Soft logging: Avoiding damage to the soil and

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Abstract:
Off-road driving in logging operations in began in the 1960´s. Those operations took place at final fellings during winter on prepared ice roads, hampering possible soil damages. Today harvesting and all operations in thinnings are mechanized, performed during the whole year. Off road may result in sever impacts from off-road operations. Soil disturbance in off-road operations may have physical, chemical, biological, hydrological, economical effects. Most serious might be the water quality. The EU Water directive has impact on operations in forests. Similar problems are encountered in Germany and North America. Off- road riving is restricted on areas close to watercourses and by planning to specific patterns and designed areas. On-going efforts in the design of vehicles and equipment are likely to improve operations. Soil damages can be avoided by planning, supported by GIS and soil radar scanning with the use of equipment making off-road driving easier.

Keywords: Ground damages, rutting, soil, forest operations, planning

1 Introduction – What is the problem?

The mechanization of logging operations in Sweden and other countries began in the 1960´s, and it led to off-road driving in order to bring timber to the landing. Those operations took place at final fellings during winter on prepared ice roads, hampering possible soil damages. Today harvesting and all operations in thinnings are mechanized, performed during the whole year due to the pulp industry demands fresh timber all year round. Off road driving is extensive on all forest land, during all seasons, - also when the ground is vulnerable to soil disturbance. In addition a great variety in the Swedish landscape in terms of topography, soils, surface water and climate has many implications for off-road operations.

In the 1980´s, a terrain classification system was developed to aid the planning of off-road driving in conjunction to forestry operations (Berg, 1992). In recent guidelines, Ring et al. (2008) address the impacts of off-road driving from a water-quality perspective. Off road driving close to surface water increases the risk for sediment load to surface water. Such sediments might be harmful to aquatic organisms (Skogforsk, 2008). The guidelines are; set aside a 5-10 m zone bordering on lakes and streams in order to mitigate sediment release to water; avoid driving in streams and wet areas; use technical devices in order to reduce physical soil disturbance at crossings; planning is an important tool for reducing such negative impacts.

1.1 Environmental and societal significance

Primary soil damage’s in conjunction with off-road driving might have secondary effects that cause physical, chemical, biological, hydrological, economical and even aesthetical impact. Although not specifically regulated in the environmental standards for forestry, the advent of forest certification, manifested in schemes like PEFC or FSC has stressed the importance of disturbance control in connection with off-road driving. One reason for this is the less permissive attitude to soil disturbance in Central Europe (Hauk,2001; Hildebrand & Schack Kirchner, 2002;) . Off-road operations increase soil density down to 50 cm, decrease soil aeration and thereby reduce root penetration (Eliasson & Wästerlund, 2007). This impact varies with moisture content. (Ziesak, 2003; Yavuzcan et al. 2005). Rutting may result in compaction (Jamshidi et al. 2008) and adverse driving conditions, which can lead to and costly interruptions and breakdowns and increase the energy use and related emissions. Reduction of soil disturbance at off-road operations can be beneficial both for the environment and for reducing costs.

Physical soil disturbances may affect biological processes like C and N-mineralization in the soil (Finér et al., 2003). This is relates to the EU soil directive (2004/35/EC), which states that processes that reduce C storage should be avoided. Increased nitrate leaching is commonly found after clear cutting and soil scarification (Ring et al., 2008) . Logging tracks often induce similar disturbances to soils and so there is a risk for elevated N-mineralization and nitrification in these areas. Final fellings might result in discharge of Hg and following accumulation in fish (Bishop et al., 2009). This is might be attributed to anoxic conditions in soil caused by raised water level in tracks.

The Swedish Environmental objectives (Swedish EPA, 2011) take into account several of these impact categories, nevertheless the responsibility to maintain the water status lies also in to the EU Water Framework Directive (2000/60/EG).

