Highway Investment Analysis Package

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The highway investment analysis package (HIAP), a computerized evaluation and investment programming model, has been developed for the Federal Highway Administration to aid state, regional, and local organizations in making the best use of limited highway funds. HIAP uses microeconomic theory to analyze individual roadway sections and limited networks of sections specified by their physical, traffic, and operational characteristics. Estimates of both highway user (i.e., vehicle operating costs, travel times, and accidents) and nonuser (i.e., noise levels and air pollutant emissions) impacts are produced. HIAP develops multiperiod investment programs by selecting those improvements that maximize either user benefits or one of several accident reduction measures. The selection process permits consideration of a broad range of funding constraints, which may be tailored to the specific needs of individual organizations. Based on marginal analysis, the process allows consideration of multiple alternatives and staged improvements at each analysis site. Great flexibility in the content and format of input data is afforded the analyst. Furthermore, HIAP includes a transformation program that allows the analysis of data already available in the format used for the 1970 to 1990 highway needs study.

The nature of the highway planning process has changed significantly in the last few years because of factors such as increasing public involvement, changing statutory requirements, and spiraling construction costs. To analyze and program highway improvements effectively, today's transportation officials require the timely application of more comprehensive and responsive procedures than traditionally have been available.

The Federal Highway Administration used such comprehensive procedures in a background study (1) for the 1972 Report to Congress on the Highway Needs of the Nation. Computer models for highway improvement evaluation and programming developed for the 1972 report incorporated state-of-the-art knowledge in highway user economics. The national orientation of the study, however, made these potentially valuable tools inappropriate for direct use by individual state or regional transportation planning organizations. Consequently, the Federal Highway Administration contracted with Multisystems, Inc., to conduct the highway investment study to expand on the original study and to develop a battery of computer programs for general use by state, regional, and metropolitan transportation planning organizations for (a) systematically analyzing and evaluating proposed highway investments and (b) combining these proposed investments into efficient investment programs. The result of these efforts is a very flexible and comprehensive model called the highway investment analysis package (HIAP) (2).

HIAP fills a gap in the existing stock of highway analysis and programming procedures by providing the following capabilities:

1. Systematic analysis of the economic and safety consequences of a wide variety of highway improvements including new construction, reconstruction, resurfacing, and isolated reconstruction of hazardous areas, structures, and railroad grade crossings;
2. Prediction of noneconomic consequences of highway improvements including changes in noise levels and air pollutant emissions;
3. Analysis and budgeting of interrelated improvements, alternative improvements at a given site, and staged-construction improvements;
4. Operation over a broad range of detail in analyst-supplied data, ranging from rough estimates to very detailed descriptions of traffic and roadway characteristics;
5. Selection of investment programs that meet a broad range of financial, political, and environmental requirements; and
6. Determination of aggregate measures of benefits and cost effectiveness for highway investment programs and the corresponding ability to test the sensitivity of such measures to changes in budgetary or other constraints.

Although HIAP forms a complete analysis and investment package, it is modular in construction. This enhances its usefulness to state and regional organizations, which operate under a broad range of planning processes. HIAP recognizes that each organization's approach to planning and programming is unique and that

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the relationship between planning and programming is changing rapidly such that previous judgmental or empirical techniques are being replaced by more systematic processes.

The two major components of HIAP, improvement analysis and evaluation and investment programming, are discussed below.

IMPROVEMENT ANALYSIS AND EVALUATION

The improvement analysis and evaluation component of the model is designed both to aid planners in generating and modifying alternative proposals for meeting specific objectives and to prepare evaluation and cost measures required in selecting improvements in the investment programming process. Key features of this component are discussed below.

Section Definition and Specification

Basic analyses are performed at the individual highway section level. Depending on the degree of detail desired for a particular analysis, any roadway segment can be defined as either a single large section or a group of smaller sections.

The analyst specifies the physical and operational characteristics of the existing and one or more proposed configurations of a section by inputting the following data for all sections:

1. Functional class,
2. Area type (e.g., rural),
3. Highway type,
4. Length,
5. Number of lanes,
6. Average highway speed (weighted design speed),
7. Capacity (default value may be calculated by using lane width and either shoulder width or lateral clearance), and
8. Surface type.

