting operations.
Keywords: Average skidding distance, Transport boundary, GIS, ArcHydro tool

CBS araçları ile eğimli arazilerde ortalama sürütme mesafesinin hesaplanması

Özet: Bölmeden çıkarma çalışmalarında, sürütme işleminin verimliliğini ve sürütme maliyetlerini belirlemek için gerçek sürütme rotasının tahmin edilmesi ve ortalama sürütme mesafesinin hesaplanması gereklidir. Bu çalışmada gerçek ortalama sürütme mesafesinin nasıl hesaplanacağı ve üç boyutlu olarak düzensiz şekillere sahip üretim bloklarında/ünitelerinde hangi operasyon adımlarının takip edileceği tasarlanmıştır. Üretim meşcereleri olan bölmeler, dağlık arazide topoğrafik yapı, akış yönü ve yolun konumuna göre belirlenen transport sınırlarına göre üretim blokları denilen bölmecik poligonlarına ayrılmıştır. En uygun yol parçası ve bu poligonların orta noktaları arasındaki yüzey uzunluğuna bağlı olan ortalama sürütme mesafesinin hesaplanması için seçici bir süreç izlenmiştir. Çalışmada raster ve vektör Coğrafi Bilgi Sistemi (CBS) araçları kullanılmıştır. Diğer yaklaşımların karşılaştırılması ve hesaplama algoritmalarının değerlendirilmesi için çok sayıda sürütme mesafesi belirleme stratejisi geliştirilmiş ve aynı test alanında uygulanmıştır. Çalışmada konumsal analizler, Türkiye'nin güneyinde bulunan Isparta Orman Bölge Müdürlüğü sınırları içindeki Pamucak Orman Planlanma Ünitesi'nde seçilen 17 bölmenin sayısal verileri kullanılarak yapılmıştır. Elde edilen sonuçlara göre, test alanında, gerçek ortalama sürütme mesafesi ile en kısa ortalama sürütme mesafesi arasındaki ortalama fark 24 m olarak bulunmuştur. Bu çalışmada hesaplanan gerçek ortalama sürütme mesafesi değerinin, üretim operasyonlarında kullanılan gerçek sürütme mesafesine çok yakın bir değer olduğu düşünülmektedir.
Anahtar kelimeler: Ortalama sürütme mesafesi, Transport sınırı, GIS, ArcHydro aracı

1. Introduction

In order to be used in operational planning and sale agreement, skidding cost and other operational costs are previously calculated. Skidding cost with the other variables is dependent on skidding distance of the harvesting unit. Before skidding operation, it is difficult to estimate real skidding route without any skid trail and to calculate average skidding distance. However, skidding distance is an interval between landing locations or road segments and log location. It is varied by extraction systems, topography, unit shape, landing and road space, etc. In spite of the other variables are fixed, calculating real average skidding distance (ASD_R) on sloping harvest units having irregular shape is very complex task. Although many theoretical methods have been developed in regular shaped geometrical areas, in practice, these methods are not useful for irregular shaped forest areas.

The studies intended to determine of skidding distance are changing with respect to aim, topographic relief, calculating methods, extraction methods, and wood materials. Many of the studies focus on reducing skidding costs. Therefore, optimal landing location and road space are considered to find the route which might be minimum skidding from stump to landing location (Matthews, 1942; Suddarth and Herrick, 1964; Peters, 1978; Sessions and Guangda, 1987; Thompson, 1992; Liu and Corcoran, 1993; Greulich, 1997; Clark, 1998; Kluender et al., 2000; Contreras and Chung, 2007; Eker, 2011). The majority of the studies related to calculating skidding distance are theoretical and generally fulfilling on flat areas having simple geometry (Matthews, 1942; Lussier, 1961; Donnelly, 1978; Garner, 1979; Greulich, 1987). In general, they are developed the model to determine skidding distances of skyline, skidder and forwarder. Some papers describe automated procedures to find skidding distance by using computer programs and GIS functions (Greulich, 1995; Tucek and Pacola, 1999; Kluender et al., 2000; Eker, 2004; Tucek and Pacola, 2005).

Theoretically, there are different approaches to determine of skidding distance in the way of choosing compartments having regular or irregular geometric shapes in 2D or 3D and of using surface lengths of skidding trails and surface areas of harvesting units. According to chosen approach, digital models (Balcı vd., 2000; Çoban, 2004) may be produced to find skidding distance by using Arc*GIS* (ESRI, 2011) which is one of the common commercial GIS software. With processing raster and vector data in GIS environment, mean slopes of compartments and surface lengths can be found, and then skidding distance can be calculated by aid of these values.