2 Technical means to mitigate ground damages

The ground damages are formed when the terrain vehicle have contact to the ground, that is by the forces and pressures that is executed on the ground by wheel or tracks. The resulting effect is compaction of soil, skidding and shearing of vegetation or soil layers. These effects can technically be avoided by either design of the machine-vehicle or mitigated with operational skills, adjusting vehicle properties by e.g. reducing the impact of the load on the ground (Ziesak 2003; 2004) or ancillary equipment (Staland Larsson, 2002) put up in the terrain along planned routs or passages over brooks or other watercourses. Planning procedures based on mapping with digitalized elevation models can be used to map soil type, vegetation type and drainage conditions for a potential logging area. This information can e.g be compared to GPS tracked wet areas (Murphy et.al, 2008; Vega et al., 2009) or logging roads.

2.1 Design of machines

By machine design basic properties of machine impact can be altered and adjusted actual conditions. This can be done by adjusting the pressure on the soil executed by the wheel by changing tire pressure (wheel width) or using wider tires (Jonsson, 2011). Tracks might be added in order to distribute forces more evenly over the ground surface, and this will also enhance the risk of shearing at turns. By adjusting air pressure in the tires to the soil and load or vice versa the operator has mean to reduce ground damages (rut-depths). Tests made with a CTI-system (Löfgren, 1994) on a forwarder showed that the rut-depth is the same with 600 mm wide tires with low pressure as 800 mm wide tires and high pressure.

Basic machine properties have impact on the ability to negotiate the terrain. The driving and the position of the wheels before obstacles by hydrostatic driving might be beneficial. The reducing and damping on vibrations has similar effect (Baez, 2008). Important is also geometric design that distributes the pressure on the wheels in a beneficial way.

2.2 Supporting equipment

With the aid of different p a technical equipment it is possible to reduce the damages to virtually nil ; but there is a cost and the issue is to have equipment on the right spot at the right occasion.

Figure 1. Bridges for crossings from left to right, semi fixed (Martinsons, http://www.martinsons.se) and Huldtins temporary steel bridge (http://www.hultdins.se/swe/index.htm). Photo Martinsons (left) Eva Ring (right).

The means are fixed or temporary bridges along the hauling route or to carry prefabricated bridges for the imminent use during the passage of e.g. a dyke. Other solutions are to work with ground cover rigs, made of timber or mats of tires. Also the use of harvest residues and downgraded wood logs are possible means. Residues can be spread out along the hauling route in order to mitigate the ground damages when passing difficult passages. The use of harvest residues is quite efficient when the issue is few passages over a difficult area. However present increasing interest for biofuels is hampering this application.

3 Planning

The issue of the right application of routs and ancillary equipment is coordinated by planning. In order to plan the operations and the use of ancillary equipment updated maps are mandatory. The basing the planning on Geographic Information System (GIS) is a great step forward compared to former methods.

Geographic Information System (GIS) is one of the technological achievements with great potentials in assisting planners and decision makers to tackle scientific questions through exploring a variety of digital layers of information, extracting required knowledge, evaluating possible alternatives and finally making appropriate decisions. The possibilities with modern planning are exemplified here with a case study in southern Sweden.

This study explains how GIS could be used to utilize the existing spatial data and provide an improved decision support system for off-road routing planning in forest harvesting sites in order to minimize environmental impacts on soil and water, caused by forest operations. Proper route alignment with respect to lateral inclination of the ground, to support loaded forwarders on steep terrains, was also considered in this method.

3.1 Study area and scenario description

The study area under consideration was the property Selesjö in Östergötland, located in south-east Sweden and was mainly dominated by Norway spruce and Scots pine (Figure 2). In close neighborhood to the harvesting area (6.72 hectares) a possible landing point was selected where the harvested timber was to be stored for further operations. This landing point was to be reached from 4 arbitrary destination points on harvesting site. However, there was a wetland between the landing point and part of the stand. This wetland needs to be protected against driving damages. This was the 'No Go' area and its border was defined by direct observation of the site. Possible route alignment to reach the destination points with minimum disturbances to the surrounding environment was evaluated under two different scenarios: in Scenario 1, the routes were expected to go beyond this sensitive part and reach the end points, while in scenario 2 the possibility of building a bridge to pass the wetland was analyzed to see how the route layout would have to be adjusted to the new condition.