For certain sections, the analyst inputs

1. Population code (urban only),
2. Terrain type (rural only),
3. Percentage of length with passing sight distance ≥ 460 m (1500 ft),
4. At-grade railroad crossings by protection type and average daily number of trains, and
5. Capital costs or detailed cost components (improvements only).

Optional data for special cases include

1. Fatal, nonfatal injury, and total accident rates,
2. Annual maintenance and administration costs,
3. Noise standard (decibels at a given observer distance),
4. Surface condition rating or index (if pavement deterioration is considered), and
5. Relocation or other data.

(Traffic data are specified independently and are discussed later.) Optional data may be supplied to override internal default values or to provide additional descriptions and impact measures for a section configuration. For example, the analyst might provide specific accident rates for a high-accident location or a strict noise standard for a section passing near a hospital.

Measurement of User Impacts

Estimates of vehicle operating costs, travel times, and expected accidents are calculated for each section. Operating costs and travel times are calculated for passenger cars and four types of trucks but are reported for automobiles, single-unit trucks, and multiunit trucks. In addition to accounting for the physical characteristics of the roadway (such as curves and grades, surface type and surface condition), HIAP also includes the effects of speed change cycles, stops, idling, and delays at railroad crossings through vehicle operating costs and travel times. These user impacts are calculated for each of six segments of the average day, representing the different levels of congestion in which traffic operates, and are aggregated to obtain average daily impacts.

Expected fatal, nonfatal injury, and total accidents (including those associated with at-grade railroad crossings) are estimated by using either rates for the specific section (supplied by the analyst) or typical rates stratified by highway design type and traffic volume.

Measurement of Nonuser Impacts

Nonuser impacts including noise and air pollution and governmental costs are also estimated by HIAP. For noise (3), the impact estimated is the maximum perceived level during the most congested portion of the day at an analyst-specified observer distance. The reported value is the level exceeded 10 percent of the time and is a function of automobile and truck volumes, travel speeds, and the steepest grade on the section. Weighted perceived noise levels and noise level distributions over the day are also calculated for informational purposes.

Air pollutant emissions (3) are calculated for automobiles and trucks by using emission rates for carbon monoxide, oxides of nitrogen, hydrocarbons, and evaporative hydrocarbons, which take into consideration average vehicle speed, increase in emissions due to vehicle age, and vehicle age composition of average traffic flows.

Estimates of governmental costs are based on the capital costs of implementing each new or improved section configuration. HIAP treats these costs as single lump sum investments to be made at the beginning of a programming period. An annual maintenance cost for each section can be either specified by the analyst or computed by using default average annual costs per 1.6 km (1 mile), which vary by functional class. If the analyst does not choose to supply annual administrative costs, the model calculates them as a percentage of the annual maintenance cost plus the average annual capital cost.

In addition to the nonuser impacts, as many as four categories of indirect effect data may be reported for each improved section.

Time-Dependent Analysis

In HIAP, the analyst establishes a planning horizon, typically 10 to 30 years, which can be subdivided into as many as four implementation or programming periods. Periods need not be the same length and can be as short as 1 year. An example with three periods is shown in Figure 1.

The model calculates the user and nonuser impacts of having each improvement alternative, including the existing condition (i.e., the null alternative), in place at the beginning of each implementation period, starting with the first period in which the particular alternative is available for implementation, and immediately after the end of the planning horizon. These measurement

Figure 1. Time-dependent analysis.

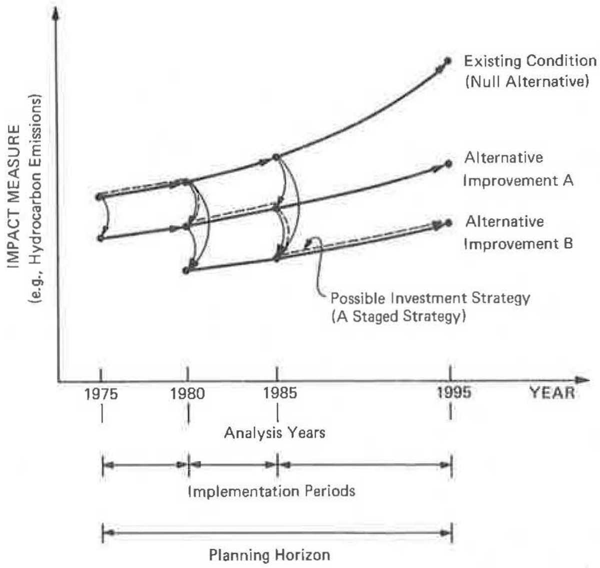


Figure 2. Analysis of interrelated improvements.

