TRANSPORTATION RESEARCH RECORD 1076

Defining Needs, Managing Resources, and Technology Transfer

TRB
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1986

Transportation Research Record 1076
Price $9.80
Editor: Elizabeth W. Kaplan
Compositor: Harlow A. Bickford
Layout: Betty L. Hawkins

modes
1 highway transportation
2 public transit

subject areas
11 administration
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.

Defining needs, managing resources, and technology transfer.

(Transportation research record, ISSN 0361-1981 ; 1076)
1. Transportation and state–Congresses.
2. Transportation–Planning–Congresses. I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 1076   380.5 s   86-23900
[HE193]   [380.5'068]
ISBN 0-309-04070-1

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Importance of Transportation to Advanced Technology Industries

NORMAN P. HUMMON, LINDA ZEMOTEL,
A. G. R. BULLEN, and JAMES P. DeANGELIS

ABSTRACT

Transportation is beginning to play a role in the economic development of advanced technology. This paper is a report on an analysis of a short mail-back questionnaire designed to gain information about the importance of transportation service to advanced technology firms in Pennsylvania. Transportation was defined in three ways: (a) transport of materials and products to and from markets and suppliers, (b) access of personnel to others in similar industries, and (c) the quality of transportation facilities and services and their contribution to making the community a pleasant place to live and work. A categorical variable regression model was used to predict transportation service preferences using the independent variables of firm type, firm size, age of technology used in production, and a Standard Industrial Classification (SIC) definition of advanced technology. The major finding was that an SIC-based variable contributed little to the prediction of transportation service preferences. Instead, type of firm, size of firm, and age of technology predicted the transportation preferences.

The promotion of advanced technology industries has become a common economic development focus of state and local governments. The commonwealth of Pennsylvania is no exception and, in 1982, initiated a technology development program to bring together research universities and the private sector. More recently, the Pennsylvania Department of Transportation has become interested in transportation infrastructure to meet the requirements of advanced technology firms.

The role of transportation in the economic development of advanced technology is beginning to receive some attention. In the Joint Economic Committee's report of 1982 (1), determinants that were found to be most important to interregional locational decisions were labor skills and availability, labor costs, and state and local taxes. The most important factors that could influence the choice within a region were labor skills, labor availability, taxes, and business climate. Proximity to customers was rated significant or very significant for the choice of location within a region by less than half of the respondents (47 percent). Proximity to raw materials and component supplies was rated significant or very significant by only 36 percent of the respondents. According to the study, "[c]learly, the traditional locational factors of access to markets and raw materials were not important factors for high technology plant location decisions." However, a good transportation system for people was rated as significant or very significant by 76 percent of the respondents.

The conclusion of the Joint Economic Committee (JEC) was that high technology companies were "footloose" because access to raw materials, access to markets, and transportation were not major locational determinants. This suggests that a less conventional view of transportation may be necessary in studying advanced technology firms. Commuting time and traffic congestion may be "quality-of-life" factors that transportation engineers should consider.

In 1983 the Pennsylvania State University's Institute of Public Administration conducted a survey of advanced technology manufacturing and service firms in Pennsylvania (2). According to this survey, the top five factors that influenced firms' decisions to locate at their present sites were (a) proximity to markets, (b) proximity to family, (c) availability of labor, (d) commuting distance, and (e) cost of property. Penn State's results appear to contradict the JEC finding because access to markets was not often cited as an important factor. The contradiction may have to be resolved by looking at the samples selected; that is, generalizations about high technology industries must be defined for type of company (manufacturing firms only or both manufacturing and service firms), area of the country (70 percent in Massachusetts and California versus all in Pennsylvania), age of technology, and size of company.

The label "advanced technology" is such an all-encompassing phrase that making generalizations about these industries may be risky. Support for this statement comes from the research of Glasmeier et al. (3) that was designed to study growth performance and locational tendencies in high technology industries. They state that their "most important conclusion is that the location and growth of high-tech industry is a very varied and disparate process which will require highly disaggregated industry-by-industry analysis."

Two groups have explicitly studied relationships between advanced technology and transportation issues. The first group, Toft and Mahmassani, pre-

N.P. Hummon, Department of Sociology, University of Pittsburgh, Pittsburgh, Pa. 15260. L. Zemotel and A.G.R. Bullen, Department of Civil Engineering, University of Pittsburgh, Pittsburgh, Pa. 15260. J.P. DeAngelis, University Center for Social and Urban Research, University of Pittsburgh, Pittsburgh, Pa. 15260.

sented a framework for planning advanced technology economic development (4). They developed a case that transportation is important in at least four areas: "(a) the journey to work of the predominately professional, white-collar workforce; (b) business air travel for scientific, technical, and business purposes; (c) high air freight volume due to high value, low bulk, time-sensitive, and fragile nature of shipments; and (d) clean, campuslike, semirural, highly visible sites in the vicinity of major arterials, Interstates, and airports" (4,p.28).

Route 202 in Chester and Montgomery Counties, Pennsylvania, was the focus of the second group, the Delaware Valley Regional Planning Commission (DVRPC) (5). This report has made planning for the transportation needs of advanced technology firms a part of the short-range transportation improvement program for the region's "high-tech corridor."

In the DVRPC survey, the investigators compared samples of high-tech and non-high-tech firms. Both groups were asked to rate seven criteria in choosing their locations. The high-tech group ranked them in order of importance as (a) existing residence of professional and managerial staff, (b) ownership or rental costs, (c) physical environment, (d) highway facilities, (e) availability of trained labor force, (f) local taxes, and (g) local government attitude or incentives. Both groups rated most criteria similarly except that existing residences were very important to 79 percent of the high-tech respondents but to only 53 percent of the non-high-tech respondents. The investigators conclude that "the best sites to promote for high technology firms are those which are nearby to good housing stock."

Another important difference between the high-tech and the non-high-tech firms is the importance of access to an airport (in this case, Philadelphia International Airport). The DVRPC study found that the airport was a highly important destination to 60 percent of the high-tech firms and unimportant to 4 percent whereas it was highly important to only 30 percent of non-high-tech firms and unimportant to 20 percent.

This brief description of some of the research being done to determine linkages between transportation needs and economic development through promotion of advanced technology industries shows the tentative nature of the results and highlights the need for more research, first into the nature of this emerging group of industries and then into its possible transportation needs, which may be different than those currently being met.

ADVANCED TECHNOLOGY INDUSTRIES

The first problem in studying transportation needs of advanced technology industries is the definition of such industries. The JEC presents a comprehensive definition (1):

> High technology industries consist of heterogeneous collections of firms that share several attributes. First, the firms are labor-intensive rather than capital-intensive in their production processes, employing a higher percentage of technicians, engineers and scientists than other manufacturing companies. Second, the industries are science-based in that they thrive on the application of advances in science to the marketplace in the form of new products and production methods. Third, R&D inputs are much more important to the continued successful operation of high technology firms than is the case for other manufacturing industries.

Other reports use some or all of this definition. Because there appears to be no general agreement in the literature on a definition of advanced technology industries, analysts use the practical approach of relying on Standard Industrial Classification (SIC) codes. Table 1 gives a summary of these definitions.

