for assignment of newly graduated officers. Other states have expressed an interest in the operation.

Although the model was developed originally for the Illinois DLE and as such is police oriented, it has potentially wider applications. Any agency that serves a large geographical area with suboffices might benefit from using the methodology. For example, highway maintenance operates generally from districts or stations. Some of their work resembles calls for service. Its allocation can be handled stochastically. Likewise, there will be other highway activities that resemble patrol. Remaining personnel can be assigned by using that methodology.

More important, however, has been the transfer of the program to the microcomputer. Applying the model to the personal computer has increased its versatility. It also has shown how the microcomputer can be used to assist in planning assignment of personnel. The computer program and documentation are available to others who are interested.

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A Procedure to Assess the Macro Impacts of Highway System Improvement and Maintenance Activities

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ABSTRACT

In the highway programming and system evaluation process it is often necessary to assess the overall impacts of various highway improvement and maintenance activities in terms of a set of performance objectives. A procedure is presented for systematic assessment of overall impacts of various highway work activities. The performance objectives considered were system condition, level of service, safety, and energy consumption. The impacts of highway activities on these objectives were assessed on the basis of an empirical approach. The empirically generated results were compared with results derived from an expert opinion poll. A comparison, using the Wilcoxon test, indicated that a poll of expert opinion can generally provide a reasonable approach to the macroassessment of highway impacts.

The 1982 Surface Transportation Assistance Act has provided a considerable amount of funding for highway reconstruction, restoration, rehabilitation, and resurfacing (4R) programs. Nevertheless, this funding still does not meet the minimum requirements for the repair of the existing highway network in many states. A multitude of improvement projects must therefore compete for highway agency funds. An evaluation of overall impacts of various highway activities is increasingly necessary in order to provide the basic information for long-range highway investment decision making. A summary of a procedure developed for systematic assessment of overall impacts of various highway work activities (1) is presented.

There are two broad categories of highway work activities: periodic improvement and routine maintenance. Periodic improvement affects highway performance to a greater extent and involves considerable capital outlay, whereas routine maintenance consists of routine work and entails less expenditure. Periodic improvement, in this study, was divided into six activities: highway reconstruction, major widening, minor widening, restoration and rehabilitation, resurfacing, and safety and traffic engineering improvement. Routine maintenance was considered as one aggregated activity consisting of pavement and shoulder maintenance, right-of-way and drainage maintenance, and the maintenance of roadside appurtenances.

Highway work activities have several major objectives: preserving system condition, providing an adequate level of service, maintaining highway safety, and reducing energy consumption and environmental pollution. Each objective is a function of the highway system and can be evaluated by a set of performance measurements. In order to assess how well a highway work activity meets a system objective, measurements must be limited to the physical characteristics of highway sections. In this way any change in highway characteristics caused by a particular activity can be correlated with an associated change in system performance.

POLL OF EXPERT OPINION

In an earlier study (2,3), the impact of various highway work activities was developed through a modified Delphi technique based on a poll of expert opinion. About 20 highway department officials in Indiana were surveyed with mail-back questionnaires, which included directions for completing the form, a brief explanation of the nature of the project, and a description of the improvement and maintenance activities. The respondents were asked to evaluate the expected impact on a scale of 0 to 10, with 10 indicating highest impact and 0 representing no impact. Some of the respondents were also contacted over the telephone for clarification. Scores grossly deviating from the majority of the responses were eliminated, and the averages were then adopted for each measure of performance.

The effective time period for different highway work activities varies. In order to account for these differences, the average scores were converted to total scores by multiplying the average scores by their corresponding period of effectiveness. The individual activity impacts were then developed by dividing the total score for each activity by the average of the most time-effective activity. The final impact values derived from the opinion poll are shown in Table 1. Although separate questionnaires were used for different highway classes, the subjective responses did not indicate any significant variation.

TABLE 1 Activity-Performance Impact Matrix Derived from Opinion Poll

Work Activity	Objective of Work Activities System Condition	Level of Service	Safety	Energy and Environment
Reconstruction	7.883	7.275	7.395	6.400
Major widening	3.063	6.540	5.205	3.975
Minor widening	1.419	2.250	3.237	2.100
Restoration and rehabilitation	3.707	2.222	1.788	1.800
Resurfacing	2.938	2.115	1.285	1.800
Safety and traffic engineering improvement	0.279	0.505	0.418	0.485
Routine maintenance	0.452	0.223	0.233	0.269

Note: Unit of measurement is based on a scale of 0 to 10 with 0 representing no impact and 10 indicating highest impact.

