TRANSPORTATION RESEARCH RECORD 1028

Planning, Programming, and Systems Evaluation in the United States and Developing Countries

TRB
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1985

Transportation Research Record 1028
Price $8.20
Editor: Naomi Kassabian
Compositor: Harlow A. Bickford
Layout: Betty L. Hawkins

mode
1 highway transportation

subject areas
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12 planning

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Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.

Planning, programming, and systems evaluation in the United States and developing countries.

(Transportation research record ; 1028)
1. Transportation–United States–Planning–Congresses. 2. Highway planning–United States–Congresses. 3. Transportation–Developing countries–Planning–Congresses. 4. Highway planning–Developing countries–Congresses. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 1028 380.5 s 85-29782
[HE203] [380.5'068]
ISBN 0-309-03919-3 ISSN 0361-1981

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Contents

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A Performance-Based Approach for Determining Cost Responsibilities of Load-Related and Non-Load-Related Factors in Highway Pavement Rehabilitation and Maintenance Cost Allocation

TIEN-FANG FWA and KUMARES C. SINHA

ABSTRACT

A methodology is presented that was developed for use in a 1983-1984 Indiana highway cost-allocation study to determine the responsibilities of load-related and non-load-related factors for pavement routine maintenance and rehabilitation costs. Proportions of the effects of the two types of factors are derived by comparing actual pavement performance curves with predicted pavement performance by using design equations. A technique is presented to estimate the amount of total pavement damage caused by load-related and non-load-related factors combined. The cost-responsibility proportions of the two types of factors are then computed. An example is given to illustrate the application of the procedure.

An old problem in highway cost-allocation studies, unresolved since the first such studies were undertaken several decades ago, involves the determination of respective proportions of traffic and environmental responsibilities in highway pavement rehabilitation and maintenance expenditures.

In cost-allocation studies, it is convenient to divide factors that affect pavement performance into those that are load related (or traffic related) and those that are not load related. Non-load-related factors include environmental variables such as temperature, moisture, soil and site conditions, material variables, soundness of engineering design, quality of construction work, and others not related to traffic loadings. Pavement deterioration may result from load-induced distress, non-load-associated distress, and interaction of the two.

It is recognized that design technology has not advanced to the stage where interaction of the distresses can be accurately predicted. Nor is there enough information to reliably separate load-related effects from non-load-related effects by physical measurement of pavement conditions. Established engineering principles therefore offer relatively little help to cost-allocation analysts in identifying the effects of such factors on pavement performance. As a result, the contribution of these two types of factors has been assigned judgmentally, if not arbitrarily, in almost all cost-allocation studies to date.

Listed in Table 1 are the proportions of allocations for pavement maintenance and rehabilitation based on load-related and non-load-related factors used by different cost-allocation studies. Also listed is the basis on which these assignments were made. The wide diversity of these allocation proportions, which vary practically from 0 to 100 percent for either of the two types of factors, indicates clearly that subjective judgment does not provide an acceptable solution to this problem.

In recent studies, there has been a tendency to employ the Delphi approach to obtain from a pool of selected experts their opinions regarding the shares of load-related and non-load-related factors responsible for pavement maintenance and rehabilitation costs. The Wisconsin (10) and Maine (8) studies are two examples of this approach. However, on a topic such as this where there is a wide disparity of views among highway pavement experts, it is doubtful that efforts to find averages from pooling would produce any meaningful results. This subjective approach provides at best only group-consensus values for cost-allocation purposes. It does not necessarily offer a more reliable answer than the judgmental decisions used in earlier studies.

In this paper a methodology is described in which estimates are obtained of total pavement damage or wear in terms of the present serviceability index (PSI) and equivalent single axle loads (ESALs) computed from a pavement performance curve. The total pavement damage is estimated by defining a zero-maintenance pavement performance curve. A technique is introduced to derive the zero-maintenance curve by considering the routine maintenance expenditures associated with the pavement sections under consideration. Last, a proportionality assumption is made to determine responsibility shares of the load-related and non-load-related factors for total pavement damage.

BASIS OF THE APPROACH

In practice, actual pavement performance rarely coincides with predicted performance based on pavement design equations. Although inaccurate design equations could lead to discrepancies between predicted and actual pavement performance, there are other factors that would contribute to these discrepancies. Four of these factors are (a) elements not considered in the design, such as inferior materials, substandard construction, and so forth; (b) incorrect assessment of the values of design parameters such as regional factors and material proper-

TABLE 1 Proportions of Allocations for Pavement Rehabilitation and Maintenance Based on Load-Related and Non-Load-Related Factors

Source	Proportions	Basis
Oregon study 1980 *(1)*	Overlay: 100 percent load related; maintenance: 10 percent environmental, 90 percent load related	Recommendation of departmental maintenance research engineers and officials
Wyoming study 1981 *(2)*	Maintenance: 80 percent non load related	Based on judgment
Maryland study 1983 *(3)*	Modified federal primary method: 25 percent environmental, 75 percent load related	Based on FHWA input
Washington study 1977 *(4)*	48 to 68 percent non-load-related, varies among highway classes	Used values intermediate to 1976 Oregon study and 1965 federal study
Georgia study 1979 *(5)* and Florida study 1979 *(6)*	Resurfacing: 25 percent environmental and aging factors; maintenance: 80 percent environmental and aging factors	Georgia study: Georgia Department of Transportation assumption; Florida study based on 1965 federal study
Kentucky study 1982 *(7)*	Rehabilitation: 100 percent load-related; maintenance: 80 percent to all vehicles by axle miles	Based on other cost-allocation studies
Maine study 1982 *(8)*	44 percent allocated by PSI; 56 percent allocated by ESAL	Delphi approach
Connecticut study 1982 *(9)*	75 to 80 percent common costs; 25 to 20 percent attributable costs	Based solely on engineering judgment
Wisconsin study 1982 *(10)*	Rehabilitation: (rural) 40 percent environmental (urban), 50 percent environmental; maintenance: 15 to 21 percent environmental, varies among highway classes	Derived from judgments of Wisconsin Department of Transportation experts and 1981 Texas study
Federal study 1982 *(11)*	Responsibility of pure environmental effects in the decision to rehabilitate: 7 percent (flexible pavement), 1 percent (rigid pavement); pavement maintenance not within scope of study	Based on distress models

Note: PSI = present serviceability index; ESAL = equivalent standard axle load.

ties; (c) faulty design; and (d) level of maintenance performed.

The Indiana Department of Highways (IDOH) pavement design method (12) basically follows the procedure described in the AASHTO Interim Guide (13). The Indiana design equations estimate the traffic-loading effects under a set of selected design conditions. The responsibility for pavement damage caused by these design load-related factors can be attributed to vehicle classes by considering the parameters in the design equations (basically the ESALs). Other pavement damage costs are due to the effects of non-load-related factors and the interaction of load- and non-load-related factors.

In Figure 1, curve 1 represents a field pavement performance curve and curve 2 the corresponding performance predicted with Indiana design equations. Area A may be considered as a measure of the pavement wear or damage due to the design load-related factors defined earlier. Area B represents further pavement wear due to non-load-related factors and interaction of these factors with load-related factors. However, area (A + B) does not truly represent the amount of damage or wear caused jointly by load-

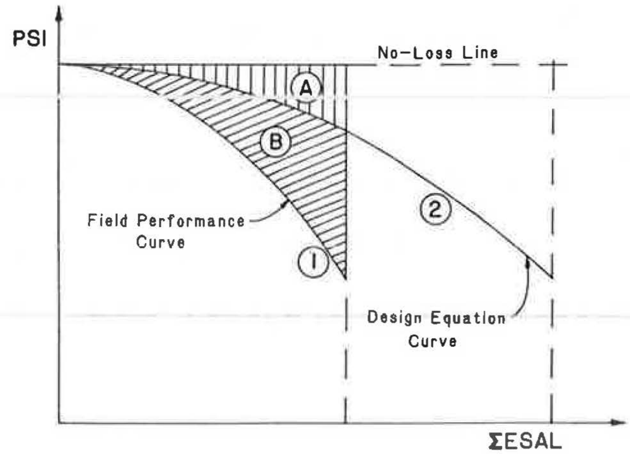

FIGURE 1 Field and predicted pavement performance.

related and non-load-related factors and their interaction. This is because a certain level of routine maintenance is always present in practice. Some of the damage caused by the various factors discussed is repaired or "recovered" by maintenance work. Therefore, the true total damage caused by these factors is greater than that represented by area (A + B) in Figure 1.

Theoretically, the true total damage may be represented by the shaded area $(A + B)_0$ between curves 3 and 4 in Figure 2. Curve 3 is a hypothetical no-loss line and curve 4 a hypothetical performance curve for the pavement concerned in a situation where no maintenance has been carried out. An actual pavement performance curve may lie anywhere between curves 3 and 4 depending on the level of maintenance performed. By considering actual performance of pavements and their associated maintenance expenditure, a technique was developed by which the zero-maintenance curve could be derived.

If the zero-maintenance curve is known, area $(A + B)_0$ can be calculated. Proportion of the damage responsibility that can be attributed entirely to design load-related factors may be computed as $A/(A + B)_0$ and the joint responsibility of non-load-related factors and interaction factors as $[(A + B)_0 - A]/(A + B)_0$. On the assumption that the share representing non-load-related plus interaction factors is the arithmetic sum of the two components and that the interaction portion is composed of two parts, namely, load-related and non-load-related parts, the total respective proportions of load-related and non-load-related factors may be computed by means of a proportionality assumption discussed later in this paper.

DERIVATION OF ZERO-MAINTENANCE CURVE AND AREA $(A + B)_0$

As mentioned earlier, the role of routine maintenance is to move the actual pavement performance curve away from the zero-maintenance curve, shown as curve 4 in Figure 2. The higher the level of routine maintenance performed, the closer the field performance curve would be to the no-loss line. Performance curves for three sections of a given stretch of pavement, each with a different level of routine maintenance, are shown schematically in Figure 3 in which maintenance level L_3 is higher than L_2 and L_2 is higher than L_1.

Each of the three performance curves in Figure 3 is also labeled with a value S_i, which is the

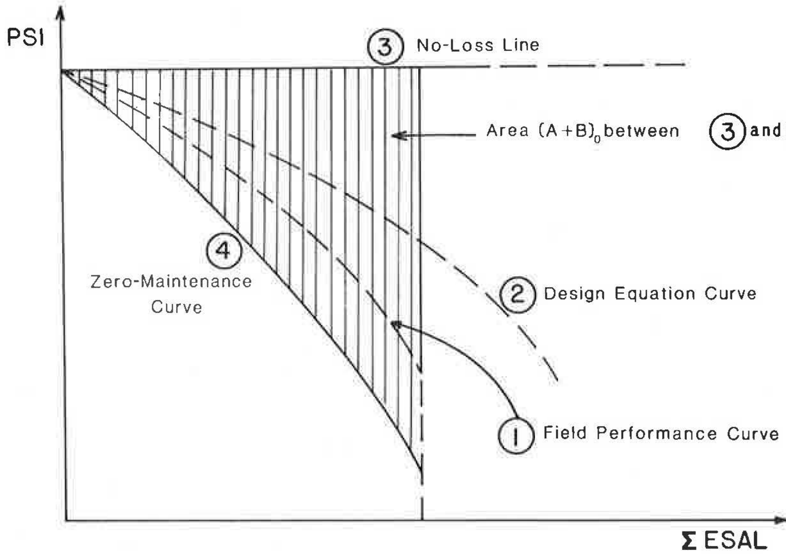

FIGURE 2 Total pavement damage as defined by zero-maintenance pavement performance curve.

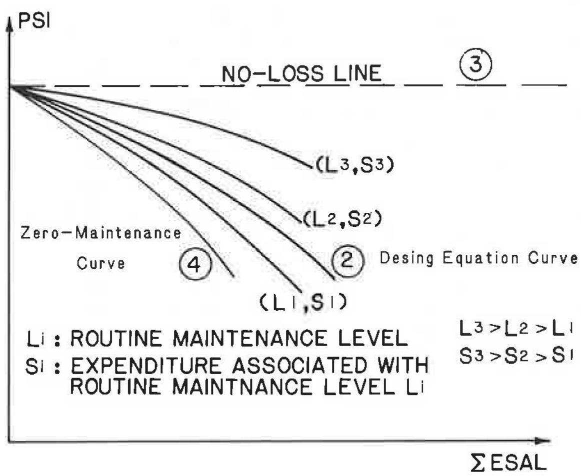

FIGURE 3 Pavement performance curves with their associated routine expenditures.

maintenance expenditure associated with maintenance level L_i. A convenient measure of maintenance expenditure would be the annual maintenance expenditure per lane mile of the pavement section under consideration. On the assumption that all three maintenance levels are performed with the same technology, it is reasonable to consider that the maintenance expenditure would be positively related to the level of maintenance performed. In Figure 3, one would expect S_3 to be greater than S_2 and S_2 greater than S_1.

The steps involved in deriving the zero-maintenance curve for a stretch of pavement are discussed in the following paragraphs.

The first step is to establish the no-loss line, defined by the design initial PSI value specified in the design requirements. In accordance with the AASHTO Interim Guide, values of 4.2 and 4.5 are commonly used for flexible and rigid pavement, respectively.

Second, the actual performance curve is determined. Many state highway agencies maintain certain forms of pavement performance records as part of their pavement management or pavement evaluation system. In Indiana, IDOH began to systematically record yearly roadmeter roughness measurements on all Interstate and state highways in the late 1970s. The use of the roadmeter permits the evaluation of extensive pavement mileage in a relatively short period of time. These pavement roughness measurements have been found to be an efficient means for screening highway pavements relative to their present serviceability (14). PSI models have been developed for Indiana to correlate measured roughness and pavement serviceability (14,15). These models and their R^2-values are as follows for different pavement types:

Asphalt:

$$PSI = 3.94 - 0.00072C \qquad R^2 = 0.79 \tag{1}$$

Overlay:

$$PSI = 4.37 - 0.00174C \qquad R^2 = 0.77 \tag{2}$$

Jointed reinforced concrete (JCR):

$$PSI = 4.69 - 0.00141C \qquad R^2 = 0.88 \tag{3}$$

Continuously reinforced concrete (CRC):

$$PSI = 4.40 - 0.00070C \qquad R^2 = 0.59 \tag{4}$$

where C is roadmeter counts per kilometer.

For a given pavement section, if a PSI value and the corresponding cumulative ESAL are known, a point on the field performance curve of the pavement can be obtained. This procedure may be repeated for other points for which data are available. The field performance curve of the pavement may then be plotted. The area between this field performance curve and the no-loss line established in step 1 is the area (A + B) in Figure 1 for this pavement section. This area (A + B) is computed by considering the cumulative ESAL over the age of the pavement section measured at the analysis year. Similarly, field performance curves for other pavement sections may be plotted and their corresponding areas (A + B) calculated.

In the third step, the routine maintenance expenditure is computed. IDOH keeps a detailed annual record of highway routine maintenance activities. An earlier study (16) developed a procedure to compute an aggregated annual routine maintenance cost for each highway section from these records. A highway section is defined as that portion of the highway that lies within the boundaries of a county. The annual routine maintenance cost per lane mile of a given highway section is obtained by dividing its annual routine maintenance costs by its total lane miles. The annual routine maintenance expenditures over the analysis period are considered to compute the average maintenance cost for the highway section under consideration. Because routine maintenance information is documented by highway section, this same section has been chosen as the basic unit of analysis in this study. When a pavement section contains more than one roughness measurement, a weighted average of area (A + B) is calculated by using the lane miles of each roughness measurement as the weighting factor.

The last step is to derive area $(A + B)_0$ of the zero-maintenance curve. Area (A + B) calculated in step 2 may be plotted against its respective average annual routine maintenance expenditure per lane mile computed in step 3. A least-squares line may be fitted to the data points. The intercept of this line with the (A + B) axis gives area $(A + B)_0$ of the zero-maintenance curve of the pavement under consideration.

Because design criteria are different for different climatic regions, highway functional classes, and types of pavement, it is necessary to group pavements by region, highway class, and pavement type. In addition, different pavement thicknesses also give rise to different design performance curves. This means that the procedure just outlined has to be carried out separately for each combination of region, highway class, pavement type, and pavement thickness. In the Indiana highway cost-allocation study, two regions, five highway classes, and four pavement types were considered. The two regions are northern and southern Indiana (17). The five highway classes include Interstates, state primary routes, state secondary routes, city streets, and county roads. The four pavement types are flexible, rigid with bituminous overlay, JRC, and CRC.

DETERMINATION OF PROPORTIONALITY RULES FOR LOAD-RELATED AND NON-LOAD-RELATED EFFECTS

A schematic diagram representing the proportion of responsibility for pavement damage of load-related and non-load-related effects is shown in Figure 4(a). The proportion of these four types of effects in pavement damage are represented by a, b, c, and d in Figure 4(b). These four values add up to 1.

$$a + b + c + d = 1 \quad (5)$$

Proportion a represents the load-related effects according to design equations. It is given by

$$a = A/(A + B)_0 \quad (6)$$

Determination of $(A + B)_0$ has been described in the preceding section. Area A is computed from design equations for the same cumulative ESAL used in deriving area (A + B) discussed earlier.

If proportion a is known, it is possible to calculate proportions b, c, and d by making a proportionality assumption as follows:

$$b/(b + c + d) = a/(a + b + c + d) \quad (7)$$

$$c/(a + b + c) = d/(a + b + c + d) \quad (8)$$

Equation 7 assumes that for a given case of purely load-related effects (proportion a), the share of the load-related effects in the remaining non-load-related and interaction effects is directly proportional to the share of the purely load-related effects in the total (a + b + c + d). Similarly, Equation 8 assumes that for a given case of purely non-load-related effects (proportion d), the share of non-load-related effects in the remaining load-related and interaction effects is directly proportional to the share of the purely non-load-related effects in the total (a + b + c + d).

In a physical sense, the proportionality assumption implies that for a given pavement and a known set of environmental conditions and time period, the higher the traffic loading, the higher share it is going to have in the interaction effects. It also implies that for the same pavement with a given amount of traffic loading, the more severe the weather and other environmental conditions, the big-

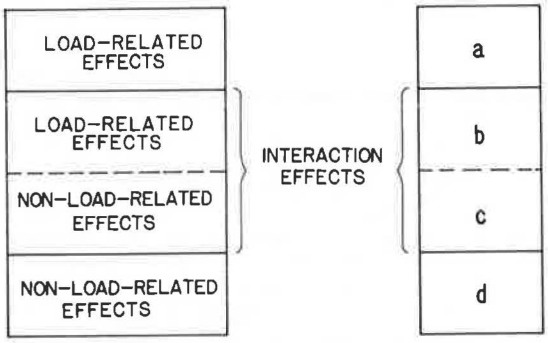

FIGURE 4 Responsibility for pavement damage by load-related and non-load-related effects.

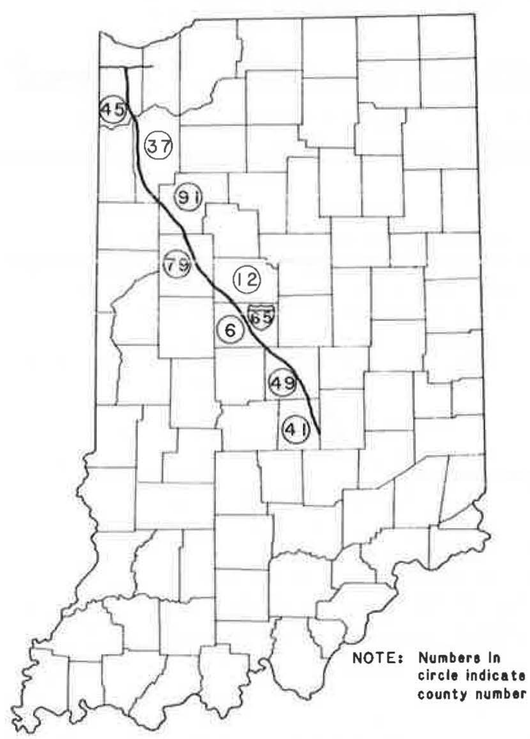

FIGURE 5 Location of the sections of I-65 analyzed.

ger share those conditions will represent in the interaction effects. This phenomenon has been confirmed by the recent research of Sharaf (17).

Equations 7 and 8 may be reduced to

$$b = a(b + c + d) \quad (9)$$

$$c = d(a + b + c) \quad (10)$$

Solving for d by using Equations 9 and 10 gives

$$d = 1 - [1 - (1 - a)]^{1/2} \quad (11)$$

Proportions b and c may then be determined by solving Equations 9 and 10. The total proportion of responsibility for load-related effects is given by (a + b) and that for non-load-related effects by (c + d).

APPLICATION OF THE METHODOLOGY

The methodology presented in this paper was applied to determine the proportions of load-related and non-load-related effects responsible for the damage to different pavement types in different highway classes in Indiana. The results of an analysis on an Interstate highway in northern Indiana are presented for illustration.

The northern half of I-65 is a CRC pavement constructed in the late 1960s. The concrete slab thickness is 10 in. Figure 5 shows the location of this highway and the numbers of the counties through which it passes. Of the eight counties concerned, maintenance and roughness records for the sections in counties 91 and 12 were incomplete. The computed areas (A + B) and average annual routine maintenance expenditures per lane mile over the analysis period for the remaining six pavement sections are presented in Table 2 and plotted in Figure 6. By using AASHTO design equations for rigid pavement, area A for the pavement was computed to be 0.2163×10^7 PSI-ESAL. This gives a value of 0.4189 for proportion a, as shown in Figure 6. Solving Equations 9, 10, and 11 gives 0.1862 for proportion d, 0.2434 for proportion b, and 0.1515 for proportion c.

The total proportion of load-related effects (a + b) is 0.6623, and the total proportion of non-load-related effects (c + d) is 0.3377. If the total pavement rehabilitation or maintenance expenditure for this stretch of pavement is known for a cost-allocation study period, the appropriate cost responsibilities for load-related and non-load-related effects can then be obtained.

Continuing research is being conducted to apply the methodology presented in this paper to investigate (a) the regional effects of non-load-related factors; (b) the effects of non-load-related factors on different pavement types, (c) the effects of load-related factors on pavements of different highway classes, (d) the variation, if any, of the proportions of load-related and non-load-related effects with traffic volume levels, (e) the effects of pavement age on the relative proportions of load-related and non-load-related factors, and (f) the effects of pavement thickness on the relative proportions of load-related and non-load-related factors.

TABLE 2 Area (A + B) and Maintenance Expenditure for I-65, North Indiana

Highway Section	County No.	Annual Routine Maintenance Expenditure per Lane-Mile ($)	Area (A + B) (PSI-ESAL)
1	6	138.75	0.3172×10^7
2	37	80.05	0.3833×10^7
3	41	173.20	0.2734×10^7
4	45	47.33	0.4570×10^7
5	49	166.80	0.2656×10^7
6	79	129.38	0.3470×10^7

CONCLUSIONS

A relatively simple procedure for the analysis and determination of the responsibility proportions of load-related and non-load-related factors has been presented in this paper. The procedure does not require an extensive amount of data collection effort. It relies entirely on measured pavement performance data, which are generally available in the records of a state highway agency. It provides a means to compute from field measurements the cost-responsibility proportions of load-related and non-load-related factors for use in highway cost-allocation analyses, thereby eliminating the undesired element of subjective judgment commonly involved in such studies.

ACKNOWLEDGMENT

This paper was prepared as part of an investigation conducted by the Joint Highway Research Project, En-

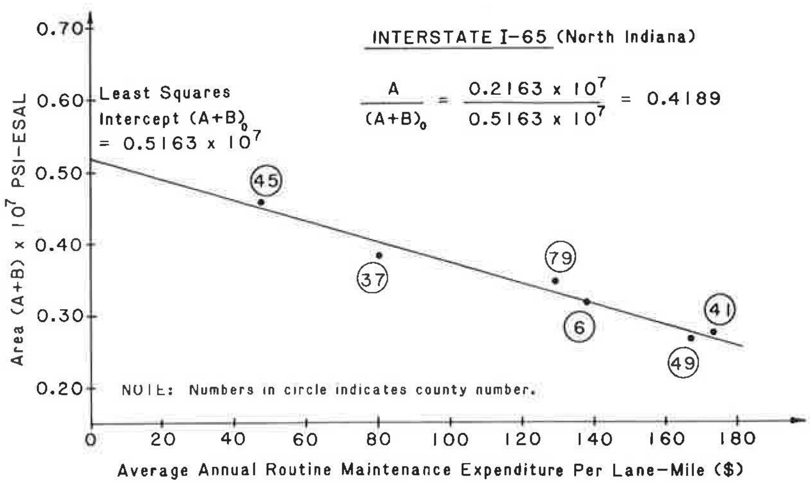

FIGURE 6 Sample plot of (A + B) versus routine maintenance expenditure.