TABLE 1 SIC Codes that Define Advanced Technology Industries

SIC Code	Definition
Joint Economic Committee (*1*)	
28	Chemical and allied products
35	Machinery except electrical
36	Electrical and electronic machinery, equipment, and supplies
37	Transportation equipment
38	Measuring, analyzing, and controlling instruments; photographic, medical, and optical goods; watches and clocks
Glasmeier, Hall, and Markusen (*3*)	
28	Chemicals and allied products
2911	Petroleum refining
3031	Reclaimed rubber
34 (part)	Arms and ammunition
35 (part)	Machinery except electrical
36 (part)	Electric and electronic equipment
37 (part)	Transportation equipment
38 (part)	Instruments and related products
Delaware Valley Regional Planning Commission (*5*)	
2831-2834	Drugs
3573-3574	Electronic computing, calculating equipment
3651, 3661-3679, 3693	Communications, electronic components
3721-3728, 3761-3769	Aircraft, space vehicles
3811-3841, 3861-3873	Instruments
7372-7391	Computer services, research and development laboratories
8071-8072	Medical and dental laboratories
8922	Noncommercial research organizations
Pennsylvania State University (*2*)	
3600-3699	Electric and electronic equipment
3811-3873	Instruments and related products
7372-7399	Business services

The reports by the JEC and by Glasmeier et al. use only manufacturing codes. Glasmeier selected 30 three-digit SIC codes representing industries with greater than the national manufacturing average of scientific and technical occupations.

DVRPC and Penn State included both manufacturing and service firms. However, the Penn State researchers considered only electronics, instruments, and business services because these "represent the core of advanced technology industry in Pennsylvania."

To date, it appears that researchers have depended on defining advanced technology industries by SIC codes, which is a reasonable approach because these codes attempt to describe in detail a firm's business activities, with an emphasis on what the firm produces. However, it is interesting to note that the JEC definition emphasizes the characteristics of the people and processes in high-tech firms rather than their products.

STUDY APPROACH

Background

As part of the effort by Pennsylvania government to foster economic development, the commonwealth's Department of Transportation contracted for research directed at "understanding the impact of transportation access and other locational factors to the establishment and growth of advanced technology firms in Pennsylvania." The research plan includes surveys of existing advanced technology firms, and the results are to be used in recommending to the transportation department ways to assist, or at least not hinder, these firms in their business activities.

The study is currently under way, and this paper is a report on the results of Phase I: analysis of a short mail-back questionnaire completed by executives of 1,136 firms in Pennsylvania.

Survey Design

The purpose of the survey accomplished in Phase I was to gain information about the relative importance of transportation to current business activities of the firms as well as some basic knowledge of the characteristics of the firms.

The questions about the importance of transportation covered three areas: (a) transport of finished products and supplies, (b) access to others in similar industries, and (c) quality-of-life factors. The questions were

> What is the relative importance of each of the following to the current business activities of your firm?
>
> > The transport of materials and products to and from markets and suppliers.
> >
> > Access of your personnel to others in your industry, such as clients, firms in similar product lines, educators, researchers, and trade representatives.
> >
> > The quality of the transportation facilities and services in making your community a pleasant place to live and work.

Respondents were asked to rate each question using a scale of "very important," "important," "neither important nor unimportant," "unimportant," or "very unimportant."

The first question about markets and supplies was designed to capture the "traditional" role of transportation service to a business. The second question about access to others was included to explore the popular notion that agglomeration factors may be more important to advanced technology firms than to non-advanced technology firms. And finally, the third question looked at transportation as a lifestyle factor that is sometimes cited as important in enabling advanced technology firms to develop and expand.

The variables that could be used to describe the firms were contained in the following questions:

> How would you describe your primary product or service? (SIC code could be determined from this open-ended response.)
>
> How would you classify the age of the technology used in producing your primary product or service? (The scale used was "less than 1 year," "1 to 5 years," "6 to 10 years," "11 to 20 years," or "over 20 years.")
>
> Approximately how many people, including yourself and part-time workers, are employed at this facility? (The respondent was asked to give the actual number of employees.)

Responses to the Survey

According to the description given for product or service, 637 firms were coded as producing a product and 498 firms as providing a service.

The median size of the firms was 22 employees, and firm sizes ranged from 23 firms with only 1 employee to a company with more than 10,000 employees. However, one-quarter of the responding firms reported 8 or fewer employees and three-quarters had 82 or fewer employees.

Responses to the question concerning the age of technology used in producing the firm's primary product or service are given in Table 2. The responses to the transportation questions are given in Table 3.

TABLE 2 Age of Technology Used in Production

	No. of Firms	Percentage
Less than 1 year	47	4
1 to 5 years	374	33
6 to 10 years	140	12
11 to 20 years	146	13
More than 20 years	365	32
Multiple responses	41	4
No response	23	2

TABLE 3 Importance of Transportation

	No. of Firms	Percentage
Importance of Transport of Materials and Products to and from Markets and Suppliers		
Very important	622	55
Important	274	24
Neither	110	10
Unimportant	63	5
Very unimportant	60	5
No response	7	1
Importance of Access of Personnel to Others in the Industry, Such as Clients, Firms in Similar Product Lines, Educators, Researchers, and Trade Representatives		
Very important	374	33
Important	391	35
Neither	240	21
Unimportant	79	7
Very unimportant	49	4
No response	3	
Importance of Quality of Transportation Facilities and Services in Making the Community a Pleasant Place to Live and Work		
Very important	409	36
Important	488	43
Neither	176	16
Unimportant	44	4
Very unimportant	17	1
No response	2	

ANALYSIS

Methodology

Using the variables age of technology, SIC code, firm size, and firm type, the sample was partitioned into 16 subsamples. All variables were dichotomized. Age of technology (AGETECH) was defined by two values: less than or equal to 5 years and greater than 5 years. Firm size (SIZE) was assigned one of two values: less than or equal to the median size of 22 or greater than the median number of employees.

SIC code, which was assigned for each firm by interpreting the response to the question, "how would you describe your primary product or service?" was used to create two variables. The first variable was firm type (FIRMTYPE), that is, a firm producing a product or providing a service. If the SIC code was less than 4000, the firm was considered to be producing a product, and if the SIC code was 4000 or greater, the firm was classified as providing a service.

The SIC code was also used to create two variables to represent "advanced technology status." The two variables were created using different definitions by which SIC codes define an advanced technology firm (ATST1 and ATST2).

For the first variable, the definitions used in the reports of the JEC and the DVRPC were modified slightly. Firms considered to be advanced technology (AT) would follow the following rules:

Firms producing a product
- 28--chemicals and allied products
- 35--machinery, except electrical
- 36--electric and electronic equipment
- 37--transportation equipment
- 38--instruments and related products
- 3944--games, toys, and children's vehicles

This definition was extended to include firms with other product SIC codes if the reported age of technology was less than or equal to 5 years:

Firms providing a service
- 48--communication
- 73--business services
- 80--health services
- 8922--noncommercial research organizations

Firms not following these rules would be considered non-advanced technology firms (NAT). This variable was designated as ATST1.