THE EMPIRICAL APPROACH

Because the impacts measured by an opinion poll were likely to be biased and subjective, an alternative procedure using the available empirical data was adopted in this study. This procedure consisted of four major steps. First, a set of performance measurements representing the system objectives was developed; then each broad category of highway activity was divided into several working items based on its definition. Next, quantitative relationships between each measurement and the constituent items within a highway work activity were developed; by adding the weighted performance measurements for each objective, the activity impact was derived. The impact of an activity on a particular objective was estimated separately for various highway classes.

To assess the impact by the empirical approach, performance measurements before and after an activity were compared. Years of effectiveness for highway work activities were also incorporated into the impact values. The four objectives are discussed in the following sections.

System Condition

The primary concern here is to assess how much a particular activity would improve the system's physical condition and thus preserve the capital invested in the highway.

Condition Rating Procedure

Performance measurements representing system conditions include pavement, structural, and appurtenance conditions. The three measurements were scaled with an appropriate rating procedure, each weighted differently, totaling 10 points: 8.0 points for pavement conditions, 1.2 points for structural conditions, and 0.8 point for appurtenance conditions. These weights represent the relative importance of the conditions in the entire highway system. Structural conditions were given only 1.2 points because structures appear infrequently along a stretch of a highway.

Pavement conditions can be measured several ways. One of the most widely used methods is the pavement serviceability rating (PSR), a numerical rating from 0 (very poor) to 5 (best condition). Because pavement condition was assigned 8.0 points in the evaluation process, any PSR rating from 0 to 5 could be transformed to a scale of 0 to 8.0 points.

Structural conditions were assigned 1.2 points subdivided into three components: appraisal of the structural condition, deck width, and the evaluation of the approach and alignment. These three components were assigned 0.6, 0.3, and 0.3 point, respectively, based on the AASHTO bridge maintenance guidelines (4,5).

The appurtenance performance rating reflects the conditions of traffic safety and other highway appurtenances. Four major component conditions were taken into account: that of guardrails, signs, the right-of-way, and drainage provisions.

Procedure to Evaluate Condition

First, threshold values were set for the performance measurements, representing the minimal conditions for which the corresponding activities are warranted. For example, highways classified as rural Interstate and other principal arterials warrant restoration and rehabilitation when the PSR is less than 2.5 (2). Thus the average PSR value of sections before receiving restoration and rehabilitation was 2.5.

Next, system conditions were estimated after a work activity was completed. If a relationship between the work activity and any component of system conditions was identified, the impact of particular activities on each of the components was assessed.

The net impact of work activities on pavement conditions was determined by taking the net change in PSR value before and after the activity and adjusting it to the given weight of 8.0 points.

Similarly for structure and appurtenance conditions, impact values of each component were estimated before and after a work activity. For example, the structure and appurtenance conditions before reconstruction can be assumed to be poor but after a work activity would be rated close to the maximum value.

For each work activity the impact values of all the components were added together to form a measure of the total impact on system conditions.

Level of Service

Level of service (LOS) is an overall measure of all service characteristics that affect users directly. The provision of an adequate level of service is a major objective of highway improvement and maintenance activities.

LOS Rating Procedure

The 1965 Highway Capacity Manual (HCM) (6) considered travel speed and volume/capacity (v/c) ratio to be the two major components in a rating of the level of service. These parameters have been widely used as performance measurements of level of service. The 1965 HCM classifies service conditions into six levels--A, B, C, D, E, F--each representing a range of operating conditions bounded by values of travel speed and v/c ratio. Because travel speed and v/c ratio are the only measurements for level of service and they are equally important, each was assigned 50 percent of the weight. By adding the average weights of these two factors, a unique impact value was developed.

LOS Evaluation Procedure

The procedure for measuring the impact of highway work activities on the level of service is shown in Figure 1 (7). In order to determine the level of service, travel speed and v/c ratio must be estimated before a highway activity is performed. Again, the concept of a threshold value applied to system conditions was adopted to represent the typical situations where appropriate work activity is considered. In the category of rural Interstates, for example, the threshold value for the v/c ratio of those sections likely to receive major widening is 0.8. The other measurement, operating speed, can then be derived directly from the 1965 HCM by the v/c ratio.

