Use of IRPM for Transportation and Land-Use Planning in National Forests

FONG-LIEH OU and JOHN RUPE

ABSTRACT

For more than a decade the U.S. Department of Agriculture (USDA) Forest Service has been developing the Integrated Resource Planning Model (IRPM) as a planning tool for integrating transportation systems and land use. IRPM is composed of several mathematical programs, including linear programming, mixed-integer linear programming, and goal programming. Its purpose is to optimize transportation systems in conjunction with resource allocation and scheduling. The model and its application procedure are presented, along with a case study. The result of the study indicates that IRPM is capable of evaluating various transportation system options, land use strategies, and environmental scenarios. Although the model was developed primarily for use by Forest Service transportation planners and land management analysts, its utilization for planning a cost-effective transportation system and optimum land use patterns could extend beyond National Forest System lands.

The use of optimization methods in developing cost-effective road networks is an increasingly important area of research in transportation and land use planning. The potential benefits of optimization models include fast response to planning issues and the capability to evaluate various resource development scenarios and transportation policies. However, an optimization model requires that both transportation and land use policies be tied together and that their related variables be considered simultaneously.

SURVEY OF EFFORTS TO MODEL TRANSPORTATION AND LAND USE PLANNING

Although the need for transportation and land use optimization models is evident (1-3), the area has not yet been adequately developed. Several transportation researchers have attempted to model a transportation-oriented planning technique. However, theory often falls short of considering transportation as one of the principal factors in formulating land use policies. Previous efforts in the field include those by Lowry (4), Herbert et al. (5), Lathrop et al. (6), Wilson (7), Bagby et al. (8), and Bammi et al. (9) in urban area planning; and those by Kirby et al. (10), Barnes et al. (11), Sullivan (12), Kirby (13,14), and Kirby et al. (15) in wild land planning. These efforts focused on forecasts of land use patterns, and their emphasis was to find the optimal transportation network for supporting a land use allocation pattern. It was assumed that the role of a transportation system is to execute the land use plan by allocating various activities. The allocations are based on simplistic descriptions of the spatial relationships between the activities involved and on existing transportation networks and trip-making behavior in a base year.

The concept of integrating land use and the transportation system for a target urban land use plan was initiated by Creighton et al. (16). Based on two sets of criteria, the researchers used a benefit-cost analysis technique to optimize the spacing of arterials and expressways for the Chicago metropolitan area. One set of criteria is related to land development issues, such as desirable relationships of land use to roads and desirable land development densities, whereas the other set is related to transportation in terms of construction and travel costs. Creighton's work has been further expanded by Schlager (17), who used a hill-climbing procedure to find a minimum for combined site and network costs. A similar effort made by Black (18) considered both land use and transportation facilities as controllable variables. To find a best combination of land use density and highway spacing, Black developed a mathematical model for optimization to relate land use planning and transportation planning. By using a random-search technique, Sinha et al. (19) also developed an optimization model for deriving a land use plan representing the optimum combination of public and private costs. Brotchie et al. (20) developed a technique for the optimum placement of activities in zones (TOPAZ) that was adopted by Dickey et al. (21) for the Blacksburg, Virginia, application and by Dickey et al. (22) for the Prince William County, Virginia, case study. The purpose of TOPAZ is to determine where to allocate the needed land use areas to minimize the public service and travel costs.

The attempt to integrate transportation and land use in wild land planning was first made by Buongiorno et al. (23). They used a separable goal-programming model to determine the geographic pattern of forest exploitation, industrial processing, and transportation that minimizes total costs. Their work has been expanded by Weintraub et al. (24), who developed a procedure for integrating silvicultural treatment alternatives and timber transport routes.

All the above efforts focused mainly on physical planning. Although there is a strong connection between physical, economic, social, environmental, and political factors, most of them were intended to be prototype endeavors.

INTEGRATED RESOURCE PLANNING MODEL

The purpose of this paper is to describe the Integrated Resource Planning Model (IRPM), which was developed by the U.S. Department of Agriculture (USDA) Forest Service based on linear programming (LP), mixed-integer linear programming (MILP), and goal programming techniques. The model can be used to obtain an optimum land use plan with minimal resource management cost, including logging cost, transportation cost, and transportation-related environmental impact cost. Its applicability has been demonstrated by a case study that analyzed resource development alternatives in a drainage of the Payette National Forest in Idaho that is susceptible to erosion.

IRPM is a tool for assisting in the design and evaluation of alternative forest road systems along with land allocation and resource scheduling (25). IRPM is designed to be used where complex information, a large variety of possible investment costs, and a wide variety of transportation possibilities complicate a planning problem. The model can analyze and display the results of the interaction between production and financing. It is site specific and emphasizes investment analysis and the analysis of environmental and physical impacts of road traffic and transportation access. At the heart of IRPM are a land allocation model (13,14) and a capacity-constrained traffic assignment model (10,15). For any given set of goals, management strategies, and road network alternatives, the model can select an optimum combination of transportation routes, resource allocations, and management scheduling.