The second method for creating this advanced technology variable used the more restrictive definition reported in the Penn State study. Only the SIC codes that describe firms producing high technology products or services were included. These were as follows:

Firms producing a product
- 3573--electronic computing equipment
- 36--electric and electronic equipment
- 38--instruments and related products

Firms providing a service
- 7372--computer programming and other software services
- 7374--data processing services
- 7379--computer related services, NEC
- 7391--research and development laboratories
- 7392--management, consulting, and public relation services
- 7397--commercial testing laboratories
- 7399--business services, NEC

This variable was designated ATST2. The possible 16 subsamples, using these four variables, are given in Table 4.

The next step was to determine if these transportation issues were differentially important for different types of firms. An appropriate statistical model to address these concerns is GSK categorical variable regression developed by Grizzle et al. (6). This statistical procedure is part of the CATMOD procedure of the Statistical Analysis System (SAS).

TABLE 4 Population Profiles

Sample	AGETECH	ATST [1 or 2]	SIZE	FIRMTYPE
1	≤5 years	AT	≤median	Product
2	≤5 years	AT	≤median	Service
3	≤5 years	AT	>median	Product
4	≤5 years	AT	>median	Service
5	≤5 years	NAT	≤median	Product
6	≤5 years	NAT	≤median	Service
7	≤5 years	NAT	>median	Product
8	≤5 years	NAT	>median	Service
9	>5 years	AT	≤median	Product
10	>5 years	AT	≤median	Service
11	>5 years	AT	>median	Product
12	>5 years	AT	>median	Service
13	>5 years	NAT	≤median	Product
14	>5 years	NAT	≤median	Service
15	>5 years	NAT	>median	Product
16	>5 years	NAT	>median	Service

The GSK/CATMOD model predicts the response probability distribution on a dependent categorical variable as a function of other categorical variables. The model normally includes an intercept parameter. When all the variables are dichotomies, as is the case for these analyses, the form of the model is particularly straightforward.

The response probabilities are transformed by a logit function, $\log[p/(1 - p)]$ and fit to the design matrix specified by the concatenation of the independent variables. The design matrix defines the subsamples of the model. The parameters for each effect or variable are constrained to sum to zero. Thus, for dichotomous variables, the parameter values for the two cells are equal in magnitude and opposite in sign. For example, in the model predicting the importance of transporting materials and products, the parameter for FIRMTYPE = manufacturing is 0.764, and for FIRMTYPE = service the value is -0.764. (These values are found in the table for Model 1-A in the following section.)

To assess the importance of these values, it is necessary to compute the predicted logit function and back-transform to the estimated probabilities. Taking into account only the FIRMTYPE variable, the predicted logit function (f) is the intercept of 1.410 plus and minus 0.764 and the estimated probabilities are 0.898 for manufacturing and 0.656 for service firms. Thus the type of firm significantly modifies the prediction probabilities.

The complete model for predicting the importance of transport of materials and products in Model 1-A for the combination AGETECH = ≤5 years, advanced technology status, small size, and manufacturing is

$$\text{pred } f = 1.410 - 0.272 + 0.066 - 0.320 + 0.764 = 1.648$$

where

Pred p = 0.8387,
Actual p = 0.8052, and
Residual = -0.0335.

Thus the model predicts that 83.9 percent of the subsample represented by the independent variables would respond that transport of materials is important, whereas the empirical response for the subsample is about 3 percent less.

Standard errors, chi-square statistics, and significance probabilities are reported for each parameter. A likelihood ratio chi-square statistic for the whole model is also reported. This statistic is computed on the residuals of the fitted model and tests the null hypothesis that these residuals are random. The small likelihood ratio chi-square values and probabilities greater than 0.05 or 0.10 indicate that the null hypothesis cannot be rejected and that the model fits the data. Finally, all parameters are estimated using the maximum likelihood option of CATMOD.

Models

Model 1

Model 1 uses the importance of the transport of materials and products as a dependent variable. First, the dependent variable is predicted using the independent variables of age of technology (AGETECH), advanced technology status according to definition 1 (ATST1), firm size (SIZE), and firm producing a product or providing a service (FIRMTYPE). No interaction terms are included in this model.

Table 5 gives the results of this categorical regression analysis. The advanced technology status variable, defined by the more inclusive set of SIC codes discussed previously, does not contribute significantly to the prediction of the importance of transporting materials and products. The parameters for the other three variables, age of technology, firm size, and firm type, are all highly significant, and the overall fit of the model is adequate with a likelihood ratio chi-square of 16.52 and associated probability of 0.0569.

TABLE 5 Model 1-A—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.410	0.121	136.33	0.0001
AGETECH	2	-0.272	0.084	10.51	0.0012
ATST1	3	0.066	0.119	0.31	0.5774
SIZE	4	-0.320	0.085	14.04	0.0002
FIRMTYPE	5	0.764	0.088	75.15	0.0001

Note: LR χ^2 = 16.52, DOF = 9, and probability = 0.0569.

When the advanced technology status variable is defined by the more restrictive set of SIC codes, the results are similar as indicated by the data given in Table 6.

Again, the advanced technology status variable is not significant, and the parameters for the other three variables are all significant. The overall fit of this model is good.

TABLE 6 Model 1-B—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.471	0.089	270.16	0.0001
AGETECH	2	-0.228	0.085	7.28	0.0070
ATST2	3	-0.111	0.085	1.69	0.1930
SIZE	4	-0.308	0.085	13.12	0.0003
FIRMTYPE	5	0.768	0.088	75.71	0.0001

Note: LR χ^2 = 11.0, DOF = 11, and probability = 0.4430.

When the advanced technology variable is omitted, a simple yet acceptable model is found (Table 7).

All parameters are significant, and the overall fit is acceptable. The mean absolute prediction error over the eight subsamples is 2.86 percent with a standard error of 1.84 percent.

The signs of the parameters indicate that firms that use newer technology and are smaller are less

TABLE 7 Model 1-C—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.456	0.088	271.54	0.0001
AGETECH	2	-0.260	0.081	10.32	0.0013
SIZE	3	-0.315	0.085	13.77	0.0002
FIRMTYPE	4	0.763	0.088	75.09	0.0001

Note: LR χ^2 = 6.21, DOF = 4, and probability = 0.1839.

likely, and that manufacturing firms are more likely, to indicate that transport of materials and products is important. These results are consistent with other research findings.

Model 2

The second set of GSK/CATMOD models is concerned with the importance of access to others in similar industries.

Model 2-A given in Table 8 and Model 2-B given in Table 9 parallel Models 1-A and 1-B. The access to industry variable is predicted by the four independent variables, with one using the inclusive definition of advanced technology and the other using the restrictive definition.

TABLE 8 Model 2-A—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.371	0.110	154.49	0.0001
AGETECH	2	0.276	0.079	12.16	0.0005
ATST1	3	-0.209	0.101	4.27	0.0388
SIZE	4	-0.266	0.074	12.87	0.0003
FIRMTYPE	5	-0.356	0.077	21.13	0.0001

Note: LR χ^2 = 18.42, DOF = 9, and probability = 0.0306.