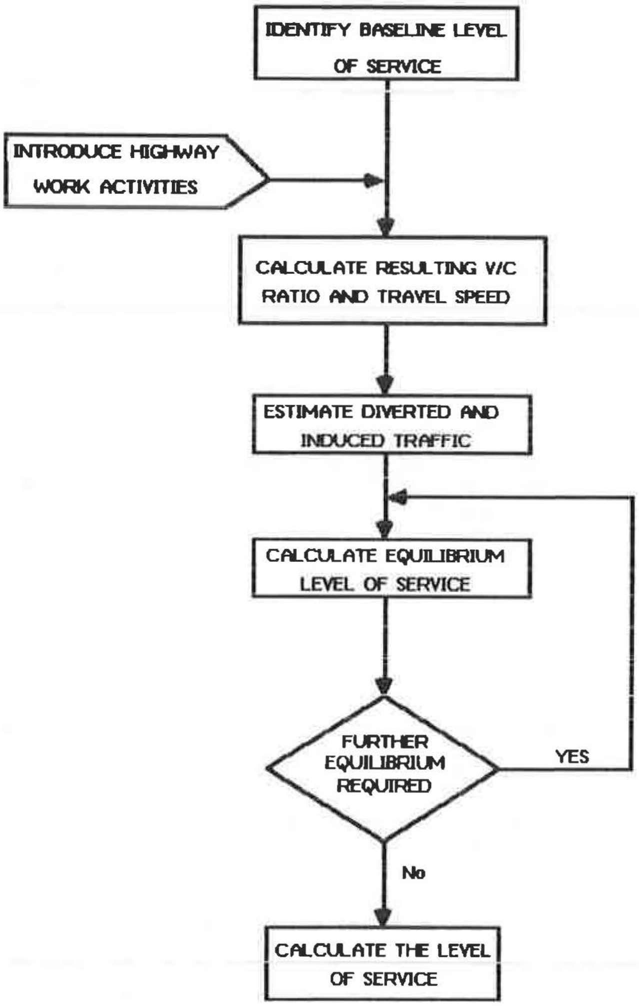

FIGURE 1 Flowchart of impact assessment on level of service (7).

The next step is the evaluation of capacity and operating speed change resulting from particular highway work activity. According to the 1965 HCM, the roadway factors that affect highway capacity and v/c ratio include lane width, lateral clearance, shoulder and surface conditions, alignment, and grades. These factors were incorporated into two adjustment attributes in the 1965 HCM: W, the adjustment for lane width and lateral clearance; and T_c, the truck factor at capacity. The ratio of capacities before and after an improvement can be found by combining the associated adjustment attributes. If the traffic volume after improvement is assumed to be unchanged, the new v/c ratio can be derived directly by multiplying the old v/c ratio by the ratio of capacities before and after an improvement. After the new v/c ratio is developed, the operating speed can be determined by applying appropriate volume-speed tables or figures for each class of highway shown in the 1965 HCM and Transportation Research Circular 212 (8).

In reality, the traffic volume changes after an improvement activity. A reduction in travel time on an improved highway section increases the volume because of induced and diverted traffic, which in turn affects the travel speed and travel time on that section. Therefore an iterative process, as shown in Figure 1, was performed to take into account supply and demand interaction until travel time and traffic volume reached equilibrium. The final values derived from the iterative process were used to evaluate the impact of level of service. The overall impact was evaluated on the basis of percentage change in both v/c ratio and travel speed for before and after situations. The percentage changes were then transformed to a base of 0 to 10 for comparison.

Energy Consumption

According to Apostolos et al. (9), the energy consumption of a proposed project can be divided into two categories, direct and indirect. Highway improvement and maintenance affect both categories of energy consumption. An estimate of these consumption levels due to various activities by each class of highway was made by using the basic approach given by Apostolos (9).

Direct Energy Consumption

Direct energy impact of a repair or maintenance activity was evaluated from the energy consumption of vehicles using the highway. The concept of supply and demand iteration used in evaluating the impact of level of service was applied here. The basic procedure for estimating direct energy impact is similar to that of the flowchart in Figure 1. After the baseline levels of service and volume of traffic were identified on a particular section, energy consumption before improvement or maintenance activity was calculated by using the appropriate vehicle fuel consumption rate. Then, through an iterative process, the equilibrium level of service and new traffic volume were determined. By applying the new fuel economy rate to the new traffic volume, the energy consumption after the implementation of an activity was derived.

