GIS Decision Support Tools to Minimize Soil and Water Damage in Logging Operations – Swedish Case Studies Show Great Potential

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Abstract:
Sever damage to the soil and water during forestry operations has been known as the side effect of higher traffics and mechanizations in forests in recent decades. These kinds of damages disturb the ecological values in the forest and thereby threaten the regrowth and sustainability under long term there. Hence increasing efforts and attentions are attracted worldwide to find out smart solutions which can reduce the damages using the knowledge and the advanced techniques which exist today. In a previous study a GIS-based model has been designed at the Forestry Research Institute of Sweden that can facilitate the task of route-planning at harvesting sites. Integrating various digital maps the model creates a cost-index surface in order to design the routes on the areas with the best bearing capacity and avoid technical problems on steep terrains. The main input materials in this model are elevation, slope, extracted from a high resolution digital terrain model (DTM), and soil type layer. In this study the model has been run on a number of test areas in different parts of Sweden, to evaluate how realistic and practicable it is in suggesting the access routes. The model will also be improved with a newly developed Canadian wetness index, called depth-to-water (DTW), which would enhance the process of detecting saturated regions around the flow channels with hopefully a good precision. A web-based interface would also be developed to ease the application of such modeling for end user operators in practice. Primary results of this study shows that all these developing steps could be quite ecologically and economically beneficial for Swedish forestry and result in substantial annual savings during in logging operations.

Keywords: GIS-based planning, forestry operation, soil damage, digital terrain model (DTM)

1 Introduction

Minimizing the impact to the soil and water in conjunction with forest operations is increasingly important in Swedish forestry and elsewhere. The main reasons are to avoid erosion and leakage of methyl mercury, to protect aquatic habitats, to prevent disturbing ecosystem pools of C and N by physical soil damages, to avoid disturbance of natural and cultural heritage environments and to minimize aesthetic disturbance. There are also legislative aspects connected to the issue, at national and EU level. Forest certification systems such as PEFC (2012) or FSC (2012) emphasize to control the consequent disturbances of off-road driving. European environmental policies also imply to avoid the processes in agriculture and forestry which in general reduce C storage (Anon. 2004, Anon. 2006).

Using Geographic Information System (GIS) and high resolution digital maps, a decision support system is being designed at The Forestry Research Institute of Sweden (Skogforsk) which can facilitate the task of off-road planning for logging activities in forestry (Berg et al. 2011). Taking advantage of the advanced laser scanning technique, it is possible to have detailed information about surface of terrains which is quite applicable and valuable for better understanding of the elevation variation, slope and steepness of the ground in form of digital maps. These data layers together with soil-type map are weighted based on their influence in determining terrains trafficabilty and then summed together to make a base map, called cost-surface map. The cost-surface map shows the ground's bearing condition and driving suitability with a measuring scale called cost-index, which varies between 1 and 5. The cost indexes are visualized with different colors on the map. The lowest cost index (1) corresponds to the best driving condition and the highest one (5) shows the worst condition regarding bearing the weight of forwarders. All the preserving parts such as key habitats, nature reserves and cultural and historical remains are considered as barriers in the terrain and are removed from the cost-surface. The decision support tool is being tested in operational forestry with promising results in optimizing ecological considerations as well as the economy in the operation. Preliminary results show increased efficiency in the logging operation, better decisions concerning where to pass streams and wet areas and less fuel consumption.

Further ongoing studies at Skogforsk for development of this model could be described as:

⇒ Further testing of the tool in practice. The aim is to minimize soil damages in general and serious damages close to water and sensible areas with nature conservation in particular.

⇒ Developing and applying a new data layer to find all flow channels and surrounding saturated soil in the terrain with an improved precision. The saturated soil would be measured with an index called depth-to-water (DTW) and will assist decision makers to decide where in the terrain they must allocate the tops and branches for route-reinforcement and where, e.g. areas with high bearing capacity, they can take the slashes out of the logging sites and use as energy assortment.

⇒ Making the tool more users friendly using though e.g. a web based service or similar. This would make it possible for planners, decision makers and those with no specific programming background to perform this kind of pre-planning on cutting areas, get informed about the risky, sensitive regions in the area, where the streams, ditches, wetlands and difficult steepness are located, evaluate different pre-assumptions about the best practical place to locate landing point for timber collection, building temporary/permanent bridges for crossing streams and finally how the cheapest route regarding the possible damages to soil and water could look like.