Although the mathematical programming of IRPM is presented elsewhere (25), several features of the model are described below. The model--

1. Considers either LP, MILP, or goal programming in the optimization algorithm.
2. Provides a method of stating for the computer certain restrictions on the inclusion of projects in the final solutions, including companion projects, mutually exclusive projects, and contingent projects.
3. Permits several alternative investment proposals for each parcel of land.
4. Permits several alternative roads to gain access to each parcel, each alternative road being an investment proposal.
5. Allows each investment proposal to be defined in terms of a mixture of several activities and corresponding costs and in terms of the resulting resource and economic responses.
6. Allows investment proposals to be defined as a multiperiod, fixed sequence of activities and identifies the period in which each activity occurs including the starting time, which is predetermined.
7. Permits alternative road construction standards--for example, number of lanes--to be governed by the amount and composition of traffic, including resource protection and maintenance, hauling of commodities, and recreational travel.
8. Allows for several classes of investment proposals: vegetative management, construction, and maintenance.
9. Permits investment proposals for land parcels to be combined into a plan in such a way that the corresponding road link investment proposals are also part of the plan.
10. Permits a variety of constraints on the investment combinations: activity levels, costs, resource responses, and economic responses.
11. Achieves an optimum solution for multiple goals at the same time.

Although most of the aforementioned features of the IRPM are self-explanatory, the first feature was designed to use decision variables for road projects that can take only values of zero for No or one for Yes. These integer variables can be included in an MILP model, which is basically a two-stage model using the branch and bound algorithm. First, an LP program is run, and, second, variables that must be integers are rounded up and down one at a time--where the LP model essentially built half a road, for instance. The value of the objective function when the variable is rounded up, and when it is rounded down, is compared with the value of the objective function for the optimum LP solution, and the closest feasible value is selected. This is repeated for all the other integer variables.

THE IRPM APPLICATION PROCESS

The process of applying IRPM to forest transportation and land-use planning can be divided into two major phases. The first phase is data preparation, which provides a data base for computer processing. The second phase is alternative evaluation, which results in the selection of a preferred alternative. The process is illustrated in Figure 1, and the steps are listed below:

1. Define problems.
2. Establish goals and objectives.
3. Collect data.
4. Develop management unit map.
5. Develop composite map.
6. Define logical relationship among projects.
7. Select units of measure.
8. Define constraints.
9. Develop planning and management strategies.
10. Formulate mathematical relationships.
11. Execute computer processing.
12. Select preferred alternative.

The first step involves defining the boundary and establishing convenient divisions of the area to be studied, and determining issues and concerns. The second step is to determine the planning and management objectives, such as maximizing timber production with heavy clearcuts or enhancing wilderness by minimizing road construction. It also requires the determination of output goals and targets, such as the volume of timber production in a specific time period.

The third step is to collect the necessary data. The data base includes information concerning soil, slope, aspect, landform, water elevation, timber stand composition, timber age class, trees per acre (or hectare), logging cost per acre (or hectare), brush disposal cost per acre (or square mile), existing road network, existing level of erosion sediment, and other characteristics.

The fourth step is to develop a management unit map based on one or more of the following elements: soil condition, slope class, topography, vegetation type, capability area, road network, and related issues. Efforts involved in developing a management unit map are selecting elements related to issues and objectives, ranking the selected elements according to their importance to the defined issues and objectives, drawing a series of overlays for each of these elements, and redrafting each overlay onto one composite overlay based on the assigned ranks.

Shown in Figure 2 is an example of three selected elements with a ranking order of soil condition, slope class, and timber age class. The composite overlay is simply redrawn from Figure 2(a) as the first step of developing a management unit map. The next step is to overlay the composite map on Figure 2(b) and draw additional subdivisions, as shown in Figure 2(d). The overlay of Figure 2(d) on Figure 2(c) resulted in a composite map, illustrated in Figure 2(e). However, the subdivision line is drawn only when the unit created is greater than the minimum size of a unit. As shown in Figure 2(f), three units were assumed to be smaller than the minimum unit size and were eliminated from Figure 2(e). The criterion for determining the minimum unit size is that the land within it can be managed in the same way, based on the capability of the land and the issues (conflicts of interest) that affect it.

After the management unit map is developed, the fifth step is to complete a composite map by identifying the possibilities for management actions on each unit. From the identified management actions,