The fuel consumption rate was evaluated according to travel speeds, travel times, congestion conditions, and traffic delays. The new travel speeds and traffic volumes developed earlier were applied directly here. Once the average fleet fuel economies and traffic volumes were determined for both the baseline and improved conditions, the direct energy consumption was measured simply by taking the difference between the new and old amounts of energy consumption.

Indirect Energy Consumption

The approach for analyzing indirect energy consumption was based on the quantity method (9), which measures the quantity of materials used in particular improvement or maintenance activities. When this is multiplied by a unit energy factor for each material, the indirect energy consumption of a project can be determined. The energy factors include the energy consumed, not only in the production of materials, but also in hauling, applying materials, and using the necessary heavy equipment.

An estimating procedure identified the typical materials used for each highway work activity and for each section of highway. Both rigid and flexible pavement types were considered. Rigid pavements include a reinforced portland cement concrete surface, subbase course, and shoulder layers. Flexible pavements have several components: an asphalt-concrete surface course, a base course, a subbase course, and a shoulder. The thickness of pavement, lane width, and shoulder width vary with each highway classification and with the traffic volume. In order to assess the average impact, a typical cross section with detailed design specifications, representing the average design volume, was defined for each class of highway. The materials used for handling drainage, signs, traffic control devices, and guardrails were also taken into account.

Total Energy Consumption

It should be noted that the direct energy consumption was computed for a given base year, whereas the indirect energy impact was estimated for the entire service life of a particular activity. Therefore, the total indirect energy consumption of a particular activity was divided by its service life to determine a yearly estimate of indirect energy consumption before it was added to the direct energy consumption to give an estimate of a total baseline energy consumption.

Safety

Improving highway safety is a major objective of highway work activities. In fact, many highway work activities are warranted solely because of severe safety problems, such as high-hazard cross sections with poor design. In this study, the safety impacts of highway improvement and maintenance activities were examined in terms of their accident reduction potential.

Highway Design Elements

The impact of different improvement and maintenance activities on highway safety was determined through the highway design elements. Numerous efforts have been made to determine the relationship between highway design elements and accident frequencies. More than 50 highway design elements affect safety (10). For the purpose of the present aggregated analysis only the 14 major highway design elements significantly affecting safety were chosen. They were selected because they can be adequately measured and their effect on accident occurrence is generally well defined. The elements included the number of lanes, the lane width, the surface type, the grade on tangents, the grade on curves, the sight distance, the degree of curve, the shoulder width, the shoulder surface condition, the delineators, the guide signs, the lighting, the marking, and the median width.

Accident Reduction Rates

In the next step, each improvement and maintenance activity was examined for relationships with any of the highway design elements. If one was identified, then the extent of improvement was assessed. For instance, reconstruction would normally affect the lane width, eliminate the grade on tangent or increase the sight distance or both, widen the shoulder, and improve shoulder condition, marking signs, and median width. The shoulder maintenance would only possibly improve shoulder surface conditions as well as marking.

The accident reduction rate for each highway work activity was then determined by combining the effects of the activity on all the design elements. However, an accident reduction rate is based on the traffic volume of a particular section of a highway. Therefore, it is unreasonable to consider the safety impact to be the same for both congested urban highways and low-volume rural collectors. It was necessary to adjust the determined accident reduction rates by appropriate traffic volumes to represent various highway classes. Furthermore, to be consistent with the other objectives, the actual reduction rates were scaled into a range from 0 to 10.

The impact values developed by the empirical approach described in the foregoing are given in Tables 2 through 5.

COMPARISON OF OPINION POLL WITH EMPIRICAL APPROACH

The two approaches used to develop the impact values have several differences. First, in the opinion survey, the responses indicated only a small variation in impact values for different classes of highway. In reality, the impact values vary by highway class and the empirical approach attempted to reflect this variation.

Second, the empirical approach included more detailed performance measurements than the opinion poll. For example, energy consumption considerations

TABLE 2 Activity-Performance Impact Matrix Derived by Empirical Approach: System Condition

	Rural			Urban		
Work Activity	Interstate	Other Principal Arterial	Minor Arterial and Collector	Interstate	Other Principal Arterial	Minor Arterial and Collector
Reconstruction	5.450	5.450	6.500	5.600	5.600	6.500
Major widening	3.000	3.000	3.712	3.315	3.315	3.712
Minor widening	0.975	0.975	1.375	1.260	1.260	1.375
Restoration and rehabilitation	2.145	2.145	2.490	2.225	2.225	2.490
Resurfacing	1.665	1.665	2.050	1.810	1.810	2.050
Safety and traffic engineering improvement	0.725	0.725	0.965	0.860	0.860	0.965
Routine maintenance	0.072	0.072	0.100	0.087	0.087	0.100

Note: Unit of measurement is based on a scale of 0 to 10 with 0 representing no impact and 10 indicating highest impact.