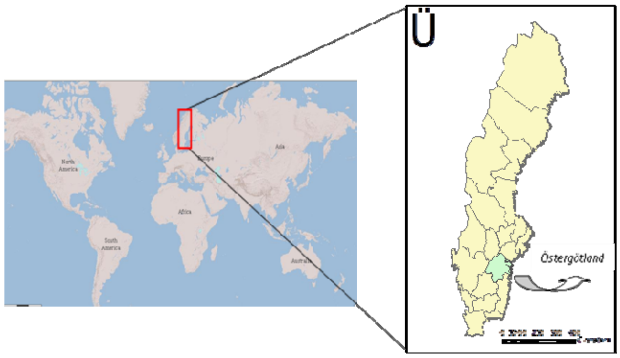


Figure 2. Location of the study in a world map (left) and in Sweden (Right).

3.2 Utilized data and software

The main utilized data sets in this model could be considered as: a raster type laser scanned Digital Terrain Model (DTM) of the area with a high resolution of 0,5 × 0,5 m provided by Foran Remote Sensing AB, a raster type Soil classes provided by Swedish Geological Research Institute , SGU. Slope and Aspect were two other data sets extracted from the DTM layer. Environmentally sensitive spots such as Nature Reserves, Key biotopes and habitat protected regions as well as historical values, prepared by the Swedish Forest Agency, Skogsstyrelsen, (http://www.skogsstyrelsen.se/), was to be set aside as protected. Separate shape layers localizing the landing point (source) and destinations were also used as inputs of the model. In this study the 10th version of the ArcGIS software packages provided by the Environmental Systems Research Institute, Inc (ESRI), including ArcMap, ArcCatalog and ArcScene, were used for data preparation, data processing, information exploration, evaluation and at the end, 3D visualization of the final results. The Slope, Aspect, Path distance and Cost Path tools available from the Spatial Analysis and the 3D Analysis extensions where used to build up the desired model within the 'Model Builder' environment of ArcGIS.

3.3 Methodology

Planning forestry operations in a sustainable manner requires simultaneous consideration of economic and ecological values in the forest. These two aspects do not always introduce similar approaches for forest managers in practice and thus, there is always an essential need to bring all the groups of interests to a consensus for evaluating and integrating various criteria and making the best decision. Simply defined by Eastman et al (1998) "decision is a choice between alternatives" and Multi Criteria Decision Analysis (MCDA) is a procedure which can unify several attributes and/or objectives in the process of decision making (Malczewski, 2006), and therefore this procedure was the base of the analysis for finding the optimal routes in this study. Weighted Linear Combination (WLC) was the applied rule in this process since it was compatible with the ArcGIS software.