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The contents of this paper reflect the views of the authors, who are responsible for the facts and accuracy of the data presented. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This paper does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Quantitative Criterion for the Evaluation of the Functional Classification of Public Roads

STEPHAN FREGGER, DALE K. STANLEY, JOHN H. SHRINER, and ROBERT G. SHIFFER

ABSTRACT

The Florida Department of Transportation is required by law to periodically evaluate the functional classification of public roads. The evaluations are to utilize formally adopted quantitative criteria. A quantification criterion, called the System Attribute Score (SAS), has been developed by the department. The procedure provides score values that indicate the probable functional classification of public roads. Its output is the product of two concurrent assessments. The first measures the satisfaction of threshold levels of certain road attributes such as traffic count, number of trucks, and length of road. The second evaluates the elemental role of a road in a transportation network that connects service end points (e.g., two urbanized areas, rural communities, and collector roads). Separate processes are included in the procedure to address the geosocial transportation differences among rural, urban, and urbanized areas. The SAS procedure provides the department with a quantitative criterion to utilize in the functional classification of public roads. However, functional classification will also consider other factors, including input from public hearings, as required by Florida statutes.

In 1977 the Florida legislature enacted a law that provided for the establishment of the functional classification of public roads in Florida. The law defined the various road classifications, established public road systems based on those classifications, and provided a mechanism for a continuing evaluation of each classified road and road system assignment.

The law also required that functional evaluations performed after 1982 utilize quantitative criteria. The Florida Department of Transportation (FDOT) has developed the required criterion, which is detailed in this paper.

CLASSIFICATION THEORY

The quantitative criterion developed by the department is to be known as the System Attribute Score (SAS). It is based on two system classification theories that augment and complement each other to produce a classification procedure of the highest accuracy. The first classification theory is based on the concept that a road, by itself, has certain inherent attributes that define its functional service. The attributes are physical and operational characteristics that naturally stratify into ranges correlating with functional classification. In its application, an analytical methodology known as Minimum Attribute Presence is used to evaluate (score) each road. The resulting score of qualifying attributes of the evaluated road is then entered into the SAS quantitative formula for functional classification.

The second theory used in SAS is based on the concept that the whole road network is made up of system elements (routes) that interconnect and link together the end points of transportation service. System elements are each defined in terms of their operation within a hierarchical order of service connections. The hierarchy forms a natural stratification that correlates well with functional classification. Consequently, an individual road can be inspected for its typical principal service and matched with its corresponding system element. Each evaluated road is assigned the coefficient value of its system element, which is then entered into the SAS quantitative formula for functional classification.

Quantitatively stated, SAS is expressed by the following mathematical notation:

$$SAS_f = s(\sum A) \quad (1)$$

where

SAS_f = SAS by functional model (rural arterial, rural collector, urban principal arterial, urban minor arterial, and urban collector),
s = system element coefficient, and
A = qualifying attribute.

In the process of criterion development, it became apparent that no single quantitative criterion could be efficiently designed to evaluate the diversity of public roads in Florida. A criterion calibrated to qualify high-traffic-volume urbanized area arterials would disqualify many rural arterials. Conversely, a criterion calibrated to qualify even moderate-traffic-volume rural arterials would erroneously qualify many urbanized area collectors as arterials. Accordingly, it was determined that Florida's road systems would best be evaluated by differentiating between three system groups: rural roads, roads in small urban areas (5,000 to 50,000 population), and roads in urbanized areas (population in excess of 50,000).

Three criteria sets were developed to model the three system groups. The rural criteria set and the urban area criteria set follow the SAS as introduced in the foregoing discussion. The urbanized area criteria set was developed from the same conceptual base; however, it was designed to draw its data from the Urban Transportation Planning System (UTPS) models, which were approved and adopted by FHWA, FDOT, and the officials of the respective urbanized areas.

The UTPS models are analytical tools with a massive data base used to predict travel demand in urbanized areas. The models are individually tailored for each urbanized area. In Florida, 15 models (one for each 1970 census urbanized area) are operational. Microcomputer models for the six additional Florida (1980 census) urbanized areas are now under development. Pending the adoption of these six new models, an interim new urbanized area functional model has been developed. Analysis of the UTPS models indicates that they have an inherent relationship to SAS theory. In an oversimplification of the model process, tables of traffic-related data (minimum attributes) are mathematically processed by computer in a program that measures productions and attractions of trips between transportation service end points (system elements). As a consequence, the mathematical notation for the urbanized area SAS is a variation of the general formula and is expressed as follows:

$$SAS_{uf} = \sum A_u \qquad (2)$$

where SAS_{uf} is the SAS by urbanized area functional model (urban principal arterial, urban minor arterial, and urban collector) and A_u is the UTPS attribute output.

TABLE 1 Minimum Attribute Levels for Rural Functional Models

Rural Arterial		Rural Collector	
Attribute	Minimum Qualifying Presence	Attribute	Minimum Qualifying Presence
Traffic factor	3,000	Traffic factor	400
Extent of road	20	Extent of road	2
Trucks	200	Trucks	50
Network factor	15,000	Network factor	1,000
Access factor	150	Access factor	25
Mobility	3	Interchange	4

Note: Rural attribute definitions are as follows: traffic factor = product of ADT and county normalizing coefficient T_{pd}, where $T_{pd} = 5/[\log_{10}$ (county population density x 100)]; extent of road = physical length of the road in miles (not necessarily the same as that of the segment being evaluated); trucks = actual count of trucks in a 24-hr period during the week, or value obtained by utilizing U.S. Department of Transportation estimated truck percentage x ADT; network factor = product of ADT and distance between arterial connections; access factor = ADT divided by number of access points per mile, where access points are road intersections, driveways, etc.; mobility = total number of counties in which the road is located; interchange = number of intersecting or interchanging arterials and collectors along the segment, including beginning and ending termini.

RURAL AND SMALL URBAN AREA CRITERIA SETS

Tables 1 and 2 detail the minimum attribute levels applied in the evaluation of rural and small urban area road segments. Rural segments are awarded a score of 1 for each attribute exhibited in excess of the minimum qualifying presence level. Attributes exhibited below the minimum level are scored zero. Urban segments are scored in the same manner with the exception of average daily traffic (ADT), which is awarded a score of 2 for qualifying presence. System elements and coefficients are detailed in Tables 3 and 4.

The product of the sum of the attribute scores and the system element coefficient is graded in Table 5, which indicates the probable functional classification of the rural or urban road segment being evaluated.

In evaluating rural and urban road segments with SAS, a designated evaluation sequence is mandatory:

1. Rural road segments must be evaluated first, because their extensions into urban areas will influence the urban classifications.
2. All segments must be evaluated in descending order of classification tests, starting with the highest level (rural arterial or urban principal arterial).
3. Evaluations terminate with the first "passing" SAS.
4. If a segment fails the highest-level test, it is then evaluated with the next-lower-level test or tests (rural collector or urban minor arterial and urban collector).
5. If a segment fails a rural collector or urban collector test, it is automatically determined to be a local road.
6. Under no circumstances can an SAS value from a test at a collector level be used to qualify a segment as an arterial.

URBANIZED AREA CRITERIA SET

As noted earlier in the section on classification theory, the urbanized area functional model combines the tandem attribute-element process of the rural and urban models into a single urbanized area system attribute set. By using the data and the UTPS model of the respective urbanized area, a set of five attributes is produced for each link (segment) in the modeled network. The attributes and their definitions are as follows:

1. Volume-trip length (VTL): product of a trip and its total trip length (from origin to destination) summed for total trips on the link over 24-hr period,

TABLE 2 Minimum Attribute Levels for Small Urban Area Functional Models

Urban Principal Arterial		Urban Minor Arterial		Urban Collector	
Attribute	Minimum Qualifying Presence	Attribute	Minimum Qualifying Presence	Attribute	Minimum Qualifying Presence
ADT	10,000	ADT	4,000	ADT	1,000
Speed	45	Speed	35	Speed	35
Traffic signals	4	Traffic signals	3	Traffic signals	1
Street length	5.0	Street length	3.5	Street length	1.5
Lanes	3	Lanes	3	Interchange	10

Note: Urban attribute definitions are as follows: ADT = average daily traffic in vehicles per day; speed = lowest posted speed (ignoring school zones) in miles per hour; traffic signals = number of signalized intersections, including termini; street length = physical length of the continuous segment in miles; lanes = total number of through roadway lanes excluding ramps, speed-change lanes, parking lanes, turn lanes, etc.; interchange = number of intersecting streets along the continuous urban street, including beginning and ending termini.

2. Free flow speed: average speed that vehicles travel on the link when there is no congestion,

3. Daily load: number of vehicles that use the link on an average weekday 24-hr period during peak season,

4. Capacity: theoretical maximum number of vehicles that may pass over the link during a 24-hr period, and

5. Number of lanes (code): 1 = five or more lanes; 2 = four lanes; 3 = two or three lanes; 4 = one lane.

Operation of this functional evaluation process is substantially computer-internal. The UTPS model program accesses the data base, computes attribute values, sums the values, and stratifies the streets in classification order. This process does not allow the "hands-on" scoring of individual roads that is permitted in the other models. The following short description of the UTPS model is provided for those who have not yet been exposed to it.

The model is driven by two data files: the Traffic Analysis Zone (TAZ) data base and the network data base. The TAZ data base contains demographic, socioeconomic, and land use data for each of the hundreds of zones included in the urbanized area. This yields a set of vehicle trips between all TAZs. The set is filed in matrix form and is known as a trip table.

The network data base is a file of street-related information including street width, length, number of lanes, operating speed, and so on. This yields a file of network characteristics for individual street segments. A mathematical manipulation of the network and trip table files then produces a computed traffic volume for every street on the urban network. At that point the computed traffic volumes are measured against actual traffic counts. Adjustments are made until the traffic is balanced. The UTPS model is then said to be calibrated.

The calibrated UTPS model data will then provide all of the attributes listed previously for every segment in the urbanized area street network. Other routines are programmed to score the attribute values for each segment, sum the segment scores, and assign the segment its probable functional classification. A computer graphics program is then applied to automatically plot the street network with color-coded ink to differentiate the assigned classifications.

TABLE 3 Rural System Elements, Definitions, Typical Functions, and Coefficients

System Element	Definition	Typical Function	Coefficient
Urbanized-to-urbanized with arterial termini	Most direct route(s) beginning at one urbanized area boundary and ending at another urbanized area boundary; route may involve a number of different roads and may pass through a number of urban areas and communities; if the distance between urbanized areas is 75 mi or less, one or two additional routes of this system element category may be designated	Principal arterial	15
Bypass with principal arterial termini	Road that serves as a bypass or circumferential route around an urbanized area, urban area, or community; must have principal arterial termini	Principal arterial	15
Alternative urbanized-to-urbanized with arterial termini	A second-most-direct route beginning at one urbanized area boundary and ending at another urbanized area boundary over 75 mi away; route may involve a number of different roads and may pass through a number of small urban areas and communities	Minor arterial	10
Bypass with arterial termini	Bypass or circumferential route around an urbanized community	Minor arterial	10
Urbanized-to-urban with arterial termini	Most direct route(s) beginning at an urbanized area boundary and ending at a small urban area boundary; route may involve no more than two different roads and may pass through a number of communities with <5,000 population; if urbanized area is oblong in shape, two or three such routes serving its greatest dimension may be designated	Minor arterial	10
Urban-to-urban with arterial termini	Most direct route beginning at one urban area boundary and ending at another urban area boundary; route may involve no more than two different roads and may pass through a number of communities with <5,000 population	Minor arterial	10
Urbanized/urban-to-multiple communities with arterial termini	Most direct route connecting one urbanized or urban area with two or more communities; communities must have a combined population of at least 5,000; route may involve no more than two different roads and each road must connect at least two communities	Minor arterial	10
Connection from rural Interstate/rural principal arterial to large municipality within urbanized area with arterial termini	Road that extends from an interchange/intersection with an Interstate/principal arterial and runs parallel to and outside the boundary of an oblong urbanized area to a municipality with a population of 25,000 or greater within that urbanized area; rural portion of the road may not exceed 5 mi in length; urban extension of the road must cross the municipality's boundary and have an arterial terminus within the urbanized area	Minor arterial	10
County seat to arterial/Interstate/county seat/urban area, county population <25,000	Road that extends from a county seat and fulfills at least one of the following conditions: (a) is over 40 mi long and connects to an arterial, (b) connects with an Interstate highway, or (c) connects to adjacent county seat or urban area in the same or adjacent county; applies only to county seats in counties where population is <25,000	Minor arterial	10
Community-to-community or to urbanized/urban area	Most direct route connecting one community with another community or with an urbanized or urban area; route may involve no more than two different roads	Major collector	5
Arterial-to-arterial, serves only one urbanized or urban area or community	Route beginning at one arterial intersection and ending at another arterial; serves only one urbanized or urban area or community at one route end; route is confined to one road	Major collector	5
Arterial-to-arterial, no communities or urban areas connected	Route beginning at one arterial intersection and ending at another arterial but not serving any urbanized or urban area or community; route is confined to one road	Major collector	5
Rural-to-urbanized or urban area or community, no arterial termini	Route beginning in rural area at one end and serving one urbanized area or community at another end; route is confined to one road and does not connect two arterial highways	Minor collector	2
Collector-to-collector or arterial, no urban areas or communities served	Route beginning at one collector intersection and ending at another collector or arterial intersection; route is confined to one road and does not serve urbanized or urban area or community	Minor collector	2
Same arterial at both ends, no bypass, no arterials or collectors served	Road that begins and ends by intersecting with the same arterial; road must not serve as a bypass around urbanized or urban area or community or intersect with other collectors or arterials	Minor collector	2
No special traffic generators	Road that does not provide service between arterials and collectors or collectors and collectors; road must not provide service to any urbanized or urban area or community	Local	1
Within community	Road that remains entirely within the boundary of community with 1,000-4,999 population	Local	1

TABLE 4 Small Urban Area System Elements and Coefficients

System Element	Coefficient
Arterial to arterial	15
Arterial to collector	10
Arterial to local	5
Collector to collector	5
Collector to local	2
Local to local	1
Arterial to dead end	1
Collector to dead end	1
Local to dead end	1

Note: These system elements and coefficients are also to be used on an interim basis for new urbanized areas.

TABLE 5 Classification Evaluation of Rural and Small Urban Area Roads

SAS Value	Probable Functional Classification
Rural arterial test	
75 or greater	Rural principal arterial
30-60	Rural minor arterial
Below 30	Fails rural arterial test (evaluate with rural collector test)
Rural collector test	
15 or greater	Rural major collector
4-12	Rural minor collector
Below 4	Fails rural collector test (automatically determined to be rural local road)
Urban principal arterial test	
60 or greater	Urban principal arterial
Below 60	Fails urban principal arterial test (evaluate with urban minor arterial test)
Urban minor arterial test	
30 or greater	Urban minor arterial
Below 30	Fails urban minor arterial test (evaluate with urban collector test)
Urban collector test	
15 or greater	Urban collector
Below 15	Fails urban collector test (automatically determined to be urban local road)

Note: This table is also to be used on an interim basis for new urbanized areas.

Inspection of the plotted network permits the identification of classification anomalies, such as the intrusion of a short segment of one classification in the midst of an otherwise continuous route of another classification. An analysis of the anomalies is made and, if warranted, their classifications may be changed. The resulting smoothed network yields the recommended functional classification of the urbanized area streets.

The attribute scoring routine requires an additional note. The range in Florida of urbanized area public road mileage (500 mi in Gainesville to 5,000 mi in Miami) precludes the use of a single set of functional classification cutoff scores for minimum attribute qualification. Consequently, a relative scoring routine was developed by using a family of regression analysis formulas that quantitatively determines functional classification gross lane mileages for each urbanized area. The analysis is based on two variables (population and square miles inside the urbanized boundary) and produces quantitative determinations of exceptional strength for urban principal arterials, combined principal and minor arterials, and combined arterials and collectors (R = .93, .96, and .99, respectively). The determined lane miles, by functional classification, are then used to set the attribute score cutoffs.

An assignment of probable functional classification for each urbanized area road segment is made by the following procedure. A quantitative model, which regresses urbanized population and urbanized area square miles as independent variables, is used to determine lane miles per functional classification. Segments are listed in descending VTL attribute value order with cumulative lane miles indicated. All segment miles falling within the determined principal arterial lane miles are awarded a score of 1. Subsequent segment miles falling within the determined minor arterial lane miles are awarded a score of 2. The segment miles for collectors are awarded a score of 3, and the remaining local miles are awarded a score of 4.

The scoring procedure is continued for each of the other four attributes. The five attribute scores for each segment are then summed and listed in ascending score order (theoretical range, 5 to 20) with cumulative lane miles indicated. By using the quantitatively determined lane miles per functional classification again, the probable functional classification for each segment is prescribed. With the aid of graphical rectification, the recommended classifications are then assigned.

SPECIAL INTERIM CRITERIA SET FOR NEW URBANIZED AREAS

In the 1980 census six additional Florida population centers qualified as urbanized areas. These new areas (Ft. Pierce, Ft. Walton Beach, Naples, Ocala, Panama City, and West Pasco) will ultimately utilize microcomputer analytical models similar to the UTPS functional models of the other 15 Florida urbanized areas. Development of these models for each of the new areas is under way. Pending completion and adoption of the models, a procedure similar to that for the small urban areas is to be used. Special interim minimum attribute levels are detailed in Table 6. Evaluated segments are awarded a score of 1 for each attribute exhibited in excess of the minimum qualifying presence level. Attributes exhibited below the minimum level are scored zero. System elements and coefficients utilized for new urbanized areas are the same as those for small urban areas and are detailed in Table 4. Quantitative functional evaluation is determined from Table 5.

TABLE 6 Special Interim Minimum Attribute Levels for New Urbanized Area Functional Models

Urban Principal Arterial		Urban Minor Arterial		Urban Collector	
Attribute	Minimum Qualifying Presence	Attribute	Minimum Qualifying Presence	Attribute	Minimum Qualifying Presence
ADT	20,000	ADT	14,000	ADT	4,000
Speed	45	Speed	45	Speed	35
Traffic signals	4	Traffic signals	3	Traffic signals	2
Street length	5.0	Street length	3.5	Street length	1.5
Lanes	3	Lanes	3	Interchange	10

Note: For attribute definitions, see Table 2.

CLASSIFICATION DETERMINATIONS

The quantitative values produced by SAS evaluate the functional classification of public roads with apparent high accuracy. When calibrated against the current official qualitatively determined classification, the SAS rural model replicates rural functional classifications at a better than 90 percent match. The apparent accuracies of the SAS urban and urbanized models are also very fine, although slightly lower. However, the issue of accuracy is not easily addressed.

If a quantitative evaluation model fails to perfectly simulate a qualitative evaluation, any apparent inaccuracies may be due to an error in either of the evaluations. That is, the original qualitative classification may have been incorrect or the quantitative model may have been incorrectly designed and be insensitive to the true classification. The likelihood of absolute perfection in either type of evaluation is improbable. Thus Florida law mitigates against errors of evaluation by requiring a forum for resolution. The paragraph of Florida law that requires that classification evaluations by the department "shall utilize quantitative criteria" also requires that "the Department shall hold a full public hearing . . . as an integral part of its evaluation procedures in order to receive public input prior to making any determination of classification."

Taking into account both statutory evaluation requirements, the department intends to utilize the SAS quantitative criteria as its principal functional classification tool. It will, however, preserve the responsibility to consider other significant data as is necessary to assure that correct classification determinations are made.

Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

The Development of Transportation Cost Functions for Three Intercity Corridors of Costa Rica

EDWARD C. SULLIVAN

ABSTRACT

The findings of a cooperative University of California-University of Costa Rica study of the cost characteristics of transportation technology alternatives in three principal corridors of Costa Rica are summarized. The cost functions developed quantify the total fixed and variable costs of moving freight in each corridor as well as the corresponding energy consumption and the cost breakdown between domestic and foreign expenditures. Conclusions are drawn regarding the implications of these findings for the future development of intercity transportation in Costa Rica.

Selected results are presented of a study on alternative transportation technologies applied to interregional transportation needs in Costa Rica (1). The economic and physical consequences of several alternative rail and highway systems, including several systems currently in place, were estimated in order to provide a quantitative basis for future transportation investment decisions. The analysis was based on the particular transportation requirements and resource constraints of concern to Costa Rica.

The results of the study are cost and resource use relationships that can be used to compare different transportation improvements in light of the quantities of goods to be transported now or in the future. It is expected that the quantitative relationships from this study will be used with alternative planning scenarios concerning the future economic structure of Costa Rica in order to help define a comprehensive long-term program for orderly national development.

In order to concentrate on a limited number of issues of practical significance to Costa Rica, attention focused on the costs and physical consequences of alternative transportation technologies in three important transportation corridors of Costa Rica (Figure 1):

1. San José-Puerto Limón (from the national capital to the major Atlantic coast port); this mountainous corridor is now served by both rail and highway;
2. San José-Puerto Caldera (from the capital to the major Pacific coast port); this mountainous corridor is also now served by both rail and highway; and
3. Puerto Caldera-Liberia (parallel to the Pa-

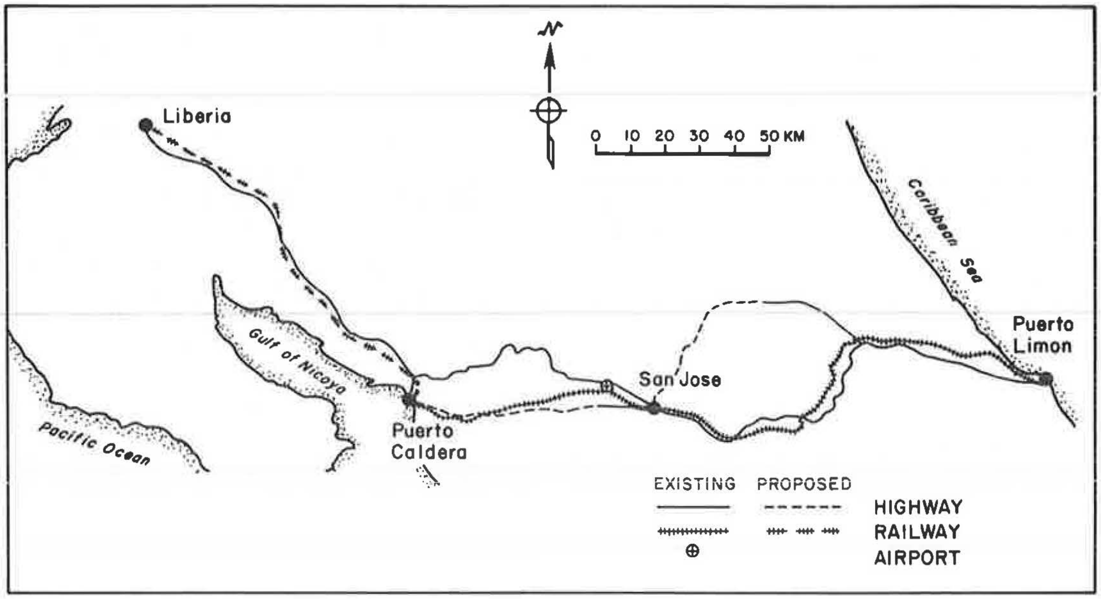

FIGURE 1 Overview of transportation alternatives.

cific coastline, north toward Nicaragua); this corridor is now served only by highway and is the location of anticipated development in agriculture and other sectors.