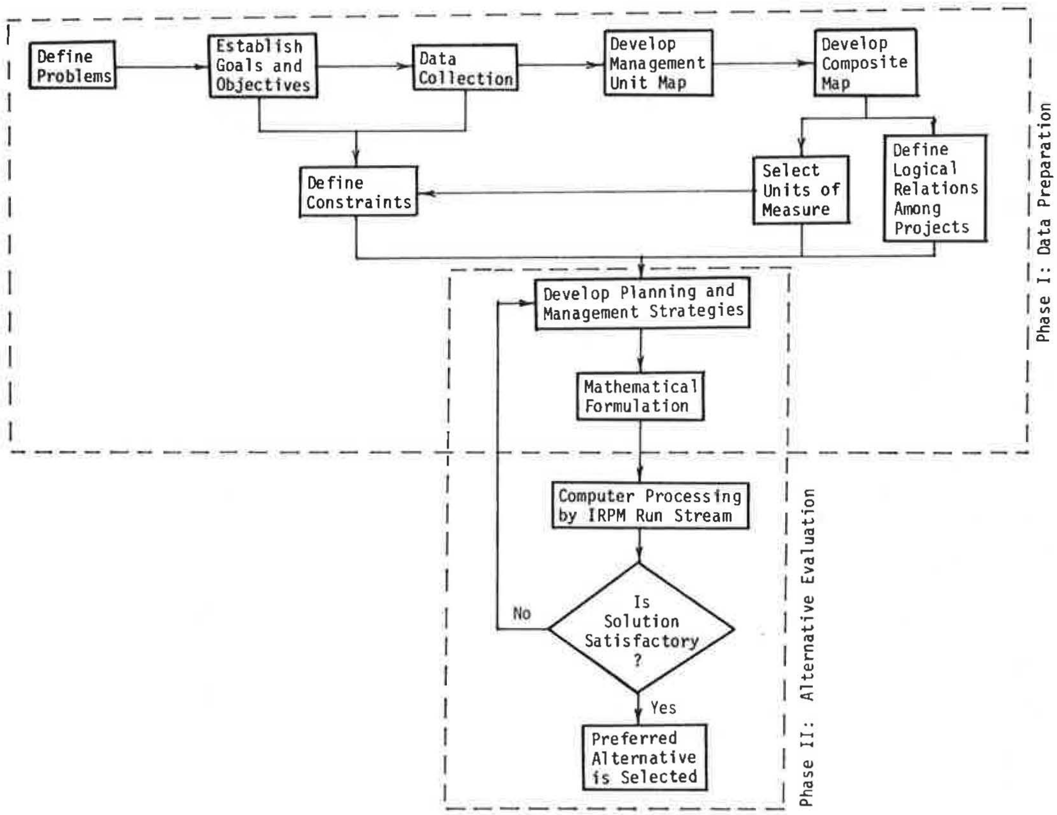

FIGURE 1 IRPM application process.

the available or feasible road network associated with any or all actions becomes clear and may be defined by nodes and links.

In the sixth step, the effort is to determine the logical relationships between the road network and the proposed resource projects--that is, where the estimated traffic generated by each project can enter the network. These relationships can fall into one of three categories: two or more companion projects must be selected as a group; only one of two or more projects that are mutually exclusive can be selected; and one of two contingent projects is required only if the other is selected.

In the seventh step, variables are defined by work, cost, outputs or effects, and benefits. Work includes the tasks or activities necessary for com-

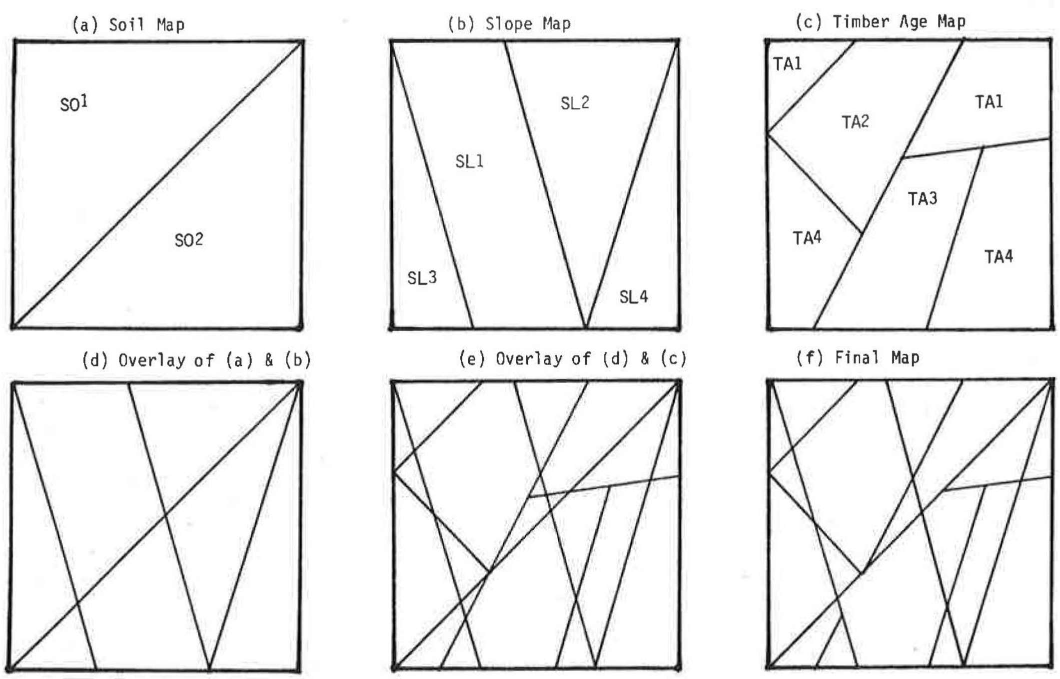

FIGURE 2 Element maps and management unit maps.

pletion of a project. Cost is determined by unit of work. Output and effect include both expected yield and expected environmental response associated with the project. Benefit is the monetary value of the output or effect.