TABLE 9 Model 2-B—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.216	0.079	236.43	0.0001
AGETECH	2	0.233	0.079	8.60	0.0034
ATST2	3	0.006	0.073	0.01	0.9340
SIZE	4	-0.278	0.074	14.17	0.0002
FIRMTYPE	5	-0.352	0.077	20.74	0.0001

Note: LR χ^2 = 15. 72, DOF = 11, and probability = 0.1519.

For Model 2-A, the parameters for all independent variables are significant, although the advanced technology status variable again contributes the least to the prediction. However, the overall fit of the model is unsatisfactory.

Substituting the second definition of advanced technology status reproduces the results found in the table for Model 2-A. This definition of advanced technology status does not contribute to the prediction.

The final model given in Table 10 drops the advanced technology status variable from the model. All parameters are significant, and the overall fit is good. The mean absolute error of prediction is 2.53 percent, and the standard error is 1.25 percent.

The pattern of signs for the parameters predicting the importance of access to the industry is different from that for parameters predicting the importance of transport of materials and products.

TABLE 10 Model 2-C—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.216	0.079	238.72	0.0001
AGETECH	2	0.235	0.077	9.33	0.0023
SIZE	3	−0.278	0.074	14.19	0.0002
FIRMTYPE	4	−0.352	0.077	20.74	0.0001

Note: LR χ^2 = 4.65, DOF = 4, and probability = 0.3251.

TABLE 13 Model 3-C—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.518	0.095	257.28	0.0001
SIZE	2	−0.466	0.095	24.24	0.0001
FIRMTYPE	3	−0.384	0.095	16.46	0.0001
SIZE*FIRMTYPE	4	0.234	0.095	6.10	0.0135

Note: LR χ^2 = 0, DOF = 0, and probability = 1.0000.

Firms with newer technologies are more likely, and smaller firms and manufacturing firms are less likely, to evaluate this type of transportation service as important. The larger service firms that employ new technology are most likely to assess this form of transportation as important. It should be noted, however, that almost all firms in the sample are small by conventional standards.

Model 3

The last set of models analyzes the relation between the importance of transportation as it contributes to quality of life and firm characteristics. Model 3-A given in Table 11 and Model 3-B given in Table 12 parallel the earlier analyses, with the two definitions of advanced technology status plus the other independent variables used to predict the dependent transportation variables.

TABLE 11 Model 3-A—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.550	0.119	170.95	0.0001
AGETECH	2	0.033	0.081	0.16	0.6873
ATST1	3	−0.186	0.113	2.73	0.0986
SIZE	4	−0.367	0.080	21.24	0.0001
FIRMTYPE	5	−0.297	0.082	13.20	0.0003

Note: LR χ^2 = 9.66, DOF = 9, and probability = 0.3791.

TABLE 12 Model 3-B—Analysis of Individual Parameters

Effect	Parameter	Estimate	Standard Error	Chi-Square	Probability
INTERCEPT	1	1.413	0.082	296.52	0.0001
AGETECH	2	−0.001	0.082	0.00	0.9936
ATST2	3	−0.005	0.078	0.00	0.9499
SIZE	4	−0.377	0.080	22.39	0.0001
FIRMTYPE	5	0.294	0.082	12.97	0.0003

Note: LR χ^2 = 13.21, DOF = 11, and probability = 0.2795.

In this analysis, both the age of technology and the advanced technology status variables are not significant, although the overall fits for the models are adequate. This suggests that a simple, two-independent-variable model may fit the data. However, the simple two-variable model does not fit, and the final model includes the size and firm type variables plus their interaction as given in Table 13.

This is a saturated model, with as many parameters as subsamples, and therefore fits the data perfectly. All of the parameters are significant.

The interpretation of the model suggests that, ceteris paribus, smaller firms and manufacturing firms are less likely to say that transportation as it contributes to the quality of life is important but that the interaction of smallness and manufacturing increases the likelihood.

CONCLUSION

Transportation service preferences are assessed differently by different groups of firms. In this analysis, transportation takes on a broader meaning than the transport of materials and products to and from markets and suppliers. Two other concerns identified important to business enterprise are access of personnel to others in similar industries and the role played by quality of transportation facilities and services in making the community a pleasant place to live and work.

To be able to study the transportation needs of emerging and growing industries in the United States, the methodology may have to change. Identifying advanced technology firms by SIC codes appears to be inadequate. This research suggests that firms should instead be grouped according to such characteristics as size, broad classes of producing a product or providing a service, and age of technology used in creating that product or service.

At the recent Conference on Innovation for Economic Growth in Pittsburgh, David L. Birch, an MIT researcher, suggested that the future of job creation lies not in strictly defined "high technology" industries but in "high-innovation" firms (7). Perhaps a new focus for researchers should be the state of the technology used by a company rather than its product. Such an approach would be more consistent with the definition proposed by the JEC. In the analysis of future transportation needs, at least, this appears to be a worthwhile direction in which to move.

ACKNOWLEDGMENT

This work was sponsored by the Pennsylvania Department of Transportation and the FHWA, U.S. Department of Transportation.

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The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the U.S. Department of Transportation, the FHWA, or the commonwealth of Pennsylvania. This paper does not constitute a standard, specification, or regulation.

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

Sufficiency Ratings for Secondary Roads: Model Development

CLETUS R. MERCIER

ABSTRACT

Work has been done to develop numerical evaluation systems for priority planning use with secondary roads. However, the resulting systems are somewhat local in orientation and are not easily usable in other parts of the country because of differences in road networks, terrain, soil and weather conditions, and even political climate. Most state highway organizations use a form of numerical evaluation called sufficiency rating systems for priority planning. However, this practice is not prevalent in county highway organizations. County highway administrators have used a priority system that is commonly the composite of (a) knowledge of the local road network and its condition, (b) comparison of road conditions with a set of objectives (whether formally or informally adopted), and (c) political expediency. The research reported here was undertaken to develop a sufficiency rating system for secondary roads in Iowa. If a usable system that would yield reasonable results were available, county engineers would have an additional tool to assist them in arriving at a defensible road improvement program. The steps taken to develop the proposed model are recounted in this paper. Described are the instrument used to gather data to choose the rating criteria, the criteria chosen, their relative weights, and the final form of the model.

Work has been done to develop and improve numerical evaluation systems for priority planning use with secondary roads (1-7). However, the resulting systems are local in orientation and have limited application to planning needs of road systems in other parts of the country. Enough differences exist in road networks, terrain, soil conditions, weather conditions, and even political climate to preclude direct application.

There are elements of these systems that are reusable in other locations. Most rating systems are patterned after the sufficiency rating system originally developed by the Arizona Highway Department in 1946. Most systems even use much the same list of rating criteria and the maximum composite rating of 100, although there are some variations in the relative importance of the criteria.

The choice of rating criteria and the relative importance of each criterion compared with the others used make it possible to tailor the system to fit local needs. This is because sufficiency ratings are "descriptive": they use a mathematical expression as a measure of immediacy of need. The choice of criteria used and their relative importance (relative weight) is an empirical process based on an evaluation of past design practice and the resulting investment.