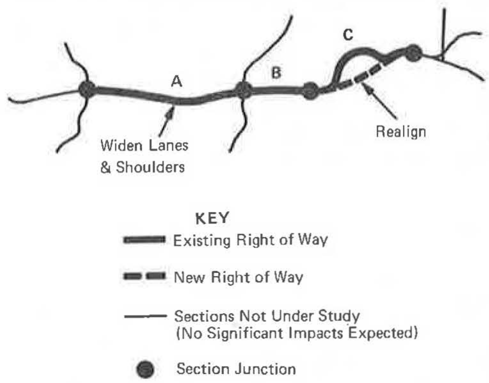
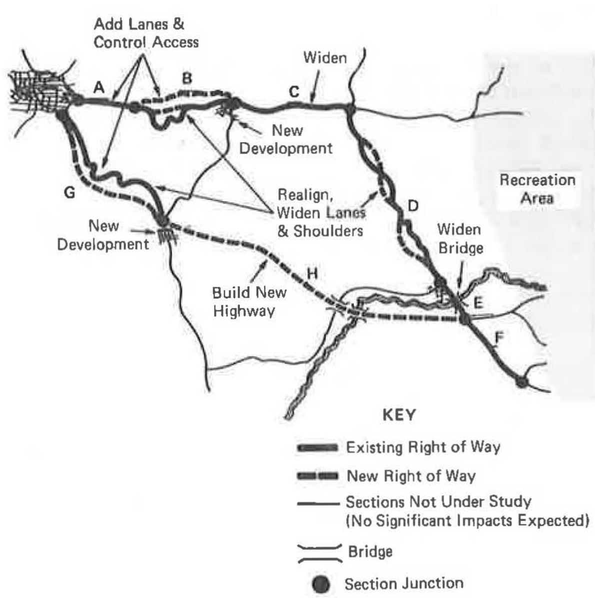


Figure 3. Analysis of multiple-alternative improvements.



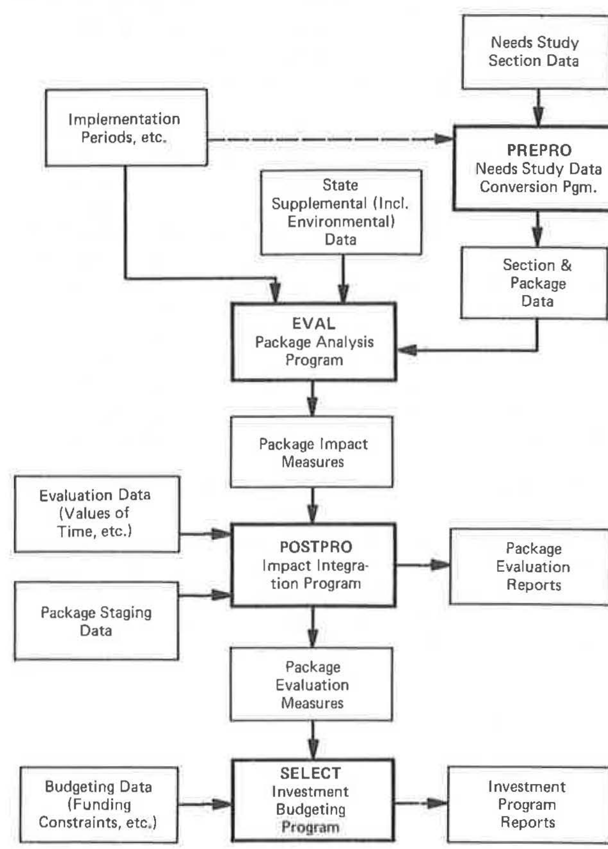
points are referred to as the analysis years; the calculated impact measures are values that would result from the section being in specific alternative configurations or physical states in an analysis year.

