Evaluating Terrain for Harvesting Equipment Selection

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ABSTRACT

A terrain evaluation model, utilizing a geographic information system, has been developed as a tool for planning large-scale industrial timber harvesting operations. The model combines terrain descriptions with machine operating criteria to produce maps delineating operable areas. The integration of the model with a harvest planning decision support system is discussed and an example is presented.

Key words: *Terrain evaluation, timber harvesting, geographic information systems, productivity.*

INTRODUCTION

Today's harvest planners operate in a planning environment in which concerns over the adverse environmental impacts of timber harvesting activities must be balanced against the economic advantages of using highly mechanized harvesting systems. In order to reduce the severity of these environmental impacts without significantly increasing harvesting costs requires that the harvest planner consider site-specific terrain factors and equipment characteristics during harvest planning. For small planning areas, harvest planners have traditionally relied upon personal experience and "rules of thumb" to determine the most appropriate harvesting system to employ on any given site. While this method may be satisfactory if the planner is well-acquainted with the harvest site, it can result in excessive site damage and uneconomical harvesting operations if the planner is unfamiliar with the area. However, these traditional planning methods may not be applicable for detailed planning on large harvesting areas with diverse terrain characteristics, especially when several equipment combinations are considered. Consequently, a more structured method of considering terrain factors is needed for harvest planning.

Terrain evaluation and classification systems have been used in Europe [3 and 5] and Canada [4] to classify harvest sites in terms of equipment suitability ratings. Two types of terrain evaluation systems have been used: descriptive classifications and functional classifications. In a descriptive classification system, the site is classified solely in terms of the terrain factors that directly affect harvesting system productivity: (ground strength or bearing capacity, surface roughness, and slope). In functional classifications, the terrain is directly classified in terms of the operability or inoperability of a particular type of equipment. The main advantage of the descriptive classification system is that the site is classified in terms of permanent terrain factors rather than on the basis of the performance of a particular harvesting machine. By concentrating on the site, rather than on the machinery, the effect of technical change resulting from equipment development is eliminated. Thus, the terrain has to be classified only once, not every time a new harvesting machine is introduced.

While the descriptive classification approach to terrain evaluation has many advantages, the time required to evaluate the terrain of large forested areas may be excessive if manual mapping techniques are used. A solution to this problem is to use the speed and efficiency of a computerized geographic information system (GIS) to evaluate terrain conditions. GIS systems combine a database with computer graphics to efficiently maintain and display spatial information. The use of these systems to manipulate spatial date can provide a faster and more efficient means of identifying potential terrain problems [1].

This paper describes a terrain evaluation model that utilizes a GIS. The model was developed as a part of a cooperative research project with a major forest products firm to investigate the feasibility of using a GIS to assist in planning timber harvesting activities. The terrain evaluation model is used to determine equipment suitability for a

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forested area in northern Maine, USA. Finally, the integration of the terrain evaluation model with a decision support system (DSS) for harvest planning is discussed and illustrated with an example planning problem.

Terrain Evaluation System

The development of a terrain classification system for use in planning harvesting activities requires three distinct steps. First, terrain factors important to harvesting decisions must be identified. Second, these terrain factors must be quantified and assigned a value. Finally, the range of the measured terrain factor values must be subdivided into classes to form the terrain classification.

While many terrain factors affect harvesting, in either a direct or indirect manner, forest terrain classification systems have concentrated on three terrain components: slope, ground strength, and surface roughness. Slope is included since it is a primary determinant of travel speed and machine stability. Often, it can be the limiting terrain factor that determines whether a parcel of land can be harvested with a particular type of equipment. Ground strength, a measure of the bearing capacity of the soil, is usually included in these terrain classifications because it affects the productivity of harvesting machines and indicates the potential level of environmental damage caused by those machines. Surface roughness, a measure of the size and distribution of obstacles, is important because it directly affects machine stability and travel speed.

To facilitate terrain classifications for large areas, the terrain evaluation model utilizes an operational GIS maintained by a cooperator in this research: Great Northern Paper Company, Millinocket, Maine, USA. The database component of this GIS contains forest cover types, terrain factors

Table 1. Criteria for evaluating slope.