In each case, several transportation technologies were considered, including the existing systems and alternatives involving significant improvement to the existing facilities. Because the study emphasized transportation service to economic development, the analysis dealt only with the transport of freight. A wide range of possible traffic volumes was considered, ranging from current levels to traffic volumes approximately 10 times those now accommodated.

The study used a microcomputer-based transportation supply model called analysis of corridors (ANCOR) recently developed for estimating economic cost functions in national transportation planning. This model uses vehicle simulation and engineering cost methods to estimate quantities of resources consumed in the process of producing transportation. Resource consumption, of interest in itself, is converted to financial costs on the basis of productivity rates and factor prices, which incorporate components of domestic expenditures and foreign exchange.

TECHNICAL APPROACH

In recognition of the need to limit consideration to a small number of practical alternatives that have a reasonable chance of implementation in Costa Rica, it was decided to perform the applied-technology analysis for the following specific alternatives:

1. San José–Puerto Limón
   a. Existing rail system (nonelectric, poor alignment),
   b. Existing electrified rail line,
   c. Existing rail line with significant alignment improvements,
   d. Electrified rail line with significant alignment improvements,
   e. Existing highway,
   f. Existing highway with significant alignment improvements,
   g. New highway currently under construction.
2. San José–Puerto Caldera
   a. Existing rail system (electrified, fair alignment),
   b. Existing rail system with significantly improved alignment,
   c. Existing railway using diesel-electric propulsion (abandon electrification),
   d. Improved railway alignment using diesel-electric propulsion,
   e. Existing highway,
   f. Existing highway with improvements,
   g. New highway on separate alignment.
3. Puerto Caldera–Liberia
   a. Existing highway,
   b. Existing highway with improvements,
   c. New electrified rail system,
   d. New rail system with diesel-electric propulsion.

The detailed data characterizing the various alternatives are described in the final report of the study (1).

The study developed for each of the foregoing alternative technologies a family of cost curves indicating how costs and resource consumption vary with increasing amounts of freight to be transported. Figure 2 shows the general form of such a cost curve. The horizontal axis represents a multiple of the total volume of rail freight traffic transported in the particular corridor in 1981. The vertical axis illustrated here represents total annual cost. In the actual results, a variety of cost types (vertical axes) appear for each corridor and technological alternative. These correspond to the different cost components of interest, such as total fixed and variable costs, total domestic and foreign exchange costs, and vehicle energy consumption. Note that when fixed costs are included in a cost curve, the initial capital outlay is converted to an annualized value by means of the capital recovery factor.

Figure 3 shows a typical corridor description required to perform a cost analysis with the ANCOR model. Base payload quantities for each of the three corridors are presented in Table 1 and average trip

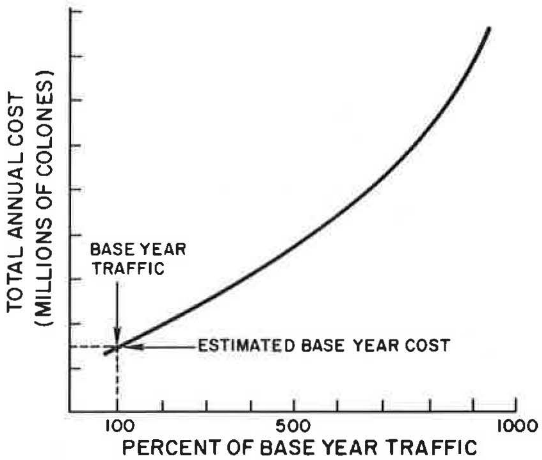

FIGURE 2 General form of total-cost curve.

lengths in Table 2. The quantities listed for the San José-Limón and San José-Puerto Caldera corridors are the 1981 reported rail volumes (2). The base volume for the Puerto Caldera-Liberia corridor was taken to be one-half of the 1981 volume between San José and Puerto Caldera.

Finally, Figure 4 shows the table of factor prices and construction productivities used to estimate all of the cost curves developed in this study. Note that factor prices and productivities are related to six different labor types and to eight major physical resources (energy sources and construction materials). These data represent 1982 prices and conditions in Costa Rica and were taken primarily from a University of Costa Rica study (3) supplemented through personal contacts.

The cost-estimation procedure and formulations of the various submodels involved in the estimation of cost for both vehicles and way are documented elsewhere (4,5).

TECHNICAL OBJECTIVES

The overall objective of the study was to develop a family of cost curves for different transportation technologies, including existing systems. All alternatives are serious candidates for implementation in the three selected corridors of Costa Rica. Among the cost curves developed for each technology are the following:

- Total annual cost (annualized fixed cost for vehicles and way plus total annual variable cost) as a function of annual payload,
- Annual vehicle operating cost as a function of annual payload,
- Vehicle energy consumption as a function of annual payload, and
- Total annual cost separated into domestic and foreign exchange components for selected alternatives.

```
#################################
Corridor:
SAN JOSE-BRASIL (NEW 4 LANE HWY)
#################################

=================================
      CORRIDOR DESCRIPTION
=================================

Number of Segments: 1
Number of Entry/Exit Points: 4

********** SEGMENT  1 **********
Length:     17 km

Topography:   ROLLING

Vegetation:   FOREST

Rainfall:     MEDIUM

Soil Type:     STABLE SOIL

Seismically Active Area

Primary Existing Land Use:
 URBAN FRINGE-LIGHT DEVELOPMENT

Span Length to Bridge Obstructions: 250 m

Beginning Elevation: 1142 m
End Elevation: 840 m

Design Speed: 100 km/hr

Representative Daily Volume of Other
  Vehicles: 6000 veh/day

Average Expected Delay from Other Than
  Congestion: .05 hrs/veh

*********************************

NO TRANSPORTATION SYSTEM IN PLACE
```

FIGURE 3 Corridor description.

TABLE 1 Base-Year Payload Volumes

	San José-Puerto Limón[a]		San José-Puerto Caldera[a]		Puerto Caldera-Liberia[b]	
Payload Type and Description	Forward	Reverse	Forward	Reverse	Forward	Reverse
5: Packaged food products (nonrefrigerated)	–	–	–	3,893	–	1,947
6: Bulk agricultural products (dry)	106,295	52,173	56,318	142,570	28,159	71,285
7: Bulk agricultural products (liquid)	–	16,922	–	539	–	269
8: Bulk industry products (dry)	149,391	12,352	28,928	97,229	14,464	48,615
9: Bulk industry products (liquid)	–	3,162	–	–	–	–
10: Wood and wood products	–	27,170	–	8,119	–	4,059
11: Heavy machinery	–	69,349	–	57,193	–	28,597
12: Packaged industrial and commercial products	1,058	26,833	287	3,123	144	1,561
13: Large fabricated structures or furniture	–	–	–	38	–	19
Total	256,744	207,961	85,533	312,704	42,767	156,352

Note: Values given in tons per year.
[a]Rail traffic reported in 1981, including bananas.
[b]Puerto Caldera-Liberia traffic arbitrarily set to 50 percent of that for San José-Puerto Caldera.

TABLE 2 Average Trip Length

Payload Type	San José-Puerto-Limon[a] Forward	San José-Puerto-Limon[a] Reverse	San José-Puerto Caldera[a] Forward	San José-Puerto Caldera[a] Reverse	Puerto Caldera-Liberia[b] Forward	Puerto Caldera-Liberia[b] Reverse
5-7, 9-13	66	63	70	73	70	73
8	66	76	70	99	70	99

Note: Values given in percentage of corridor length.
[a]Rail traffic reported in 1981, including bananas.
[b]Puerto Caldera-Liberia traffic arbitrarily set to 50 percent of that for San José-Puerto Caldera.

These results are available for use in future studies where different economic growth and transportation demand scenarios would be evaluated with respect to their total life-cycle transportation costs, energy use, and balance-of-payments implications.

RESULTS

Only the highlights of the results of this study for one corridor, that between San José and Puerto Caldera, are given here. A complete tabulation of results appears in the final report (1).

The total estimated economic costs for the existing electrified railway between San José and Puerto Caldera are shown in Figure 5. Three annualized cost curves are shown, each assuming that the entire payload being considered would be transported exclusively on trains of the stated size. In each case, the length of the train, in number of cars (wagons), is controlled by the available power of the single locomotive, based on the ruling grade of the existing railway.

Figure 6 contains a second family of cost curves for the electrified railway between San José and Puerto Caldera. In this case, the alignment of the railway is assumed to have been improved signifi-

FACTOR PRICES

Labor (colones/hr) — For Labor Type*	1	2	3	4	5	6
	12.96	17.80	225	62.50	900	30

Materials (colones/ton) — For Material Type**	1	2	3	4	5
Foreign Exchange Component:	466	13964	10660	1181	100
Domestic Expense Component:	233	3423.6	5330	319	32

Direct Propulsion (colones/)	gasoline (/liter)	diesel fuel (/liter)	electricity (/kw-hr)
Foreign Exchange Component:	21	16	1.36
Domestic Expense Component:	1.10	0.85	0.58

Land (colones/hectare) — For Land Use Category***	1	2	3	4
	30,000	40,000	2,500,000	10,000,000

Economic Discount Rate (%): 15

CONSTRUCTION PRODUCTIVITIES

Activities	Units	Labor by Type* (hours/unit) 1	2	3	4	5	6	Equipment & Supplies (colones/unit) Foreign Ex.	Domestic
Site Preparation	m^2	.0005	.0001		.00001		.000007	.223	.009
Earthwork (cut)	m^3	.050	.060		.006		.003	124.5	5.19
Earthwork (fill)	m^3	.111	0.133		.0133		.0067	252	10.51
Minor structures	lane-km	437	328		32.8		16.4	140	6
Bridge & Tunnels****	way-km	7200	3600		360		180	405,000	15,580
Surface Material Placement: Concrete	ton	0.139	0.062		.0062		.0031	100	4
Surface Material Placement: Steel	ton	0.230	0.460		.046		.0230	4,000	170
Surface Material Placement: Wood	ton	0.115	0.230		.230		.0115	2,100	85
Surface Material Placement: Asphalt	ton	0.100	0.075		.0075		.0038	125	5
Surface Material Placement: Gravel	ton	0.028	0.011		.0011		.00063	50	2
Final Site Details	m^3	.0834	0.035		.0035		.0017	25	1

*Labor Types: 1 = General (domestic) Labor; 2 = Skilled Crafts (domestic);
3 = Skilled Crafts (foreign); 4 = Professional (domestic);
5 = Professional (foreign); 6 = Administrative (domestic)

**Material Types: 1 = Concrete; 2 = Steel; 3 = Wood;
4 = Asphalt; 5 = Gravel

***Land Use Categories: 1 = Underdeveloped or Public Reserve
2 = Agricultural
3 = Urban Fringe - Lightly Developed
4 = Urban Fringe - Heavily Developed

****Major Structures' Productivities Based on Two-Lane Highway

FIGURE 4 Price and productivities.

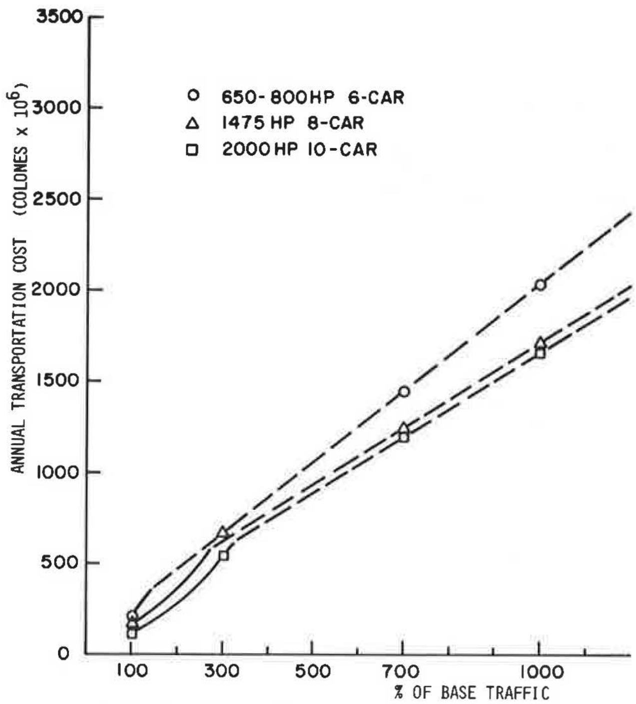

FIGURE 5 San José-Puerto Caldera rail electric technology on unimproved way.

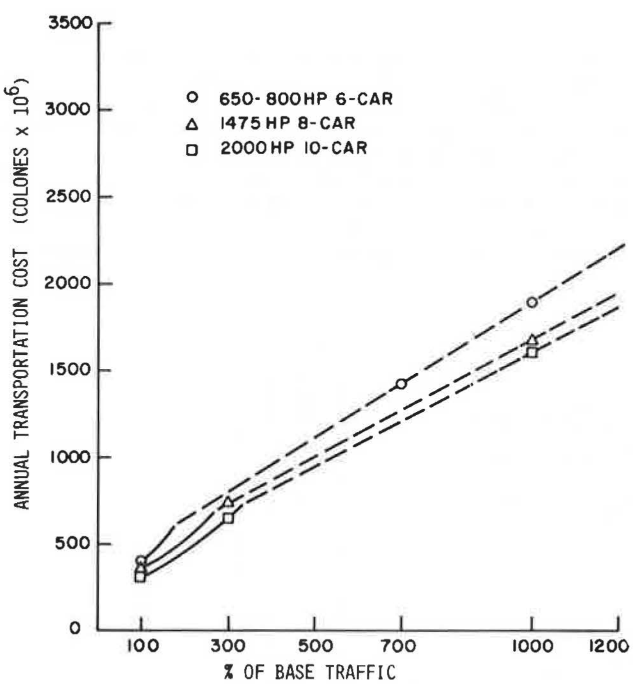

FIGURE 6 San José-Puerto Caldera rail electric technology on improved way.

cantly. The general shapes of these cost curves are similar to those of the unimproved railway; however, total costs for low traffic volumes are greater because of the construction cost of improving the way.

Other data for diesel-electric locomotives were developed for comparison only and show the logical result that the electric railway technology is more economical, particularly when the significant capital cost of electrification has already been incurred.

Figure 7 shows the family of total cost curves developed for three highway alternatives in the San José-Puerto Caldera corridor. In all cases, it is clear that the total annualized cost for highway transportation exceeds that for rail. Reconstruction of the current low-standard sections appears justified at a traffic level 5.0 times the base traffic.

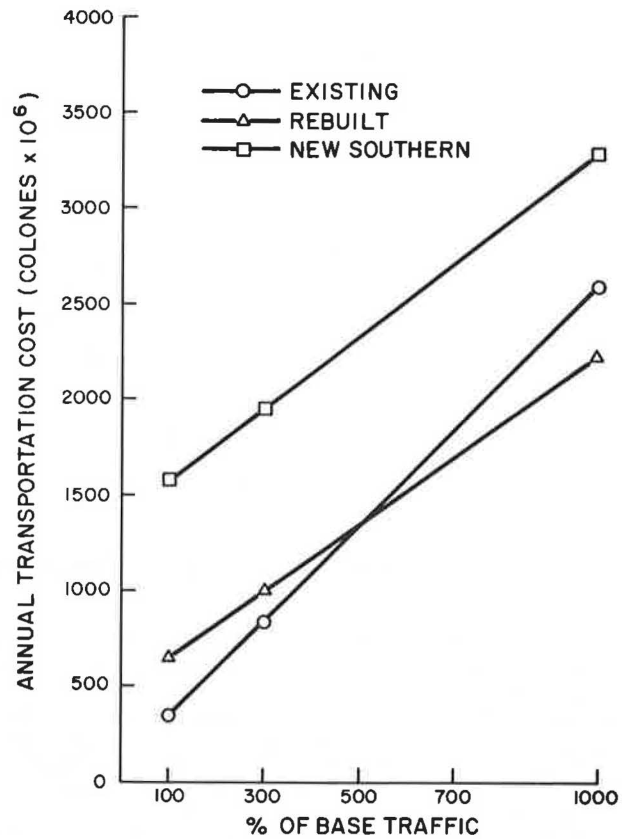

FIGURE 7 San José-Puerto Caldera highway.

Figure 8 is a composite total-cost curve showing the least-cost alternatives for freight movement in the corridor. The analysis indicates that the current electrified railway is optimum up to about 3.0 times current (1981) traffic, at which point double-tracking is economically justified. At approximately 7.5 times current traffic, substantial alignment improvements are justified.

Figure 8 includes two fiscal break-even points in addition to the economic break-even points of principal interest in this study. These fiscal break-even points indicate the traffic levels at which upgrading would be justified on the basis of capital cost savings alone. The fiscal break-even points are of particular significance to the capital expenditure side of transportation planning.

Figure 9 presents the energy intensities of the alternative technologies. The rates shown indicate only direct vehicle energy consumption. They illustrate the relative energy savings in reduced consumption per ton-kilometer of transportation that can be accomplished by various technological improvements. Improving the alignment yields approximately 10 percent energy savings, although this benefit overlooks the direct energy cost of the construction itself. Note that the energy intensities for electric and diesel propulsion alternatives have different scales and are not directly comparable.

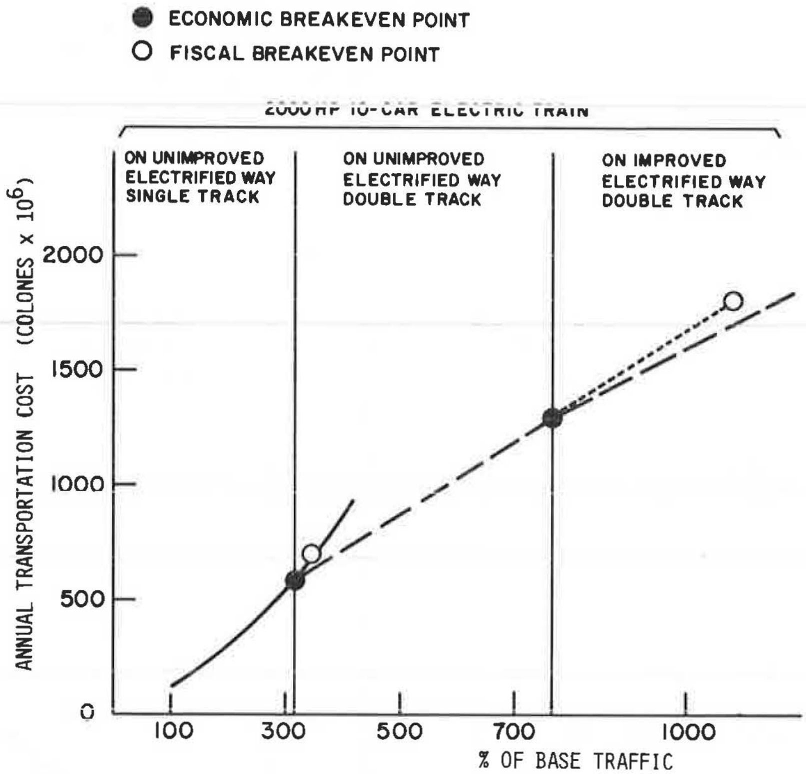

FIGURE 8 San José-Puerto Caldera corridor lowest-cost alternative.

Figures 10 and 11 show a more detailed breakdown of costs associated with a selected vehicle technology operating on the electrified railway between San José and Puerto Caldera. Figure 10 shows total lifetime fixed costs of the alternative, representing primarily the capital costs of vehicle acquisition. Note that the lifetime fixed costs include the present value of obsolete-vehicle replacement costs, which make up a significant portion of the fixed costs of all alternatives being considered. Figure 11 shows vehicle operating costs and the variable costs of railway maintenance and operations. For the alternative illustrated here, most variable costs are domestic expenditures, with the principal exceptions being the foreign expenditures for replacement parts of vehicles and other maintenance supplies.

Figures 12 and 13 show the lifetime fixed costs and annual variable costs (foreign and domestic) of

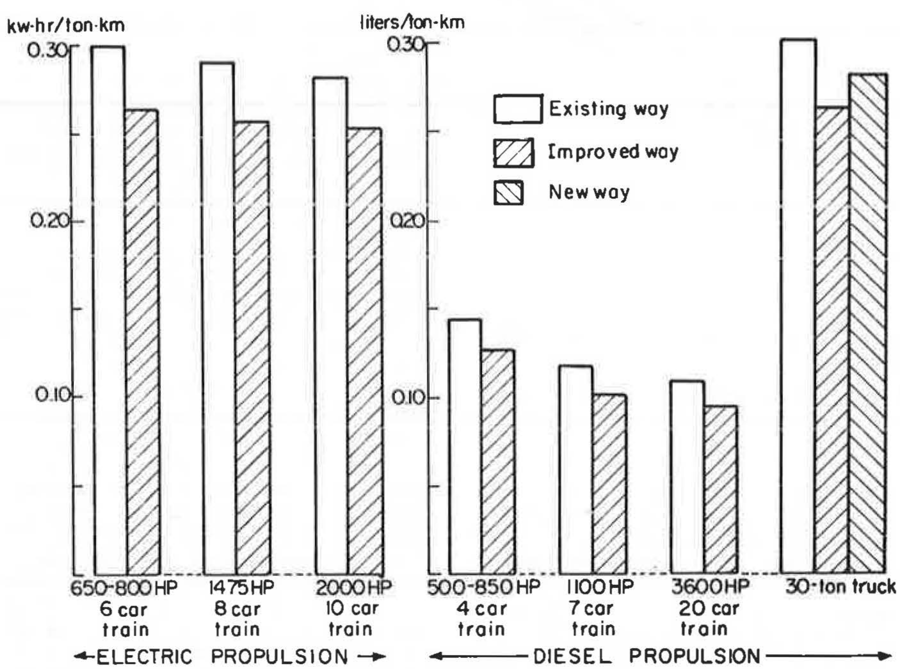

FIGURE 9 Energy intensities of alternative technologies: San José-Puerto Caldera.

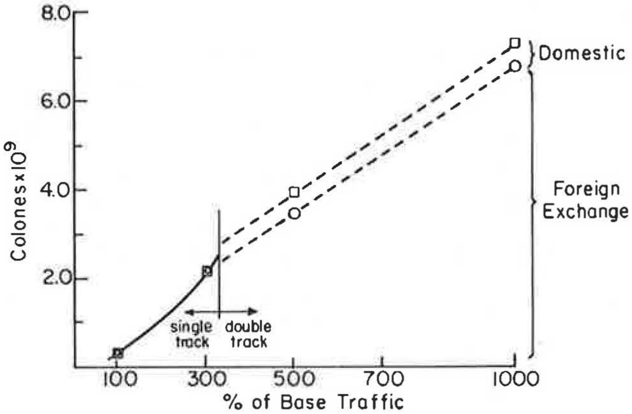

FIGURE 10 Cost breakdown (vehicles and way) for 2,000-hp, 10-car electric train on unimproved way, San José-Puerto Caldera: lifetime fixed cost.

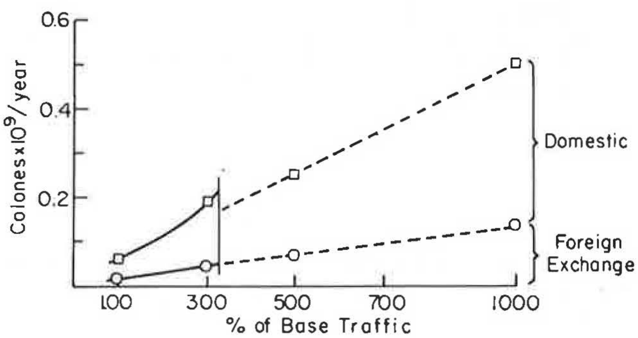

FIGURE 11 Cost breakdown (vehicles and way) for 2,000-hp, 10-car electric train on unimproved way, San José-Puerto Caldera: annual variable cost.

