A Microcomputer Program to Assist in Low-Volume Road Rehabilitation Decision Making

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An approach to optimizing expenditures of road rehabilitation funds is outlined using U.S. Forest Service roads in the Appalachian region as an example. Main components of the approach are a technique for identifying deficient road links, a line deterioration model, and a network investment strategy optimization model. The focus of this paper are the details of a guided decision-making tool for determining whether a road link is a candidate for upgrading. From a list of physical and operational roadway characteristics warranting upgrading, a flowchart was developed to encourage engineers or planners to think in a logical step-by-step fashion about the rehabilitation needs of a particular roadway link. An interactive microcomputer program has been written for both the Apple and IBM PC computers to facilitate use of the model. By considering one link at a time and answering yes or no to questions about roadway characteristics, the user branches through the program until reaching one of two possible outcomes: (a) upgrading is not warranted, or (b) upgrading is warranted and the link should be included in the network optimization model. Program output is a list of those road links in a jurisdiction that are candidates for rehabilitation. The paper contains a detailed flowchart of the model. Although originally developed for the Appalachian region, the model is flexible enough that it can be easily modified or enhanced based on local conditions and the experience of the user.

Low-volume rural roads, those carrying 400 vehicles/day or fewer, are vital to the U.S. economy. State farm-to-market roads, county roads, and township roads provide the accessibility required by agricultural commerce. Forest and park roads are necessary for the operation, maintenance, and accessibility of forests and parks.

Although low-volume roads in the United States carry only about 8 percent of total highway travel, they are economically important because they constitute more than two-thirds of public highway mileage *(1)*. Because the limited financial resources available have to be spent over so many miles, low-volume roads have historically been designed and operated at minimal cost. Most of the existing low-volume road system has been built using design, operational, and maintenance practices that have evolved from subjective experience and judgment rather than from an objective evaluation of quantifiable performance. Because they are the largest single class of highways, objective guidelines for design, operation, and maintenance of low-volume roads are imperative to optimize the use of available funds.

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Properly designed low-standard earth and gravel roads are usually adequate to handle the initially imposed traffic. Over time, however, such roads may become deficient. For example, under conditions of increasing traffic volume (perhaps due to change in functional use), maintenance and vehicle operating costs increase, making it necessary to consider upgrading the road. Other factors that may cause roads to be considered as deficient include inadequate geometrics, poor drainage, inadequate bridges, and weak subgrade soils. In view of these factors, agencies responsible for low-volume roads must continually analyze their road networks to identify and upgrade deficient road links. However, it should be noted that by law most local agencies deal with either maintenance or construction in most cases. There is a definite need for a third category of activity, that of rehabilitation.

Within the low-volume road network of a particular jurisdiction are many road links. For purposes of discussion, a road link is defined as a length of road with uniform characteristics. Because the road network, for the most part, is composed of low-cost, low-volume links, its management is quite different from that of higher type road networks. The planner or engineer must always be aware of the adverse effects that are sometimes caused by the special constraints and characteristics of low-volume roads.

At one or more times during the life of some of these road links, major construction or reconstruction activities may be needed to provide the level of service desired. However, within a planning period, if the needed upgrading efforts are not scheduled with sound engineering judgment, the road links may deteriorate substantially. This deterioration not only increases recurring maintenance and vehicle operating costs, but makes the cost of upgrading greater in the end as well.

The economic evaluation of maintenance and upgrading activities is based on the premise that the role of maintenance is not merely to preserve the road. Rather, it is to keep the road in a condition that permits vehicles to operate at the cost level at which the total transport cost is lowest. Total transport cost is the sum of the construction, maintenance, and vehicle operating costs *(2)*. This combination implies a systems maintenance effort, that is, drainage structures must function, brush must be controlled, and slides and slumps must be repaired.

Routine maintenance is used here to refer to those items regularly performed by maintenance crews throughout the year. Examples of routine maintenance include blading and smoothing the surface, patching isolated areas where surface material has been lost, cleaning and repairing culverts, cleaning ditches, cutting vegetation, and repairing bridge decks and railings. Scheduling and performing this work normally are responsibilities of the front line supervisors of the crews, within the overall plan and budget.