Although most state highway organizations use sufficiency rating scores for priority planning, the

Department of Engineering, 403 Marston Hall, Iowa State University, Ames, Iowa 50011.

practice is not prevalent in county highway organizations. County highway administrators have used a priority planning system that is commonly the composite of

1. Knowledge of the local road network and its condition,
2. Comparison of road conditions with a set of objectives (whether formally or informally adopted), and
3. Political expediency.

Job longevity is at least partly based on how well the administrator's perception of priorities matches that of the local population. A numerical evaluation system can help simplify the priority planning process and provide defensible results for the county highway administrator, but only to the extent that the results coincide with local perception of needs. This suggests that county highway administrators are the people best qualified to choose the rating criteria and their relative weights. In Iowa these people would be the county engineers.

The research reported here, sponsored by the Iowa Department of Transportation, was undertaken to develop a sufficiency rating system that could be used for secondary roads in Iowa. If a usable system that would yield reasonable results were available, county engineers would have an additional tool to assist them in arriving at a defensible road improvement program.

PROCEDURE

There were several assumptions made at the outset:

1. County engineers currently use at least a limited set of decision criteria in making decisions regarding project priorities.
2. Some degree of consensus exists among the county engineers about which are the most important criteria and their relative importance.

A questionnaire was developed to be used as a survey tool. Results of the survey were used to develop a final list of weighted rating elements that in turn were used as part of the proposed sufficiency rating system.

The purpose of the questionnaire was to determine whether any degree of consensus existed among the county engineers about preference for a set of rating criteria and the relative importance of each. If such a consensus existed, it could be used as a basis for choosing the rating criteria and their relative weights for use in a proposed sufficiency rating system for county roads.

The rating criteria list included in the questionnaire represented a composite list of criteria employed by 12 states currently using sufficiency rating systems. They were arranged by the categories of condition, safety, and service. (These were the categories first used in the Arizona rating system and they have also been used in most rating systems developed since that time.) Two lists of criteria were provided in the questionnaire, one for roads with the functional classification of either trunk or trunk collector and one for roads classified as area service. [Most of the paved secondary roads in Iowa are classified as trunk or trunk collector, and little of the mileage of area service roads is paved (8).] It was anticipated that county engineers would show different preferences for rating criteria for the different functional classes.

One additional element was included in the questionnaire. Most systems developed to date have grouped the rating criteria into the categories of condition, safety, and service. Respondents were asked to place the categories in rank order first and then to designate how they perceived their relative importance by inclusion of a weighting factor. (Respondents were asked to rank the categories as 1, 2, or 3, designating the most important a 1, followed by the other two in rank order. Relative importance was to be indicated by assigning the relative weight of 10 to the most important category and smaller relative weights, ranging from 9 to as low as 1, to the other two categories.)

This portion of the questionnaire was included in case there was no consensus on the ranking and weighting of the rating criteria. A measure of agreement about the ranking or weighting, or both, of the rating categories might prove to be useful in identifying the most appropriate criteria to use. A brief description of each of the rating elements was enclosed with the questionnaire to aid the respondents.

DATA ANALYSIS

Response to Questionnaire

A total of 108 questionnaires were mailed to county engineers and engineers from the Iowa DOT. Of these 108, 71 were completed and returned, providing a return rate of 67 percent. The 71 received included 66 from county engineers (67 percent return rate) and 5 from Iowa DOT engineers (56 percent return). Figure 1 is a map of the state of Iowa that shows the political boundaries of the 99 counties. Responses were received from engineers in the shaded counties. Most of the counties with larger urban areas returned completed questionnaires. Rural sections of the state are well represented.

Identification of Preferred Rating Elements

The initial step in processing the raw data was to place them in a computer file, using a data processing format.

Frequency distributions were then computed for each rating criterion listed in the questionnaire by category, rank, and weighted rank. The form shown in Figure 2 is the same as the one provided in the questionnaire.

Mean and median scores plus the standard deviation from the mean were also computed for each criterion. Although the mean, median, and standard deviation were of value, frequency distributions were the most useful in isolating those rating elements deemed most important by the respondents. As expected, the weighted rank of the rating elements identified the preferred rating elements most clearly.

The frequency distributions were carefully examined to identify a set of rating elements that consistently ranked high in comparison with all of those suggested. Although provision was made on the questionnaire to write in additional rating elements, only one respondent did so. Therefore only those elements listed on the questionnaire were considered.

Examination of the frequency distributions produced some fairly conclusive findings in terms of selection of a set of preferred rating elements. The results are described next.

Selection of Preferred Rating Elements

A total of 15 rating elements were consistently ranked high by respondents. These elements were regarded as important in evaluating trunk and trunk

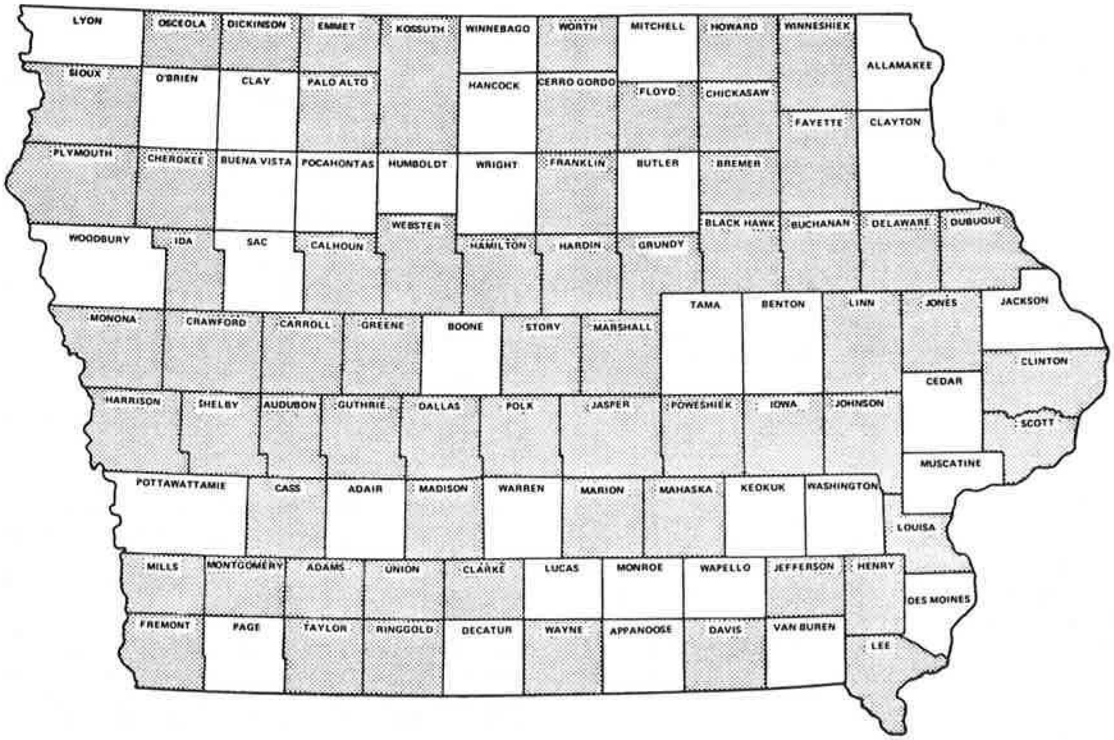

FIGURE 1 Counties responding.