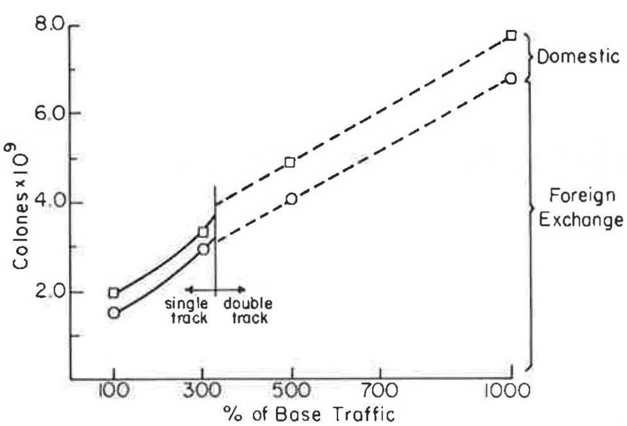

FIGURE 12 Cost breakdown (vehicles and way) for 2,000-hp, 10-car electric train on improved way, San José-Puerto Caldera: lifetime fixed cost.

significantly improving the alignment of the electrified way between San José and Puerto Caldera. Of interest is the fact that the increased fixed domestic expenditure due to railway reconstruction is relatively small compared with the foreign capital expenditure on vehicles. The operating-cost advantage of the improved way shows up as expected in both the domestic (mostly labor) and foreign exchange components of variable costs.

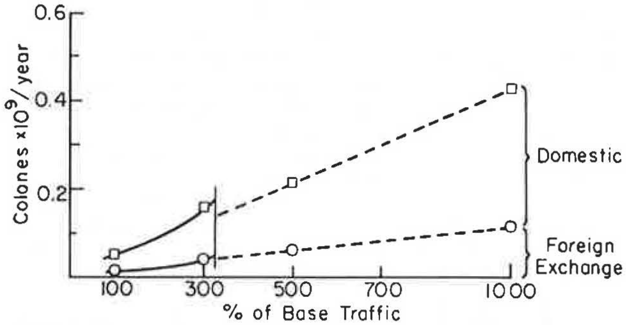

FIGURE 13 Cost breakdown (vehicles and way) for 2,000-hp, 10-car electric train on improved way, San José-Puerto Caldera: annual variable cost.

CONCLUSION

This research utilized an innovative transportation corridor cost model to explore the costs and resource consequences of several transportation technology alternatives for three major transportation corridors of Costa Rica. The output of the analysis is a collection of economic cost curves that were used to draw some initial conclusions regarding desirable directions for future transportation investment in Costa Rica. This study considered only conventional technological options that were believed to be strong candidates for adoption within the upcoming decades.

The cost curves developed in this study are valid for broad comparisons among technological options at the level of national transportation planning. They are not sufficiently accurate to be used as the basis of final decision making. These results are intended to show broad trends and comparisons, indicating the general direction in which the transportation technologies of Costa Rica should develop.

The study provided a number of specific recommendations with respect to the different technological alternatives considered in the three corridors of interest. These are documented in the final report (1).

As in all studies of this type, it is not possible to do everything that could be done. There always remain questions and opportunities for discovery that simply cannot be accommodated within the scope and resources of the study. The following are areas of additional work that would be useful extensions of these investigations:

- Because of the need to address the practical problems of immediate concern to Costa Rica, the novel transportation technologies discussed in an initial working paper (6) were not subjected to quantitative analysis. These include such options as electrified highways and hybrid locomotives able to function in both the pure electric and diesel-electric modes. The ANCOR model is capable of analyzing novel technologies in the same manner as existing technologies, and analyses of this nature would be a worthwhile extension of the work.
- This study was restricted to three corridors of Costa Rica to the exclusion of other potentially interesting transportation corridors, such as the proposed dry canal route connecting the Pacific with the Caribbean Sea through the underdeveloped northern part of the country. A combined analysis of transportation technology options and economic development opportunities for this and perhaps other corridors would be very interesting indeed.
- The ANCOR model was developed several years ago as part of a research program for the government

of Venezuela, but the current study is its first large-scale practical application. Although most relationships embodied in the model have been validated in their original form, there has never been a full validation of the complete ANCOR model with a comprehensive empirical data base. To the extent that reliable and disaggregate construction and operating-cost data can be obtained for the rail or highway modes in Costa Rica, this presents a valuable opportunity to evaluate comprehensively the strengths and weaknesses of the current model and to suggest directions for possible improvements.

In addition to the ANCOR model used in this research, two other corridor cost models have been developed: ANCOR-AGUA, which performs cost and resource use analysis for water transportation systems, and ANCOR-AIR, which analyzes air transportation technology alternatives. It would be of interest to utilize these models to explore non-land-transportation options in suitable settings.

ACKNOWLEDGMENTS

The author would like to express his appreciation to a number of fifth-year students in civil engineering at the University of Costa Rica and to their faculty advisors, without whose excellent thesis work the analysis reported in this paper would have been impossible. Thanks also to Ann Stevens and C.-K. Kong, both graduate students at Berkeley, who patiently produced the many computer runs required to develop these results, and to Juan Manuel Guell and Leonardo Castro, also Berkeley graduate students, whose personal knowledge of Costa Rican conditions made valuable contributions during the data acquisition phase of this research.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Research on Appropriate Planning Methodology in Developing Countries

C. JOTIN KHISTY

ABSTRACT

Developing countries have generally adopted the planning methodology conventionally practiced by developed countries. The results have not been encouraging. There is a dire need to evolve inexpensive appropriate methodology especially applicable to developing countries, which will help policymakers reduce the inefficiencies in transport, correct misguided priorities, promote equity, and enhance the quality of life. The following topics connected with appropriate planning methodology are examined in this paper: development and diffusion of planning methods, basic problems of land use and transportation planning, the meaning of need as compared with demand, distributional effects of current planning methods, appropriate planning methodology, and the ethics of methodology assessment. The issues concerning appropriate planning methodology are clarified and areas where further research is needed to improve the planning process are identified. An agenda for action is included.

Recent interest in appropriate planning methods stems from the general dissatisfaction with the planning and development process expressed by the public in developing countries. Planners dealing with the planning process in these countries have also expressed frustration with applying the conventional sophisticated planning methods. The objective of this paper is to clarify the issues concerning appropriate planning methodology applicable to developing countries and to identify areas where further research is needed to improve policymaking in the choice of methodology. Although the focus of this paper is directed toward land use and transportation planning, the ideas expressed can be extended for general application to the planning of the urban and rural infrastructure. The organization of this paper hinges around seven tasks: (a) to understand the development and diffusion of planning methods, (b) to identify the problems of land use and transportation planning in developing countries, (c) to differentiate between need and demand, (d) to understand the distributional effects of current planning methods, (e) to investigate appropriate planning methodologies, (f) to examine the place of an ethics of methodology assessment, and (g) to describe research issues applicable to developing countries. This speculative paper is an attempt to seek answers to the topics listed and to question some of the conventional answers that are generally taken for granted within the profession.

A word needs to be said about form in presenting this paper. The subject discussed here lies in the realm of metamethodology, which means methods of selecting methods: a progression from theoretical enquiries toward practical solutions.

SOME DEFINITIONS AND DESCRIPTIONS

In most of the discussion in this paper the terms "methodology," "technique," and "technology" are used interchangeably. Gendron's definition of technology captures the meaning of the other terms (1):

> A technology is any systematized practical knowledge, based on experimentation and/or scientific theory, which is embodied in productive skills, organization, or machinery.

Also, because this paper is essentially concerned with the assessment of planning methodology appropriate for developing countries, Coates' definition of technology assessment is applicable (2):

> Technology assessment is a class of policy studies which systematically examines the effects on society that may occur when a technology is introduced, extended, or modified. It emphasizes those consequences that are unintended, indirect, or delayed.

Technology and society are tightly intertwined by complex mutual causal relationships. Hence assessment may take on a normative or planning character by establishing a technological path from the present to a future state, where goals reflecting the social values of society can be achieved (3).

Although the terms "appropriate" and "intermediate" have been used in connection with planning and technology since 1973, no formal definition of the terms has been put forth so far. Darrow and Pam's description of appropriate technology covers the key elements. They stated (4):

> "Appropriate technology" is a term that represents a particular view of society and technology. It suggests that technology is neither neutral nor does it evolve along a single path. It recognizes that different cultural and geographical groups will have different technologies that are appropriate to their circumstances; that technological self-determination is essential to cultural identity (and political independence). It suspects that the only wise technologies are those which seek to accommodate themselves to the biological environment within which they are used. It assumes that the purpose of economically productive activity is to produce what is determined by need, in an enjoyable, creative process; not what is determined by endless greed, in an alienating, repetitive production process. It stresses that every society has a technological tradition and that new technologies must grow out of this tradition. And it presumes that the only development that makes sense is development of the people and their skills, by the people and for the people.

The implications of appropriate planning methodology are taken up in a later section of this paper.

PLANNING METHODOLOGY: DEVELOPMENT AND DIFFUSION

Model building and methodology are fundamental to policy analysis. Orderliness, predictability, controllability, and reduction of and allowance for error are some of the hallmarks of methodology. Because methods are the outcome of complex social demands, it is obvious that one can predict what will happen to methods if one can predict what will happen to society. There is yet a deeper aspect to method. A knowledge of method shapes the perception and ultimately the organization of the world by those who possess it. In this sense, method becomes the organizing basis for a world view (5).

Methods originate, modify, and change over time because of the environment in which they are applied. Figure 1 shows the four phases of the development of methodology: definition, formalization, maturity (and diffusion), and decline (5). Methodological development is naturally a dynamic process with a feedback element.

Figure 2 shows how a method is under constant revision as the needs of society warrant change. For example, with the decline of innovative method I, another appropriate method II will take over, and so on.

PROBLEMS OF LAND USE AND TRANSPORT PLANNING IN DEVELOPING COUNTRIES

Although modern urban planning techniques have been used in developing countries for a couple of decades, surprisingly little is known about the outcome of short-term and long-term strategies and investments used in these countries (3). Comparative studies of the factors influencing the development and quality of transport systems are now gaining some recognition.

Almost every transportation-related decision is really a public issue. The transport system impinges on those who use it and also on those who do not. "If there is one inescapable conclusion from a study of the world's major cities, it is that people everywhere are dissatisfied, often to the point of public protest with their transport, with the way it is developing and the effects it is having on their cities" (6). The problems are all the more intense

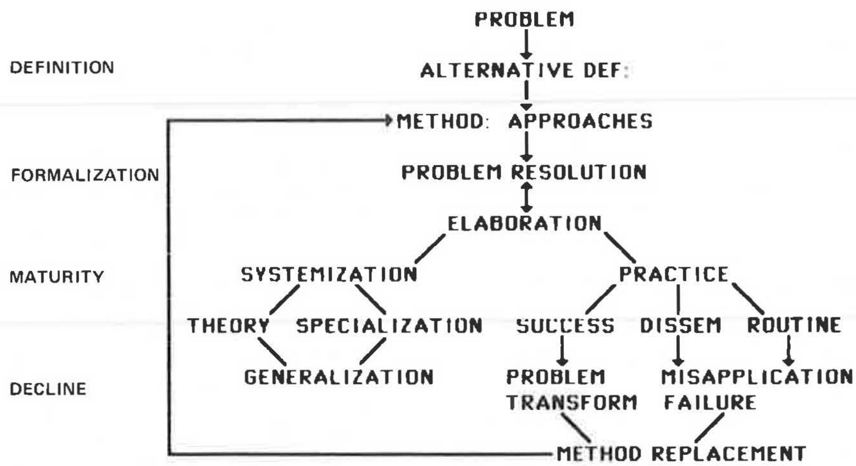

FIGURE 1 Elements in methodological development *(5)*.

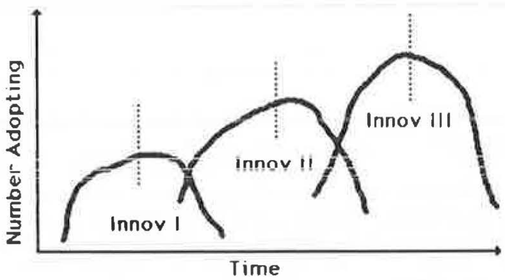

FIGURE 2 The effect of discrete innovation in reproducing change.

in developing countries. The need for transportation arises because of the existence of time and space, and the cost of transportation determines the current transportation technology, the size of cities, and hence the human opportunities for work and leisure, for the choice of jobs, and the quality of life in general (7).

Transportation is only one of the many necessities required to accelerate the pace of economic progress, but in many situations it plays a key role, and in all cases it sets the limits of improvements. Inadequate supply of transportation services for both goods and people has plagued the developing countries. The high influx of rural migrants usually seeking employment in urban areas is straining the already overutilized infrastructure. For instance, in India during the decade 1961 to 1971 the urban population has increased by about 20 percent (8).

There is a wide divergence of opinion on how to solve urban and rural transportation problems, but the common aim is to search for the best solution given the resources available. Land use and transportation planning studies have been conducted according to more or less standard procedures and methodology in most major cities of the developed world since the 1950s. This remarkably uniform methodology, consisting of the five-step sequential models of land use, trip generation, trip distribution, modal split, and traffic assignment, has been referred to as the conventional urban transportation planning process. Because of the necessity of considering many land use and transportation alternatives, efforts have been made in the last decade to evolve simplified urban travel demand models, chiefly to reduce the cost, time, and complexity of analyzing options (9).

The current situation of urban and rural planning in developing countries is alarming. Further deterioration is in prospect if present trends are allowed to continue unchecked (10). In the last decade many developing countries used travel models similar to the ones used in the United States and other developed countries. These procedures, methods, and models are highly sophisticated, very data hungry, and extremely costly and require specialized trained personnel to run them. Some work has also been done to adapt these sophisticated models to suit the requirement of developing countries, but still the cost of running these sophisticated models is horrendous. Unfortunately, all this work and expense, although intrinsically valuable, has not helped the developing countries and the results have been disappointing. The reasons for this disappointment are not difficult to comprehend, and some of the glaring ones are noted as follows (11,12):

1. The planning objectives and policy variables formulated for developing countries have usually been those meant for advanced societies of the world, instead of being related to the social needs and the economic status of developing countries. Similarly, the constraints encountered in developing countries are much more severe than those in developed countries. Some of the chief planning constraints are limitations on capital and resources; the capacity to pay for travel; limitation on available expertise to plan, implement, and maintain the transport system; the problem of benefitting the maximum number of people; and the conservation and use of carce resources, such as energy.
2. Cities in developing countries have grown enormously. Some cities have grown by 300 percent within 30 years. Such growth has brought with it immense problems for public authorities who have to eventually provide the life-support system essential for the survival of these cities.
3. Heroic responses by public authorities to cope with rapid urban growth have often been really ad hoc reactions. There has thus been no time to adapt and evolve as cities have grown in size. Diffusion of innovation, the pace of technical change, and the rate of income growth are all out of balance. Also, economic, social, and political institutions have not kept pace in regulating patterns of growth.
4. The analysis of cities is highly complex in developing countries because of the coexistence of the different kinds and levels of technology. Electric trains run side by side with hand-pulled carts,

bicycles, cars, and pedestrians. Moreover, there is a marked lack of research into the growth and structure of cities in these countries. Naturally, the transferability to developing countries of sophisticated transportation and land use planning methodology as practiced in the United States is, to say the least, highly questionable. There is currently a lack of suitable tools for analyzing and understanding urban structure in cities of developing countries.

5. The lack of data to fuel any kind of urban activity-transportation model is one of the main bottlenecks. With over 30 years of experience, transportation planners have realized that the quality of results expected from sophisticated models is chiefly dependent on good, sound, reliable data. Developing countries are unable to collect the large amount of data to fuel sophisticated models, mainly because of financial constraints. The prime concerns of transportation planners operating in developing countries are how to collect data for input into land use and transport models as cheaply as possible and in the shortest time, how to transfer effectively the sophisticated methods currently being used by developed countries, and what the possibilities are of applying modified, simple methods capable of providing answers suitable for developing countries.

6. Because of the rapid and uncertain rate of urbanization, planners have usually concentrated on short-term plans. In most cases this has been a disaster because by the time the plans are completed, they are already obsolete.

The experiences of the past 30 years in planning methodology applied in developed countries have taught policymakers and planners several lessons. One of the main ones has been to recognize the limitations of methodology--that methods must be tailored to fit the task and the budget. This experience leads to the following suggested rules (3,12):

1. Initial application of planning methods should start with sketch planning, which is generally small-scale, quick, and manageable;
2. Methods should generally have a fast turnaround time to make the results responsive to policy needs and issues;
3. Detailed information on operating and fixed costs of transportation modes should be collected;
4. The patterns of human activity and their clustering characteristics should be known to discover clues to the reasons for agglomeration; and
5. The dilemmas of growth, control, and distribution as observed in developing countries should be analyzed.

NEED VERSUS DEMAND

As pointed out earlier, the constraints on planning are much more severe for developing countries than for developed countries. In an economy faced with scarcity, the priorities and the provision of transport supply have to be carefully estimated. The general run of transportation models provides answers that depend on the concept of demand for travel. The concept is founded on traditional economic theory. Demand for travel is based on the willingness-to-pay concept. Those with low incomes and no automobiles are less likely to demand travel.

In contrast, the social concept of need is not clearly defined (13):

> Travel needs may be considered as fixed amounts of travel that are deemed necessary to provide an adequate standard of living. This quantity is not affected by the price of travel. That is, a person may have a need to travel independent of the ability or willingness to pay. In this context, need is an equity criterion, indicating that a deviation from an established norm should be corrected.

The assessment of needs is a crucial part of the planning process.

Burkhardt (14), in describing a case study of transportation needs, provided a procedure for estimating trips needed by households in five rural areas. In his conclusion he suggested that future research should focus on a concept of need that refers to transport services that would be used, instead of those that should be used. Need must therefore be based on actual behavior (or estimates of actual behavior), not on some idea of what people ought to do. Bradshaw (15) has expressed similar ideas by classifying need into four categories: expressed, felt, comparative, and normative. Expressed need is what people think they want and is the most obvious measure of need, whereas normative need postulates a standard below which one is not expected to fall. According to Burkhardt (14), "it is thus an objective measure based on a subjectively-determined norm." A method of assessing need for travel in developing countries is sorely lacking.

DISTRIBUTIONAL EFFECTS OF CURRENT PLANNING TECHNIQUES

In the Western world public decisions for public projects most frequently use the benefit-cost model for evaluation. The model rests on the assumption that in any public-decision problem an attempt must be made to maximize the net benefit to society (16). This traditional process has been used by planners working on projects in developing countries. It is a consensus-seeking process because it assumes that a system can be constructed that will produce an aggregated net social benefit conceptualized in terms of the public interest. The general logic of benefit-cost analysis is well documented and so are its shortfalls (17-19). In this context Bolan's observations are most appropriate. He says (20):

> Our concepts for optimality, our focus on an abstract welfare function, and our concern for an illusory greater good (or public interest) is brought into serious question . . . . Planning is being challenged more and more, not on its service to an overall public, but rather on the differential and distributional aspects of its results affecting particular publics.

These observations are particularly apropos to the problems of equity and distribution one constantly encounters in less-developed countries.

Benefit-cost analysis is grounded in the 19th-century social philosophy of Jeremy Bentham concerning the need for pursuing a course of action that would provide the greatest happiness for the greatest number in any public decision. Bentham's model, like cost-benefit analysis, was consensus seeking and thus ignored distributional issues by concentrating on net aggregate benefits. Cost-benefit analysis, when used for assessing net aggregate benefits for purposes of evaluating alternative courses of action, makes use of the Pareto optimality condition, which states that if one person gains and nobody else loses, there is a net gain in welfare. If some gain while others lose, however, the method can provide little guidance, although the Kaldor-Hicks criterion states that an allocation of resources is warranted if those that gain could in theory compensate those that may lose. In actual practice, this does not require that compensations be paid nor does it imply that gainers and losers be identified (21). The implications of the Kaldor-Hicks criterion for potential Pareto improvements is highly questionable and is of special importance when the socioeconomic standards of the community are so distinct that transportation improvements frequently benefit particular groups of society systematically at the expense of others (22).

In comparison with Bentham's theory of utilitarianism, which aimed at the greatest happiness of the greatest number, Gandhi and Bhave went a step further in an attempt to establish a new social and economic order based on human values--a decentralized, self-governing, nonexploitative, cooperative society. Gandhi gave that society the name "sarvodaya," meaning the uplift of all, that is, a society in which the good of all is achieved (23).

The concept of sarvodaya is the most original contemporary contribution to political thought. It postulates that development of self-governing village communities, decision of local issues by near unanimity, limitation of needs, and the development of the capacity to manage affairs with minimum governmental control and assistance will lead to the welfare of all. Bhave's cogent example of a mother distributing food to her children, not on the basis of mathematical equality, but taking hunger and digestive capability into account, drives home the point on the exercise of discriminative equality (24).

As much as sarvodaya is attractive there are questions that must be resolved. First, does the sarvodaya theory postulate a condition? In other words, does sarvodaya call upon the human race to grow towards sarvodaya, which sarvodaya alone can create? Second, in the face of growing complexity of modern life can one apply the principle that government is best that governs least? And third, how can the winds of change blowing from the developed world be prevented from adversely affecting the people of developing countries (24)?

APPROPRIATE PLANNING METHODOLOGY

The term "appropriate" is itself one of the general terms that has come from the literature on planning, technology, and development. Most authors agree that the fundamental requirement of appropriate technology is that it make optimum use of the available resources in a given economic environment (3). Schumacher, the originator of the idea and philosophy of appropriate technology, illustrates the value dependence of economics by comparing two economic systems embodying entirely different values and goals. In one system the quality of life is measured by the amount of annual consumption. In the other system, the aim is to achieve a maximum of human well-being with the minimum of consumption (25).

Leopold Kohr has answered several questions raised in connection with the meaning of the term "appropriate," which implies the existence of limits. Beyond certain limits technology not only ceases to be a solution but is actually the most intractable obstacle to it. Planning and technology are most efficient when they provide humanity with the cultural, political, economic, and convivial ingredients that make up the good life. The question of size is also important. Explaining the meaning of limited size, Kohr says (26),

> Today, improvements in transportation and communication have made it possible to extend city size limits to perhaps 12 or 15 million. But beyond this, no further technological improvement can match the geometrically multiplying problems of scale setting in. They now turn into diseconomies of scale.

Planning and technology are described by their input requirements--labor, capital, and materials--along with the expertise required to plan. The answer obviously lies in reducing and/or in balancing the input requirements to dimensions where "appropriate" tools for human improvements can be furnished through simpler, cheaper, and transparent methods.

Modern methods of planning and the application of the latest technology as used in the developed industrial world have traditionally been recognized by developing countries as the driving force behind the apparent growth and prosperity of the Western world. This prosperity and growth is reflected in the quality of life and again the apparent well-being of the people inhabiting the developed industrial world.

The general problems and specific failures of modern planning methodologies and the application of technology in developing countries prompted Schumacher to advocate appropriate technology as a means of improving the condition of the nonindustrialized world.

There is naturally a lot of controversy regarding appropriate planning and technology. The advocates of current planning and technology believe strongly that greater economic growth through capital-intensive and energy-intensive plans is the way to go, whereas proponents of appropriate technology claim that current planning and technology have resulted in negative impacts to the environment and the quality of life. Indeed, it is claimed that in countries where high technology is practiced, a point of diminishing and even negative returns to scale has been reached, as shown in Figure 3 (27).

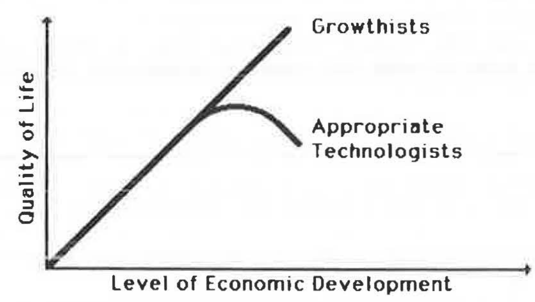

FIGURE 3 Growthist and appropriate-technologist perspectives (27).

Equity, as pointed out earlier, is another important factor affecting developing countries using traditional planning and technology borrowed from the West. Environmental factors, including a focus on energy use, is yet another problem in these countries.

The choice and application of appropriate planning methods in developing countries is one of the most important collective decisions confronting any country. It is a choice that determines, among other things, how, when, and where improvements should be made to the infrastructure in keeping with community goals and objectives, and this decision in turn affects the whole quality of peoples' lives (28).