Slope Class	Slope Description	Slope Range (%)
1	Level	0 - 2
2	Slight	2 - 8
3	Gentle	8 -15
4	Moderate	15 - 25
5	Steep	25 - 45
6	Very Steep	> 45

(including elevation, slope, and aspect), site classes, inventory data, and information on past harvesting, silvicultural and protection activities for 971,250 hectares (2.4 million acres) of company-owned forest land in northern Maine. In addition, roads, major rivers and streams, lakes, wetlands, regulatory zones, and corporate and political boundaries are stored in geographical form. Each type of information is stored on separate thematic levels or layers within graphic design files.

The database and the graphic design files are maintained on a generalized interactive computer mapping system developed by Intergraph Corporation. The Intergraph system consists of a VAX 11-750 minicomputer, a dual screen color graphics workstation, a digitizer, a plotter, and Intergraph graphics (Interactive Graphics Design Software) and database (Date Management and Retrieval System) software.

The classification system developed for evaluating terrain in northern Maine is a modification of the terrain classification system developed for Canada by Mellgren [4]. Each of the three terrain components (ie. slope, ground strength, and surface roughness) is measured and classified separately according to procedures detailed by Davis [2]. Slope values are determined from elevation date contained in U.S.G.S. 7.5-minute Digital Elevation Models. The resultant slope values are divided into six classes (Table 1) to form the slope classification. Normally, soil surveys are used to determine the ground strength rating for an area. However, since this information is not available for northern Maine, ground strength ratings are determined from cover type and land use data stored in the GIS.

Using the rating criteria in Table 2, the species information from the GIS is classified (Figure 1) in terms of ground strength. Attempts to classify surface roughness through remote sensing techniques proved to be unsuccessful. Consequently, surface roughness values are based on field surveys that assess the number and size of obstacles in the survey area. The criteria used to develop the surface roughness classification is listed in Table 3.

The final step in the classification of the terrain involves the creation of a composite (descriptive) terrain classification. The composite classification for an area is created by overlaying and intersecting the individual terrain classifications polygons (i.e. slope, ground strength, and surface roughness) to

Table 2. Criteria for evaluating ground strength.

Ground Strength Class	Ground Strength Description	Soil Moisture	Soil Texture	Forest Cover
1	Very Good	Very Freely Drained	Coarse Sands, Gravel	Jack Pine, W. Spruce
2	Good	Freely Drained	Sandy Loams, Med. Coarse Sands	Balsam Fir, W. Spruce, Aspen, R. Spruce, W. Birch, W. Pine
3	Moderate	Fresh	Fine Sands, Sandy Silt, Clay Loams,	Balsam Fir, R. Spruce, Aspen, W. Spruce, B. Spruce
4	Poor	Moist	Fine Sands, Sandy Silt, Clay Loams	Balsam Fir, B. Spruce, Poplar, R. Spruce
		Wet	Silt, Clay, Silty Clay, Sandy Clay, Organic < .6m	B. Spruce, Tamarack, Eastern W. Cedar
5	Very Poor	Very Wet	Organic > .6m	B. Spruce, Tamarack, Willow
6	Unknown	?	?	?
7	Water	—	—	Water Bodies

form a descriptive terrain classification for that area. Following the overlay process, the descriptive terrain classification for each area (in polygon form) is stored as an attribute in the GIS [2].

Example Terrain Evaluation

To illustrate the use of terrain evaluation model, a terrain classification was performed on a 506 hectare (1250 acre) forested area in northern Maine. The area was classified in terms of each of the three terrain factors and then the three resultant classifications were combined to form a descriptive terrain classification. The ground strength classification, illustrated in Figure 2, indicates that the area is predominantly classified as having either good (167.5 ha.) or moderate (243.6 ha.) ground strength. Of the remaining area, 42.1 ha. is classified as having very poor ground strength, 47.8 ha. (mainly road right-of-ways) is classified as having an unknown ground strength, and 6.5 ha. is classified as having poor ground strength. The surface roughness classification, illustrated in Figure 3, indicates that the area is predominantly classified as being slightly uneven (233.9 ha.) or uneven (174.8 ha.). The area classified as being very rough (19.4 ha.) corresponds to the presence of exposed ledges that would prevent the operation of mechanized harvesting systems. The slope classification, illustrated in Figure 4, indicates that the area is predominantly level, with 447 hectares having a slope less than 8 percent.