	RANK BY CATEGORY	OVERALL RANK	WEIGHTED RANK
CONDITION			
Foundation	___	___	___
Wearing surface	___	___	___
Shoulder	___	___	___
Drainage	___	___	___
Remaining life	___	___	___
Maintenance economy	___	___	___
SAFETY			
Pavement width (surface)	___	___	___
Shoulder width	___	___	___
Right-of-way width	___	___	___
Stopping sight distance	___	___	___
Passing sight distance	___	___	___
Hazards (safety)	___	___	___
Alignment consistency	___	___	___
Traffic control	___	___	___
Accident rate	___	___	___
SERVICE			
Alignment (horizontal)	___	___	___
Alignment (vertical)	___	___	___
Pavement width (surface)	___	___	___
Improvement continuity	___	___	___
Ride quality	___	___	___
Surface type	___	___	___
Shoulder width	___	___	___
Snow problems	___	___	___

FIGURE 2 Form for rating element weights for trunk and trunk collector roads.

collector roads as well as area service roads, although there was some variation in ranking for the different road classifications.

Table 1 gives a brief summary of the survey results. A decision was made to include only those criteria that were consistently ranked high by the respondents. A weighted rank of 80 was chosen as the lower limit. Table 1 gives the cumulative percentage of the frequency of responses that ranked the criteria at a weight of 80 or higher.

TABLE 1 Survey Responses (cumulative percentage, weighted rank = 80+)

	Trunk and Trunk Collector	Area Service	Average
Condition			
Foundation	54	64	60
Wearing surface	60	60	60
Shoulder	14	13	12
Drainage	38	60	49
Remaining life	34.7	24.5	29.6
Maintenance economy	57.1	63.3	60.2
Safety			
Pavement width (surface)	38	30	34
Shoulder width	18	16	17
Right-of-way width	4	10.2	7.1
Stopping sight distance	58	52	55
Passing sight distance	40	34	37
Hazards (safety)	70	64	67
Alignment consistency	44	36	40
Traffic control	48	46	47
Accident rate	56.3	50	53.2
Service			
Alignment (horizontal)	42	48	45
Alignment (vertical)	38	42	40
Pavement width (surface)	26	22	24
Improvement continuity	24	20	22
Ride quality	44	44	44
Surface type	20	32	26
Shoulder width	8	10	9
Snow problems	36.7	48	42.3

Six of the most preferred rating elements received consistently high weighted rankings from respondents for all secondary roads:

1. Maintenance economy,
2. Foundation,
3. Wearing surface,
4. Drainage,
5. Hazards, and
6. Stopping sight distance.

Though not equal, they consistently ranked high in comparison with all other rating elements.

Two additional rating elements were also ranked high for all secondary roads, though at a lower level:

1. Traffic control and
2. Pavement width.

However, pavement width was double-listed on the questionnaire; it was included under both Safety and Service. An evaluation of the responses showed that (when both listings were considered) pavement width (roadbed width) should be considered one of the most important of the rating elements.

A third cluster of rating elements on the preferred list was ranked differently for area service roads than for trunk and trunk collector:

1. Passing sight distance,
2. Accident rate,
3. Ride quality,
4. Horizontal alignment,
5. Vertical alignment,
6. Alignment consistency, and
7. Snow problems.

The responses suggested that there should be some differences between the sufficiency rating system proposed for trunk and trunk collector roads and the system for area service roads. These differences were considered when the suggested scales for the rating elements were developed.

The list of criteria, together with a first draft of the proposed model, was presented to an advisory committee composed primarily of county engineers. The committee concurred with the findings with minor exceptions. They suggested deleting alignment consistency and adding surface type (for unpaved roads) and shoulder width (for paved roads).

The final list of criteria chosen includes 14 for paved secondary roads and 14 for unpaved. The survey results did not suggest, however, that each criterion should be given equal weight. Instead results suggested that the criteria should be scaled to provide for differences in emphasis. Before proceeding, a determination was made of the logical rating category for each element to simplify the weighting procedure.

The first four rating elements--maintenance economy, foundation, wearing surface, and drainage--all relate quite well to the Condition category. They all are strongly associated with the condition of the roadbed. Logically, all four should be included in that rating category.

Most of the rest of the preferred rating elements represent some characteristic of safety, and it would be consistent to include them in that category. Rating elements of that type are enumerated next, and a brief explanation of the rationale for inclusion is presented.

1. Accident rate and hazards are obvious choices for inclusion under Safety. By definition, a hazard represents an accident risk.

2. Stopping sight distance represents a potential for accident in that, at design speed, a driver cannot see far enough ahead to make an emergency stop. Traffic control covers stop signs and other traffic control devices and indicates the existence of any problem traffic control sites, which also present potential safety problems.

On the other hand, restricted passing sight distance could present two different problems--one related to Service, in its constraint of traffic capacity, and the other to Safety, in that a driver could take an unnecessary risk in attempting to pass a slower vehicle. Because traffic is usually light on secondary roads, the threat to safety represents the greatest problem, so this criterion has been included under Safety.

3. Pavement width or roadbed width has an effect on both safety and service. Being too narrow can make driving somewhat hazardous, but it also affects driving comfort and traffic capacity. A decision to place this rating element in either category is arbitrary, but including it under Service appeared to be more appropriate. Ride quality and surface type were also placed under Service because they relate mostly to that category.

4. Horizontal alignment is another rating element that can affect both a road segment's relative safety (by reducing visibility or forcing a reduction in speed to safely negotiate a curve or both) and service (by affecting driver comfort and road capacity). As was the case with pavement width, placement is somewhat arbitrary, but the decision in this instance was to include it in the Safety category.

However, the inclusion of vertical alignment in the system model presents a dilemma. Poor vertical alignment can result in portions of a road segment with safe stopping sight distance or safe passing sight distance problems, or both, but these are elements already included in the proposed rating system. Even though vertical alignment can affect service (lowered capacity, higher operating costs, and lessened driver comfort), these factors are less important for secondary roads. For these reasons, this rating element was not included in the proposed model.

5. Shoulder width is associated with both safety and service. However, because it applies only to paved roads, it was placed under Service because it then balances surface type. (Shoulder width is included under roadbed width for unpaved roads.) Snow problems are more obviously associated with service in that they can restrict access to a road.

If the rating elements were placed in rating categories as previously suggested, there would be four under Condition, six under Safety, and four under Service. The following table gives the suggested breakdown by rating category.

Rating Category	Item Rated
Condition and maintenance experience	Foundation
	Wearing surface
	Drainage
	Maintenance economy
Safety	Accident rate
	Hazards
	Stopping sight distance
	Passing sight distance
	Traffic control
	Horizontal alignment
Service	Pavement (roadbed) width
	Ride quality
	Snow problems
	Surface type (unpaved roads)
	Shoulder width (paved roads)

Proposed Relative Weights--Rating Categories

As noted earlier, most rating organizations use a maximum composite rating of 100, with each rated criterion assigned a maximum value. Each of the three rating categories is assigned a share of the 100 points, with the rating elements allocated a fraction of that share.