Very little systematic research has been conducted into appropriate planning methodologies applicable to developing countries. The reasons for this situation are not difficult to find. First, innovation in planning is almost always induced as a response to a perceived need. Second, there appear to be economies of scale in the research and development field for evolving such techniques. Third, the existing examples of planning adaptations of Western techniques in developing countries have been erratic. Little is known about their success. It could be generally concluded that major planning adaptations falling in the category of appropriate planning will not be forthcoming if research and development is left solely to private researchers (11).

ETHICS OF METHODOLOGY ASSESSMENT

The importance of the ethical dimension in assessing the short-term and long-term effects of methodology has been recognized from the earliest stages of technology assessment. Unintended consequences are likely to result from implemented methodologies and policies if rigorous assessment is not conducted. The question before planners and policymakers as they seek to improve anticipatory methods research is how the assessment itself can be used to promote gains in the quality of life. The task becomes one of ascertaining the limits of methodology and the limits of being able to assess that methodology vis-à-vis the value system of individuals who make up society as a whole, and the possible linkages between the region and the communities at the local level (29).

Jessen says (29):

> Technology assessment and social impact assessment lie at the crossroads of tension between the value free (properly translating a modern problem in technological and human terms) and the value laden (implementation consequences: bridging the gap between findings, policy recommendations and political actions to carry out the policies).

Jessen's statement is appropriate. He says,

> We professionals who use only the narrow, specialist training of sterile quantitative methods, without taking into consideration the qualitative aspects and the broader understandings and insights of citizens regarding their world view in their own situational complexes, cannot adequately define the problem and therefore cannot adequately provide prognosis to accompany our diagnosis.

In summary, it is maintained that the application of some kind of ethics of assessment is necessary in order to maximize positive results in the predictive enterprise of methodology assessment.

RESEARCH ISSUES

Because the concept of appropriate planning methodology in developing countries is quite new, there are barely any results of such research available. Although there has been much advocacy and theory, there has been little scientific examination of the dimensions of appropriate planning methodology.

Any innovation in developing and applying appropriate planning methodologies would necessarily have to go through several stages (11):

1. Evolution of new methodologies particularly meant for application in developing countries or the modification of existing know-how based on proven cases;
2. Organization of possible innovations for ready application in test cases for the most part and in actual application in some cases where the method appears to have a fair chance to succeed;
3. Development of the methodology for regular use, in the form of "canned" or packaged programs based on the success observed in test cases;
4. Evaluation of proven methods for their appropriateness--cost, stability, applicability, robustness, and so on; and
5. Diffusion of appropriate planning methods, so that indigenous planners in developing countries are familiar with their use, limitation, and strengths.

Because very little systematic documentation is available regarding appropriate planning adaptation in developing countries, a high priority should be placed on recording how innovative appropriate methods of planning were introduced, by whom, at what cost, and where, together with information regarding the ambient political and social conditions prevailing at the time of application and adaption.

Records must also be maintained on the diffusion of appropriate planning methods. Instances have come to light from several countries that indicate that the diffusion process invariably neglected the important issue of assimilation capability, which depends in most cases on the level of technological development of the transferee.

In preceding sections of this paper several questions have already been posed in the hope that a cutting edge will be available to researchers to begin a systematic examination of appropriate methods. In addition the following questions emerge:

1. Given the limitation on the cost and availability of data, what performance criteria might be realistically adopted for the evaluation of appropriate methodologies?
2. Is enough known about cities in developing countries? Is enough known about changes in travel behavior over time in developing countries to take them into account in the planning process?
3. How can the planning process be made truly sensitive to the needs of the community?
4. What means should be used in developing countries, under different systems and styles of political systems, to promote an appropriate interface between planning and the political process?

AN AGENDA FOR ACTION

Where does the foregoing leave those concerned with evolving appropriate planning capability for developing countries? An agenda for developing that capability is outlined as follows:

1. The first task should be development of a clearinghouse of information regarding land use and transportation methodologies used by planners. Preliminary work of this nature has begun in the shape of newsletters from the Subcommittee on Transportation and Land Use Planning in Developing Countries of TRB. Similar endeavors of the Institute of Transportation Engineers are emerging.
2. The second task should be to inventory existing and emerging land use and transportation planning methods currently used in developing countries in the form of a sourcebook. Details provided would include such topics as data base used, time line, costs, manpower needs, results of application, and special problems. The scale and level of detail could follow the matrix indicated in Table 1.

TABLE 1 Methodology Scale Matrix

Methodology Application	Scale: Rural	Urban Microscopic	Urban Metropolitan	Interurban	Regional
Data needs and collection	X	X	X	X	X
Socioeconomic forecasts	X	X	X	X	X
Land use planning	X	X	X		
Alternative scenarios	X	X	X	X	X
Travel characteristics analysis	X	X	X	X	X
Quick-response and sketch planning	X	X	X	X	X
Operations planning	X	X			
Strategic planning	X	X	X	X	X
Long-range planning	X	X	X	X	X
Short-range planning	X	X	X	X	X
Intermodal planning	X	X	X	X	X
Goods movement planning	X	X	X	X	X
Investment analysis	X	X	X	X	X
Technology transfer	X	X	X	X	X
Policy planning	X	X	X	X	X
Impact assessment	X	X	X	X	X

3. The third task, which is an offshoot of Task 2, should be to inventory existing and emerging methods currently being practiced in the United States (and other developed countries) that have been proven to work, either as is or with modifications, in developing countries. A range of proven methods would naturally emerge from this exercise, possibly fitting the matrix in Table 1. Although the foregoing agenda is not exhaustive or revolutionary, it does recognize that any headway in methodological innovation will have to be incremental in nature.

4. The fourth task should be to seek out methodologies developed in one country that can be transferred to and adopted for use in another country.

As a closing comment, it should be recognized that the evaluation of planning methods and their practical applications in the developed countries of the world has spanned a period of over 25 years. Therefore, it should not come as a surprise if the process of seeking appropriate methods, identifying gaps between theory and practice, developing research to fill the gaps, and documenting the results takes considerable time and effort.

CONCLUSIONS

It is apparent that there are no easy answers to issues concerning appropriate planning methodology development and adoption. Criteria for identifying appropriate methods are needed. It is also apparent that planning cannot be done by central office bureaucrats who are not familiar with the culture and microscopic details of the country where appropriate planning application is proposed. Planning cannot be from the top down and cannot stifle the originality, energy, intelligence, and innovative drive of a country's existing organization. It must incorporate these qualities and blend them into what is appropriate.

Finally, it is critical to obtain a greater factual base of methodology that is currently being used in developing countries, to monitor the results, and to build on such methods in the light of the best knowledge available.

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Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Business Plan for Engineering Districts: The Pennsylvania Experience

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ABSTRACT

During 1984 the Pennsylvania Department of Transportation embarked on a key initiative designed to improve the overall planning process. To facilitate a businesslike approach to operating Pennsylvania's 11 engineering districts, individual 4-year business plans were developed. Although Pennsylvania's capital improvement projects are coordinated through a 12-year transportation improvement program that is reviewed, revised, and adjusted every 2 years and maintenance projects are developed for each county through an annual work plan, the 4-year business plans for the first time combine these two program elements into a multiyear strategic management document. The 4-year business plans are intended to assist the district engineers in working toward the common objectives of the department. Business plans encompass manpower needs, physical plant, equipment, and materials requirements associated with district and county activities. The business planning process also provides each county manager with the opportunity to examine the anticipated multiprogram effects on the transportation system.

The Pennsylvania Department of Transportation (PennDOT) is "big business." It is expected that the total revenues in 1984-1985 will be around $2.0 billion. This will include $1.4 billion from Pennsylvania's Motor License Fund and $550.5 million from federal sources; $870.7 million in Motor License Fund monies will support departmental highway and bridge programs; the balance, $534.1 million, will be used to fund local government transportation programs and debt services. This magnitude of revenue places PennDOT among the top 250 corporations in America.

The department's responsibilities are very diverse. It serves all motorists with a variety of driver and vehicle transactions, 25 million each year. The department spent $460 million underwriting local transportation systems in FY 1982-1983. This included over $180 million in municipal assistance and over $144 million for public transit operating assistance. PennDOT maintains almost 45,000 mi of roadways, more than the combined state highway mileage in the six New England states plus New York and New Jersey. Percentagewise, PennDOT controls 40 percent of all roadway miles in the commonwealth, compared with an average of 20 percent in other states.

The network of roads and bridges in Pennsylvania today is the fourth largest in the nation and represents an investment by taxpayers of more than $50 billion.

Not only is the department big business, but the environment in which the department operates is becoming more and more complex and demanding. The areas of uncertainty are increasing, and change is all around; it appears, in fact, that the rate of change is accelerating.

What does this mean for management? It means that there must be better leadership, planning, direction, control, and response than ever before. It means that there must be effective organization and management concepts. There must be the ability to understand the environment and anticipate change. There must be flexibility; flexibility is needed toward missions and in functions and actions. Finally objectives must be known in order to shape and redirect program-level activities. PennDOT utilizes a strategic management process to effectively provide products and services. The key to this strategic management process is the selection and achievement of departmental major objectives. These major objectives set the tone and guide the department's activities.

The department is organized with several departmentwide functions at the central office level and 11 engineering district offices delivering products and services to Pennsylvania's citizens. A map of Pennsylvania's counties and engineering districts is shown in Figure 1.

The 4-year business plans are an integrated part of PennDOT's overall planning network. The planning network communicates the manner in which the department operates, from the broad organizational level of planning to the more specific project-level planning. The 4-year district plans provide an important communication link between the county and district offices and central office management.

PLAN DEVELOPMENT

Plan Guidelines

Guidelines were provided to the district engineers covering overall plan development, content, time frame, and necessary supportive detail. The guidelines focused on procedures, products, and budget.

A number of points or considerations are particularly noteworthy with respect to the Pennsylvania business planning initiative. The following are examples of how certain facets of operation were emphasized in the business planning guidelines:

- PennDOT will continue to be a maintenance-first organization.
- Multiyear surface improvement mileage targets are to be a principal output of this year's efforts.
- Resources are limited. Districts will need to give appropriate attention to the commonwealth's Interstate system, the priority commercial network, and selected roadway segments from the other state-owned system consistent with current program and budget guidance.
- Districts should identify criteria employed for making choices that meet district requirements. District requirements and environments differ; however, the need to identify selection criteria as the basis for decision making is a pervasive requirement.
- The $1.4 billion bridge program will be the major thrust of the department's bridge efforts. All available federal critical bridge funds will be utilized during this period. Each district has an established responsibility for bridge projects, and this needs to be particularly addressed in the 4-year business plan effort.
- Two areas of construction are part of the department's major objectives: Interstate completions (all remaining work needed to initiate construction of Pennsylvania's Interstate system will have been completed by the end of 1986) and the completion of critical missing links in the state's highway system.

District Variations

The 4-year district business plan guidelines provided the basis for general uniformity in plan de-

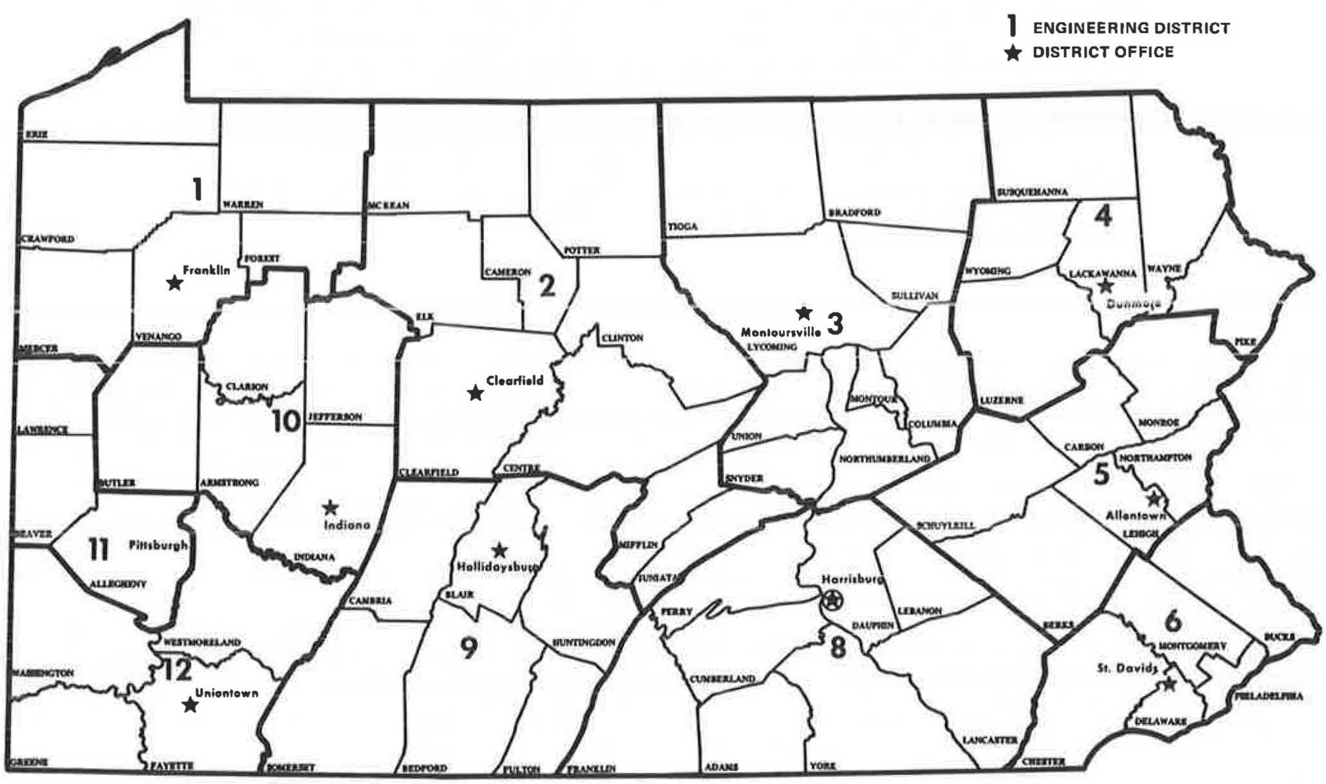

FIGURE 1 Pennsylvania counties and engineering districts.

velopment. However, the commonwealth of Pennsylvania consists of 45,000 mi^2 of land area with a population of 11.8 million residents. With the reality of distinctions in Pennsylvania's physical features, socioeconomics, and climate, there are extreme differences among the priorities and operating requirements of the 11 engineering districts.

Sharp variations in topography create natural boundaries throughout the commonwealth. Pennsylvania is generally composed of mountain ranges and large plateaus with a coastal plain in the southeast corner of the commonwealth. Three major river systems and other waterways pose obstacles that must be traversed by the transportation system.

Pennsylvania has two large metropolitan areas--Philadelphia and Pittsburgh; they are leading centers of industrial production and advanced technology. These two areas account for approximately half of the commonwealth's population.

Despite the numerous cities and towns, large sections of the commonwealth are still rural. In fact, Pennsylvania has the largest rural population of any state in the nation. An extensive agricultural industry along with the mining of vast deposits of coal and the lumbering of 15 million acres of forest land pose unique demands on even the most rural of districts. This is especially true concerning the increased size and weight of trucks hauling these natural resources on Pennsylvania's secondary highway system--highways that were not designed or built for these demands.

The considerable variations in population, topography, and socioeconomics create distinct differences among engineering districts. This influences the type of transportation system necessary for each area. It also relates to the unique problems imposed on that system or the district's ability to provide a proper level of service.

Throughout the planning process, the uniqueness of each engineering district was acknowledged. Business plan guidelines were purposely kept general to recognize district variations and not inhibit the planning process in any way.

Planning Organization

The components of the 4-year business plans were developed based on the present and future demands of the engineering districts. The business plans were organized into the following major components:

- Maintenance
- Highway transfers
- Integrated bridge program
- Capital improvements
- District capabilities (organization/management)
- District concerns (emerging issues)

The first four components are the major appropriations to the annual district operating budget (Figure 2). These appropriations result in the major maintenance and capital improvement programs in each district. The final two components of the plans (district capabilities and district concerns) were designed to give each district the latitude to express their abilities and shortfalls in accomplishing the major objectives of the department.

The district capabilities component provides the forum for discussing the ability to accomplish design, construction, inspection, and maintenance activities as well as the current policy for providing services through department versus contracted personnel.

A component was left open to items of district concern that may affect district or county operations or productivity. For example, this component was used to describe difficulties in retaining construction or materials inspectors, need for specific areas of manpower training, and so forth. This component existed in order to provide an opportunity for the district to elaborate on any district or state concerns that had not been previously discussed.

Planning Time Frame

District business plans covered the 4-year period from FY 1983-1984 through FY 1986-1987. The district planning period began in FY 1983-1984 because this year provides the most known data. Districts had a 4-month period in which to prepare the plans. The schedule was aimed at completion for a May 1984 presentation of the plans to the Secretary of Transportation and the Strategic Management Committee. A review of progress was conducted periodically throughout the planning period.

Budget Assumptions

Districtwide and programmatical budgets were developed as part of the planning guidelines. These budget assumptions were developed as the most probable for the 4-year planning period. Funding levels were provided for each category of district program activity.

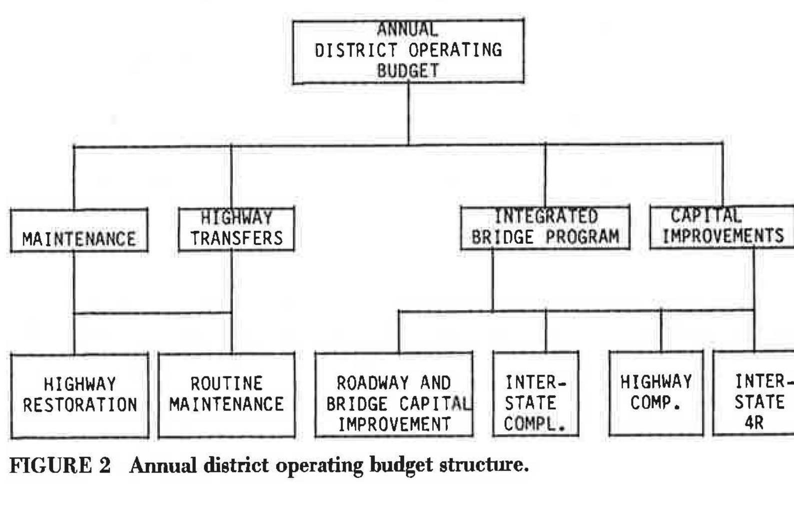

FIGURE 2 Annual district operating budget structure.

Tabulations

Each district engineer was provided with a set of preprinted forms for tabulation purposes. A copy of a maintenance activity form is shown in Figure 3. Both production units and costs are documented for each programmatic activity. Departmental recommended cycle lengths are shown where applicable. The preprinted forms facilitated uniformity wherever possible.

BUSINESS PLANNING RESULTS

The preparation of business plans for each engineering district in Pennsylvania was an unequivocal success. It was successful not only in the documents produced, but in the institution of a multiyear planning process in each of the district offices. It began the evolution of planning as a generic function of district office management.

Results of the 4-year business plans were presented to the Secretary of Transportation by each of the respective district engineers. The plans focused on achieving the department's major objectives and certain other strategic activities in the following areas:

* Roadways
* Bridges
* Highway transfers
* Equipment
* Buildings and grounds

Within each area, the district engineer evaluated the district's key assets, services, and products. Personnel were evaluated from an overall complement level as well as individually within each service or product area. Material requirements to accomplish goals were an inherent part of plan development.

The results of the plans indicate that general statewide objectives can be met. However, during the presentations, it became apparent that minimum requirements for an adequate level of service could not be fulfilled in all counties with present and projected revenues. A number of issues and concerns were also raised that involve department policies and programs. Addressing these concerns at the top level of management will improve the overall operational framework of the department.

Some highlights of the business plans follow.

Roadway Program

In the roadway program the district 4-year business plans included routine highway maintenance, highway restoration, resurfacing, and capital improvements.

PennDOT continues its commitment to being a maintenance-first organization. Maintenance remained the department's top priority throughout the business plans. A continuing effort will be made to preserve the roadways on the state-owned system in order to keep them in an acceptable condition.

PennDOT established the major objectives of restoring and reconciling Pennsylvania's state system of highways and bridges. Integral to meeting these objectives is the resurfacing of 625 mi of non-Interstate highway annually and the application of surface treatment to 5,460 mi of relatively low-volume state highway. Table 1 compares the annual goals (based on the major objectives) with the level

DISTRICT: ____________

COUNTY: ____________

ITEMS	RECOMMENDED CYCLE	83/84		84/85		85/86		86/87		TOTAL	
		$	P/U	$	P/U	$	P/U	$	P/U	$	P/U
MANUAL PATCH - TONS	AS NEEDED										
MECHANIZED PATCHING-TONS	AS NEEDED										
LIQUID BITUMINOUS SURFACE TREATMENT-GAL.	5 - 7 YEARS										
SKIN PATCH - GAL.	AS NEEDED										
CRACK SEAL - GAL.	AS NEEDED										
SCRATCH COAT - TONS	5 - 7 YEARS										
JOINT SEAL - GAL.	5 YEARS										
SHOULDER GRADING-FEET	AS NEEDED										
SHOULDER CUTTING-FEET	3 YEARS										
DITCH CLEANING FEET	AS NEEDED										
PIPE REPLACEMENT - FEET	METAL 30 YEARS										

FIGURE 3 Selected routine maintenance activities.

TABLE 1 Surface Improvements

District	Resurfacing		Surface Treatment	
	Business Plan	Goal	Business Plan	Goal
1-0	61	49	665	532
2-0	27	27	574	545
3-0	54	32	766	650
4-0	50	47	565	495
5-0	83	65	481	436
6-0	120	148	386	325
8-0	95	87	752	756
9-0	43	38	645	535
10-0	31	32	259	484
11-0	35	59	281	170
12-0	45	41	710	531
Total	644	625	6,084	5,460

Note: Improvements are expressed as miles resurfaced or treated annually.

of activity in each district based on the business plans.

District efforts in achieving surface improvement goals are shown schematically in Figures 4 and 5. Although statewide surface improvement goals were met, specific districts could not meet their individual goals for resurfacing or surface treatment. In addition, in several business plans concerns were expressed about the impact of truck traffic, climate, and drainage factors on goal achievement.

Roadway plans also included the completion of the Interstate system and selected economic development highways within the commonwealth. Routine maintenance activities evaluated included manual patching, mechanized patching, liquid bituminous surface treatment, skin patching, crack sealing, scratch coating, joint sealing, shoulder grading, shoulder cutting, ditch cleaning, and pipe replacement. These activities were covered in relation to cycle times. Although most districts were addressing routine maintenance at an acceptable level, several concerns were raised as to the trade-offs between maintenance activities and goals in surface treatment or resurfacing.

All roadway activities were viewed from the perspective of decisions to make or buy, that is, whether the department should contract for services or perform the services with department personnel. It was generally agreed that there is a need to develop general methodologies to decide which activities are most cost-effective when done by consultant and which when done in house.

Integrated Bridge Program

Pennsylvania's bridge problem differs in many respects from its roadway problem. Deficient bridges are a major deterrent to the overall commonwealth goal of economic development. Whereas poor roads affect all vehicles, weakened bridges initially affect just heavier trucks. A deteriorated bridge system hinders development of natural resources such as bituminous and anthracite coal, natural gas, and timber; the shipment of agricultural and manufactured products; as well as economic development opportunities.

Pennsylvania's billion-dollar bridge program has made Pennsylvania a national leader in bridge repair and replacement. However, this extensive program has only scratched the surface of the bridge problem. Much more needs to be accomplished to eliminate the backlog of bridge restrictions on the commonwealth's highways. There was general agreement that although this program is having a major impact, there is a need to find ways to extend the program if Pennsylvania's highways are to be kept open to heavy traffic.

The 4-year business plan developed an integrated bridge program. Plans included not only necessary capital improvements but rehabilitation, corrective and preventive maintenance, and bridge painting. The business planning process provided the first opportunity for PennDOT and each district to examine the total program being applied to bridges. This was particularly evident in the importance placed by each district on evaluating its proper level of preventive and corrective maintenance.