2 Methods for model development

2.1 Practical test of the model

In order to make the model as practicable as possible and calibrate it with reality we have started to run the model on approximately 15 harvesting areas with various topographic and soil type properties in eastern and western parts of Sweden. To this date half of these areas have been felled, thus the tracks of logging machines and the level of ground disturbances were traced and registered afterwards using a GPS and a field computer. This information which was saved as shape layers would then be exposed on model's created cost-surface layer to evaluate how close and realistic the model has been in determining and localizing the risky parts and the areas with low bearing capacity in the cutting fields. On the other half of the study areas, which were planned to be logged soon, the model was also run. For each area a cost-surface and a set of accessing routes were suggested by the model. As mentioned earlier ecological and technical factors (elevation, soil type and slope) are involved in classifying the harvesting areas to different degrees of suitability for driving. Afterwards in the second phase, the main access routes in the cutting field were suggested by the model while considering both ecological and economical values. Economic aspects are involved through finding the shortest least costly paths.

The suggested routes and the cost-surface were then provided to forwarder drivers as planning helps for performing the cutting. The suggested routes would require to be reinforced with slash to ensure minimum damage to the most trafficked parts of the terrain. The drivers were asked to fill out a questionnaire during the job to evaluate the models performance in both cost-surface and routes determination. They were asked to clarify where the model has been helpful in finding difficult areas and in which places it failed, how realistic the route layout has been in the terrain regarding encountering steeped parts and hilly regions, what would be their suggestions to improve the models performance and so on.

2.2 Providing more precise data layers into the model

Right now the altitude within the logging site is used as a simplified model for predicting the wet areas in the terrain. It has been assumed that the lower the elevation in an area, the higher the probability of wetness occurrence there, and thus the driving conditions would be worse on the low elevated areas. On the other hand the high elevated parts are assumed to be drier and consequently they would have a much better bearing properties. However, this procedure for wetness prediction is not always successful, e.g. it cannot always find those shallow wet parts which are located along elevated regions and are not simply just on the lowest part of the terrain. And hence in order to enhance functionality of the model for better route localization we have now started a cooperation with the University of New Brunswick in Canada which have already developed a new algorithm to find almost all existing flow channels in the terrain and thereby measuring the degree of soil saturation with the DTW index which in fact represents the elevation difference between the soil and the closest water feature (Murphy et al. 2009a, Murphy et al. 2009b). This algorithm would first be tested on two different part of Sweden, east and west, to examine its precision and accomplishment in finding wet regions and then in case of finding great potential for improving our model's performance, it would replace the simple elevation layer in the input material.

2.3 Creating users friendly interface for final users

The last but not the least step of model development would be to create an easy to use web service for planners and drivers, through which the users themselves can decide about the relative importance of each data layer based on the terrains property and/or climate condition. Since even wet areas might be possible to drive on under very cold and frozen Swedish winter, it would be quite applicable for the users to be able to justify model's pre-condition independently in each case. The interface would also provide the users the opportunity of evaluating different rout layout designed for different possible landings. It can also assist in examining whether it would be economically feasible to build bridges at wetlands/stream location, considering the cost of bridge and the reduction in driving distance, or if it is worthier to go around a difficult part to reach the landing.

3 Results

Preliminary results from the field tests carried out during the summer 2012 show less damages, shorter driving distances in the logging site, decreased fuel consumption, driving on better conditions and avoiding sensitive terrain. In addition it increases the information and knowledge for the forest machine operator and thereby facilitates the work in the forest. In the presentation at the FORMEC conference, the results will be presented in more detail.

4 Discussion

A 5 % decrease in driving distance would result in a reduced logging cost with c. 0.05 euro per m3. This is a quite small reduction, but applied in a greater scale savings are still significant: 2,500-5,000 euro per year for a forest contractor, and c. 5,000,000 euro for Swedish forestry in annual savings without expensive investments.

With a similar type of reasoning, optimizing stream passes and location of landings can save more than 10,000,000 euro per year in Swedish forestry by taking a shorter way through the forest.

Obviously this also leads to less fuel consumption and thereby less emissions of C02, which is a very important goal for the future. In conclusion this sort of decision tools can constitute the next big technical step in the forestry and an important factor for continuing the increase of productivity.

There is of course an essential need to evaluate the model's performance sensitivity to the quality and precision of each of the input layers in future studies. It is quite important and applicable to study how the resolution of LiDAR derived DTMs can affect the procedure of finding flow channels and measuring the saturated soil around them, how exact and detailed the soil type and the preserved-areas data layers need to be so that they can be quite effective for designing less disturbing routes in the logging sites.

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