As used here, upgrading and rehabilitation refer to the more extensive maintenance and construction activities that are required only every several years. Examples include resurfacing with gravel, paving a gravel road, resurfacing a paved link, modifying geometrics, and replacing a bridge structure. Because these activities are usually expensive, authority for planning and scheduling rests with someone higher than first-line supervisors.

Typically, funds are not sufficient to meet all of the upgrading needs. The engineer or planner must therefore decide not only what schedule of upgrading is appropriate for each deficient road link, but also which links require an investment in upgrading at all. In addition, political realities of public pressure and political influence may require that certain upgrading activities be planned regardless of other indications.

This study was undertaken to try to develop an objective, technically sound methodology, applicable to forest roads in the Appalachian region, for identifying deficient road links and for determining optimum timing for their upgrading. The methodology, which is an aid in the decision-making process, addresses the following questions.

1. Which of the road links within a jurisdiction may warrant upgrading at some time during the planning period?
2. Within this period, what would be the optimal schedule for implementing the needed upgrade for each link so as to minimize the total costs for upgrading, maintenance, and vehicular operation of the entire plan?

Although there is a brief discussion of the systems approach used to meet the second objective, the focus of this paper is primarily on the first objective, that is, identifying links that are candidates for upgrading.

LITERATURE REVIEW

This section contains the results of that portion of the project literature review concerned with identifying factors that affect road-upgrading decision making in general and in the Forest Service road network of the Appalachian region in particular. A number of researchers have investigated the inclusion of a variety of factors related to decisions about upgrading or rehabilitating low-volume roads. Because space does not permit a complete review of the literature, only the major references pertinent to the study in question are presented.

Among the most prominent research that has been conducted relative to improvement investments on low-volume roads have been that of Robinson et al. *(3)* and Parsley and Robinson *(4)*. Their efforts have been helpful in defining factors pertinent to optimum timing of road-upgrading activities. The factors identified in their research were used to predict surface deterioration, rehabilitation costs, maintenance costs, and road user costs. Some of the general categories of factors considered were the following: route location, road design standards, terrain information, properties of construction materials, construction unit costs, environmental factors, vehicle operating costs, traffic and vehicle loading data, maintenance policy, and maintenance unit costs. These factors were considered relative to earth, gravel, and paved roads.

Three references in the literature were valuable in assisting the researchers in determining factors relevant to the optimal timing problem in the Appalachian region. Howlett and Hudson et al. enumerated many factors characteristic of low-volume roads that are not characteristics of higher type roads *(5, 6)*. In addition, they mentioned some special factors that are unique to the management of Forest Service roads.

Koger's report included a thorough review of Forest Service literature related to the construction, rehabilitation, and cost of Forest Service logging roads in the Appalachian region *(7)*. His review resulted in a lengthy list of important factors affecting road construction and location. Major categories of factors included topography, soils and geology, road standards, and maintenance policies. In addition, Koger presented the following list of conditions, characteristic of many Forest Service roads in the Appalachian region, that may present construction or maintenance problems *(7)*.

- Low or swampy areas,
- Long level sections with poor drainage,
- Rocky areas,
- Steep side slopes requiring large cuts and fills,
- Sharp curves or switchbacks,
- Steep grades,
- Streambeds and frequent stream crossings,
- High water tables with many springs and seeps,
- High natural soil erosion and slope instability, and
- Northern exposure.

From the literature review, the researchers identified many factors relevant to road-upgrading decision-making in the Appalachian region. The following list of factors was believed to be pertinent by the researchers.

Age of roadway surface
Annual maintenance costs
Construction costs
Degrees of roadway deterioration:
  Roughness
  Rut depth
  Cracking
  Gravel loss
  Patching
Delay costs
Design standards
Gradient
Horizontal curvature
Maintenance policy
Material costs
Performance rates (equipment and staff)
Planning horizon
Resource (equipment and staff) availability
Roadway surface type
Roadway width
Soil characteristics
Traffic control
Traffic loads

Traffic volume (ADT) and composition
Vehicle running costs:
  Fuel
  Oil
  Depreciation
  Maintenance
Vehicle speeds
Vehicle types
Weather:
  Temperature
  Rainfall