Since the primary purpose of the terrain evaluation model is to assist the harvest planner in making decisions concerning the use of harvesting equipment, the descriptive terrain classification, described above, may not be directly useful in the planning process. However, this descriptive classification may be converted to a functional

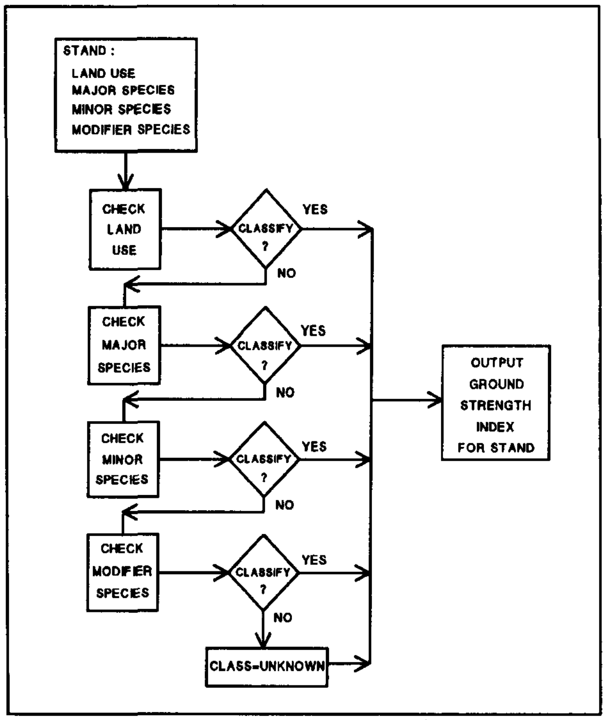

Figure 1. Procedure for determining the ground strength classification of a stand.

classification by considering the limiting operable terrain factors for different harvesting systems. These limiting factors, shown in Table 4, were developed for each of the three harvesting systems commonly used by Great Northern Paper in northern Maine (i.e. manual fell/cable skidder, feller-buncher/grapple skidder, and feller-forwarder) and then used to convert the descriptive terrain classification into a functional classification by equipment types.

The functional terrain classification, illustrated in Figure 5, explicitly indicates to the harvest planner which areas may be harvested with each harvesting system. For the 506 hectare (1250 acre) area used in the example, 210 hectares is suitable for the operation of the feller-forwarder system and 205 hectares are suitable for the feller-buncher/grapple skidder system. The remaining 91 hectares are only operable using the manual fell/cable skidder system.

Integration With a Harvest Planning Decision Support System

While the terrain evaluation system described above provides harvest planners with useful information about equipment operability, it does

Table 3. Criteria for evaluating surface roughness.

Surface Roughness Class	Surface Roughness Description	Obstacle Height or Depth (cm)	Number of Obstacles per 100 Sq. Meters
1	Very Even	10 - 30	0 - 4
2	Slightly Uneven	10 - 30	> 4
		30 - 50	1 - 4
3	Uneven	10 - 30	> 4
		30 - 50	5 - 40
		50 - 70	1 - 4
4	Rough	10 - 30	> 4
		30 - 50	5 - 40
		50 - 70	1 - 4
		70 - 90	1 - 4
5	Very Rough	10 - 30	> 4
		30 - 50	> 40
		50 - 70	> 4
		70 - 90	> 4
		> 90	> 0

