Wood Transportation Systems-A Spin-Off of a Computerized Information and Mapping Technique

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Abstract: A computerized mapping system originally developed for planning the control of the spruce budworm in Maine has been extended into a tool for planning road network development and optimizing transportation costs. A budgetary process and a mathematical linear programming routine are used interactively with the mapping and information retrieval capabilities of the system to determine the allocation and association of wood sources and markets.

INTRODUCTION

In December 1975, a short term project (see Appendix) was completed that allowed the computerized mapping of locations and levels of spruce budworm infestation in Maine. This conformed to a sampling system employed by state officials whereby data on infestation was taken periodically by a series of sample units each equal to an area of approximately 600 acres. Each unit became the basis for a data (information) point and it became clear that the mapping routine offers potential well beyond its original intent. It is currently in use for the annual state budworm survey (Simmons and others 1976).

Besides the opportunity for additional informational overlays beyond budworm infestation indices, the relational properties of each unit to another possessed the potential to be mathematically manipulated, thus allowing location strategies of wood origins and potential markets to be correlated very accurately and rapidly. Transportation phenomena is the focus of the correlation. Existing road networks have been visually and mathematically related to data points. Specific requirements for new roads are integrated onto the overall system, and transportation and handling cost formula are available to interpret wood movements strategies in terms of a definable optimum. The system is designed to be open-ended in regard to this formulization so as to allow logical choices as to appropriate cost components. Algorithms for selecting applicable cost configurations depending on the trafficability of various road classes and/or transportation means (trucking or rail) have been developed within a framework of resource available and consumption requirements. Mathematical programming offered high potential for selection of optimal transportation strategies. These strategies involved not only specifics on the movement of wood, but also priority criteria for the resource areas on which to concentrate harvesting efforts when large wood surpluses are in excess of short-term market needs.

The budgetary process as well as the mathematical programming routine is directly interactive with the mapping and information retrieval system, and is designed to be a sub-system to the overall system. Aspects of costing in any category of operating expenses for transportation or handling and those expenses relating to new roads can be included in the whole system and are relatable to data points. Existing road networks are known by the system and also referenced to specific data points where information on trafficability, etc., can be stored. Travel patterns are developed by summarizing data points between any combination of wood origins and wood destinations which are themselves merely data points. Preliminary estimates indicate that the accuracy in measures of various forms of distance exceeds the probable accuracy of maps from which data point references were established. New roads are hypotheticcally constructed between appropriate wood origins and existing roads by logical rules internally maintained by the computer system. Rapid and precise evaluations can then be made for given market transport possibilities when periodical levels and locations of available wood and of market requirements are offered to the system. Optimal strategies can be made available directly from this system, which allows ready updating of information on any data point and selection of modes in costing suitable to the planner.

The methodology suggested may well have wider application beyond Maine, possibly on a regional basis or for other state or provincial areas in North America. The techniques are structured so that implementation elsewhere can readily be facilitated and not necessitate a new total effort.

THE TRANSPORTATION SPIN-OFF

Since the spacial arrangement of wood origins, wood markets, and transportation networks can be determined from the data organized by map location, it is possible to automatically develop transportation routes from each wood origin (source) to each wood market (destination), where each of these is represented by a map data point. Transportation routes are developed so as to minimize transportation costs; they assume cost linearity (that is, the cost from A to C through B equals the cost from A to B plus the cost from B to C).

The transportation cost is composed of two elements--the cost of building new roads (or transportation networks) and the unit cost of transporting the material over the transportation network. New roads are generally costly both to build and maintain; therefore, in developing routes, a goal is to approach a minimum of new road construction. This is accomplished by a two-pass computer processing of source points. During the first pass, the closest road is located through an outward scanning of surrounding data points and the straight line distance to this road is calculated. The source points are then sorted for reprocessing such that those points closest to a road are processed first. During the second pass, another search for the closest road is made. When it is located, a hypothetical new road connecting the source point with the road is added to the map road system by the computer program. This hypothetical road then becomes available to subsequent source point processing. Although this method does not necessarily yield an absolute minimum amount of new road construction, it should closely approximate the minimum.