3.4 Model Description

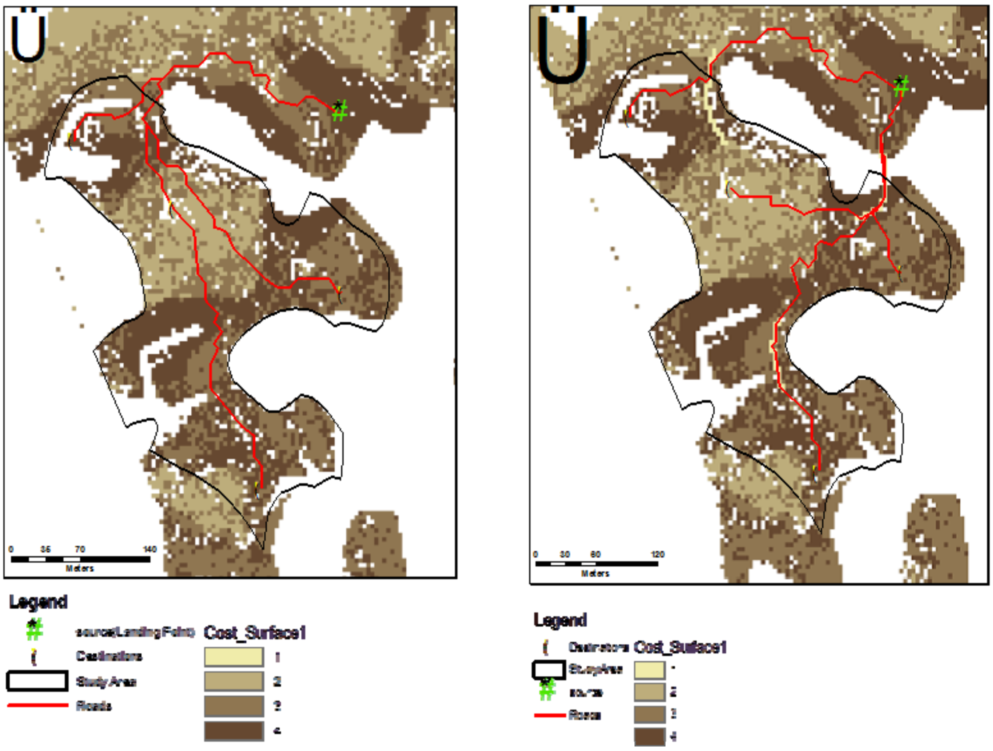
The model was supposed to plan the least costly routes through the best directions from destination points to the available landing point(s). Meanwhile it would help plan the routes with a proper orientation with respect to direction of the slope of the ground. Applying MCDA a single map surface, a cost-index surface was created as the base for distance analysis. Within this procedure elevation, slope and soil classes were regarded as factors, determining the level of suitability of the area for driving. Reclassifying all these factors to a common scale of 1 to 5, called cost-index values, using 'Weighted Overlay' toolset of the ArcMap, the cost-index surface was created illustrating 5 levels of suitability, the lower the cost the better was the overall condition of the ground. Later on, soil classes with low bearing capacity (such as wet land, peat lands), as well as steep slopes (> 18 degree) and ditches were regarded as constraints of the study area and were extracted from cost-index surface, Table1.Afterwards, feeding the cost-index surfaces together with the landing point layer, as source, DTM layer as surface raster and Aspect as the horizontal factor in to the Path Distance tool, the least accumulative cost of getting back to the cheapest landing point, and also the proper direction for moving to the neighbor cell was determined. Maximum inclination of 5 degrees with respect to the slope direction of the ground was meant to be achieved in this model. the outcomes of this part aligned with the destination layer were inserted into the Cost Path tool to design the route layout in the harvesting site.

Tabel 1 Summary of the data reclassification.

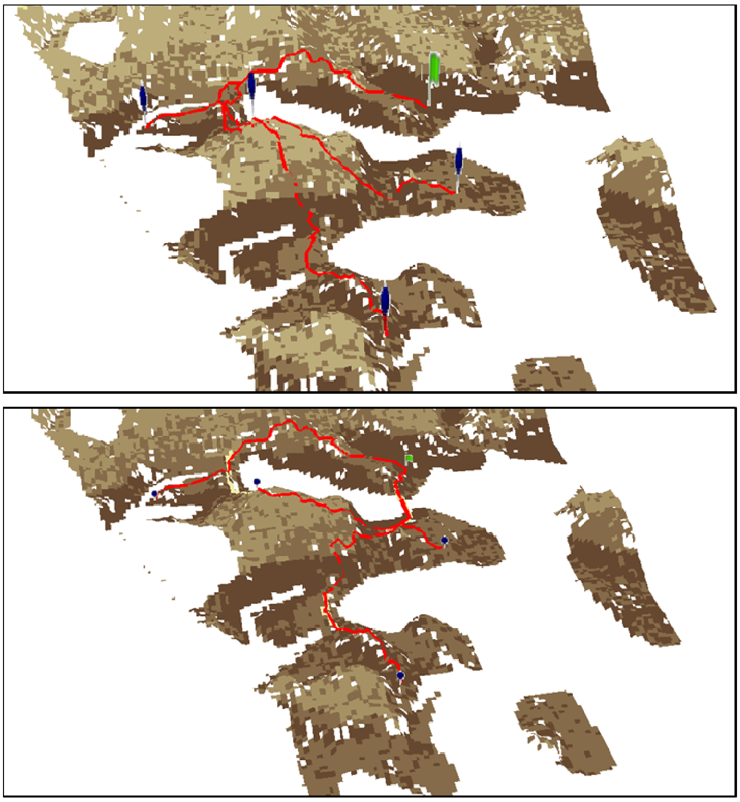
Factors	% of influence	Factor classification	
		Old values	Cost-index values
Elevation	50%	65 – 60	1
		60 - 55	2
		55 - 50	3
		50 - 46	5
		0 – 6	1
Slope	30%	6 – 11	2
		11 - 18	3
		18 - 27	4
		27 - 90	5
		Rocks-outcrop	1
Soil classes	20%	Till	3
		Silt	5
Sum	100		