To be balanced of supply and demand relation of the wood and to be increased competition strength of forest administration at national or international scale it is need to product of wood with low cost. In this point, before starting harvesting process, it is required to determine skidding distances justly and accurately for both forest administrative and forest workers.

The aim of the study is to develop a practical methodology to determine ASD_R of harvesting compartments in the stage of harvesting planning by using GIS. Another aim is to explain how skidding distance can be calculated the most suitable manner in the target harvesting compartments having homogenous stand structure with irregular shaped before harvesting and taking into consideration all characteristics of area during calculating cost after to be proven efficiency of this methodology.

2. Data

Geographic data used in this study were acquired from on-screen digitizing paper maps in Arc*GIS* environment. These maps consist of topographical maps containing elevation data (10 m contour interval) and stand type map including geographic details such as compartment, road and stream definitions. Stand type map of this planning unit has been produced from aerial photogrammetry applications and intensive field studies performed on sample areas. For this reason, this map contains quite reliable field data. Both the topographic and stand type maps are related with Pamucak Forest Planning Unit. 17 compartments from this region were chosen for GIS spatial analyses. The size of the study area is 839.98 ha (Figure 1).

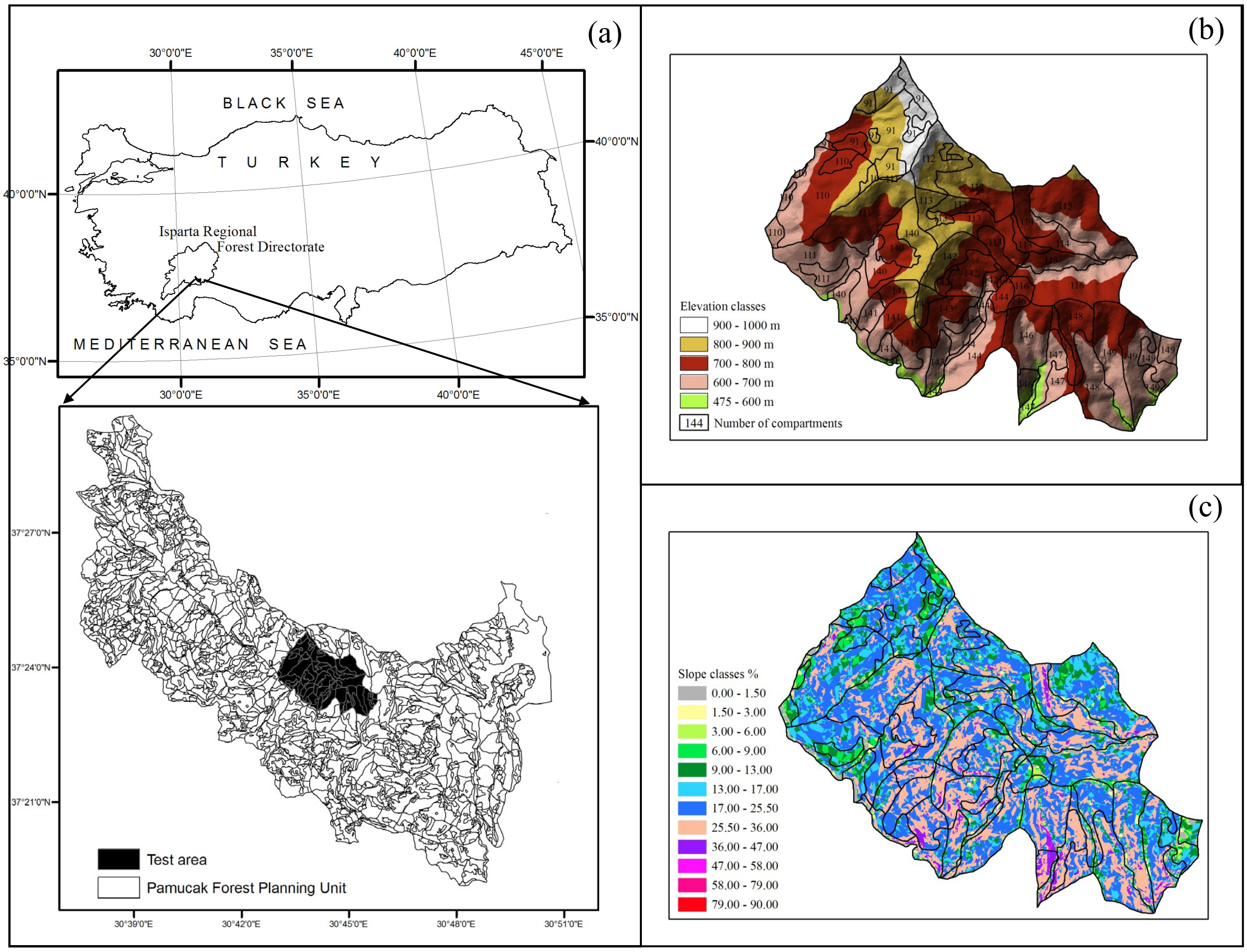

Figure 1. Spatial characteristics of study area; a) Geographic location, b) Elevation classes of test area, c)Slope classes of test area

Topographical vector maps and stand type map at 1:25000 scale were used in the study. All graphic data were geometrically co-registered to each other, using a first order polynomial transformation (root mean square error of less than 5 m).Topographic vector maps of 1:25000-scale used in the study are composed of digital elevation maps. These maps were produced by the General Command of Mapping-Turkey by using Universal Transvers Merkator (UTM) projection and ED-50 datum. Therefore the original projected coordinate system, UTM, European Datum 1950, Zone 36N, was selected for all maps.

ArcGIS Desktop (ver. 10) available in Süleyman Demirel University Faculty of Forestry GIS Laboratory and Erdas Imagine (ver. 2011) software available in Süleyman Demirel University Faculty of Forestry Transport and Geomatic Laboratory were used in this study.

3. Methods