The proposed rating system is also based on a maximum value of 100 because it is familiar to most highway engineers. What remains is to determine the relative share that should be assigned to each category.

The completed questionnaires contained sufficient information to approach this problem from three directions. An evaluation of the three approaches yielded a reasonable range of values. They are described briefly next.

1. An analysis of the category rank suggested by respondents. Respondents were asked to rank the three rating categories in order of perceived importance.
2. An analysis of the category weights suggested by respondents. After the respondents ranked the rating categories, they were asked to weight each category relative to the other two.
3. A weighted average that used the preferred rating elements and their relative weights. Some of the rating elements were considered more important to the rating system than others. An evaluation of these differences in relative weights of the rating elements, combined with others in the most logical rating category, could serve as a guide to the appropriate weights of the three rating categories.

The following range of values was suggested:

1. Condition--30 to 38 points,
2. Safety--32 to 47 points, and
3. Service--20 to 32 points.

An analysis of the simple ranking of categories suggested a breakdown of 38 points for the Condition category, 37 points for Safety, and 25 points for Service (for trunk and trunk collector roads) and 37-32-31 (for area service roads). An evaluation using weighted category ranking results in a proposed breakdown of 35-35-30 (trunk and trunk collector) and 36-32-32 (area service). The third approach used the weighted preferred rating criteria, with the rating criterion of horizontal alignment shifted from Service to Safety. This results in a suggested scale of 30-47-23 (trunk and trunk collector) and 30-44-26 (area service).

The method used in Approach 2 best reflects the opinion of the respondents to the questionnaire, in that they were able to weight the rating categories as well as rank them. Moving horizontal alignment from Service to Safety and the deletion of vertical alignment from Service would change the proportions of Safety and Service from 35-30 to 40-25, which comes close to that suggested by the third approach. Therefore the proposed scale was

1. Condition--35 points,
2. Safety--40 points, and
3. Service--25 points.

Analysis of the completed questionnaires did suggest a slightly different breakdown of points for the model between trunk and trunk collector roads and area service roads. This resulted in a slightly higher total for the Service category than for Safety. This variance was reflected in the use of the model and forms for the first trial run, but its effect on the resulting ratings was negligible. Therefore the same breakdown of points has been proposed for all secondary roads to be rated.

Proposed Relative Weights--Rating Elements

The final step in the formation of the proposed model was to ascertain the appropriate maximum point value for each included rating element. The list of preferred rating elements and their relative weights, referred to earlier, were used to resolve this last problem. All that remained was to make such adjustments as were necessary to the individual weights to match the category weights in the proposed models.

For example, the proposed weight to be applied to the Condition category is 35 points (of a possible 100). Four rating elements were included in that category: foundation, wearing surface, drainage, and maintenance economy. Respondents ranked foundation, wearing surface, and maintenance economy about equally, and drainage was ranked slightly lower. Dividing the 35 points that were allocated to that rating category among the four rating elements resulted in the following breakdown:

1. Foundation--9 points,
2. Wearing surface--9 points,
3. Drainage--8 points, and
4. Maintenance economy--9 points.

A similar procedure was used for the rest of the model. Respondents weighted snow problems slightly heavier for area service roads than for trunk and trunk collector roads, and there was a corresponding decrease of the rating element ride quality. This one minor adjustment was made in relative weights in the model for the first trial run. However, as noted earlier, its effect on the resulting ratings was negligible. Therefore, except for variations relating to surface type, the same basic model is proposed for all secondary roads.

It should be noted, however, that some minor variations in its use are applicable, depending on the road's surface. These variations are described next.

1. If the road is paved, pavement (roadbed) width refers to hard-surface pavement width. If the road is unpaved, this rating element refers to the width of the traveled way. This width is the distance between the top of the foreslope on one side of the roadway and the top of the foreslope on the other side. For sufficiency ratings, this distance will be compared with the design standard for that particular functional classification expressed as the sum of all lane widths and shoulder widths.
2. If the road is unpaved, shoulder width becomes part of the roadbed width. Therefore it is not rated separately but becomes part of the traveled way and is rated as part of the pavement (roadbed) width.
3. If the road is unpaved, its surface type will be rated. A paved road will receive the maximum rating (in terms of surface type) no matter what design standard applies. Therefore inclusion of this rating element will not result in any loss of points and this element need not be included. Any existing road surface of a lesser quality on the rated road segment will result in the inclusion of the surface type rating element, so it can be compared with the design standard.

Table 2 gives the resulting model with the maximum weight of each criterion listed.

TABLE 2 Final Proposed Sufficiency Rating System Model

Rating Category	Item Rated	Maximum Points
Condition and maintenance experience (35 points)	Foundation	9
	Wearing surface	9
	Drainage	8
	Maintenance economy	9
Safety (40 points)	Accident rate	6
	Hazards	9
	Stopping sight distance	8
	Passing sight distance	5
	Traffic control	6
	Horizontal alignment	6
Service (25 points)	Pavement (roadbed) width	9
	Ride quality	5
	Snow problems	6
	Surface type (unpaved)	5
	Shoulder width (paved)	(5)

Trial Run of Model

A limited number of road segments were evaluated to provide an abbreviated trial run of the initial form of the model. The roads evaluated were located in central Iowa and ranged from a heavily traveled trunk road to lightly used area service roads. The sample was chosen with the expectation that the sufficiency ratings for these roads would encompass scores ranging from excellent to scores that would suggest critical needs.

Minor changes were made in the model on the basis of the first trial run. The revised model was then used in a more extensive test in another Iowa county. A sample of about 20 percent of the county's secondary roads was rated and the results were used to derive the final form of the model and rating forms recommended in the project report.

Questionnaire responses had suggested that there be slight differences in the point breakdown of the model for trunk and trunk collector roads and for area service roads. However, as noted earlier, the first trial run indicated that the same model could be used for all secondary roads for the second trial because differences in results were negligible. This also makes the model easier to use. The first trial run did not suggest any other changes, except for some revisions in record keeping.

Because the second trial run used a much larger sample of roads, it was possible to make some comparisons of the ratings. Use of the rating system yielded what appeared to be reasonable results. For example, scores on the trunk roads in the sample ranged from 73 to 96. The 96 score was for a nearly new, straight road in excellent condition. The road with the 73 score is much older and has narrow pavement and a number of curves. By most measures, it would be considered tolerable and the score indicates that. However, it is the most heavily used road in the county's secondary system, and the high accident rate would appear to reflect this combination of heavy use and road deficiencies. The score also suggests that this road should receive a high priority for improvement.

Choice of design standard also affected the ratings. One trunk road received a score of 80, but it was scored this high only because its traffic count was less than 200 vehicles per day (vpd). Had it been more heavily used (more than 400 vpd), it would have received a score of 71. It would appear that use of the design standard would help the county engineer to maximize the effect of tax funds spent by better meeting consumer needs.

The trial runs indicate that the proposed sufficiency rating system is feasible. However, the first time a sufficiency rating system is used for a given county, some extra effort will be required to gather data, especially data related to road geometrics. Once this has been done, however, much of the data gathered will be easily reusable; only those elements that change from year to year will need to be evaluated.