With roads to each source point, minimum transportation cost from each source point to each destination can be calculated. Computer scanning of map data allows transportation networks to be followed. Starting from a destination point and successively adding the cost of transporting to all adjacent road points, a transportation cost to the destination is determined for all road points including all source points. Always extending from the least cost end first produces minimum cost values with a single scanning of road points. The cost of transporting to an adjacent point can either be based on a function of distance (as determined from the geometry of the area represented by a data point), or with known costs of traversing a particular area, can be uniquely specified for each point and thus can include trafficability factors-- e.g., road quality, average speed, and traffic load.

Following these methods, the cost of transporting from all source points to all destination points is determined. This information, combined with data on wood volumes available at each source and the requirements at each market, is fed into a linear programming transportation model to determine allocation and association of wood sources and markets.

BACKGROUND INFORMATION

The extent and importance of the wood-using industries in Maine can be sumarized (for 1973) as follows:

(1) Three out of ten Maine workers are employed in the wood-using industries.

(2) The industries ranked first in value of manufactured product (1.3 billion dollars).

(3) Eighty-six percent of Maine's land area is in commercial forests (17 million acres).

(4) A total of 3.14 million cords of pulpwood was harvested, with 56% of this in spruce-fir. For sawlog harvest, the total was 354 million board feet, with 57% in spruce-fir.

Approximately one-third of the State's forest area is currently under the threat of spruce budworm devastation. The epidemic can be expected to produce high mortality, particularly in balsam fir and to a lesser degree in spruce, if adequate control measures are not forthcoming. Trees that succumb to the insects' attack must be harvested within a two- or three-year period or the physical deterioration of the wood will be too advanced to allow its commercial use. The timing of a planning effort becomes more critical considering that the area represented to be approaching an epidemic stage contains, at a minimum, a twelve-year supply at Maine's current wood consumption levels.

Under normal harvesting procedures, species present in a forest stand with fir and spruce, and not affected by the budworm, would also have to be removed with economical wood handling and transportation methods.

Preliminary study by the Corps of Engineers on the feasibility of a major hydroelectric project in Maine was begun this past year. The associated dam and its head waters will take out of production thousands of acres of Maine's timberlands. Agents of the Corps of Engineers have already contacted this investigator for estimates on the market potential of salvaged timber and for information on harvesting-transportation problems relating to the salvage. These estimates represent only preliminary appraisals; actual planning will eventually be required if the timber area is to contribute effectively to this State's wood resource requirements.

Considering the potential for an evaluation system such as those discussed here, at least three areas of immediate concern are benefited. These include planning in regard to wood flow within the region:

(1) As typical yearly wood consumption patterns are encountered.

(2) As wood surplus resulting from budworm devastation occur.

(3) As timber area losses in hydroelectric development are considered.

The need to expand the opportunities for systematic evaluation of wood movement strategies is most timely as the concerns for wood utilization, especially in light of the budworm and the hydroelectric development, are and will surely remain key issues in the State of Maine, in New England, and in Eastern Canada for the remaining years of this decade.

Models developed from the proposed investigation are not intended to be useful solely in the shortterm, as suggested by problems like the budworm and developments that affect large forest acreages, nor will they necessarily remain local in the spread of their use. Their nature fully dictates that they can find application in the evaluation of transportation aspects inherent in marketing strategies of a long-term nature. The techniques utilized, if not the data structures, should prove of value to other regions as well.

PREVIOUS STUDIES

Past efforts of a statewide scope have proved fruitful in understanding wood distribution and the means thereof (Corcoran 1964, Schroeder and Corcoran 1965, Corcoran and others 1966). These particularly focused on truck-supported wood movements and included not only descriptive information but system planning pertinent to the times. Forest road location theory continues to be advanced (Ashley and others 1973, Corcoran 1973). Appraisals of the current situation are available in regard to enterprises that produce Maine's wood supply (Corcoran and Sarna 1973), to computer-based mapping routines (Phillips and others 1976) and to export market potential (Corcoran 1976). Wood movement strategies have also been explored in regard to general models for regional applications (Holland and Judge 1962, Thompson and others 1968, Anderssen 1971) and to the budgetary planning of a single firm (Bartelheimer 1973, Sowell and others 1975, Newham 1975, Wimble 1975, Bailey 1973). Mapping by computer has found favor in recent years (Harding 1973, Nez 1971) especially for visual descriptions of use patterns, vegetative cover, and urban planning schemes. However, those for the most part were subjective in nature and have not taken advantage of mathematical potential inherent in a computer-based system. Numerous other works could be listed that are commonly known and well documented in established computer bibliographies on operation-research (Martin and Sudak 1973, Field 1974) and on the budworm itself (Corcoran and Simmons 1975). Information systems and decision theory have been explored by many authors within a workshop format (Stone and Ware 1971) and in a publication supporting needs for an information bank (Wolf 1970). Information systems pertaining to Maine have received international attention (Corcoran and Simmons 1976, Corcoran 1976).