In developing the list, all variables that were enumerated in the literature review were evaluated to determine their suitability to the problem of modeling road-upgrading decision making. Evaluation of factors was based on appropriateness of the variable to the Appalachian region and on data availability. The list contains only those physical factors and operational characteristics of road links that can be quantified. For example, although social or political pressure may play an important role in determining when a road is upgraded, this factor has not been added to the list because it is difficult to quantify. The factors on the list were included because over an extended planning period they affect road-upgrading decision making in one way or another. For example, traffic loads, maintenance policy, roadway surface type, and weather factors all affect road surface condition, which in turn affects upgrading costs, routine maintenance costs, and vehicle operating costs. Because the list developed was too lengthy to be used in its entirety in the modeling process, it was reduced in size by combining some factors into fewer categories and by eliminating other variables.

PROBLEM APPROACH

The basic approach to achieving the objectives outlined earlier is shown in the flowchart in Figure 1. The first step in the procedure is to identify the set of road links under study along with the physical and environmental characteristics and operational status of each link. The planning period (in years) is also established. Using the decision-making framework to be described here, those links that are, or may soon become, deficient are identified using the candidate link identification model. These links are considered candidates for the upgrading and rehabilitation funds. Knowing the candidate links and their deficiencies, a number of feasible alternative link investment strategies can be generated. A link deterioration model is needed at this point to determine how the various road links will degrade over time, given certain climatic and soil characteristics and a specified maintenance or upgrading strategy. This deterioration may have to be estimated from local experience because at the present time there is no universally applicable roadway deterioration model.

As noted by Harral et al. *(8)*, road deterioration is a function of original surface design, material types, volume and axle load configuration of traffic, climate, and maintenance policy. Although extensive research has been conducted in North America, Europe, and Australia into the performance of

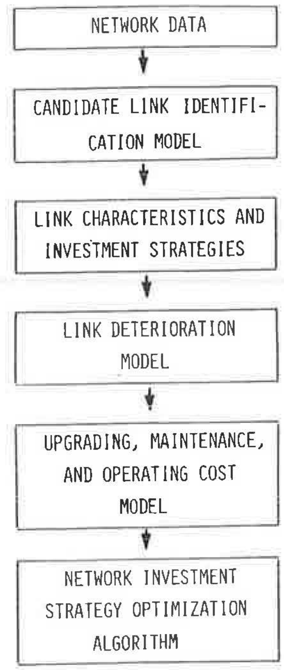

FIGURE 1 Form of approach taken to address optimal timing problem.

high-standard pavements, only limited research has been carried out on low-standard pavements. Deterioration of unpaved roads is measured in terms of surface roughness, rutting, depth of loose surface material and, for gravel roads, loss of gravel. Deterioration is caused by two factors: traffic and time-related weathering effects. Only limited data are available relative to isolating the time-related weathering effect from the traffic effect.

Similarly, the impacts of different levels of maintenance expenditures on road condition and subsequent deterioration, and, hence on road user costs, have only recently been measured scientifically. Such relations are not yet well established for the complete range of maintenance activities, traffic, and environmental conditions found throughout the United States. Considerable progress has been made in recent years through the research process. Some of the results have been reported in the proceedings of the Third International Conference on Low-Volume Roads *(9)*.

With the deterioration data, costs of implementing each link investment strategy can be estimated for the set of candidate links, including upgrading and vehicle operating costs. These two major elements of the economic evaluation are difficult to determine exactly. Thus, the experience, competence, and judgment of the engineers play a key role in system management. The total net present value of each category of costs associated with each link investment strategy is computed. Using these costs as input to a zero-one integer programming model, the network investment strategy, that is, the set of strategies that minimizes the total costs for a given budget, is identified.

IDENTIFYING LINKS FOR UPGRADING

An effort was made to refine the approach just described and apply it to roads within the Monongahela National Forest in

West Virginia. However, even before local deterioration models or appropriate integer programming models could be developed, it was believed that a better decision-making process was needed for identifying road links that were candidates for upgrading. Of most value to engineers and planners would be some type of guided decision-making scheme using specific objective criteria and based on link information already available.

The list of factors in the road-upgrading decision compiled from the published literature was reviewed with Forest Service engineers. These discussions identified other variables and quantitative criteria for road upgrading. Thus, a final list of conditions warranting upgrading was prepared. A flowchart format appeared to be the most appropriate way to adapt this information to practitioner needs. Using this format, a decision-making guide was developed. By structuring the analysis process, the format permits doing with the computer what has previously been done manually.