After the variables are defined, it is possible to determine the constraints. Thus, based on the identified issues and objectives, the eighth step is to suggest possible quantitative targets or limits to be tested for their effects on the overall selection of alternatives.

The ninth step is to develop planning and management strategies. The four factors considered in strategy formulation are the time frame, management options, logging methods, and brush disposal methods. Because each timber age class can be treated differently, resource projects are defined for multiple time periods; each period is specified by a particular management option. For example, a young growth may be treated by commercial thinning in the first period and by clear-cutting in the third period. The management options include wilderness preservation, commercial thinning, partial-cut, clear-cut, and so forth, and the logging method consists of tractor, skyline, high-lead, and helicopter. Brush disposal is determined by both management option and logging method with consideration of such geographical factors as soil condition and slope.

Based on the formulated scenarios, the tenth step is to develop the relationships between variables and their constraints into equations for obtaining the highest benefit at the lowest cost. The eleventh step is to execute IRPM for alternative evaluation. It involves writing card statements, establishing files, and using runstreams.

The final step is to interpret the output of IRPM, which lists projects and summaries of work, costs, and outputs according to the conditions set up for each run. A map of the area is prepared showing allocation of various types of projects and the road network chosen. If no solution is selected, management policy must be redefined. In other words, the ninth through twelfth steps must be repeated until a preferred solution is selected.

Although the above process was developed to provide a better understanding of the IRPM algorithm, data preparation does not necessarily follow the steps in sequence. Sometimes a single task may accomplish the requirements of several steps.

USE OF IRPM IN PAYETTE NATIONAL FOREST

The first step of IRPM was to select the South Fork of the Salmon River drainage of Idaho's Payette National Forest as the study area. As shown in Figure 3, the study area is located east of McCall, Idaho, in the Boise and Payette National Forests. The South Fork flows north and drains into the main fork of the Salmon River at Mackey Bar. The northern, lower end of the South Fork drainage is essentially roadless, and current management direction is that the area will remain basically without roads. The upper portion of the drainage has a skeletal road system in place, and some timber harvest activities have occurred in the past. This study will analyze the Payette National Forest portion of the upper end of the drainage which covers part of the Krassel Ranger District, a 160-square-mile area south of the confluence of the South Fork with the Secesh River.

Most of the existing roads were constructed and most of the timber harvest occurred in the drainage before 1964. In the winter of 1964-1965 a major storm caused excessive amounts of road surface erosion and mass stability failures. The storm completely destroyed much of the fishery, which is just now recovering. After the 1965 storm, the Forest Service began a self-imposed moratorium on road construction and timber harvest in the drainage. Ten years later, the South Fork Unit Management Plan was implemented, allowing for a minimal level of activity. This plan has been in effect to the present. As needs for wood products increase, added pressure will be placed on the Payette National Forest to allow road building and timber harvest within the South Fork drainage.

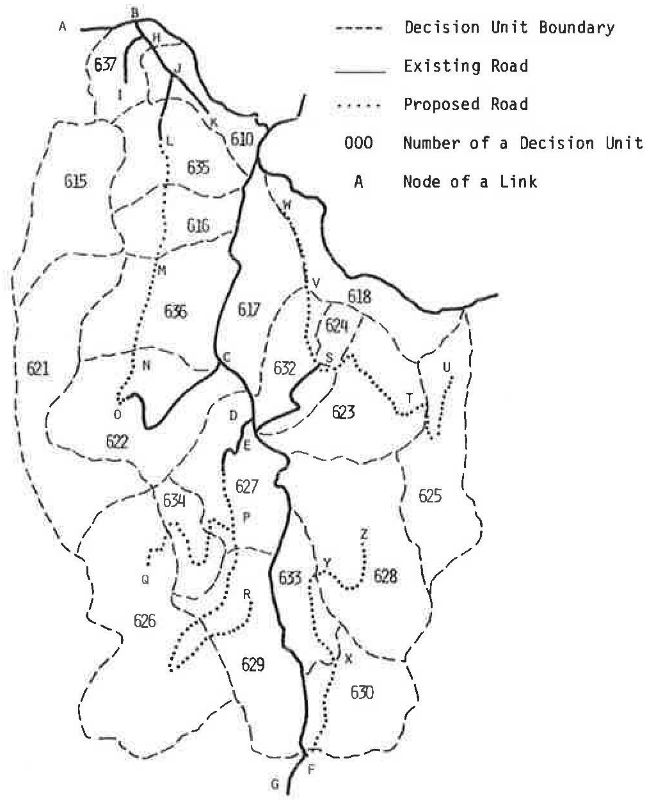

FIGURE 3 The study area.

Based on the defined problems, the second step established the objective of this application. Because timber production has been established as the desired goal, it is important to evaluate the impact of timber production and the required transportation network on erosion, which has a critical effect on anadromous fisheries in the area.

The third step was data collection. The data used in this evaluation were collected for the Forest Plan. Most of the basin has side slopes in excess of 45 percent, and some areas are more than 60 percent. This makes tractor logging of most timber impossible because tractors cannot maneuver on slopes this steep. Much of the timber will be harvested by skyline or cable logging.