Bridge painting was found to be an area where funding is generally not adequate. Business plans expressed special concern for painting of large

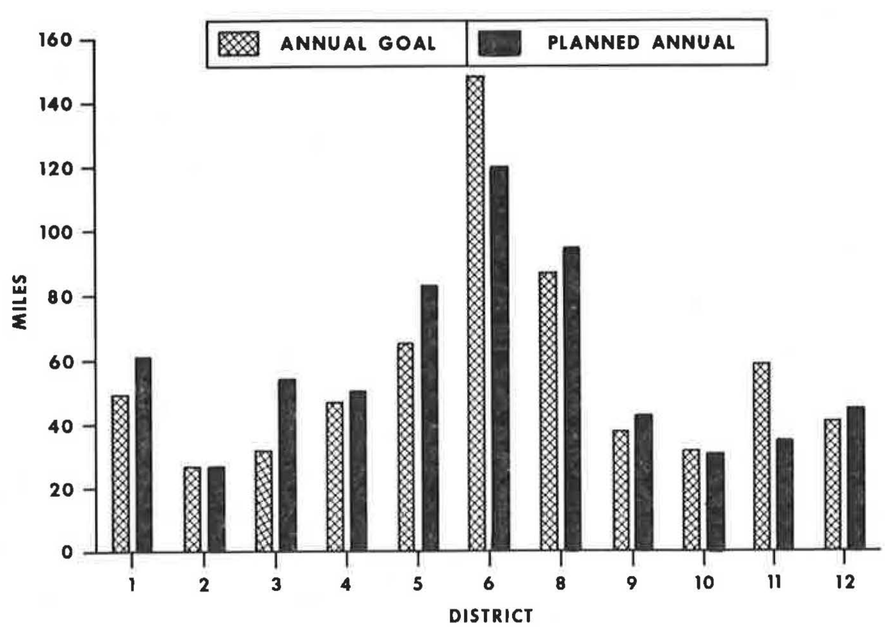

FIGURE 4 Resurfacing: business plan versus annual goal.

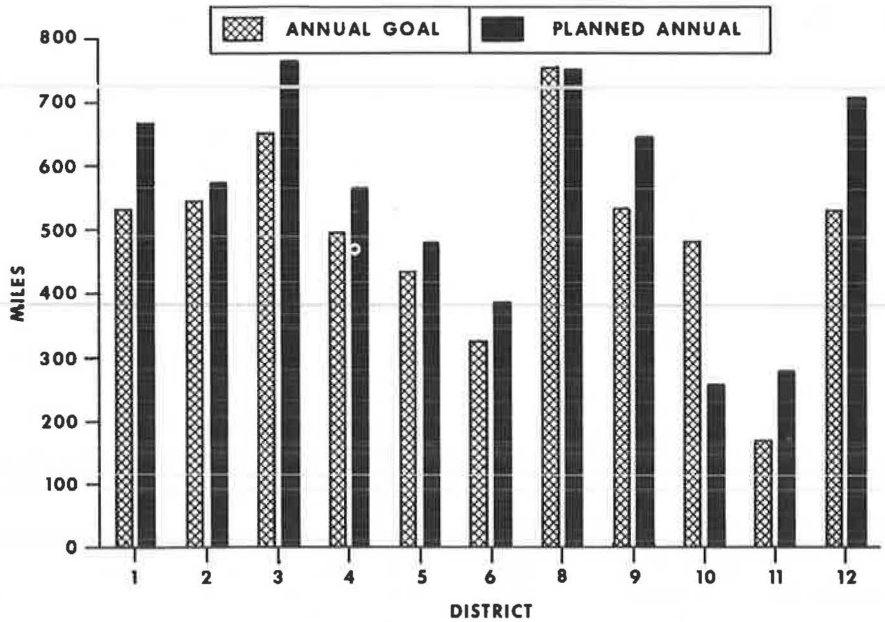

FIGURE 5 Surface treatment: business plan versus annual goal.

steel structures. Cost for bridge painting is currently funded from general county maintenance budgets, but the cost of painting such large structures is sometimes beyond the capability of a small county. Several plans requested an examination into gaining federal participation in this program. Although there is no surplus of federal aid, this approach would allow greater flexibility in dealing with county funding limitations.

Highway Transfer Program

One of the key elements in moving the department toward a cyclical maintenance approach is the reduction of the overall size of the state highway system. As started earlier, PennDOT is responsible for twice the percentage of mileage that most other states assume. By transferring the functions of local roads to municipalities, the department will be able to concentrate its efforts on those roads that serve a statewide purpose. Legislation in 1983 established funding for highway transfer rehabilitation and annual maintenance. This funding has been very effective in encouraging Pennsylvania's municipalities to assume ownership responsibility. In short, the program is beneficial to the department and to the local governments.

The business plans developed strategies for transferring mileage to local governments as well as strategies for the prerequisite rehabilitation efforts. Over the 4-year planning period approximately 1,700 mi can be transferred out of a total candidate number of nearly 12,000 mi. All districts believed that this program was working well, but additional funding is needed to transfer responsibility for additional mileage.

Equipment

Although the equipment budget and requirements appear meager compared with the highway and bridge program requirements, it is vital that an adequate and modern equipment fleet be maintained in order to provide the commonwealth with transportation services.

Business plans evaluated the 4-year projections of the equipment fleet from an age and utility point of view. District equipment considered in the planning process included large equipment such as trucks, loaders, and graders as well as snow plows, crew cabs, spreaders, and pothole-patching equipment.

With only a few exceptions, there was a belief that there exists a backlog in maintenance equipment replacement. Specifically, crew cabs and older trucks are requiring extensive repair and breaking down too frequently. The department's maintenance costs, and in some cases maintenance service, are being adversely affected by equipment age. The department's $16.3 million equipment budget is extremely small in relation to the programs it supports. Larger equipment is also procured on lease-purchase agreements. An increasingly large portion of the equipment budget is being directed along this line, which results in less available dollars for purchase of new equipment.

The majority of districts are requesting specialized equipment for productivity improvements. Of special interest are microcomputers and computer-assisted drafting and design equipment.

Buildings and Grounds

As with equipment, a minimum program for buildings and grounds must be sustained in order to productively support the department's other program requirements.

Although the business plans recommended various repairs and improvements to existing district and county office buildings for energy conservation and other purposes, the principal effort was related to the department's program of consolidating and developing its winter services stockpiles. It became evident that the department must accelerate installation of salt storage facilities through a rational process that takes into account the environment of each situation.

Human Resources

Another area addressed in the district plans pertained to personnel. Several points emerged from the plans:

- There is a need to better focus training toward real work activities. One business plan suggested use of field trailers so training could be held near work sites.
- Cross-training is becoming an effective method of achieving better production from the work force.
- The department's extensive plan to add and update new computer systems creates a considerable need for systems training and orientation. This need must be met if the department is to realize gains in productivity.
- Because the department relies more heavily on consultant design agreements, it is imperative to ensure responsible performance from these consultants.
- A number of districts presented profiles of employee age. Some districts project specific needs in critical work areas or skills. This will greatly assist the Bureau of Personnel in determining where the greatest recruitment and training efforts should be concentrated to avoid lapses in delivering transportation services.

FUTURE DIRECTIONS

One of the greatest benefits of the 4-year business plans, beyond the guidance of the documents themselves, was the initiation of the planning process in the district offices by district management.

An immediate outgrowth of the business planning process was the development of a categorical budget for the department. District evaluations of minimum service levels served as the basis for requirements of both a capital and operational nature at the district level. District business plans will now serve to rebudget resources and to document requirements for future funding initiatives.

Four-year district business plans were initially successful in Pennsylvania and will be continued as overall guidance to district engineering operations. The plan presentations proved to be a valuable communications tool. These presentations provide a unique opportunity for each district engineer to meet with top management to discuss the operations, successes, and shortfalls of the district.

In summary, the 4-year district business planning process is a major initiative of the department. This multiyear planning process at the district level will assist the districts in

- Working toward the department's major objectives,
- Ensuring that individual annual program-level elements are developed and implemented consistent with the department's major objectives, and
- Supporting a businesslike approach to management at the district level.

The business plans integrate individual district planning efforts into a single unified operating document and form the blueprint of district capability, with the intent to develop an annual process that will produce the variety of annual program elements as byproducts of a larger integrated management process.

Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Microcomputer Allocation of Manpower to Illinois State Police Districts

RICHARD A. RAUB

ABSTRACT

Mathematical models developed to allocate police officers have been oriented toward urban policing. As such, they depend on a backup police unit to service a call when the primary unit is not available. The number of units assigned minimizes response time while maximizing use of available manpower. Policing in a large geographic area such as a state has different constraints. Secondary responding units rarely are available immediately. Allocation of a scarce resource statewide must equitably satisfy both the high and low demand for services, and it must provide visible preventive patrol. The model developed for the Department of Law Enforcement of the state of Illinois attempts to provide adequate administrative assignment, satisfy demands for response, and equalize patrolling. Administrative support required to run the operation both centrally and on the district level is decided a priori. It is excluded from the mathematical allocations. Response to calls for service is handled by individual patrolling units with one or more officers. The number required depends on the expected number of calls and their duration. On the other hand, patrolling visibility is dependent on the size of the rural population and the length and volume of traffic on various types of rural highways. This model can be run on a microcomputer. Its current version allows allocations for up to 110 counties combined into 30 district commands. The processes are described briefly and the output generated is shown. It is also shown that the model is applicable to uses other than those of state police.

The Illinois Department of Law Enforcement (DLE) required a method for allocating officers throughout the state. Procedures originally used had been designed around obligated and unobligated time (1). These, however, gave too much weight to service in urban areas and tended to ignore rural areas. Existing mathematical models developed by Larson (2), Chaiken (3), and LeGrande (4) also apply to urban areas. They depend on availability of more than one unit to service a call and minimize response time. On a statewide basis, this condition does not exist. Response time is measured in the tens of minutes and is not as critically related to the police role as it is in an urban area. Finally, preventive patrol plays an important role.

In designing a model for the DLE state police, two factors were taken into account: balancing response to calls for service and providing a visible patrol throughout the state. Further, because the state police operate from more than two semiindependent substations, called districts, allocations had to account for administrative activity.

A model for the Division of State Police was developed in 1981. By 1982, the department was operating it on the main computer. State police executives were using it to help plan staffing for district operations, to assign newly graduated officers, and to support budget requirements. Several reports by Raub and Sweat have described this model in great detail (5,6). To make it more efficient, the methodology has been revised and programmed for a microcomputer (Apple II Plus in BASIC). This paper describes the model briefly and shows the type of output available.

METHODOLOGY

General Description

The model has three sections: administrative support, response to calls for service, and preventive patrol, which is titled Policing and Patrolling. Administrative support is fixed by the police executives for districts and the central office. Allocations for the other two sections are computed for each county for the three shifts and then aggregated to districts (Figure 1). There is flexibility in that either a fixed body of officers can be allocated or the total strength required can be computed from a given set of parameters.

Administrative Support

The number of officers needed to administer the state police are established externally to the model. Each district commander along with the superintendent and staff review their needs for command personnel and for officers assigned to specialized details such as public information. Officers in these categories are not expected to be available, generally, to respond to accidents or to patrol. This group constitutes the administrative support. It is subtracted from the number of officers to be assigned before operation of the model.

The administrative support is established for each district as well as for the central office. Its distribution is shown on the output summary sheet. That a given number of officers is assigned to administrative support in a district does not affect how the model assigns the remaining officers to that district. All districts receive allocations of remaining officers (after subtracting administrative support) based on the needs of those districts.

Calls for Service

Officers must be available to answer calls for service. These are classified as responses to events normally not seen on patrol. The two that account for most of the time are accidents and criminal com-

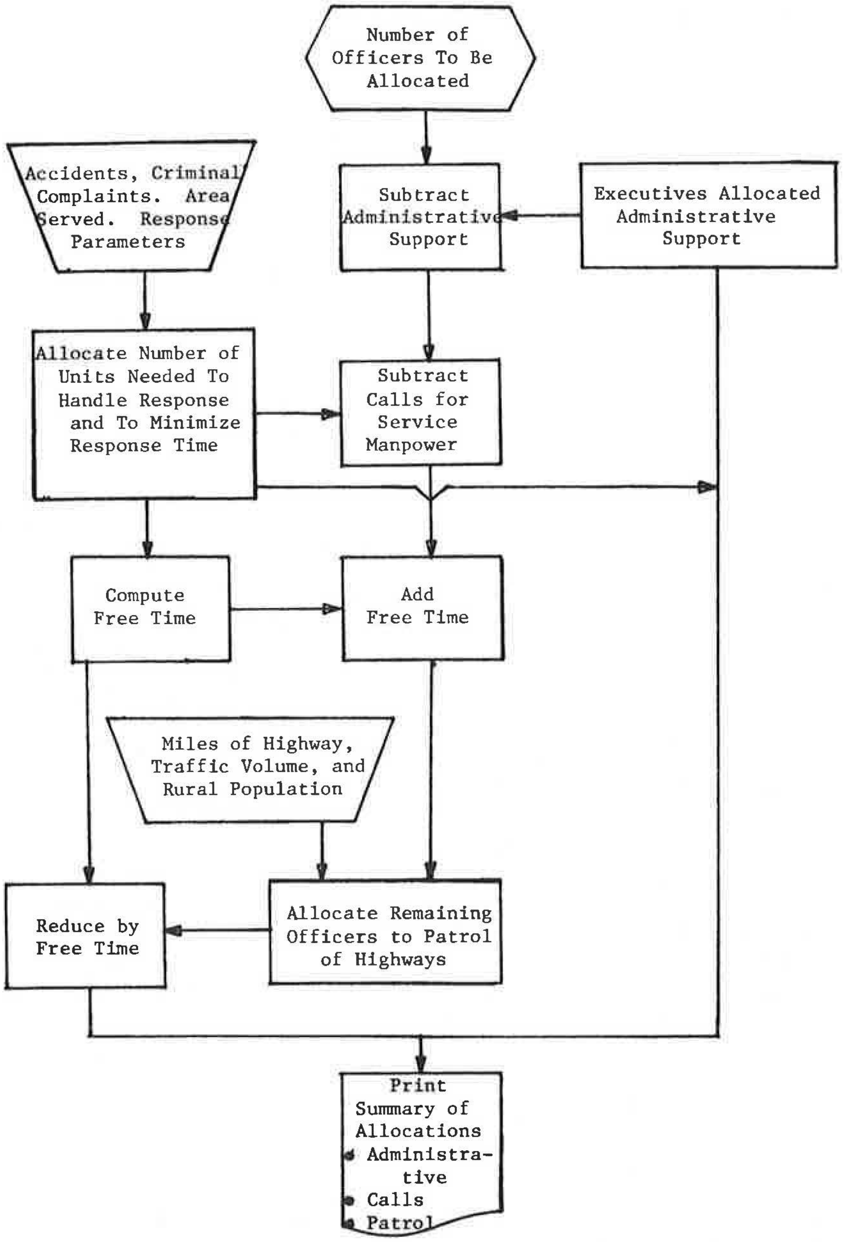

FIGURE 1 Allocation methodology.

plaints. In both cases, these responses are limited to events in rural areas, except for accidents occurring on all Interstate highways outside the city of Chicago.

The bases for assignment are accidents and criminal complaints handled in the previous year. There is potential for bias resulting from using self-reported statistics; however, the occurrence of both events is beyond the control of the police. Also known for each accident and criminal complaint is the average time taken to handle one event. Their occurrence, because it is random, is best predicted by a Poisson distribution using for lambda a uniform expected rate during the time required to handle one event.

The model assumes that one patrolling unit is assigned to one event. Therefore, by predicting the percentage of the time that zero, one, two, or more events will occur, it predicts the number of patrolling units required. At some point, the addition of patrolling units is not practical. If one unit will handle 95 percent of all occurrences, the second will handle less than 5 percent. Addition of a second unit may not be practical in terms of resources expended to serve a small fraction of activity. In reality, the police do not handle all events as they occur. The queue is served from other resources including other law enforcement agencies, delayed response, or reassignment of an active unit. Therefore, the limit to assignment of patrolling units is set at a service level expressed at some percentage less than 100.

Average rate of event occurrence per shift (lambda):

$$m_s = tpX'_s/(365h_s) \quad (1)$$

where

m_s = lambda or average rate per period t;
t = time taken to handle one event, accident, or criminal complaint;
p = proportion handled (used to adjust arrival

rates when other conditions are being tested);

X_s' = number of accidents or criminal complaints during shift s; and

h_s = hours of work during shift s for each of 365 days.

Likelihood of event occurrence:

$$P(X)_s = \exp(-m_s) m_s^X / X! \quad (2)$$

$$\text{Repeat until } \sum_s P(X)_s \geq q_s \quad (2a)$$

where

$P(X)_s$ = probability of X events occurring during shift s,

exp = natural log,

X = any integer $\geq$ 0, and

q_s = proportion of calls (accidents or criminal complaints) to be served immediately during shift s.

Note: $P(X)_s$ is computed separately for accidents and for criminal complaints.

The model solves for the number of units needed for each shift within a county to respond to accidents and criminal complaints. These are combined to become number of units required for calls for service. Because of the relative infrequency of events in many locations, zero units will be required. Yet, because of the statewide function of the police, there must be a unit available, even if that patrol covers more than one county.

The number of patrols required if there are insufficient patrols to handle calls for service then is the number needed to meet a maximum response time for each shift. State police executives establish this maximum for each shift. The number of patrols needed to meet the maximum response time is the average travel time between any two points divided by the maximum response time. Congestion and the type of roads available are considered in the equation when the number of patrols required is computed. The average mileage that translates to travel time in two counties may be the same, but because congestion reduces the average response speed in one, the number of patrols required to meet the response time differs. For the model, congestion is a function of average daily traffic (ADT); its formulation is based on the AASHTO results (7,p.96). Although this is a simplistic approach, its purpose is to distinguish between rural and urban areas; it is not for precision.

Reduction in speed for congestion:

Interstate

$$f_j = [55 - 0.07(V_j w_s)^{1/2}]/55 \quad (3a)$$

Two-lane heavily traveled

$$f_k = [55 - 0.04(V_k w_s)^{1/2}]/55 \quad (3b)$$

where

f_j, f_k = reduction in speed resulting from congestion on Interstate (j) and heavily traveled two-lane roads (k),

55 = assumed maximum speed and basis from which congestion is computed,

w_s = proportion of ADT during shift s, and

V_j, V_k = ADT on Interstate (j) and heavily traveled two-lane roads (k).

Reduction in emergency response speed:

$$v' = (f_j M_j + f_k M_k)/(M_j + M_k) \quad (4)$$

where v' is the proportionate decrease in emergency driving speed and M_j, M_k is the miles of highway in any county, Interstate (j), and heavily traveled two-lane road (k).

Number of patrols required to serve maximum response:

$$X_d' = 2(Q)^{1/2}/3(d_s v') \quad (5)$$

where

X_d' = number of patrols required to minimize response time,

d_s = maximum response time during shift s, and

Q = area of a county in square miles.

The number of units assigned to calls for service or response time (Figure 2) depends on which need is greater. These then are aggregated by shift and then by county into districts. Patrolling positions are converted to officers. It takes between 1.5 and 2.0 officers to serve one patrolling position on a year-round basis. This value is derived from the number of annual hours in a shift divided by the number of manhours of work performed annually by one officer. For the model, the number of manhours worked per year is entered as a parameter.

Number of patrols to handle call:

$$X_c' = \max(X_a' + X_b', X_d) \quad (6)$$

where

X_c' = number of patrols needed to handle calls for service,

X_a' = number of patrols to handle accidents from the integer X in Equation 2 that satisfies expression 2a, and

X_b' = number of patrols to handle criminal complaints from expression 2a.

Number of officers:

$$X_c = X_c' c_s \quad (7)$$

where X_c is the number of officers assigned and c_s is the conversion factor for patrols to officers found from dividing annual manhours by manhours worked per officer.

When a fixed number of officers is allocated, the number required for calls could exceed the available amount. Decreases in allocation would arise from reducing the percentage of calls served immediately or increasing response time. A sample of the output received from a microcomputer for this section is shown as Figure 3.

Policing and Patrolling

After administrative support and calls for service are subtracted, some officers remain unallocated. In addition, some officers who have been allocated to calls for service may not be busy with a call. Only a small percentage of the manhours allocated to calls for service is required to handle those services. Much of the time is available for other work or is not obligated. This time is also available for preventive patrol. The total of officers not assigned and not obligated is allocated to patrolling highways and assisting local law enforcement officers as shown in Figure 4.

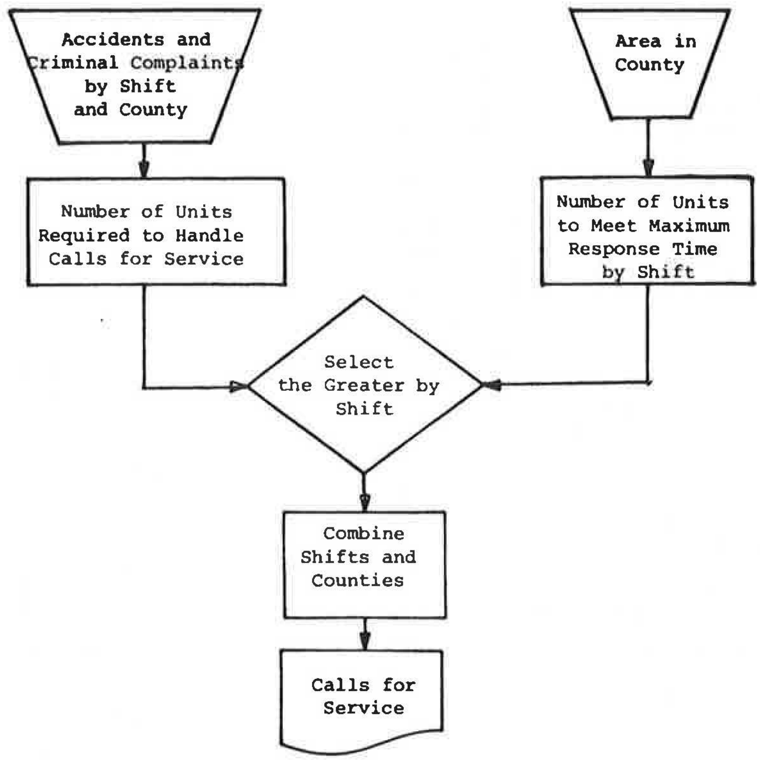

FIGURE 2 Allocating to calls for service.

Manpower to be allocated 380
Allocated to calls 113.2

ACCIDENTS

Dist.	Total NBR	1st NBR	1st POS	2nd NBR	2nd POS	3rd NBR	3rd POS
1	4154	671	2.0	1850	5.0	1633	5.0
2	7280	1020	2.0	2950	6.0	3310	7.0
3	1308	261	0.0	484	5.0	563	5.0
4	876	186	0.0	331	4.0	359	4.0
TOT	13618	2138	4.0	5615	20.0	5865	21.0

CRIMINAL COMPLAINTS

Dist.	Total NBR	1st NBR	1st POS	2nd NBR	2nd POS	3rd NBR	3rd POS
1	2142	530	2.0	966	3.0	646	3.0
2	3701	886	2.0	1730	4.0	1085	3.0
3	519	97	0.0	232	0.0	190	0.0
4	1237	247	1.0	474	1.0	516	2.0
TOT	599	1760	5.0	3402	8.0	2437	8.0

MINIMUM RESPONSE
Positions Per Shift

Dist.	1st	2nd	3rd
1	.4	1.6	1.6
2	.2	1.0	1.0
3	1.1	4.3	4.3
4	.8	3.1	3.1

TOTAL MANPOWER ALLOCATED
Positions Per Shift

Dist.	1st	2nd	3rd	Total Officers	Equiv. Patrols
1	4.0	8.0	8.0	33.2	22.3
2	4.0	10.0	10.0	39.8	20.7
3	1.1	5.3	5.2	19.2	16.1
4	1.6	5.0	6.0	20.9	17.0
TOT	10.7	28.3	29.2	113.2	76.1

Totals

Accidents	13618
Criminal Response	7599
Allocated to Calls	113.2

FIGURE 3 Microcomputer output: calls for service.