The flowchart aids in identifying common deficiencies characteristic of road links in the Appalachian region that would indicate that a link should be considered as a candidate for upgrading. Information on the following link characteristics was included in the flowchart:

- Stream siltation,
- Gating,
- Forecasted use,
- Surface type,
- Surface condition,
- Number of lanes,
- ADT,
- Drainage,
- Horizontal curvature,
- Sight distance,
- Turnouts,
- Roadway width,
- Bridge adequacy, and
- Subgrade soils.

Note that most of the information included is of the type with which the analyst would be familiar based on the analyst's experience with the road system or that could be acquired through standard condition surveys.

By considering one link at a time and answering yes or no questions about the characteristics noted, the engineer or planner branches through the flowchart until reaching one of two possible outcomes: (a) upgrading is not warranted, or (b) upgrading appears warranted and the link should be included in the network optimization model. Output is a list of those road links in a jurisdiction that are candidates for upgrading or rehabilitation.

A draft version of the flowchart was prepared and reviewed by Forest Service engineers. Suggestions made for improving the flowchart were incorporated into the final form of the model. The decision-making flowchart is shown in Figure 2.

Caution must be used in interpreting output from the model. There may be links for which the model indicates upgrading is not warranted when in fact it should be considered and vice versa. Experience of the engineer plays a major part in determining how effectively the flowchart meets its intended objectives. It must also be kept in mind that the flowchart has been developed for the Appalachian region. Users elsewhere may find some sections inappropriate or feel a need to include some additional capabilities. Because it is relatively easy to make such modifications, the model's flexibility as a decision-making aid is enhanced.

The logic of the process, shown in flowchart form in Figure 2, was such that it was relatively easy to develop an interactive microcomputer program to implement the model. Both an Applesoft BASIC for the Apple II computer and a Microsoft BASIC for the IBM PC are available from the author. The former operates on a 48K Apple II microcomputer with one disk drive under the DOS operating system. The MS BASIC version requires an IBM PC or compatibility with at least 128K RAM, one disk drive, and MS-DOS.

Once the candidate links and their deficiencies have been identified, the analyst can generate several different feasible alternatives for upgrading each link. For example, given a road that needs to be surfaced with gravel, a strategy must be considered that reflects different schedules of when the graveling is to take place.

The zero-one integer programming optimization algorithm (work on which is still in progress) requires as input costs of different link design and maintenance options, including different time-staging strategies. Costs associated with each investment strategy are those for the upgrading activities, recurring maintenance activities, and vehicular operation. These costs, which will be the basis for making upgrading decisions, are dependent primarily on the rate of deterioration of the road. Additional discussion of integer programming is beyond the scope of this paper. Interested readers are encouraged to consult texts on operations research for more information about integer programming and available computer programs for handling such problems.

CONCLUSIONS AND RECOMMENDATIONS

The candidate link identification flowchart and the microcomputer program can help engineers and planners identify road links that warrant upgrading. It is an easy-to-use interactive program that can be used by persons with little or no computer background. However, the model does require that the user be familiar with the links being evaluated. Although not a panacea, the program forces the user to think in a logical step-by-step fashion about the upgrading needs for a particular link. When used with experience and judgment, the model should result in decision making that is improved over previously used subjective approaches. The program should not be applied blindly; it is intended to be a flexible tool, really a starting point, that can be modified, changed, or enhanced based on local conditions and the experience of the user.

The guided decision-making model for identifying links warranting upgrading was developed for the Appalachian region. Although the microcomputer program has been used by Forest Service engineers in Monongahela National Forest, a formal evaluation has not been conducted. It is recommended that the flowchart be applied to a low-volume road network so that its usefulness can be evaluated. Undoubtedly, certain modifications will need to be made. The applicability of this tool to forest roads in other areas of the country should be investigated.