The soil is almost entirely decomposed granitic sandy loam. The area is part of the Idaho Batholith, a large intrusive granite formation covering most of central Idaho. The sandy soil has low cohesion and easily crumbles and erodes when exposed to air. The lack of cohesion is attributed to the low bearing capacity of the soil. Mass stability problems are acute. In this context, road building activities need to be limited to minimize the possibility of clogging adjacent streams. Early logging on steep ground in the area was done by jammer, with closely spaced roads. The intensity of roading was so great that the impacts of sediment were especially high.

As indicated previously, the fourth step developed the management unit map by overlaying the influencing factors based on their importance to the issues. In this application, the two most important factors are soils and land slope. Because these two factors do not vary much throughout the area, the 160-square-mile river drainage was divided into 17 decision units according to tributary stream drainage and collector road influence zones. As shown in Figure 3, each of the 17 decision units is numbered with a three-digit number starting with a 6.

The fifth step identifies the projects. The road projects shown in Figure 3 represent all the collector roads that would be necessary if the entire drainage were allocated to timber harvest. Of course, this is not likely to happen because of competing fishery goals. Instead, only the roads necessary to reach the selected areas for timber harvest are mandated. The nodes are labeled alphabetically. Loaded truck traffic is assumed to be unidirectional except on the main road A-B-C-D-E-F-G, and on the loop road B-H-J-L-M-N-O-C.

Although these roads provide the major access for the area, they actually are intended to be single-lane, dirt facilities because maximum traffic for the roads will be less than 50 vehicles per day, consisting almost entirely of logging trucks, Forest Service administrative vehicles, and other vehicles related to timber sales. The roads are intended to contour along the hillsides as much as possible to minimize large cuts and fills and thus reduce total impacts on the land. As such, the collector roads basically will conform to the same standard as local roads, with the design standard established by a concern for minimizing surface erosion and mass stability failures and improving trafficability.

The sixth step was performed to define logical relationships among projects. Because basically the same standards will apply to local and collector roads, some assumptions can be made about road links for each land unit and about where the harvested timber will enter the road network. It will be assumed that the entire road will be constructed to the end of the decision unit if timber is harvested within the area. In reality, the average trip on the segment will be about halfway along the link, as very few logging trucks will enter the collector road at the far end of the unit. The road on the far end is essentially a local facility. However, because the local road and collector road standards will be the same, nodes can be set where roads cross unit boundaries. It will be assumed that trucks enter the road network at the nodes because two trucks entering in the middle of the unit between two nodes is the truck-mile equivalent of one truck at each node.

Table 1 shows the impacts of each road segment if it were selected. Construction costs are for new segments of the route, and reconstruction costs are for reuse of existing roads. Reconstruction could vary from simply blading and reconditioning the road to virtually rebuilding it.

The sediment impacts are listed according to a scale developed by the Payette National Forest. The Forest is using a scale based on the activities that occurred during the large 1964 flood, which destroyed the fish population in the river, and natural rates. It assumes that one scale unit is equivalent to the amount of natural sedimentation from 1 acre of loamy clay soil on side slopes less than 45 percent. As soils vary from clay to sand, and as slopes get steeper, particularly on south-facing aspects, the natural rate is as high as 50 scale units per acre. Harvesting timber approximately triples the sediment rate, mainly from local road construction. The impact of access roads varies from 500 scale units to as high as 20,000 scale units for a particular link. These calculations are based on an estimate of cut and fill and road surface erosion, plus the effects of probable mass failures.

A high-intensity and a low-intensity timber harvest option was chosen for each decision unit. Either one option or the other, a percentage or split of both, or neither of the options can be selected for each decision unit. The high-intensity option takes 25 to 30 percent of the standing timber volume in the area. The low-intensity option takes 10 to 20 percent of the volume. The amount of timber in each option plus the sediment and cost impacts are displayed in Table 2.

In choosing which timber would be taken in each option, it was estimated that about 50 to 60 percent of the high-production site old-growth stands on flat ground would be taken first, followed by moder-

TABLE 1 Road Construction and Reconstruction Cost and Sediment by Management Unit

Unit Name	Construction			Reconstruction		Sediment Impacts (scale units)
	Link	Miles	Cost ($)	Miles	Cost ($)	
Secesh Face	HI	NA	NA	5.6	28,000	3,716
Cow Creek	HJ, JK, JL	3.2	133,000	4.6	53,000	19,424
North Fork Fitsum	LM	NA	NA	6.3	31,500	1,772
Fitsum Creek	MN	2.1	100,000	1.0	50,000	2,832
North Fork Buckhorn	NO	4.3	166,000	NA	NA	541
Buckhorn	OC	2.7	123,000	9.0	45,000	18,953
Cougar Creek	PD	3.3	152,000	7.7	54,000	8,344
South Fork Cougar Creek	QP	4.6	253,000	NA	NA	4,158
White Rock Peak	RP	3.0	123,000	NA	NA	16,745
Indian Ridge	WV	2.6	123,000	NA	NA	1,489
Krassel Creek	WV	2.6	123,000	NA	NA	1,480
Phoebe Creek	VS, SE	3.5	172,000	5.8	29,000	5,898
Camp Creek	TS	8.5	283,000	NA	NA	2,570
Caton Lake	TU	5.0	188,000	NA	NA	2,333
Fourmile Creek	YZ	3.6	176,000	NA	NA	3,601
Silver Creek	XY	3.1	176,000	NA	NA	7,369
Goat Creek	FX	5.4	269,000	NA	NA	10,486

Note: NA = not applicable.