TABLE 3 Activity-Performance Impact Matrix Derived by Empirical Approach: Level of Service

	Rural			Urban		
Work Activity	Interstate	Other Principal Arterial	Minor Arterial and Collector	Interstate	Other Principal Arterial	Minor Arterial and Collector
Reconstruction	1.520	2.020	2.150	1.480	2.040	2.240
Major widening	2.115	2.835	2.722	2.085	2.655	2.917
Minor widening	0.290	0.270	0.300	0.300	0.315	0.365
Restoration and rehabilitation	0.325	0.460	0.470	0.310	0.440	0.425
Resurfacing	0.425	0.435	0.425	0.395	0.375	0.410
Safety and traffic engineering improvement	0.210	0.245	0.270	0.190	0.260	0.315
Routine maintenance	0.012	0.016	0.021	0.013	0.013	0.021

Note: Unit of measurement is based on a scale of 0 to 10 with 0 representing no impact and 10 indicating highest impact.

TABLE 4 Activity-Performance Impact Matrix Derived by Empirical Approach: Energy

	Rural			Urban		
Work Activity	Interstate	Other Principal Arterial	Minor Arterial and Collector	Interstate	Other Principal Arterial	Minor Arterial and Collector
Reconstruction	4.460	3.790	3.950	4.290	3.520	3.560
Major widening	2.595	2.002	1.920	2.137	1.432	1.290
Minor widening	1.215	0.980	0.775	1.120	0.000	0.920
Restoration and rehabilitation	1.975	1.420	1.435	1.780	1.790	1.495
Resurfacing	2.020	1.410	1.330	2.005	1.815	1.380
Safety and traffic engineering improvement	1.455	1.215	1.190	1.210	0.340	1.155
Routine maintenance	0.115	0.105	0.182	0.169	0.090	0.160

Note: Unit of measurement is based on a scale of 0 to 10 with 0 representing no impact and 10 indicating highest impact.

TABLE 5 Activity-Performance Impact Matrix Derived by Empirical Approach: Safety

	Rural			Urban		
Work Activity	Interstate	Other Principal Arterial	Minor Arterial and Collector	Interstate	Other Principal Arterial	Minor Arterial and Collector
Reconstruction	2.560	1.070	0.240	10.000	3.180	1.380
Major widening	1.672	0.472	0.090	6.510	1.890	0.615
Minor widening	0.250	0.200	0.045	0.975	0.625	0.300
Restoration and rehabilitation	0.325	0.130	0.030	1.265	0.440	0.170
Resurfacing	0.275	0.115	0.025	1.070	0.395	0.195
Safety and traffic engineering improvement	0.725	0.260	0.060	2.825	0.755	0.405
Routine maintenance	0.017	0.012	0.001	0.075	0.017	0.011

Note: Unit of measurement is based on a scale of 0 to 10 with 0 representing no impact and 10 indicating highest impact.

were divided into separate direct and indirect components. Also, the performance measurements for each objective were refined to be more applicable to the evaluation of the impact of highway activities. For instance, the pavement, structure, and appurtenance conditions were evaluated in a more disaggregated manner than in the opinion poll.

Statistical Testing

The two sets of impact matrices were developed through different procedures, and a nonparametric testing was considered to be suitable for their comparison. As these two sets of data were matched in pairs for different measurements (system objectives) and treatments (highway work activities), the Wilcoxon test, one of the most powerful nonparametric tests for comparing the identity of two matched data sets, was used. This test, also known as the rank-sum test, considers both the sign and the rank of two sets of data (11). The final results of all the comparisons are given in Table 6.

Discussion of Results

It should be noted that in the opinion poll approach the energy impacts were considered in combination with environmental impacts, but in the empirical approach the environmental effects were not included because of insufficient data. Nevertheless, the energy impacts can reflect environmental effects to a considerable extent. For example, work activities that result in conservation of energy through smoother traffic flow also reduce environmental pollution. Consequently, the energy impact values obtained from empirical data were compared with the impact values related to energy and environment from the opinion poll.