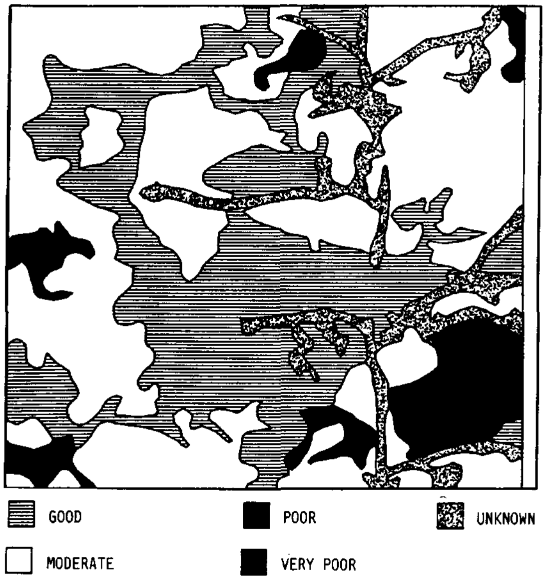

Figure 2. Ground strength classification for the 506 hectare (1250 acre) area in northern Maine.

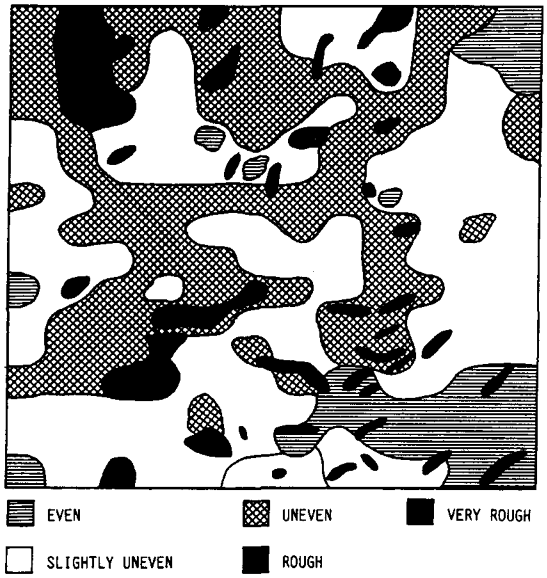

Figure 3. Surface roughness classification for the 506 hectare (1250 area) area in northern Maine.

Table 4. Limiting terrain factor values used to create the functional terrain classification for the 506 hectare (1250 acre) area in northern Maine.

Harvesting System	Minimum Ground Strength	Maximum Surface Roughness	Maximum Slope
Feller-Forwarder	moderate	uneven	8-15%
Feller-Buncher/ Grapple Skidder	poor	rough	15-25%
Manual Fell/ Cable Skidder	very poor	very rough	25-45%

not explicitly consider the economic aspects of harvesting equipment selection. To address this question, a modification of the terrain evaluation system has been developed for use with a harvest planning decision support system (HPDSS). HPDSS consists of an operational GIS, a set of operations research models, and an interactive display system. HPDSS is designed to assist harvest planners in determining optimal harvesting equipment assignments based upon terrain/productivity relationships and operating costs.

Since the cost of acquiring surface roughness information may be prohibitive for areas larger than the 506 hectare (1250 acres) demonstration area, the terrain evaluation system utilized by HPDSS has been modified to consider only ground strength and slope informations.

Since the terrain evaluation system is an integral part of the decision support system, the data required of the harvest planner to determine optimal system assignments is limited to basic productivity rates and operating costs. Through the use of "on-screen" date prompts, the harvest planner enters this productivity and cost information and delineates the area to be considered in the equipment assignment analysis. HPDSS then determines the optimal assignment of harvesting equipment using a mixed integer programming formulation and displays the results, in graphical and tabular forms, for the planner's review.

To demonstrate the utility of the terrain evaluation system and HPDSS in assigning harvesting systems, an example harvest plan, corresponding to a five-year planning period, was prepared for a 10,250 hectare (26,000 acre) forested tract in northern Maine. The three harvesting systems utilized by Great Northern Paper were the only systems considered. Date inputs to HPDSS included: (a) the available harvesting system resources (i.e. system days) for each year in the planning period, (b) production rates, operating costs, and limiting operable terrain classes for each system, and (c) the percentage reduction in productivity rates for each harvesting system due to terrain factors.