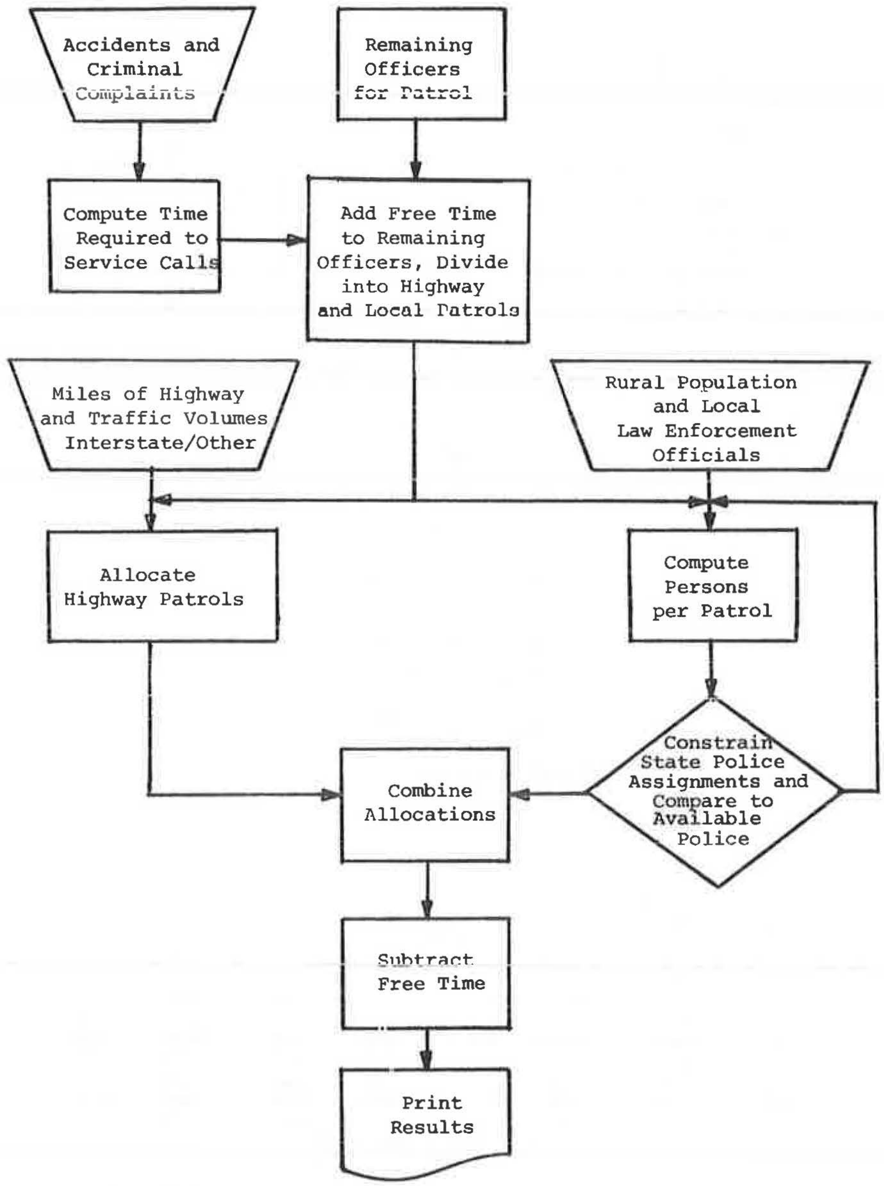

FIGURE 4 Policing and patrolling allocations.

Officers available:

$$X_p = T - O - X_c \quad (8)$$

where

X_p = officers not otherwise allocated,
T = total strength, and
O = administrative support.

Adjusted number including unobligated time:

$$X_p' = \{X_p + [(m - m')(X_c - \bar{t}C)]/m\}/c_s \quad (9)$$

where

X_p' = equivalent positions for patrol;
m = number of annual manhours worked per officer;
m' = number of nonproductive hours, generally represented by 2 hr for each working day ($m' = 2m/h_s$, where h_s is hours of work during shift s for each of 365 days);
$\bar{t}$ = average time to handle one call (accident or criminal complaint); and
C = number of calls (accidents and criminal complaints).

Available for patrol:
Interstate

$$X_f' = p_f X_p' \quad (10a)$$

All other highway

$$X_o' = p_o X_p' \quad (10b)$$

Rural law enforcement

$$X_r' = p_r X_p' \quad (10c)$$

where X_f', X_o', and X_r' are positions available for Interstate and two-lane patrol and for rural law enforcement and p_f, p_o, and p_r are proportion of positions to be assigned to Interstate patrol, other highway patrol, and as assistance to local law enforcement officers.

In allocating positions to patrolling, the user has the option of how much weight, in terms of percentage of available positions, is placed on each of the three categories of patrol: Interstate highway, other highway, and assistance to local law enforcement personnel. Distribution of positions by the model to counties is made according to the miles of highway based on the average speed of a patrolling vehicle, which is a function of congestion and stops to handle traffic incidents. Assistance to local law enforcement is dependent on the rural population.

Volume of traffic affects the number of miles to be patrolled. The annual time taken for traffic enforcement and assistance to motorists shows a strong linear relationship to daily vehicle miles. This time is subtracted from available time before patrolling mileage is computed. The amount of miles that can be patrolled depends on patrolling speed; this decreases because of congestion, which has earlier been shown as a function of ADT. Because a fixed number of officers is being allocated among all highway mileage, the average miles of patrol per unit is solved. The following equations show the solution for both Interstate and other highways.

Time required for traffic-related work:

$$t_j = 0.96 M_j V_j w_s \quad (11a)$$

$$t_k = 3.56 M_k V_k w_s \quad (11b)$$

$$t_l = 1.15 M_l V_l w_s \quad (11c)$$

where

t_j, t_k, t_l = time in hours required to enforce traffic laws,
M_j, M_k, M_l = miles of highway in each county for each of the three types of highway,
V_j, V_k, V_l = ADT on each type of highway, and
w_s = percentage of traffic in shift s.

Positions remaining for patrolling:

$$X'' = X'_f - \sum_i [\sum_s t_{jsi}/(365 h_s)] \quad (12)$$

where

X'' = number of positions available for patrol less time taken for traffic-related activities,
t_{jsi} = time required to perform traffic-related functions on Interstate highways from Equation 11a during shift s in county i, and
h_s = hours in shift s.

Note: the time is summed over all shifts s and all counties i.

Average miles of patrol per position:

$$\overline{M}_j = \sum_s \sum_i (M_{ji}/f_{jsi})/X'' \quad (13)$$

where

$\overline{M}_j$ = average miles of patrol per position on Interstate highways (j),
M_{ji} = miles of Interstate highway in county i, and
f_{jsi} = reduction in speed because of congestion during shift s in county i (from Equation 3a).

After the average miles of patrol statewide is computed, the number of positions per shift is obtained. This is done by dividing the adjusted miles in each county (adjusted for congestion by shift) by the average miles of patrol statewide as shown in Equation 13. Equations 12 through 14 are shown for Interstate highways. The formulas for computing patrols on other highways are similar and are shown starting with Equation 15.

Patrol positions during shift s in county i:

$$X'_{fsi} = [M_{ji}/(f_{jsi}\overline{M}_j)] + [t_{jsi}/(365 h_s)] \quad (14)$$

where X'_{fsi} is the positions for patrolling Interstate highways in county i during shift s and all other variables have been described earlier.

Two-lane highway patrol:

$$X'' = X'_o - \sum_i [\sum_s (t_{ksi} + t_{lsi})/(365 h_s)] - [\sum_i M_{li}]/\overline{M}_l \quad (15)$$

where

t_{ksi}, t_{lsi} = time required to perform traffic related activity, from Equations 11b and 11c,
M_{li} = miles of low-volume highway in county i, and
$\overline{M}_l$ = average miles of patrol for low-volume highways (must be supplied externally).

Average miles of high-volume two-lane patrol:

$$\overline{M}_k = [\sum_s \sum_i (M_{ki}/f_{ksi})]/X'' \quad (16)$$

Patrolling positions for all two-lane roads:

$$X'_{osi} = [M_{ki}/(f_{ksi}\overline{M}_k)] + [M_{li}/\overline{M}_l] + [(t_{ksi} + t_{lsi})/(365 h_s)] \quad (17)$$

Rural Patrol

Allocation to assist rural law enforcement is based on rural population. The model solves for the number of rural persons per police patrol (state and local combined) and then allocates all rural police on the basis of that rural population. State police are assigned only when there are not sufficient local police. To prevent assignment of all available state police to one county, a maximum number of positions is set for any county. Likewise, negative assignment is possible but not necessarily desired. A minimum number of positions per county controls this.

Estimated rural population per law enforcement patrol:

$$R = \sum_i P_i/(X'_r + \sum_i L_i) \quad (18)$$

where

R = persons per law enforcement patrol,
P_i = rural population in county i, and
L_i = local law enforcement patrols in county i.

Note: for each county, the number of state police patrols is computed per shift from

$$X'_{rsi} = P_i/R - L_i \quad (19)$$

X'_{rsi} is constrained to a minimum and a maximum and then $\sum X'_{rsi}$ is compared with X'_r. If the former is larger, R must be increased. If it is smaller, R is decreased. The computation again is performed.

Once all equivalent positions are allocated, the free time from officers allocated to calls for service is removed according to the percentage of free time originally added. Remaining are those positions allocated to policing and patrolling. These positions also are summed by the three shifts in each county and then summed into districts. The output from a computer program to operate the model is shown in Figure 5.

Adjustment factors:

$$f_d = \sum_s \sum_i [X'_{psi}/(X_{csi} + X'_{psi})] \quad (20a)$$

$$u_{dsi} = f_d(X_{csi} + X'_{psi})/X'_{psi} \quad (20b)$$

Policing and patrolling positions:

$$X'_f = u_{dsi}X'_{fsi} \quad (21a)$$

$$X'_o = u_{dsi}X'_{osi} \quad (21b)$$

$$X'_r = u_{dsi}X'_{rsi} \quad (21c)$$

where

- f_d, u_{dsi} = adjustment factors, where f_d is the general statewide factor and u_{dsi} is the factor for each county and shift;
- X'_{psi} = adjusted number of positions available for policing and patrolling from Equation 9;
- X'_f, X'_o, X'_r = final positions assigned to Interstate, two-lane, and rural patrols; and
- X_{csi} = persons assigned to calls for service from Equation 7.

Officers assigned:

$$X_f = X'_f c_s \quad (22)$$

where X_f is officers assigned and c_s is officers per position. (Note: X_o and X_r are solved similarly by substituting X'_o and X'_r for X'_f.)

Adding together administrative support, calls for service, and policing and patrolling for each district yields the number of officers that should be allocated (Figure 6). During this process, the distribution, except for administrative support, has

Available to be allocated 178.9

FOUR-LANE HIGHWAYS

Dist	Total Miles	Positions Per Shift 1st	2nd	3rd	TOT
1	102.0	4.4	4.6	4.6	13.6
2	180.0	8.6	9.8	9.6	28.0
3	204.0	0.0	7.8	7.8	15.6
4	123.0	0.0	4.8	4.8	9.6
TOT	609.0	13.0	27.0	26.8	66.8

OTHER HIGHWAYS

Dist.	Total Miles 2-Lane	Other	Position Per Shift 1st	2nd	3rd	TOT
1	830.0	465.0	2.5	3.5	3.3	9.3
2	240.0	100.0	1.0	1.8	1.7	4.5
3	2140.0	2020.0	0.0	6.9	6.6	13.5
4	1390.0	1335.0	0.0	4.6	4.4	9.0
TOT	4600.0	3920.0	3.5	16.8	16.0	36.3

RURAL LAW ENFORCEMENT

Dist	Local Police	Positions Per Shift 1st	2nd	3rd	TOT
1	38	0.0	0.0	0.0	0.0
2	74	0.0	0.0	0.0	0.0
3	26	0.0	1.5	1.5	3.0
4	27	0.0	.8	.8	1.6
TOT	165	0.0	2.3	2.3	4.6

MANPOWER ALLOCATED

Dist	Positions Per Shift 1st	2nd	3rd	TOT	Total Officers
1	6.9	8.1	7.9	22.9	38.0
2	9.6	11.6	11.3	32.5	53.9
3	0.0	16.2	15.9	32.1	53.3
4	0.0	10.2	10.0	20.2	33.5
TOT	16.5	46.1	45.1	107.7	178.7

Miles of Patrol Per Position

4-Lane	17.3
2-Lane	306.2
Other	6000

Rural Pop./Police Officer 6265

Total Allocated to Patrol 178.7

FIGURE 5 Microcomputer output: rural patrol.

Dist.	Admin. Support	Calls for Service	Police and Patrol	Total Allocation
1	18	33.2	38.0	89.2
2	22	39.8	53.9	115.7
3	10	19.2	53.3	82.5
4	8	20.9	33.5	62.4
Staff	30			
TOT	88	113.2	178.7	379.9

FIGURE 6 Microcomputer output: summary of allocations.

been generated mathematically. Control is exercised through parameters that can be changed to reflect different policing philosophies. For example, greater involvement in handling accidents would result from increasing the average time taken to handle an accident. More emphasis on supporting rural law enforcement is established by assigning a greater percentage of patrolling to this function.

This methodology, although it includes a substantial number of steps, is not complex. It lends itself readily to computer application. For this reason, the Illinois DLE has prepared the program for an Apple II in Applesoft BASIC and will be converting it to an IBM PC XT.

COMPUTER APPLICATION

Overview

The model is run in two programs: FACTOR INPUT and MANPOWER. It requires both parameters and variables. Parameters generally are those values that affect the overall operation of the model. Variables are the base data generally available for each county. A separate program handles initial entries or updating of the parameters and variables. All values are stored permanently; one read-write disk is all that is required to run the entire program. Currently the computer used can handle up to 110 counties and 30 districts. The limitation is the 32,000-byte free storage on the Apple II Plus; recoding to the IBM PC XT will allow a larger base for allocation.

There are 18 sets of parameters that must be entered, including 39 different values. These are summarized as follows:

- Total officers to be allocated
- Number of counties in state
- Number of districts in state
- Manhours per year per officer
- Enforcement time (time per stop in hours)
- Minimum and maximum number of state police patrols per shift (rural)
- Percentage of ADT during each shift
- Maximum response time in minutes for each shift
- Patrol miles per position for other rural roads
- Percentage of patrolling assigned to four-lane and other highways and to rural policing
- Accidents and criminal complaints (percentage handled)
- Accidents (time in hours to handle)
- Accidents (percentage queued during each shift)
- Starting and ending times of each shift
- Shift coverage factor for each shift in each district

All, except the shift coverage factors, apply to the state as a whole. Shift coverage is a binary integer where 1 is coverage and 0 is no coverage. It is considered one parameter even though there are three factors for each district representing each of the three shifts.

Entry of Parameters and Variables

Both the variables and parameters can be entered or changed either by running the program FACTOR INPUT directly or through the main program MANPOWER, which automatically calls FACTOR INPUT. This program then allows the user to enter or change any piece of information in either the parameter or variable data file. The user also can print out the values of either of the files.

Variables represent those values that are used as the data base from which the model derives its computations. Except for the administrative support (overhead), which is shown for each of the districts, all remaining values apply to each of the counties. The variables for the model are as follows:

- Administrative support for each district (k) and central office
- Administrative support for central office
- Accidents for each shift for county i
- Criminal complaints for each shift for county i
- Miles of four-lane, two-lane, and other rural highway for county i
- Two-lane, high-volume, and other rural
- Volume of traffic, expressed in thousands of vehicle miles, on four-lane, two-lane, and other rural for county i
- Rural population for county i
- Area in square miles in county i
- Local law enforcement officers in county i

Entry of data into either the parameter file or the variable file is performed in the same manner. The computer displays a list of parameter or variable names along with the current value of each. When data first are entered, the values are blank. For the variables, except for the first two pages shown on the monitor (number of counties and districts and administrative support), each page shows all variable values for each county number. Individual values may be changed or skipped. Entire pages may be skipped or recalled.

Running the Allocation Model

The operation of the allocation model is controlled by the program MANPOWER. Because of the length and amount of output, a printer must be available. Once the program is started, and there are no changes to parameters or factors, the allocation runs automatically. Computations are made and output generated on the printer. Because of the large number of computations that are made, the program runs on the Apple II at the rate of approximately 4 min for every 10 counties.

Changes can be made to parameters in order to examine the effect of these changes on the allocation. Any changes must be made at the start of the allocation program, and then the entire program is run. Because of the limited space in the computer, such changes must be stored permanently. Only one run is made for each set of parameters. However, when conversion is made to a more powerful microcomputer, the user will be able to establish a range for one or more parameters. The program will automatically generate output for each of the parameters selected.

SUMMARY

More than 3 years have passed since the model first was loaded on the DLE main computer. Numerous runs have been made. The Division of State Police has used it frequently both as a tool for planning and 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.

ACKNOWLEDGMENT

The initial development of the model was a joint effort between the author and George Sweat, Commander, Criminal Intelligence, for the Illinois Department of Law Enforcement. Through his efforts the concepts were organized and tested. Additional acknowledgment is given to the Division of State Police; its recently retired Superintendent, R. Joseph Miller, now with Federal Training Academy; and to Deputy Superintendent William Pierce. They have used the output and made numerous valuable suggestions for its improvement.

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Publication of this paper sponsored by Committee on Manpower Management and Productivity.

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

KUMARES C. SINHA and KANG HU

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

	Objective of Work Activities			
Work Activity	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.

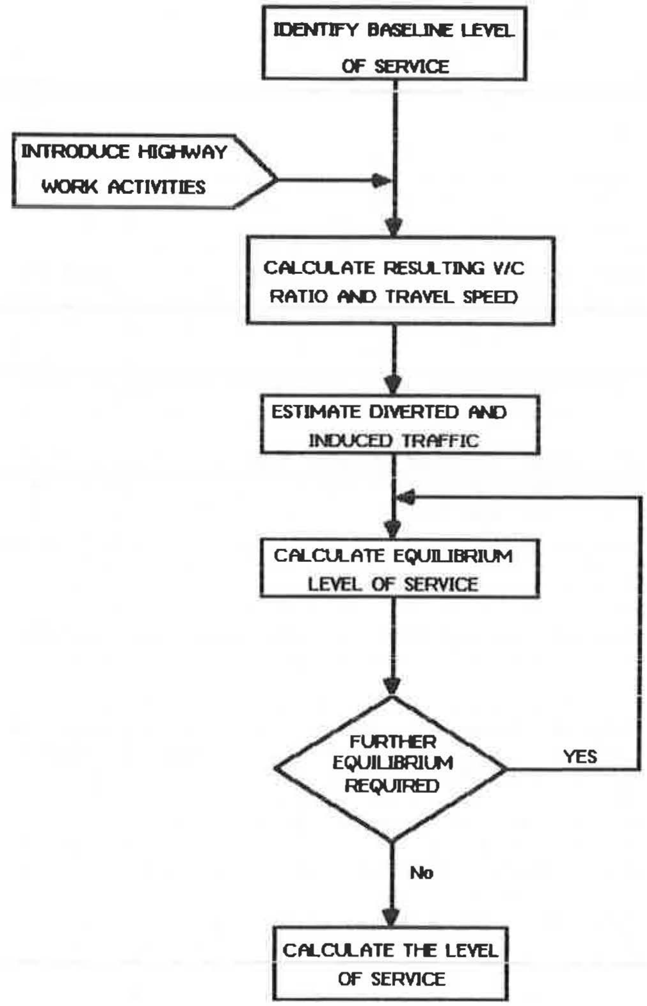

FIGURE 1 Flowchart of impact assessment on level of service *(7)*.

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.

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.

ACKNOWLEDGMENT

This project from which the paper has been prepared was funded by a contract from the Research and Special Programs Administration of the U.S. Department of Transportation. The authors acknowledge the assistance of T. William Patterson and Ellen Moodie in editing the manuscript.

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The authors are solely responsible for the contents of this paper.

Publication of this paper sponsored by Committee on Transportation Programming, Planning and Systems Evaluation.

Development of a Strategic Management Process: A Case Study of the Pennsylvania Department of Transportation

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ABSTRACT

There is a paucity of literature concerning strategic planning in the public sector. The purpose of this paper is to fill this gap with a case study of the Pennsylvania Department of Transportation (PennDOT). Strategic management in PennDOT evolved as a result of top management's determination to establish priorities and set direction for the agency. A broad organizational-level perspective was pursued; program and project-level planning were decentralized. A strategic management committee and seven substantive subcommittees have been established to set direction and manage change. This committee structure has been the focal point for the strategic management process in general and more specifically for organizational direction setting. PennDOT has applied strategic management in several ways. A concept of business groups has evolved as a new way of thinking about the agency. Major objectives for 1983-1986 have been defined that are the basis for overall department accountability and direction. Strategies to achieve them have been systematically formulated. Four-year district business plans tied to the major objectives have been initiated as a means for management and program planning at the district level. The strategic management process has been fused with the annual budget process for the development of the 1985-1986 budget. In the near future, additional activities and functions such as management development and training, information systems, and internal resource allocations will receive increased strategic attention. Efforts will be undertaken to make the process more useful throughout the department. A key challenge is to preserve this process in a political environment.

The purpose of this paper is to present a case study of how a strategic management process has been conceived and nurtured in the Pennsylvania Department of Transportation (PennDOT). It is also intended to show why a strategic management framework makes sense for a state department of transportation.

A necessary introductory aspect to this paper is to briefly clarify the terms "strategic planning" and "strategic management." The two processes are very closely related. Strategic planning is the foundation of strategic management (1,pp.4,5). Strategic planning provides perceptive analysis; it provides the framework for addressing change. It focuses on establishing priorities for resource allocation. It provides an understanding of the future impacts that may result from current decisions. Strategic planning is the major process in the conduct of strategic management.

Strategic management is more encompassing. It takes its advice from the planning function. Then it goes on to make strategic decisions concerning the timing and context for deploying capital, technical, and human resources (2,p.3-2). Although planning is dedicated to insight, strategic management emphasizes control. Strategic management shapes the corporate culture. Its objective is the effective management of change (2). In PennDOT, strategic planning is seen as a generic function of management.

To date, strategic planning and management have been largely associated with the private sector. Yet, their application in the public sector offers an opportunity to substantially improve public planning and managerial effectiveness (3,p.20). Strategic planning is increasingly being applied in public transportation agencies with a fair amount of perceived success (4).

A recent article by Michael Meyer in Transportation Quarterly described several examples of strategic planning efforts in public sector transportation agencies in the United States and Canada (4). Meyer points out that the need for this type of planning can be just as great in the public sector. The environment of the public sector is clearly as dynamic as that of the private sector (4).

An appropriate starting point for discussing strategic management in PennDOT is with the organization's mission. PennDOT's legislatively prescribed mission is to provide safe and efficient transportation facilities and services at the lowest reasonable cost. Coupled with the mission are the goals and objectives of the administration. The Governor of Pennsylvania has identified economic development and community conservation as primary goals to be pursued by the commonwealth's agencies. The most salient and strategic focal point then is to determine how to tailor PennDOT's programs in pursuit of these missions and goals. Although the missions and goals are straightforwardly simple, the challenge is to effectively meet them given the size and diversity of PennDOT's responsibilities and operations. These include the maintenance, operation, and improvement of the state's system of 44,000 mi of highways and 26,000 bridges; the operation of four state airport facilities; and the provision of technical and financial assistance to support local mass transit, rail freight service, local airport development, and maintenance of locally owned roadways. The department's total revenues for FY 1984-1985 will equal about $2.0 billion--a big business by any measure.

In order to navigate this large organization toward its mission and goals, there must be a forward-looking management system that is both proactive and adaptive to environmental change. Although many believe that public management is completely constrained because of legislative dictates, the experience in Pennsylvania has shown that top management can make a substantial difference in how resources are deployed and in the organization's degree of success. A strategic management process has been established in PennDOT to set direction and manage change--and it is making a difference.

The method for this case study is part of the actual evolution of the strategic management process. With the understanding at the outset that the process was unconventional given the history of the organization, a chronology of the process in the form of various documents has been maintained. In a fortuitous way, that detailed chronology serves as the primary resource for the writing of this paper. The case study is an objective review and reflection of this chronology or history of events.