This analytic approach (4) yields impact estimates that are sensitive to time-dependent changes in traffic volume and composition and provides the basis for evaluating both single- and two-stage investment strategies. A single-stage investment strategy is defined as the implementation of a specific improvement in a specific period. For example, in Figure 1, the implementation of alternative improvement A (which might be the widening of a particular section from two to four lanes) in the second period would constitute a strategy. A two-stage strategy would add a further investment in a later period. The dashed line in Figure 1 indicates such a strategy in which alternative improvement B is implemented in the third period after alternative improvement A has been implemented in the second. (Alternative improvement B might call for the widening of the original section to six lanes.) The null strategy calls for the retention of the existing section throughout the planning horizon; it is the base against which all investment strategies are compared.

Analysis of Interrelated Improvements

The simplest application of HIAP occurs when a single highway section can be extracted from the highway network and analyzed in isolation. In this application, the desired objectives can be met by improving only that single section, with negligible impacts on adjoining sections. In a more typical application, objectives can be achieved only by making related improvements to adjoining sections, which cannot be analyzed realistically

Figure 4. HIAP structure.



in isolation because improvements to one section may increase traffic on adjoining sections or change traffic patterns in the immediate network.

HIAP deals with this additional complexity by calculating the impacts of proposed improvements on an entire analysis site consisting of several individual, but interrelated, roadway sections. The analyst can select combinations of section configurations, one for each section in the site. Each combination of section configurations forms a package, the basic unit of investment in HIAP. The null package, the combination of existing configurations, provides the basis for comparative analyses. In addition to improved and new sections, sections in their existing configurations can also be included in the investment packages.

Traffic data (both volume and composition) are specified for each package. In the null package, traffic data must be provided for all sections. In investment packages, these data must be provided for all new and improved configurations. In addition, revised traffic data may be provided for sections remaining in their existing configuration so that the increased congestion due to the adjacent improvements can be evaluated. The analysis site example in Figure 2 shows three serially connected sections A, B, and C. The investment package consists of improvements to sections A and C. The impacts induced on section B are included in the analysis.

Analysis of Multiple Alternative Improvements

The analysis of multiple alternative improvements for a given site is easily accomplished by building several packages, each consisting of a unique combination of possible section configurations, that describe the alternatives under consideration.

A complex situation is shown in Figure 3. The analysis site is a corridor between a major metropolis and a recreational area. In this case the three interrelated objectives are to (a) improve the accessibility of the recreational area, (b) improve the accessibility of intermediate sites, and (c) reduce the accident rates on specific sections.

The first objective can be achieved by upgrading the existing route (ABCDE) or constructing a new route (GH) or by doing both. If the new route (GH) is built, some traffic will be diverted to it from the existing route (ABCDE). This diverted traffic may be either specified by the analyst or computed internally by using diversion curves based on the ratio of travel times on the parallel routes. The second objective can be achieved by upgrading sections A, B, and G, and the third can be achieved by improving sections B, D, and E. Section F has been included in the analysis site because it will carry increased traffic when the first objective is met.

Many possible alternative packages designed to meet some or all of these objectives and covering a wide range of investments and benefits can be analyzed by HIAP. In addition, the staged implementation of these packages can be specified. For example, a first-stage package involving improvements to sections A, B, D, and E might be followed by either a package containing improvements to C plus further improvements to A or a package containing improvements to G and the construction of H.

Package Evaluation

The impacts estimated for alternative packages are compared to similar estimates for the null package. These comparisons are used to develop two categories of package evaluation measures: economic measures and effectiveness measures.

Economic Measures

HIAP calculated (a) total economic benefits (highway user plus maintenance and administration cost savings) of implementing each investment strategy and (b) corresponding net present value and benefit-cost ratios. These benefits are developed from the package impact measures in the following manner.

1. In accordance with microeconomic theory, the annual changes in consumer surplus for each section in each analysis year for travel time, vehicle operating cost, and fatal, nonfatal injury, and property-damage-only accident expectancies are calculated (assuming a linear demand curve).
2. Section benefit components (i.e., annual changes in consumer surplus) are summed into package totals, and average values of time and accidents are applied to convert these components into dollars. All package components are summed to total user benefits for the investment package in each analysis year.
3. The benefits in the years between analysis years are calculated by using linear interpolation, and benefits beyond the planning horizon are assumed to remain constant.
4. The time stream of total annual user benefits and annual maintenance and administration costs (expressed as the algebraic difference between the null and investment package costs) is discounted to the first year of the planning horizon and summed to get the total economic benefits that would result from implementation of an improvement package in the first year of the period under consideration.