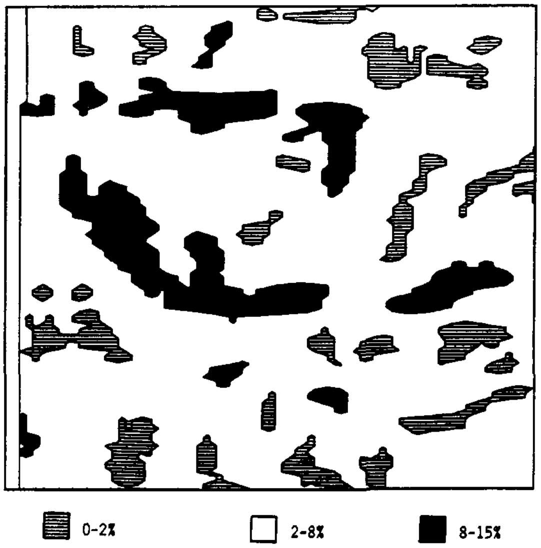

Figure 4. Slope classification for the 506 hectare (1250 acre) area in northern Maine.

Based on this information and a list of stands schedules for harvest, (either generated by the harvest scheduling module in HPDSS or directly input to HPDSS by the user), a mixed integer program determines the least cost assignment of harvesting systems to those stands while also satisfying system resource constraints and operability restrictions. The solution to the mixed integer program is displayed in graphical form by HPDSS for the planner's acceptance or modification. A stand map of the northern third of the forested tract, with system assignment represented as shaded areas, is illustrated in Figure 6. In addition to the map

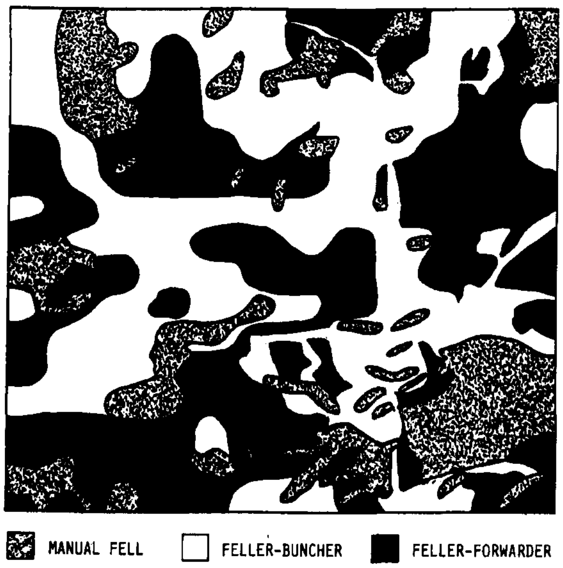

Figure 5. Functional terrain classification for the 506 hectare (1250 acre) area in northern Maine.

display, HPDSS provides printed reports of the optimal system assignment. A portion of the report for the 10,250 hectare area is shown in Table 5. The report details the system assignment for each stand, including the cost and number of resources (i.e. crew or machine days) required to harvest that stand. A summary report of areas cut and total costs incurred by each system during the five-year planning period is also provided.

For a complete description of HPDSS and its capabilities consult Davis [2].

Table 5. Example of printed output for the harvesting system assignment for the 10,520 hectare (26,000 acre) tract in northern Maine. (a) system assignments for year 1 of the planning period. (b) system assignments for the five-year planning period.