EVOLUTION OF STRATEGIC MANAGEMENT IN PennDOT

Strategic management evolved as a result of the current administration's efforts to set priorities, establish direction and effective operations, and, above all else, provide a transportation system capable of meeting the needs of Pennsylvania's economy and citizenry.

Reordering Priorities

At the outset of the current administration (1979), attention was focused on regaining management control over the department's maintenance operations, fiscal and electronic data processing systems, and fragmented program functions. Foremost among these was the commitment to make the department a "maintenance-first" organization. This priority was tantamount to survival. The new management team quickly made the dollar and program changes needed to put the maintenance program on track. Beginning with basic roadway and bridge maintenance activities, the philosophy eventually spread throughout all aspects of managing the business of the department. Today, maintaining computer systems and paying close attention to the most important resource of all--people--are seen as essential to accomplishing everything that the department undertakes. Simply put, the philosophy is one of maintaining those things that are important.

Another change was to adopt a pay-as-you-go policy for highway construction--no highway bonds have been floated since 1979. Other priorities receiving attention were the maximization of federal funds and the attainment of predictable state revenue. In addition, the computer systems function became a ubiquitous element in the department's drive for increased productivity and improved service delivery.

The department's fragmented programs were integrated into a logical and controllable programming process in which selecting projects on the basis of merit and sound financing was emphasized. Top management set its attention doggedly toward priority setting within a systems framework, and fiscal responsibility. A Program Management Committee was created during 1980 with a staff-level Program Development and Management Center within the Office of Planning to support it. This new approach was successful--top management's policies and priorities became reflected in the Transportation Program's development. The program's financing was placed on a realistic and responsible pay-as-you-go basis. The Program Management Committee became the bellwether of the strategic organizational approach of targeting resources to key areas of department responsibility.

Need for Organizational-Level Planning

With the immediate problem of management control over maintenance, finance, and transportation improvement programming resolved, the department's top management was in a better position to step back and assess how the planning function should further evolve. What emerged was a fundamental decision that top management planning should focus on the broad organizational-level perspective of agency policy and direction setting. It followed that traditional program and project-level planning should become a more decentralized responsibility of program and project managers. This would narrow the gap between planning and implementation. Establishing this change became a formidable challenge. A major change reflecting this new orientation was the restructuring of the Advanced Planning Bureau into a Bureau of Strategic Planning. This change refocused staff activity toward assisting in the development of a strategic managerial decision-making process within the agency. In other words, the Central Office planning function began to tilt toward organizational-level planning, whereas program and project planning shifted more heavily to the program managers, especially in the field.

Management Conference as a Direction-Setting Tool

An important step in the evolution of the strategic management approach was a 2-day conference held for 50 of the department's top managers in April 1982. In a setting away from the distraction of daily duties, the attendees discussed the theme Challenges and Choices for the Future. Managers were requested to identify the crosscutting issues that constrained their ability to act and the opportunities and problems that would likely face the department over the next 5 years. The content of this conference was preserved for use by top management as the basis for a policy initiatives document. Looking back on the participative nature and the insightful output generated by this initial management conference, it could be said that it was a key stepping stone toward the strategic management process. Because of its success, the management conference approach has been further utilized as a key activity for facilitating departmental direction setting.

The policy initiatives document was valuable because it provided an indication of those policy issues important enough to be considered as candidates for organizational objectives. The policy initiatives also brought to light a new way of viewing PennDOT's organization--the business group. This is, the policy initiatives appeared to be more manageable if they were dealt with in categories broadly reflective of the major areas of the department's operations. A concept of four business groups emerged in top management's thinking. (The business groups are further discussed in a later section.) Once there was a firm handle on the policy initiatives of importance, attention turned to designing an appropriate organizational-level structure for direction setting.

Strategic Management Process and Strategic Management Committee

The eventual strategic management structure took a broad approach: It absorbed the existing Program Management Committee and went well beyond transportation programming to provide strategy development in areas such as data processing, federal and state legislation, and management development and training.

A Strategic Management Committee (SMC) was created during the latter part of 1982. The SMC is made up of the department's six top managers--the Secretary as chairman and the five Deputy Secretaries as members. The creation of the SMC reflects a top-level commitment to make the process work. Further evidence of this commitment is the frequency of SMC meetings. The committee meets monthly, which is no small feat for the six top people in an organization of 13,000. The SMC draws staff support from the Director for Strategic Planning. Because of the broad top management orientation of the strategic process, the PennDOT experience has found that full-time staff support requirements need not be extensive.

The SMC has responsibility for the forwarding or evolution of the PennDOT strategic management process. The objectives of the strategic management process are to

- Facilitate determination of the major objectives of the organization and, in turn,
- Determine the policies and strategies that govern the acquisition, use, and disposition of resources to achieve identified objectives.

Specific elements and aims of the process are to

- Review and define the department's mission or missions,
- Improve understanding of the department's internal strengths and weaknesses and of the external environment in which it operates,
- Set annual performance goals and define program objectives,
- Determine alternative strategies for best utilizing resources available to the organization (consistent with defined objectives) and estimate time and resource requirements, and
- Allocate all resources available to the department.

These objectives and elements are implicit in the following description of the strategic management process.

The process (Figure 1) is a simple and yet unifying framework that provides overall direction for the complex programs and services that the department delivers. The process has as its foundation the mission of the department. Analyses are performed of internal and external factors affecting the department, for example, environmental scanning to promote understanding of the department's external operating environment and its internal strengths and weaknesses. The activities of the Legislative Review Committees are a good example of environmental scanning in the context of monitoring how legislative activities affect department programs and operations. In a more proactive vein, these two committees not only respond to legislative developments, they also try to shape them. In doing so, the strategic loop is closed; the environment has been scanned and strategies, reactive and proactive, are pursued.

The next step--determination of major objectives--is probably the most important in terms of organizational direction setting. Most significantly, the major objectives provide the broadest basis for organizational accountability; they serve as a "report card" for the entire organization and represent where the department wants to be within a specific time frame. Over time, attention is turning to building increased levels of organizational commitment among employees in order to have them rally for the accomplishment of these major objectives. Once the major objectives have been established, alternative solutions or strategies are formulated for their accomplishment within the respective management committee forums. It is in these forums that ideas, alternatives, and strategies are carefully considered and preferred courses of action emerge. In the process a lot of healthy communication occurs between individuals who may not normally have the chance to interact on a regular basis.

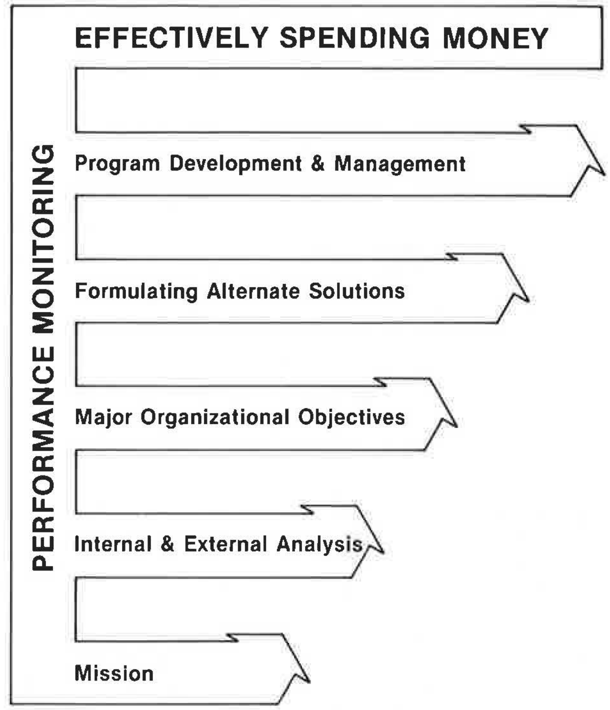

FIGURE 1 Strategic management process.

Upon concurrence by the SMC, the selected strategies move into the program development and management stage. The ultimate purpose of this process is to effectively spend the limited dollars available. It is important to note that performance monitoring crosscuts the entire process. Deviation from the department's mission or major objectives or both can easily and unintentionally occur at any stage of the process unless there is continuous feedback to top management. This feedback takes the form of macro-performance reporting geared to the information needs of top management.

Although the SMC has overall charge of the process, it is assisted by various subcommittees with substantive roles. Together they constitute the PennDOT planning and decision forums (Figure 2). The SMC is responsible for the planning and utilization of all human, financial, technological, and contractual resources available to the department. It provides overall direction for initiatives, programs, and agency operations. It also allocates all resources available to the department.

The subcommittees provide a resource for focusing on areas of key importance to the department's oper-

FIGURE 2 PennDOT planning and decision forums.

ations. The subcommittees and a brief description of their roles are as follows:

- Legislative Review Committees: Responsible for analyzing and developing information relative to federal and state legislation that may affect department objectives, programs, and funding.
- Consultant Selection Committee: Responsible for selecting consultants for all department purposes with the intent to obtain the best expertise at a reasonable cost to the commonwealth.
- Program Management Committee: Responsible for both long-range and annual program planning.
- Electronic Data Processing Management Committee: Responsible for both long-range and annual planning for the use and deployment of computer facilities and resources.
- Management Development and Training Committee: Responsible for the development and training of management employees. This includes the establishment of training and development objectives and the monitoring of the progress toward these objectives.
- Driver and Vehicle Policy Committee: Responsible for forming policy and establishing objectives in the areas of driver licensing, motor vehicle registration and titling, and highway safety. It is responsible for monitoring progress toward these policies and objectives.

These seven subcommittees are strategic in the truest sense of the word. Their role is to establish direction and overall guidance as opposed to management by committee. It is important to emphasize that the members of these committees hold specific upper management positions in the department. They are not expected to play their specific management role per se in their committee assignment. Rather they provide strategy and direction and assign management responsibility to ensure successful implementation.

It is important to point out how the SMC and subcommittee structure relates to the department's staff and management functions. The structure is not to be confused with the department's functional organizational chart. This is an important distinction in understanding PennDOT's strategic orientation. The committee structure shown in Figure 2 reflects the organization for strategic direction setting. In a three-dimensional sense, one could think of this strategic structure as being overlaid on the functional structure or organizational chart.

Some other important relationships should be mentioned. First, each committee includes representation from various functional areas of the department. Therefore, the composition of the committees does not resemble any particular bureau or office. Second, the output of the committees is simply direction and guidance for the seven various substantive areas; this direction then becomes the major input for the activities carried out by the agency's management and staff. In other words, the link between the strategic structure and the organizational structure is a link between direction and product.

The SMC and subcommittee structure represents the highest level of organizational decision making in the department. Its responsibility is truly direction setting and policy making. In general, this strategic management structure could be appropriate for other state transportation departments. The substantive roles of the committees should be tailored to suit the given organization. What should be maintained, in the authors' estimation, is the structure of a top-level strategic committee and a number of subcommittees. They are the core of any strategic management process.

Other organizations give credence to the structure advocated here. The Province of Ontario's Ministry of Transportation and Communication has engaged in strategic management for a number of years. The ministry's structure for conducting the process closely resembles that of PennDOT. There is a principal corporate committee--the Strategic Policy Committee (SPC)--which has overall responsibility for policy development and for establishing strategic directions (5,p.9). These strategic directions guide the various ministry programs for a 5-year period. The SPC is made up of the Minister, the Deputy Minister, and eight senior executives. There are also seven subcommittees of the SPC; they are responsible to the SPC for the effective management of the ministry's programs and the resources available to the ministry. Five of the subcommittees deal with the key program areas of the ministry, one focuses on resources management, and one handles operational issues. Each of the subcommittees is chaired by a senior executive.

PRODUCTS AND APPLICATIONS OF THE STRATEGIC MANAGEMENT PROCESS

One of the most important products, or perhaps a by-product, of the strategic management process is a new way of thinking about the organization.

Business-Group Concept

Through the evolution of the process, participants began to see that the department meets Pennsylvania's transportation needs through four primary product and service delivery groups with missions that are very distinct from each other:

• Commonwealth Transportation Systems Group: The Commonwealth Transportation Systems Group provides transportation service in support of economic development and community conservation through those facilities owned and operated by the department (e.g., state-owned highways and bridges).

• Driver and Vehicle Services Group: The Driver and Vehicle Services Group serves vehicle owners and operators through the licensing of drivers, the titling and registering of vehicles, and the administration of programs to improve highway safety.

• Transportation Grants Management Group: The Transportation Grants Management Group influences others, such as local governments, in the delivery of transportation services by providing them with both financial and technical assistance.

• Departmentwide Group: The Departmentwide Group provides services in overall support of all aspects of the department's operations.

The business-group concept came about as a natural outgrowth of the review of the department's missions. As pointed out earlier, this review is basic to the strategic management process. The department is viewed as a public service organization consisting of a set of discrete businesses, each with a mission tied to the larger overall department mission--to provide safe and efficient transportation facilities and services.

The business-group concept was developed for several reasons. The first was to provide a basis for managing discrete groups of transportation activities; that is, the Commonwealth Transportation Systems Group owns and operates roadways and thus fully controls key performance areas; by comparison, through the provision of transit technical and financial assistance, the Transportation Grants Management Group seeks to influence rather than control; finally, driver and vehicle activities require a greater customer service and quality control orientation because day-to-day contact with Pennsylvanians is the rule.

Second, the concept was developed to encourage managers to begin thinking in businesslike terms and to understand the bottom line or equivalent of profit for each business group; for example, increased efficiency and reduced overhead can translate into a greater level of on-the-road improvements. Lowering capital costs to transit authorities through provision of a statewide bus pool-purchase improves both operating efficiency and subsidy utilization. Reduction in the error rate of driver and vehicle transactions not only improves quality but also speeds delivery of service, enhancing customer satisfaction.

The third reason was to establish a structured basis for providing common services that crosscut each business group, that is, providing the strategic framework for developing and deploying electronic data processing resources; programming the varying manpower, plant, and equipment requirements unique to the respective businesses; and managing the administrative and fiscal aspects of each group's transactions.

In summary, the real advantage of the business-group way of thinking is that it brings order to a complex and often confusing array of activities. In turn, the ever-difficult area of performance monitoring becomes more manageable and meaningful. An understanding of the mission of each business group makes the entire process of performance monitoring far more meaningful and manageable.

Development of Major Objectives

The business-group framework has been utilized in defining major objectives for the department. These multiyear objectives (1983-1986) represent a real milestone in the department's strategic management process. Setting objectives is the principal direction-setting activity in the process. There are 24 major objectives; each is categorized by business group. The major objectives were presented to Governor Thornburgh in June 1983 as the department's agenda through 1986. As previously noted, this makes them the focus of PennDOT accountability to the administration and to the citizens of Pennsylvania. Internally, accountability is assumed by the department's managers, who have the responsibility for achieving the major objectives.

It should be pointed out that the role of the management conference was significant in the development of these objectives. Their origin was in the policy initiatives that were articulated at the Challenges and Choices for the Future management conference. Once the policy initiatives were translated into the major objectives, another management conference was held as a first step in conveying these objectives to the department's managers. The theme of this conference was, appropriately, Setting the Course. This conference was a useful starting point for such important matters and issues as initiation of major objective strategy development, performance monitoring, and elaborating on a value system that top management hoped to see permeate the organization to bolster the achievement of the major objectives. More important, it was a first step in communicating the major objectives to the entire organization. Since this conference, strategies have been developed for each major objective. Major objective progress reports have been prepared and a slide presentation has been developed that clearly communicates the substance and the importance of the major objectives to all employees.

Formulation of Major Objective Strategies

An important application of the strategic management process has been the formulation of the strategies to accomplish the major objectives. This step is the interface between defining the objectives and program implementation. Strategy determination is a key step in the process, as pointed out earlier in the discussion of the objectives of the strategic management effort. The formulation of strategies relied on the strategic structure--the management leadership of the SMC and its subcommittees as forums for the setting of strategy. An example of this is the development of an electronic data processing (EDP) leading-edge plan under the direction and guidance of the EDP Management Committee. This strategic plan is in support of a major objective that aims to "maintain the EDP systems of the Department at the leading edge of this advancing technology." Moreover, a distinct EDP strategic planning process has been developed and instituted. The department strongly encourages this type of spin-off in a functional area. The key point is that through those committees, the strategic context of each objective is allowed to freely evolve, something that would not likely occur through a conventional organizational structure with all of its red tape. The important aspect to remember is that the committee framework has provided a structure for strategy development and that this same framework tracks strategy all the way through to program implementation.

Four-Year District Business Plans

The overall strategic management process, with its emphasis on placing program planning in the hands of program managers, has led to the development of 4-year district business plans by each of the department's 11 engineering districts. District personnel began work on them in November 1983. The plans were individually presented to the SMC by each District Engineer in May 1984. The 4-year business planning process is a major initiative of the department, which is intended to assist the District Engineers in working toward the objectives of the department. Within the overall strategic management process, the district 4-year business plans represent the formulation of strategies--that is, strategies for meeting the major objectives in the roadway area. The plans encompass program, manpower, physical plant, and equipment and materials requirements associated with all district and county activities. This planning process will ensure that annual program-level elements are developed and implemented consistent with the department's major objectives and will support a businesslike approach to management at the district level. These plans are part of the overall strategic management effort. The district 4-year business planning process has proven successful and a new cycle of such planning has been initiated.

Integration of Strategic Management with the Budget Process

Finally, the most important application to date of the strategic management process has been its integration with the department's budget process. It has been pointed out in the literature that integration with other agency planning-related efforts, such as budgeting, is one of the most important characteristics of effective strategic planning (4). The strategic system is irrelevant if it is not integrated with the total management process of decision making and resource allocation.

For PennDOT this meant requiring managers to address the major objectives in their budget development for FY 1985-1986 by articulating the activities and dollar resources necessary for their accomplishment. Effective allocation of resources is one of the chief purposes of the strategic management effort; the department sees this as the primary end product of the process. Having the major objectives emphasized in the budget preparation process is consistent with this purpose. By this effort, the major objectives--the key directions--drive the budget request. In a budgetary sense, this application for the first time provided managers with a mission and framework to consider the relative importance of their programs and activities. From the top management viewpoint, the final resource allocations may be determined with respect to congruence with or divergence from the major objectives.

WHAT DOES THE FUTURE HOLD?

Looking to the future, there are several opportunities for further application of the strategic management process. And there are challenges to be faced as well.

Opportunities for Further Applications

There are several areas in which the strategic management process will be further applied in PennDOT. They include the following.

Emphasize Training

The SMC Management Development and Training Committee has already begun to consider key directions in training. To gain some outside insights into this area, the committee includes the commonwealth's Director of Training and Development. They have actively sought input from the private sector. The department will continue to emphasize training at all levels of the organization, and training will become increasingly focused on those activities that have either a short-term or long-term payback. Evaluation will become an integral feedback loop for training management in order to ensure that training efforts are producing their intended results.

Optimize Allocation of Resources to Business Groups

The intent here is to increase the capability for developing optimal targeting of physical, human, and financial resources in a way that will develop and strengthen the overall organization. This will require strengthening management's analytical skills and the quality of information to support decisions.

Stay Close to Department's Customers

In broad terms, department managers must think in terms of a market approach; that is, greater attention will be given to recognizing the diversity across Pennsylvania, understanding the specialized needs of geographic service areas, and providing services accordingly.

Develop Greater Reliance on EDP Information Systems

The SMC will seek ways to expand the application of electronic data processing in order to increase productivity and to make an overall improvement in the information resource.

Institutionalizing Strategic Management

As an organization-wide policy-making and direction-setting activity, strategic management's policies and directions become operational at the program and project (service delivery) levels of the agency. To increase effectiveness, opportunities can be taken to make strategic management and planning more influential at all levels of the organization.

The role of management will include the development of the culture of the organization. Culture is expressed in the shared values that an organization holds; they represent the organization's beliefs and define what it stands for. They are expressions of its philosophy and spirit and are the basis for its policies and actions. Values set an organization's style of operation and therefore affect its performance by building unity and pride in the organization.

The task of shaping organizational culture is a prime management responsibility. The Secretary sees his job as shaping the values of the organization. Values such as service, integrity, excellence, work ethic, and interest in people have been the key factors to many of the department's successes. Wider adoption of these values will help the department to achieve its major objectives. And, perhaps even more important, these values will become part of the institutional memory, effectuating a positive style of performance that will build pride among the employees as well as respect from those whom it serves. Values, if they are to be the cohesive and driving force that they can be, should be conveyed and evidenced at all levels of the department. Inculcating a set of desired values among the 13,000 employees of PennDOT is perhaps one of the greatest and most challenging tasks before the department's top managers. Communicating values is by no means a guarantee of transmitting values. The rest of the equation is to abide by these values and, in doing so, to hope that they will be shared by a large number of employees.

Additional steps at institutionalizing the strategic management process will consist of the production of video presentations of the department's values and its major objectives. These presentations will be widely disseminated among managers and staff to create understanding and interest.

Challenges

There are challenges to be faced in implementing strategic management in a public works agency as well as limitations because of the significant constraints of a public-sector environment. The process must remain relevant for dealing with organizational policy development and direction setting. How to maintain its vitality in a political environment that has relatively frequent changes of top management is a valid concern. Its acceptance by a new set of top leaders will depend on their view of the utility of the activity and the extent to which it has been built into the organizational memory and culture.

Top management can meet this challenge if the usefulness of the process is clearly shown throughout the department. This can be achieved by periodic reporting on what has been accomplished through the use of good vertical communication throughout all levels of management and staff. Moreover, enhanced participation in the process by lower echelons of management and staff should promote wider use of the process. Decentralized strategic planning, such as PennDOT's 4-year district business plans, exemplifies the value of diffusing this process.

CONCLUSION

A case study has been presented of the development of a strategic management process in PennDOT and how the process evolved. Various products and applications of strategic management in the department were discussed. A look at the future and some expected opportunities for further application and increased effectiveness of the process at PennDOT were included.

The department's current top management took over in 1979. Recognizing not only that PennDOT's size and diversity of operations are great but also that important priorities then existing had to be reordered, top management set about establishing a businesslike management style. It was recognized that there was a need for a management process that is proactive--able to establish policy, set directions, and manage change.

Department top management has been active in implementing the strategic management process. The consideration of identified policy initiatives and study of department missions has led to the concept of four corporatelike business groups. This new way of viewing the organization encourages management to think in businesslike terms and to better concentrate on the four discrete groups of transportation activities provided by the department.

The determination of major objectives is a fundamental reason for the existence of strategic management in PennDOT. The SMC determined the department's 24 major objectives by mid-1983. Covering the period 1983-1986, the major objectives establish overall direction for the agency. They serve as a focus for department activity for the second 4 years of the current department administration. The major objective strategies serve as the mechanism whereby the policies, functions, and activities necessary to achieve the major objectives are determined. And they also provide a means whereby the SMC and its subcommittees can monitor progress being made toward the objectives. And the strategic management process has been linked to the budget process, facilitating the identification of the resources needed to make progress toward the major objectives.

The experience of PennDOT is that strategic management has been useful. It has permitted top management to establish direction for the agency. The structure of the SMC and its subcommittees has been set in place and is working. Top management has been setting the course for the department through the process of establishing objectives, determining strategies, and linking them with required resources.

Strategic management provides several opportunities that a state department of transportation should consider. It helps management in evaluating the mission of the organization--to study what the business of the agency is. Engaging in strategic management forces the establishment of objectives for the organization, that is, identifying where the agency would like to be. It facilitates consideration of the activities and resources required to best meet the identified objectives. This builds management skills and provides opportunity to consider the entire agency, its environment, and its operations.

The management structure to carry out the process need not be elaborate. A principal committee of top-level management and a number of subcommittees to provide direction and guidance in key areas of department operations has been a workable structure in PennDOT.

The participants will strive to make strategic management a continuously more beneficial and workable activity because of a belief that is best put by James F. Lyon (6): "Strategic management will increasingly gain acceptance as the best vehicle for improving large complex companies. Effective strategic management can pull together a diverse organization, communicate clear objectives and values, and achieve the creative integration of capital, technical and human resources."

Suffice it to say, this is the vehicle for PennDOT.

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Publication of this paper sponsored by Task Force on Strategic Planning Process.