TABLE 2 Sediment and Road Cost by Resource Project

Unit Name	Timber Intensity	Timber Volume (MMBF)[a]	Sediment Impact (scale units)	Cost (million $)
610 Cow Creek	High	19.2	4,600	3.10
	Low	6.1	2,000	1.55
616 Fitsum Creek	High	19.5	25,000	5.10
	Low	11.6	5,660	3.01
617 Krassel Creek	High	20.0	66,400	5.66
	Low	9.1	24,500	2.57
618 Indian Ridge	High	14.3	67,600	4.68
	Low	8.4	24,800	2.46
622 Buckhorn Creek	High	37.2	45,000	9.71
	Low	18.5	5,900	4.81
623 Camp Creek	High	21.2	23,700	6.13
	Low	11.1	17,600	3.19
625 Caton Lake	High	19.7	18,000	5.72
	Low	10.4	14,000	3.03
627 Cougar Creek	High	27.4	29,300	7.17
	Low	13.2	8,900	3.44
628 Fourmile Creek	High	40.6	106,200	11.91
	Low	23.1	17,300	6.63
629 White Rock Peak	High	26.8	23,900	7.83
	Low	13.2	10,600	3.84
630 Goat Creek	High	16.0	17,900	4.37
	Low	10.3	6,400	2.75
632 Phoebe Creek	High	12.4	10,400	3.33
	Low	6.6	6,900	1.79
633 Silver Creek	High	14.8	37,300	4.41
	Low	7.5	10,200	2.22
634 South Fork Cougar	High	10.8	6,100	3.06
	Low	4.7	3,900	1.28
635 North Fork Fitsum	High	18.6	19,300	5.08
	Low	11.5	7,100	3.05
636 North Fork Buckhorn	High	29.0	35,800	7.55
	Low	13.8	15,100	3.58
637 Secesh Face	High	12.5	20,800	3.72
	Low	7.1	13,900	2.08

[a]Million board feet.

ate-production site old growth, then younger age classes and less productive sites. The estimated board feet and cubic feet for each option are entered into the model as if 100 percent of the option was selected for an area. If a lesser percentage of the option were selected, the model would take a lesser percentage of the timber. Splits of high and low intensity allow a great degree of flexibility in interpreting the results of the model. Essentially, such a split would represent a moderate intensity.

The seventh step was to select the unit of measure. Table 3 shows the timber coefficients that were selected. These vary according to the different classifications that have been mapped in the forest. Two major classifications are (a) mixed conifer, consisting of Douglas fir, ponderosa pine, and Engelmann spruce on high or very productive sites,

TABLE 3 Timber Stand by Species and Condition

Species[a]	Condition[b]	Board Feet per Acre	Cubic Feet per Acre
MCH	MS	20,333	4,333
MCH	IS	11,621	2,754
MCH	PS	3,741	1,287
MCH	SS	1,960	590
MCO	MS	14,415	3,085
MCO	IS	9,343	2,238
MCO	PS	2,542	1,761
MCO	SS	1,960	590
MCH-MCO	LS	8,311	2,026

[a]MCH represents mixed conifer with Douglas fir, ponderosa pine, and Engelmann spruce on high or very productive sites, and MCO denotes mixed conifer on other, less productive sites.
[b]MS is the mature and overmature sawtimber, IS specifies immature sawtimber, PS describes poles with saplings, and SS denotes seedlings and saplings.

and (b) mixed conifer on other, less productive sites.

Each classification consists of one or more condition classes; these would include (a) mature and overmature sawtimber (more than 140 years old), (b) immature with some overmature sawtimber (more than 80 years old), (c) poles with some saplings (more than 40 years old), and (d) seedlings and saplings (less than 10 years old).

Sediment yield depends on the type of land affected. Land types were classified according to natural sediment production, which is a function of slope, aspect, and soil type (clay to sand). Land types also were mapped in slope classes to determine how the unit would be logged because tractor logging does not occur on side slopes of more than 45 percent, where cable logging is performed. In addition, harvest is very difficult on sustained slopes of more than 60 percent.

Cost data were developed on a per-acre basis depending on the slope class. Local roads were estimated to cost $6,000 per mile. Logging costs were estimated according to the costs of felling, bucking, yarding, and loading, as well as costs associated with manufacturing.

Coefficients used in the model were $1.20 per truck per mile for hauling and $3.00 per truck per mile per year for maintenance of the double-lane, graveled main road. For the dirt penetration roads, costs were $2.40 per truck per mile for hauling and $1.00 per truck per mile per year for maintenance. One truck is assumed to haul 5,000 board feet of timber.