(a) <u>Harvesting System Assignments in Year 1</u>

Stand Id	Area (ha)	System Type	System Resources Required (system days)	Total Cost ($)
113	26.2	Feller Forwarder	24	18565
114	15.6	Feller Buncher	20	13955
410	196.2	Manual Fell	717	183782
433	27.3	Feller Forwarder	28	22047
655	56.3	Feller Forwarder	60	46346

(b) <u>Harvesting System Assignment for Five-Year Planning Period</u>

Stands	Area (ha)	System Type	System Resources Required (system days)	Total Cost ($)
17	727.6	Manual Fell	2672	686233
13	376.0	Feller Buncher	440	305616
15	495.5	Feller Forwarder	586	455005

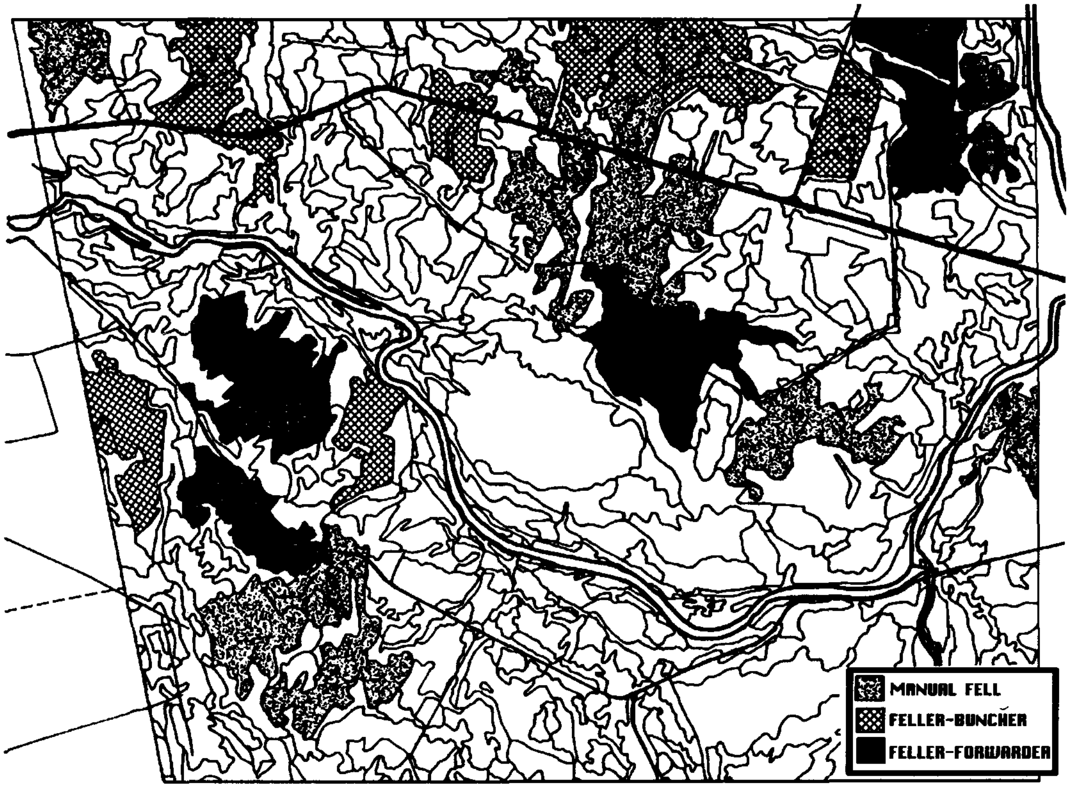

Figure 6. Map, showing harvesting assignments, produced by HPDSS for a portion of the 10,520 hectare (26,000 acre) tract in northern Maine.

SUMMARY

The complex planning environment encountered by today's harvest planners requires that site-specific terrain data be considered in decisions concerning harvesting system selection. The computer-based terrain evaluation model, presented in this paper, has been developed as a tool for planning large-scale industrial harvesting operations. It provides an efficient means of classifying forest terrain in terms of its individual component terrain factors. The model utilizes a geographic information system to store, display, and manipulate the large amount of resource and terrain date required for the terrain classification. Terrain is rated and classified in terms of ground strength, slope, and surface roughness. This terrain classification is then combined with harvesting machine operating criteria to produce maps that delineate areas where each harvesting system may operate economically and with minimal environmental damage. The terrain evaluation model has also been used in conjunction with a decision support system consisting of mathematical programming models to determine optimal harvesting system allocations. Ultimately, the inclusion of terrain information in the timber harvest planning process should enable harvest planners to produce more economically and environmentally acceptable timber harvest plans.

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