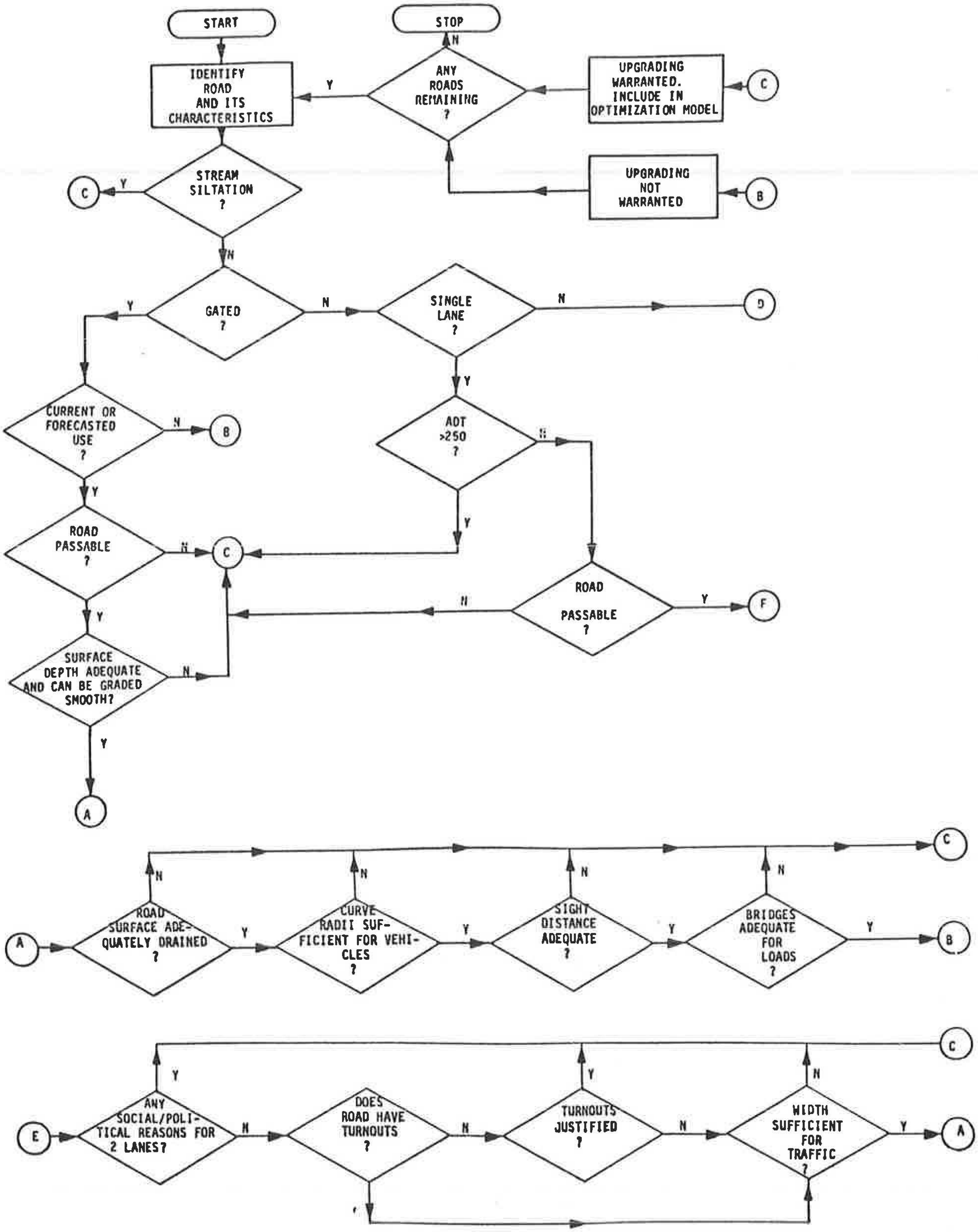

FIGURE 2 Decision-making process for identifying road links in Appalachian region warranting rehabilitation.