Effectiveness Measures

HIAP produces the following effectiveness measures for all packages: relocations or other information input by the analyst; fatal, nonfatal injury, and total accidents; emissions of carbon monoxide (CO), oxides of nitrogen (NO_x), and hydrocarbons (HC); noise levels as compared to a standard and to the null package; and a daily congestion index.

Threshold Tests

The analyst may establish threshold levels against which to test the environmental impacts of each package in each analysis year. If a test is made and the package fails, the analyst has two options: (a) flag all investment strategies that include the package as having environmental problems but allow them to be included in the programming process or (b) exclude from further consideration in the programming process all investment strategies that include the package.

Investment packages may be tested against the following thresholds:

1. The percentage of increase in CO, NO_x, and HC emissions over the null package,
2. The decibel increase in maximum perceived noise levels (package noise level minus noise standard or package noise level minus null package level), and
3. The maximum acceptable value for analyst-supplied package characteristics.

INVESTMENT PROGRAMMING

The investment programming process of HIAP develops highly efficient highway investment plans subject to a

large number and variety of possible expenditure constraints. Its key features are discussed below.

Evaluation Measures

HIAP makes use of much of the quantitative impact information it produces to develop evaluation measures that can be used to generate investment programs. Programs may be chosen that seek to maximize one of four evaluation measures: (a) economic benefits (i.e., travel time, vehicle operating cost, and accident benefits plus maintenance and administration cost savings) generated, (b) fatal accidents eliminated, (c) fatal plus injury-producing accidents eliminated, or (d) total accidents (of any kind) eliminated.

Flexibility

Investment plans can be developed for as many as four periods within a planning horizon. In each of these periods, HIAP allows the analyst to impose both maximum and minimum expenditure constraints. Maximum constraints restrict total expenditures within each budgetary period and are typically based on projections of future needs, revenues, and allocation policies. These constraints ensure that investments programmed in any period do not exceed realistic funding levels. This is important because a maximum constraint affects not only the choice of investments in the period for which it is specified but also the possible choices in all succeeding periods.

Minimum constraints provide the analyst with an effective mechanism for spreading expenditures over a variety of funding categories, thus ensuring that a desired balance is maintained. For example, the expenditures in each geographic, legislative, or administrative area of a state can be dispensed equitably by the proper application of minimum constraints; this precludes the possibility that so much money is spent in one area that other areas get practically none. Also, expenditures in each funding class can be constrained to ensure the optimal use of assistance from federal or other sources.

The model permits great flexibility in defining the funding categories to be constrained. Three basic categories may be defined and used in the selection process. Within each category, many individual minimum expenditures (e.g., for specific counties or administrative districts) may be specified. A fourth funding category allows the analyst to subdivide one of the three basic categories. This feature would be used, for example, if a specific allocation of funds by functional class were required within each district of a state. Without this feature, the investments in a particular functional class might all occur in only one or two districts. In the event that the analyst requires a minimum constraint structure that cannot be handled directly by HIAP, it often can be accommodated through an option facilitating sequential processing.

When comparing alternative investments, HIAP can simultaneously consider up to 99 improvement packages for each analysis site. (The total number of packages that can be handled in one period is a function of the primary computer memory available. A computer with 256 000 bytes of core can process approximately 4000 packages.) In addition, HIAP can program two-stage investments in which each stage is implemented in a different period. The second stage of the package cannot be selected unless the first stage has already been chosen in an earlier period. The second stage then must compete with all other packages still available for selection; if it is chosen, the complete staged investment is accepted.

Program Selection Process

Marginal analysis procedures were chosen as the most suitable methodology for the HIAP budgeting process because they can produce very good results at a relatively low cost and handle a large number of alternatives and expenditure constraints. This approach (5) consists of starting with no packages in an investment program and successively adding the best possible improvement package to a selected package list until the overall programming period budget is expended. The best possible improvement package at any point in the process is the one with the highest ratio of evaluation measure to cost (EM-C). If other improvement packages exist for the same analysis site, their marginal EM-C ratios are calculated and used for the remainder of the selection process. Any previously selected package for that site is replaced on the list by the latest package selected.

This process seeks to maximize the total net returns (of a particular type) of the investment program for any given expenditure level. After the analysis for a programming period is complete (i.e., the budget is expended), the evaluation measures and costs for unselected packages are adjusted to reflect the one-period delay of package implementation, and these packages are carried over into the next programming period for possible selection.