APPENDIX

Effective planning for control of the spruce budworm in Maine requires knowledge of the distribution of the budworm as well as the condition and susceptibility of the trees in the areas of infestation. Currently, a hazard rating based on sample measurements of such factors as previous damage, current defoliation, tree vigor, and egg mass density is calculated for various localities throughout the state. A map of the state showing the location and hazard rating of each of the sampled points is prepared and areas of infestation are marked. These provide a visual indication of the distribution of budworm threat to the forests of Maine, and allow planning of such activities as spraying and salvage.

In order to facilitate the production of these maps, a computer program has been developed which will produce maps of the state on a computer line printer. The state is divided into small sections corresponding to the state fire control divisions. These sections are subdivisions of the U.S Geological Survey 15-minute quadrangle maps and are found by dividing each of the U.S.G.S. maps into 9 blocks and each block into 25 sections, each 1 minute by 1 minute. Thus a section is 1/225th of a U.S.G.S. quadrangle and covers approximately 591 acres.

A two-dimensional array is allocated within the program storage with each cell corresponding to one of the sections of the state. The section of the state in which the sample was taken, along with the data collected, is fed into the program. The rather complex designation of U.S.G.S. quadrangle, block, and section used in the field is converted by the program into a two-value designation indicating the row and column of the section within the state and thus the cell of the array corresponding to the location. This simplification allows adjacent cells to be easily determined and examined. The program calculates the hazard rating from the data and stores the computed value in the appropriate cell within the array. Both the array of computed hazard ratings and the original data for additions and further analysis can be saved.

From the data stored in the array, requests can be made to print all or portions of the state. Increasing integer digits indicate increased hazard value. Cells which fall inside the state boundary are distinguished from those that do not. This allows the portions of the state not sampled to be indicated by a printed character or characters while areas outside the state are void of such characters.

The size of the map produced may be varied by specifying a scaling factor. The smallest (largest scale) map produced uses one character to represent a single section. This map is approximately 27 inches wide by 34 inches long when the entire state is printed. Because the spacing on a printer is relatively fixed, the small map distorts the state slightly, making it an average of 14% wider than it should be. For most applications, this level of distortion presents no problems since a general feeling for spatial distribution is the primary goal. Specific locations can be determined from grid coordinates and the U.S.G.S. maps if required. The distortion can be virtually eliminated if a larger map is formed using multiple characters to represent one section. This could have the additional benefit of allowing more than one piece of information about a sector to be printed on a map. Any of these maps may, of course, be reduced to a more convenient size through photoreduction techniques.

Although the current program would only replace the manual system being used at present, several factors make this system more desirable. One is the speed with which maps can be produced. This will allow the production of preliminary maps as the data is collected. These could then be used to help define areas which require more sampling to delineate spray, salvage or other boundaries.

Another factor is the capability for future expansion existing in the system. Among some of the more interesting possibilities are extensions which would allow any specified linear combination of the current or previous year's hazard rating factors to be mapped. This could be used to compare visually the distribution of such factors as previous damage and current infestation level, which might provide insight into changing trends in infestation. Comparisons of linear combinations of current and previous year's samples might be used to refine the formula used to compute the hazard rating. Another possibility for extension is the inclusion of fixed information about a section. Such information as forest cover type might be used to modify the hazard rating. The inclusion of information on road networks and market locations would be used to determine the most economical and efficient salvage locations and transportation routes in the event of high losses.

A second potential capability is use of the system to display a variety of other forest-related surveys. Other forest insects and forest diseases could be mapped annually from annual survey data. Annual tree mortality data could be mapped as well as forest age data or, for that matter, any resource data base covering the state or portions of the state. Such a system might eventually form the basis of a general resource data base display system for the entire state of Maine.

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