In this application, steps eight and nine--defining constraints and developing management strategies--were performed simultaneously. Although IRPM is capable of dealing with multiple time period problems, this study used a single 20-year period to keep the model size small enough to allow several runs. This assumption is reasonable because it is a generalized first cut analysis for the South Fork and because cumulative impacts influence much of the decision making. Therefore, an analysis can be based on total impacts rather than on yearly impacts. As such, this application is essentially a study in land allocation, not in scheduling.

Several scenarios were created by varying the target for timber harvested in the 20-year planning period and then by attempting to minimize either cost or sediment. In the IRPM runs, a timber constraint was set for the timber target, and the objective function was either minimize cost with no constraint on sediment or minimize sediment with no constraint on cost. These two runs essentially set upper and lower bounds of sediment and cost for each level of timber. The minimize-cost run produces an upper level of sediment and the minimize-sediment run produces an upper level of cost.

Although the performance of step ten for formulating mathematical relationships and step eleven for executing computer programs is not discussed in this report, the selection of a preferred alternative in the last step of IRPM application remains a task for the decision maker.

RESULTS OF THE APPLICATION OF IRPM TO PAYETTE NATIONAL FOREST

The scenarios that minimized cost and minimized sediment were examined for various levels of harvesting timber. At low levels, both the minimize-cost and minimize-sediment runs selected similar projects. The minimize-sediment runs chose Cougar Creek units 627 and 634 at 25 million board feet (MMBF) and Cow Creek unit 610, Buckhorn Creek unit 622, and Fitsum

Creek unit 616 at 50 MMBF. The minimize-cost runs chose Cow Creek unit 610 and the adjacent Secesh Face unit 637 at 25 MMBF and included Cougar Creek unit 627 at 50 MMBF.

The significant feature about the Cow Creek and Cougar Creek drainages is that access roads already exist; thus sediment and cost impacts for the amount of timber harvested are minimized. The reason these areas have roads is that harvest techniques are easier, so harvest costs are lower, which further drives the minimize-cost runs to these areas.

As timber-harvesting levels are increased, new roads must be built because the planning area is largely without roads. Thus, the model had more choices, and the minimize-cost and minimize-sediment runs produced different results. The minimize-cost runs selected Goat Creek units 628, 630, and 633, Phoebe Creek unit 632, and the remainder of the area on the east side of the planning area. The model picked the Fitsum Creek and Buckhorn Creek drainages only at very high harvesting levels.

The minimize-sediment runs did the opposite. The model picked Fitsum Creek and Buckhorn Creek at moderate timber levels, and as the target level was increased, Phoebe Creek was selected, and Goat Creek was selected at higher levels.

Figure 4 shows sediment as a function of timber, and Figure 5 shows cost as a function of timber. The minimize-cost and minimize-sediment curves enclose the range of programs that might be selected. A decision maker could select any program within this envelope. As can be expected, the envolope is narrow at low volumes because both objectives harvest timber in the areas with roads. At moderate volumes, the envelope is wide, representing the maximum range of choices among projects. At high volumes nearly all the projects need to be included; therefore, there will not be a wide variation in the runs.

A series of runs was made to show the trade-offs between cost and sediment when the target for harvesting timber was set at 200 MMBF for the 20-year period, or 10 MMBF per year. At this timber level, the minimize-cost run resulted in heavy cutting in Cow Creek 610, Goat Creek 628, 630, and 633, and Phoebe Creek and Indian Ridge 617, 618, 623, and 632. The minimize-sediment scenario has a more developed road system and resulted in fairly even cutting across the planning area, except for Secesh Face 637, White Rock Peak 629, and Indian Ridge 617 and 618. At cost and sediment levels between the above two scenarios, the model selected a composite of the two scenarios at differing degrees.

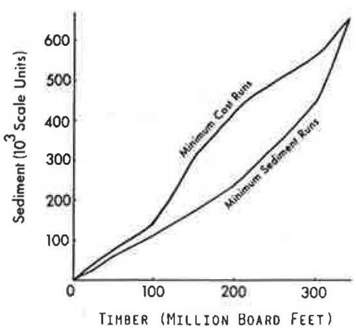

FIGURE 4 Sediment produced for different timber volumes.

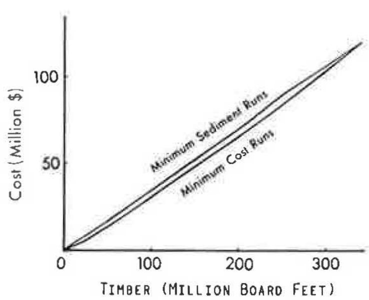

FIGURE 5 Cost for different timber volumes.

CONCLUSIONS

This study has demonstrated the capability of IRPM to evaluate transportation and land use alternatives in Idaho's Payette National Forest. The model also can be applied to wild land outside of National Forest System lands. The results of the computer runs can provide land managers with a general idea of the impacts on stream sedimentation that result from timber harvest and road construction at various levels of investment.

The results can aid in the development of a basinwide environmental assessment that addresses total impacts on the stream. This can help in showing the trade-offs in cost and timber harvest when a sediment constraint is imposed to meet state water-quality guidelines. The results will also show which timber and road projects are generally preferred.

ACKNOWLEDGMENT

We wish to express our gratitude to Malcolm W. Kirby for his technical assistance in the computer application.