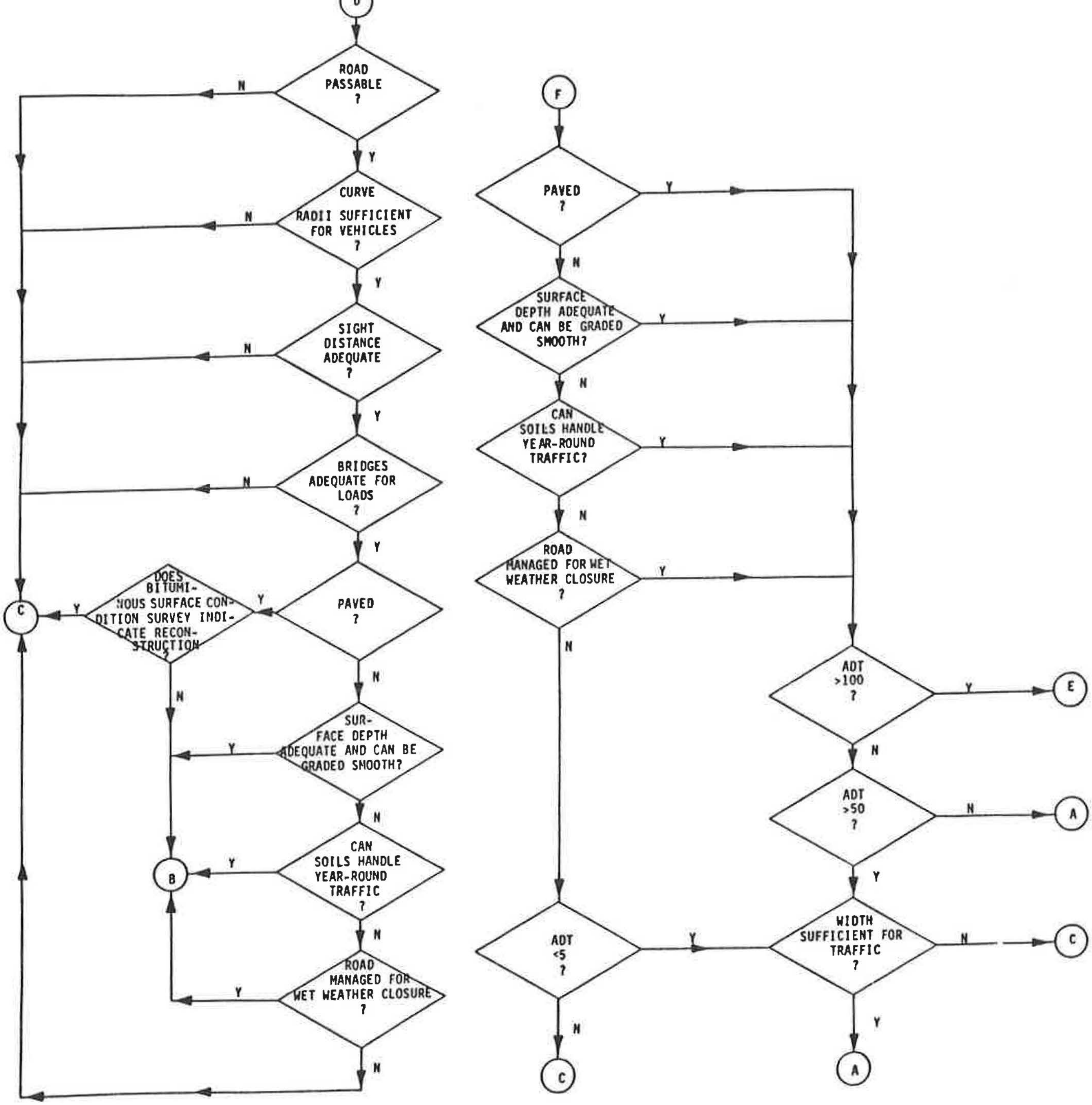

FIGURE 2 *continued*

No approach to the problem of optimum timing for road upgrading can be considered complete without some sort of link deterioration model. Such a model uses various input data to predict the deterioration of a road surface as time passes and as vehicles travel over the road. This is vitally important in decision making because vehicle operating costs are significantly affected by road surface condition. Likewise, the life of the roadway and future rehabilitation costs are heavily dependent on the level and timing of maintenance, which in turn is a function of road deterioration. The approach developed herein lacks this component because at present, there is no suitable forest road surface deterioration model for the Appalachian region.

Assuming that the optimization model currently under development can be implemented successfully and that a link deterioration model can be developed, it would be desirable to assemble a complete package of computer models for a comprehensive approach to the problem. The link identification model has already been implemented on a microcomputer. The link deterioration model and optimization algorithm would also be computer based. Development of a computerized costing algorithm and linkages between the models would be the only items needed to provide a complete computer package for low-volume road maintenance management.

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