MODEL STRUCTURE

HIAP is designed to provide the analyst with a great deal of flexibility. Many program options and parameters are available that allow the analyst to tailor the improvement evaluation and program selection processes to his or her specific needs. In addition, its highly modular structure allows easy modification, substitution, or addition of components and simplifies the effort required to incorporate new technology. For example, it would be easy to update or replace the methods now used for estimating noise and air pollution when better procedures are developed.

HIAP is composed of three basic computer programs—EVAL, POSTPRO, SELECT—and an auxiliary program, PREPRO. The modular structure of the HIAP system is shown in Figure 4, and each of these programs is briefly discussed below.

PREPRO converts needs study data to a format suitable for use in the HIAP analysis program (EVAL). This includes editing and supplying highway and traffic data where necessary to standardize and augment the needs study data.

EVAL performs all highway section analysis, i.e., calculation of travel times, vehicle operating costs, accidents, noise levels, and pollutant emissions. It assembles these impact measures into package economic (changes in consumer surplus) and effectiveness (accident and emission totals and maximum noise impact) measures. If desired, great detail can be reported, including impacts by vehicle type on each section.

POSTPRO produces evaluation measures for staged improvements, creates summary reports, and prepares the final input to the investment programming routine. Summary economic measures are calculated based on the impacts estimated in EVAL, analyst-supplied values of time and accidents, and a discount rate. Environmental acceptability of each package is determined by comparing nonuser impact levels to threshold values. The evaluation parameters (unit values, discount rate, and thresholds) are introduced in POSTPRO to facilitate sensitivity testing by enabling the user to change these parameters and develop new evaluation measures without repeating the impact analysis (EVAL).

SELECT is designed to produce multiperiod highway investment programs that satisfy various budgetary and legislative constraints and maximize a specified evaluation (i.e., economic or effectiveness) measure. Although SELECT does not guarantee a globally optimal solution to complex investment programming problems, it produces very efficient solutions that satisfy all constraints, providing a first cut at a program and a starting point for further discussion. SELECT can be used to quickly analyze the implications of various investment policies on the composition and benefits of investment programs.

INTERPRETATION OF RESULTS

The results from any analytic capital budgeting procedure must be correctly interpreted. By their very nature, such techniques cannot incorporate all relevant considerations (especially the subjective ones) that must be made in developing an organization's investment programs. For instance, HIAP assumes that values of costs and benefits are in constant dollars. This does not mean that inflation is totally ignored, only that the relative values of the components remain constant over the planning horizon. The analyst should remember that HIAP is designed not to produce absolute values of the quality of each investment but to provide a consistent and logical method of comparing investments and selecting a set for implementation.

The results of HIAP can best be described as an efficient tentative investment program, a starting point for discussion of issues that cannot be incorporated into the initial (analytic) selection process. Although a state may choose a single evaluation measure as most relevant to its needs, development of alternative programs using other measures may often be instructive. In addition, alternative programs could be developed that reflect different parameter values, such as the discount rate and a highway user's value of time. By comparing these programs, the decision maker can identify those improvement packages that are likely to produce the most beneficial overall program.

CONCLUSIONS

HIAP represents a major step forward in highway investment analysis and programming models. It expands on the detailed highway user analyses of its predecessor (the highway user investment study) by adding a more flexible time framework of investment periods and allowing the analysis of alternative (including staged) improvements. In addition, it analyzes nonuser impacts, specifically air and noise pollution. HIAP is capable of analyzing complex improvements involving several interrelated highway sections as well as those proposed for a single section.

The analysis component of HIAP can be used both as a design tool to evaluate candidate improvement packages at a given site and as part of an investment programming process to prepare evaluation measures for improvements to several sites.

In developing investment programs, HIAP can be used to select the combination of packages in up to four investment periods that best achieve the analyst's objectives, while meeting a broad range of financial, legislative, and community constraints. The model is unique in its ability to properly consider the change in benefits due to delaying the implementation of a package.

HIAP will be tested in one or more states and revised as necessary before its general release. The model should prove valuable to state, regional, and local organizations in developing, analyzing, and programming highway investments. The HIAP program selection process should be easily adapted to multimodal analysis.

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