REFERENCES

1. R. E. Engelen. Coordination of Transportation System Management and Land Use Management. NCHRP Synthesis of Highway Practice 93, TRB, National Research Council, Washington, D.C., 1982.
2. S. Putnam. Integrated Policy Analysis of Metropolitan Transportation and Location. Office of Transportation Economic Analysis, U.S. Department of Transportation, 1980.
3. M. R. Kihl. Land Use, Transportation, and Energy Integrated Planning in Mid-Sized Cities. In Transportation Research Record 940. TRB, National Research Council, Washington, D.C., Jan. 1983.
4. I. S. Lowry. A Model of Metropolis. The RAND Corporation, Santa Monica, Calif., 1964.
5. J. D. Herbert and B. H. Stevens. A Model for the Distribution of Residential Activity in Urban Areas. Journal of Regional Science, Vol. 2, No. 2, 1960, pp. 21-35.
6. G. T. Lathrop, J. R. Hamburg, and G. F. Young. Opportunity-Accessibility Model for Allocating Regional Growth. In Highway Research Record 102, HRB, National Research Council, Washington, D.C., 1965, pp. 54-66.
7. A. G. Wilson. A Statistical Theory of Spatial Distribution Models. Transportation Research, Vol. 1, 1967, pp. 253-269.
8. G. Bagby and A. Thesen. A Network Flow Model for Allocation of Land Use to Sectors. Management Science, Vol. 22, No. 11, 1976, pp. 1221-1228.

9. D. Bammi and D. Bammi. Land Use Planning: An Optimizing Model. OMEGA, The International Journal of Management Science, Vol. 3, No. 5, Paragon Press, Inc., Elmsford, N.Y., 1975, pp. 235-239.
10. M. Kirby, P. Wong, and W. Cox. Optimization of Rural Road Networks--An Application of the Timber Transshipment Model. In Roads of Rural America. Report 74. Economics, Statistics, and Cooperatives Service, U.S. Department of Agriculture, 1979, pp. 17-26.
11. B. Barnes and E. C. Sullivan. Timber Transport Model, Version 2.0. Research Report UCB-ITS-RR-79-18. Institute of Transportation Studies, University of California, Berkeley, 1980.
12. E. C. Sullivan. A Transportation Analysis Technique for Natural Resource Management. Presented at the International Conference of Transportation Research, Bruges, Belgium, 1973.
13. M. Kirby. An Example of Optimal Planning for Forest Roads and Projects. Proc., Symposium on Planning and Decisionmaking as Applied to Forest Harvesting, Oregon State University, Corvallis, Sept. 1972.
14. M. Kirby. Land-Use Planning, Transportation Planning and Integer Programming. Proc., Systems Analysis and Resource Management Workshop, Athens, Ga., 1975.
15. M. Kirby, P. Wong, and W. A. Hager. Guide to the TRANSHIP Model. Management Sciences Staff, U.S. Department of Agriculture Forest Service, Berkeley, Calif., 1981.
16. R. L. Creighton, I. Hoch, M. Schneider, and H. Joseph. Estimated Efficient Spacing for Arterials and Expressways. HRB Bull. 253, HRB, National Research Council, Washington, D.C., 1960, pp. 1-43.
17. K. J. Schlager. A Land Use Plan Design Model. Journal of the American Institute of Planners 31, 1965, pp. 103-111.
18. A. Black. Optimizing Density of Development with Respect to Transportation Cost. In Highway Research Record 207, HRB, National Research Council, Washington, D.C., 1967, pp. 22-31.
19. K. C. Sinha, J. T. Adamski, and K. J. Schlager. Use of Random-Search Technique to Obtain Optimal Land Use Plan Design. In Highway Research Record 422, HRB, National Research Council, Washington, D.C., 1973, pp. 53-65.
20. R. Sharpe, J. F. Brotchie, and A. R. Toakley. Use of Systems Techniques in Urban Planning. Presented to Australia-New Zealand Association for Advancement of Science Congress, 1970.
21. J. W. Dickey, P. A. Leone, and A. R. Schwarte. Use of TOPAZ for Generating Alternative Land Use Schemes. In Highway Research Record 422, HRB, National Research Council, Washington, D.C., 1973, pp. 39-52.
22. J. W. Dickey and C. Leiner. Use of TOPAZ for Transportation-Land Use Planning in a Suburban County. In Transportation Research Record 931, TRB, National Research Council, Washington, D.C., Jan. 1983.
23. J. Buongiorno and N. Svanqvist. A Separable Goal-Programming Model of the Indonesian Forestry Sector. Forest Ecology and Management, Vol. 4, No. 1, 1982, pp. 67-78.
24. A. Weintraub and D. Navon. A Forest Management Planning Model Integrating Silvicultural and Transportation Activities. Management Science, Vol. 22, No. 12, 1976, pp. 1299-1309.
25. M. Kirby, P. Wong, W. A. Hager, and M. E. Huddleston. Guide to the Integrated Resource Planning Model. Management Sciences Staff, U.S. Department of Agriculture Forest Service, Berkeley, Calif., 1980.

Publication of this paper sponsored by Committee on Low Volume Roads.