Skidding distance is a route length used for the purpose of extracting of wood between stump of log and the shortest road or another transport facility, and generally is expressed "average skidding distance". Skidding distance relates to area named "transport unit" and its borders named "transport boundaries". Transport boundary is a border which separates harvesting units and depends on surface relief on mountainous territory. In contrast to mountainous areas these boundaries are being in the middle of the neighbor roads on flat areas (Erdaş, 1997).

To calculate ASD_R of compartments it was required that to calculate ASD_R of transport units in each compartments. Transport boundaries surrounding transport units were determined by evaluating together with stream/road data layer, contour layer, and harvesting unit layer according to natural signs such as stream and ridge, artificial sign such as roads, and flow directions (Eker, 2004; Eker and Çoban, 2010). In this way, by using Arc*GIS* software, existing compartments were divided into areas named "harvesting unit" which was saved as a data layer in the geographic database.

3.1. Determination of Skidding Distance

In forestry, skidding distances are three types: theoretic average skidding distance (ASD_T), the shortest average skidding distance (ASD_S) and ASD_R. ASD_T is the mean of the shortest distances between endless points distributing on ideal opening up area and the nearest road. ASD_S is the mean of the linear distances measured perpendicularly between endless points distributing on ideal opening up area and the nearest road. ASD_R is the mean of real distances with sinuous trace both horizontal and vertical lines between endless points distributing on opening up area and the nearest road or landing location. In practice, skidding distance depends on field conditions, silvicultural techniques, and extraction techniques. There is a relation with $ASD_R > ASD_S > ASD_T$ among different skidding distances (Erdaş, 1997). To convert ASD_S and ASD_T into ASD_R correction factors called winding, wandering, and sinuosity factors can be applied (Bayoğlu, 1972; Donnelly, 1978; Twito and Mann, 1979; Sundberg and Silversides, 1988; Thompson, 1992). In this study, it was discussed to calculate ASD_R and ASD_S quantity. ASD_T has theoretic structure and limits on topographic relief so that there is very low possibility of using it.

In the operational planning methodology, in order to be estimated ASD_R of a compartment, ASD_R of it's sub-compartments called transport units can be calculated first by doing surface flow analysis on digital maps with aid of GIS tools (Eker, 2004). All operation steps used in calculating of real average skidding distance are below:

1) All of the digital maps have been prepared as a geographic data layers. In addition, digital elevation model has been produced by using digital elevation data.
2) Watershed model of study area has been constituted by using ArcHydro tool (CRWR, 2011) in Arc*GIS* environment. In the model, there are several geographic data layers such as catchments, drainage lines, drainage points, and flow directions. While transport borders were designated, it was benefited from flow routes in flow direction layer which was the most close to real and reflecting the nature of skidding (Figure 2). Nevertheless transport borders which were formed harvesting units were drawn by using data of streams, roads, and ridges in contour and compartment layers.
3) Mean slopes of transport units and compartments were calculated.
4) Plane areas and 3D surface areas of transport units and compartments were calculated.
5) Polygon centroids of each transport unit (Figure 3) were achieved in Arc*GIS* environment.
6) Two different ways were tested while skidding distances of transport units were determining. These skidding routes were saved as a line data layer (Figure 4).
a) According to flow direction, linear skidding route was drawing from polygon center to road line directly without any deviation.
b) According to flow direction, curvilinear skidding route was drawing from polygon center to road line with possible deviation.
7) Length and surface lengths attributes were added to the geographic database of linear and curvilinear skidding route layers using Arc*GIS* tools. In this way, skidding distances of each transport units were found.
8) After finding real mean skidding distance of each transport unit, at the end of the query and analysis performed in geographic database, real average skidding distance of each compartment was calculated both linear and curvilinear form for plane and 3D surface area.

3.2. Implementation of the Model in Test Area

To achieve required geographic database consisted of digital maps and its attributes, 17 compartments were selected for this study from Pamucak Planning Unit of Isparta Forest Region, in Southern of Turkey. The above described methods were examined in the chosen these compartments step by step. Digital elevation model was produced with 10 meter pixel resolution by using ERDAS Imagine (ver. 2011) software. The entire compartments were operating for harvesting purpose. It was accepted that the distribution of trees for all these stands was uniform and all structural characteristics of the stands such as tree species, age, canopy closure etc. were the same. These compartments have been allocated as production forest in own multifunctional forest management plan (2007-2017) and it was decided to clear-cutting for them in silvicultural prescription.

For this region, it was chosen ground-based extraction method based on gravity and human force (70 %) mainly. The remaining portion of the skidding operation was to be carried out by animal force (20%) and by agricultural or forest tractors (10%). Therefore ground-based extraction method was preferred for calculating skidding distance according to existing forest road network. However there was no applying optimization method to determine landing or loading location.