3.5 Results

Figure 1 illustrates how the model planned the least costly routes from the destinations to the source while compensating for surface distance and horizontal factor, which is the orientation of slope within the context of two different scenarios. As explained earlier, there was a wetland in the way of connecting the destinations within the site to the landing point, outside the harvesting border. In Scenario 1, the model was supposed to plan the routes while going beyond this restricted part while in Scenario2, the possibility of building a bridge over the wetland was evaluated to examine how the model would adjust the route alignment to the second introduced condition. Figure 2 demonstrates 3D visualization of the suggested routes of both Scenarios in the ArcScene 10 environment. Comparing the route alignments before and after inserting the bridge in the surface of possibilities revealed that the suggested bridge could contribute in a reduction of almost 700 m in the length of the routes to be passed from destination points to the landing point. In order to transport harvested volume in the area along the new route layout, based on the acquired information on the timber volume from the laser scanned data by Foran Remote Sensing AB, there would be a need of 79 number of loaded forwarder, corresponding to 158 passages. Assuming the maximum velocity of forwards as 0.8 m/s and their average cost of operation as 850 SEK/hour, the second route layout over the bridge would result in a reduction of 32000 SEK for the whole forwarding operation. The estimated cost of the bridge and its construction was 5000 SEK, less than the saved operational cost in Scenario 2.



Figur 3 Suggested route layout by the model for Scenario 1 (left) and Scenario2 (Right), white spots in the harvesting border represent all the restricted areas.



Figur 4. 3D view of the route layout and the cost-index surface exposed on the DTM of the area in ArcScene environment

4 Discussion

As widely known, issues concerning sustainability are today high up on any agenda, and especially on forestry´s. Forest operations are conducted in landscapes and impacts from its activities are seen by many. Negative chemical, biological and physical consequences from soil damages are verified (cf; Finér et al., 2003; Bishop et al., 2009). There has also been a growing awareness of the social values of the forests manifested in Standards for Forest Certification (cf. FSC and PEFC). As a part of standardization it is important to show that you have identified the aspect and that you are undertaking actions to remedy or improve deviations from the standards. That is operations must be close to best practice.

Means are available to mitigate damages, and they are equipment for the crossings of water streams and wetlands or tracks for mitigate rutting. The reason why some equipment is not used is many times it is not on the right place at the right time. Financial or managerial incitement to bring them or to start building passes are missing. The advent of better preplanning tools with the aid of GIS can improve this. As shown in the case study above even small improvements make sound economy. Digital maps in general use with information about e.g. wet areas or other safeguard objects of concern, can assure more improved plans in achieving sustainable forests in practice, probably more economically rewarding and likely to be asked for by the auditors from any certification agency.

The vehicles contact to the ground is depending on its basic design and load- The damages caused is a combination of the driving and planning. Improvements in machine properties will take a long time before it has an effect in the fleet of logging machines some will be better than others. The planning tools will make possible better allocation of logging machines to appropriate logging areas.

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