It may be noted from Tables 1 and 2 that the impact values on system condition derived from the two approaches varied considerably. In general, the highway experts and specialists overestimated the impact of reconstruction and routine maintenance and underestimated the impact of safety and traffic engineering improvements.

As for the impact on the level of service, the results for all highway classes except urban minor arterials and collectors showed significantly different orders for the various highway work activities. In the opinion poll, reconstruction had the highest impact values among all the activities studied. However, in the empirical results, major widening had the highest impact values. In the empirical approach, the impact on service depended mainly on the change in capacity when there was no significant improvement in operating speed. Because major widening directly increases the capacity of a highway most, it had the greatest impact on the level of service.

It can also be noted that the impact values for the level of service derived from the empirical approach were lower than the corresponding values from the opinion poll. This is because, in the empirical approach, the change in volume as a function of a change in the level of service was considered in detail. The traffic volume attracted to a highway after an improvement would increase the v/c ratio and would thus to some extent reduce the positive impact on the level of service. Moreover, in the empirical method the impact on service levels was evaluated in terms of the net change in v/c and in travel speed expressed as a fraction of baseline conditions. Even the highest impact value developed by the empirical approach was only about one-third of the corresponding value derived through the opinion poll.

It is interesting to note that although the two

TABLE 6 Results of Wilcoxon Test for Comparing Highway Work Activity Impact Values Derived from Opinion Poll and Empirical Data

	Rural			Urban			
Objective	Interstate	Other Principal Arterial	Minor Arterial	Interstate	Other Principal Arterial	Minor Arterial	Avg Value
System condition	Identical	Identical	Identical	Identical	Identical	Identical	Identical
Level of service	Not identical	Not identical	Not identical	Not identical	Not identical	Identical	Not identical
Safety	Identical	Not identical	Not identical	Identical	Identical	Not identical	Identical
Energy	Identical	Identical	Identical	Identical	Identical	Identical	Identical

Note: The level of significance was 0.05.

sets of energy impact values were developed through totally different approaches, the Wilcoxon test showed no significant difference in the impact values of highway work activities between these two approaches at a level of significance of 0.05. The only exception was that the empirical data indicated minor widening to have less impact on energy consumption than restoration and rehabilitation or resurfacing. The reason for this result is that the widening of lane widths or shoulder width does not have as much of an energy impact as does the improvement of road surfaces and the subsequent smoothing of traffic flow.

The results of the comparison of safety impacts were not uniform. For Interstate and urban other principal arterials, the safety impact values of the two approaches were not significantly different, whereas for the rural minor arterials and collectors and rural other principal arterials, a significant difference was observed between these two approaches at a level of significance of 0.05. However, the average safety impact values for all highway classes showed no difference between those of the opinion poll and the empirical data-based matrix. Similar to the LOS impact findings, the opinion poll suggested much higher safety impact values than the empirical approach, especially for low-volume highways such as the rural minor arterials and collectors. The empirical approach indicated small changes in safety for the rural other principal arterials and for rural minor arterials and collectors, and even for reconstruction and major widening. In addition, the empirical approach showed that minor widening had less impact on safety. The reason is that most existing highway mileage satisfies the maximum design standard for lane width and shoulder width, and further widening would not appreciably increase traffic safety. On the other hand, the opinion poll underestimated the effect of safety measures and other traffic engineering improvements. Because these work activities are safety oriented and include high-hazard location improvement and roadside obstacle elimination, their impact on safety should be high.

CONCLUSIONS

This paper has presented an empirical procedure for assessing the impact of various highway work activities on highway improvement objectives. The results indicate that the impact of highway work activities is different for different highway classes. In the cases of system conditions and safety, work activities have a greater impact on urban highways than on rural highways. As for the LOS and energy aspects, no significant differences were found between impacts on rural and on urban highways.

As can be expected, routine maintenance affects the achievement of system objectives the least. Of the work activities, reconstruction has the greatest impact on all objectives except level of service, for which major widening provides the greatest impact.

These results are best used as a guide for long-range highway programming. They will provide decision makers with a clear picture of the relative effectiveness of highway work activities. The procedures used in the study can also be useful in assessing the standards for 4R activities.

A statistical comparison of the results of the empirical procedure with those generated from an opinion poll indicates that for highway system conditions and energy consumption, the values are identical at a level of significance of 0.05, whereas significant difference exists between the two matrices for impacts on the level of service. Thus, when there are insufficient data and limited time, the use of the opinion poll is a good alternative for the estimation of the overall impact of highway improvement and maintenance activities.

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