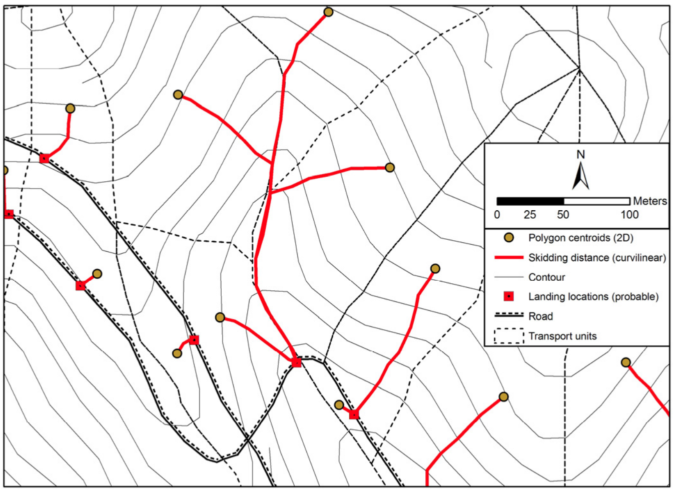

Figure 2. Determination of flow directions using ArcHydro GIS tool

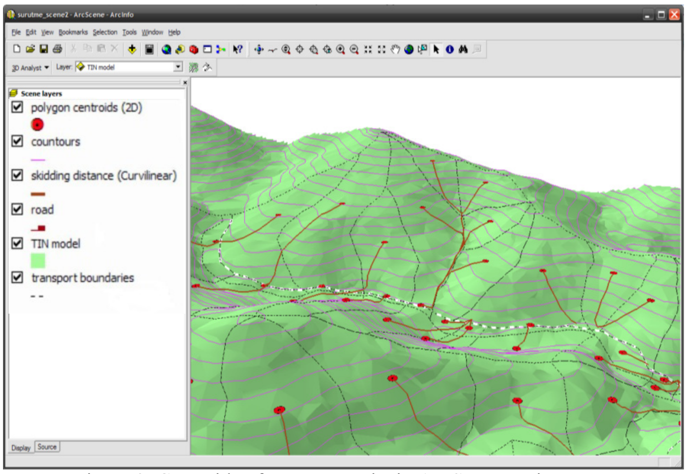

Figure 3. Centroids of transport units in Arc*Scene* environment

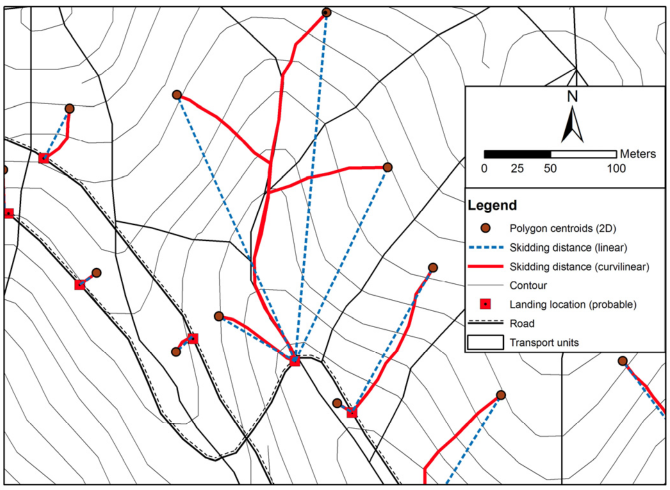

Figure 4. Linear and nonlinear skidding routes from centroids to road of transport units

4. Results

Results of the GIS iterative solutions for linear and curvilinear routes are summarized in Table 1. While calculating ASD_S in fourth column of the table terrain slope was not taking into consideration. On the other hand, in the fifth column of the table linear lengths were found by considering terrain slope. In the sixth column of the table there were considered topographic conditions, surface lengths, and flow direction to calculate ASD_R. Here, the water flow directions in other words dry streams or water channels on the terrain were followed. In the reality, skidding works have been made by forest workers with tracing these directions. Therefore sinuosity and wandering factors and terrain slope could have been implicitly included in calculations developed by this methodology, so that ASD_R was found bigger than other distances. It can be said that the ASD_R is too close to real skidding distance for harvesting operations and this approach can be a good mimic model for skidding operations. The mean difference between ASD_R and ASD_S was found amount approximately 24 meters for 17 compartments. In other words, on the average, the ASD_R values were greater than 14.31 percent of the ASD_S values. Because of used ArcHydro tool, it was not additionally necessary to use both sinuosity and wandering factors. This is an advantage of this method.

At the same time, while average skidding distance was calculating from geometrical and flat hypothetical terrain in the literature, we computed skidding distance with close to real on sloping and irregular shaped terrain in the study. Only vector-based digital maps were used in this study. This methodology is a computer aided system and presenting an iterative solution for all Arc*GIS* users. However it is available for different strategies in both theoretic and practical.

Particularly this methodology can be used to calculate operational skidding costs by the Chief of Forest Planning Unit (end-user) using forest information system based on GIS. Therefore forest administrations carry a fair and scientific approach on today for calculating skidding costs.

Table 1. Different skidding distances for each compartment

Compartment Number	Surface Area (hectare)	Mean Slope (%)	Straight Line (linear) Distance (meter) (ASD_S)	Rectilinear (sloping) Distance (meter)	Real Average Skidding Distance (meter) (ASD_R)
1	*2*	*3*	*4*	*5*	*6*
91	70,22	30,71	349,33	364,12	380,45
110	61,51	31,34	122,73	128,14	134,07
111	74,33	34,50	118,51	124,86	131,19
112	50,30	34,69	120,97	127,61	136,83
113	63,25	33,88	115,47	121,51	137,83
114	23,79	42,63	127,53	138,52	146,85
115	45,70	31,61	188,80	197,25	211,60
116	41,40	36,82	79,32	84,21	89,39
140	58,30	39,19	130,99	140,21	152,50
141	57,22	44,60	211,64	231,39	246,62
142	40,46	40,08	372,60	400,24	432,80
143	41,00	43,57	291,24	317,30	336,39
144	35,29	37,63	108,53	115,81	122,88
146	36,54	46,91	103,29	114,04	119,78
147	28,72	46,66	141,84	156,52	165,85
148	41,86	39,76	132,72	142,41	157,24
149	70,09	34,74	137,54	145,07	159,17
Total:	839,98				
		Mean values:	167,83	179,37	191,85

5. Conclusion

This method was developed by using ArcHydro Tools in Arc*GIS* environment with semi-automatic approach. Iterative process has shown that it is possible to find skidding distance which is the closest to real one. Studies advised for designating skidding distance that is more similar to real field conditions are below:

- Using LIDAR (Light Detection and Ranging) remote sensing data, high spatial resolution satellite data, and aerial photographs to make more sensitive digital terrain model,
- Developing to find weighted 3D centroids depend on micro relief of 3D terrain surfaces,
- Optimization of new road landing locations and calculating ASD_R according to these locations,
- Derivation Arc*GIS* scripts or extensions for an automatic procedure.

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