SUMMARY AND CONCLUSIONS

The objective of this study was to produce a sufficiency rating system that could be used to evaluate the adequacy of secondary roads in Iowa. The system developed should be reasonably easy to use yet yield results that are compatible with processes currently used in priority programming.

The model that is proposed uses the same format as that used by the Arizona Highway Department for the first sufficiency rating system developed in 1946. This format was adopted because it is well known, widely accepted, and comparatively easy to use. It is also considered to yield reasonable, reproducible results.

Models currently being used for primary roads are empirical in nature; they are numerical ratings that relate well to experience-based adequacy ratings. It follows that the experience of local engineering practitioners should figure heavily in determining the form of the proposed model. To that end, a questionnaire was developed that could be used to survey local engineering practitioners--mostly county engineers. A statistical analysis of the responses provided the basis for the formation of the model proposed in this paper.

Selection of rating criteria (and their relative weights) was based on the responses to the questionnaire. Scaling factors were based on the relative weights suggested by the responses and the model used by the Iowa DOT for primary roads. Maximum scores were established using a set of design standards adopted for the model.

To refine the model, some additional effort is needed to more easily access available data and more input is needed from potential and actual users. The comparative results produced by the trial runs suggest that the model is usable and should prove to be compatible with other processes used to form priority lists for project programming. It should provide results that are reproducible and defensible.

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

A System for Forecasting and Monitoring Cash Flow as an Aid to Rational Financial Planning

GARY R. ALLEN

ABSTRACT

The research on which this paper is based was performed as part of a study to develop an improved system for generating a 2-year forecast of monthly cash flows for the Virginia Department of Highways and Transportation. It revealed that current techniques used by the department to forecast right-of-way payments; salaries and wages; and allocations to cities, counties, other state agencies, and transit properties require no change. On the other hand, it showed that forecasts of expenditures on materials, supplies and equipment, and maintenance contracts have overestimated actual cash outlays by significant margins. In addition, this research revealed that success in forecasting federal revenue reimbursements is, at best, likely to be spotty and that forecasts typically will be overly optimistic. For state revenues, official forecasts approved by the Office of the Secretary of Transportation of Virginia serve as the basis of the official cash forecast; nevertheless a technique is proposed for early identification of significant changes in state revenue collections. The use of techniques derived from this research in a December 1983 forecast of cash flows for January through July 1984 showed that the estimated cash balance for the end of the period was within $4 million of the actual balance. As of August 1985 the forecast was within $11 million of the actual balance. Among the major recommendations is that it may be reasonable to establish cash balances at contingency levels consistent with the expected excess of expenditures over revenues for the months of July through October.

Methods for forecasting and managing cash flow are well established in the private sector where inadequate cash balances can mean bankruptcy and excessive balances can result in forgone business opportunities. In the public sector, until fairly recently there was less perceived need for close forecasting and monitoring of cash flow. However, during the past several years, revenues for most transportation departments have become volatile and unpredictable, and construction expenditures have been subject to unprecedented rates of inflation. During such periods, a public works agency such as the Virginia Department of Highways and Transportation (VDHT) runs a serious risk of encountering inappropriate cash balance levels in carrying out its construction and maintenance program.

Virginia Highway and Transportation Research Council, Box 3817 University Station, Charlottesville, Va. 22903-0817.

This risk can be minimized by (a) maintaining large cash balances that divert funds from current needs or (b) developing and using reliable management tools for short-term forecasting and monitoring of cash inflows and outflows. From the standpoint of sound public finance principles, the latter alternative is preferred. However, comparisons made of the cash balances that were forecast in July 1983 and the balances that actually occurred show a consistent tendency to underestimate cash balances over the forecast period. This stems from underestimates of revenues, overestimates of total expenditures, or offsetting errors in estimates of federal aid and state revenues. For example, the forecast for the period from May to September 1983 overestimated federal aid by $28.1 million, underestimated state revenue by $28.5 million, and overestimated total outlays by $62.0 million. From October 1983 through June 1984, this July 1983 forecast overestimated federal aid by $53.8 million, underestimated state revenue by $44.3 million, and overestimated total outlays by $71.6 million.

PURPOSE AND SCOPE OF STUDY

A major objective of the study was to develop an improved system for forecasting, monitoring, and managing cash flow over the short run. An equally important objective was to provide guidelines for estimating and establishing reasonable minimum cash balances for contingency purposes. A third objective was to create a heightened awareness on the part of both management and the staff responsible for the programming, scheduling, and advertisement of construction projects that an improved cash flow forecast can be a significant aid in implementing the construction program.

In this paper are described the techniques proposed for forecasting monthly variations in state revenue collections; federal aid reimbursements; contract maintenance payout; expenditures on materials, supplies, wages, equipment, and right-of-way; and payments to localities, state agencies, transit properties, and contract consultants. Also described is the performance of the contract construction payout forecasting technique implemented by the VDHT as a result of earlier work (1).

STUDY APPROACH

The forecasting techniques proposed in this paper are based on an examination of the historical pattern exhibited by each line item in the VDHT's Revenue, Expenditures, and Cash Balances Report. For most revenue and expenditure items, 52 months of data were collected. Each line item was subjected to at least two kinds of tests. First, the estimate of total payout was examined to determine its stability as a percentage of a major line item, such as total state revenue, in the department's budget. Second, the U.S. Department of Commerce, Bureau of Economic Analysis's Seasonal Adjustment Program (2) was used to test the monthly variations for a stable seasonal pattern and to estimate monthly distribution factors that would accurately mirror seasonal payout variations. In addition, regression analysis was used to test the accuracy of previously used techniques for forecasting monthly variations in state revenue and federal aid reimbursements.

The technique for forecasting contract construction payout alluded to in this paper is described fully elsewhere (1).

FORECASTING MONTHLY VARIATIONS IN REVENUE

State Revenue

Performance of Current Technique

The official forecast of revenues that comprise the Highway Construction and Maintenance Fund is issued through the Office of the Secretary of Transportation of the commonwealth and is based on estimates of the major revenue sources prepared by the Division of Motor Vehicles and the Corporation Commission.

Estimates of monthly revenue collections for the cash forecast have historically been calculated by multiplying the percentage of annual revenue that has, on average, been collected for each month by the official estimate of total revenue. This forecasting technique has two sources of error: (a) errors in the official forecast of total revenue and (b) errors in the estimates of the monthly percentages that are applied to the forecast. The reader should note that even if seasonality (monthly percentages of collections) is perfectly forecast, a 24-month cash forecast can be no more accurate than the official forecast.

Statistical analysis was used to examine the accuracy of the estimates of monthly variations in revenue based on applying the department's seasonal distribution factors to the official forecast. The results showed that a March 1982 forecast of revenue flows for the following 20 months explained only 47 percent of the variation in actual collections. The standard error was $7.5 million per month. Using official updates of the original forecast throughout the period improved performance somewhat, but the standard error remained high at $5.03 million per month. With the official updates, 77 percent of the monthly variation was tracked by the forecast.

Proposed Improvements

Potential improvements in the revenue flow forecast were examined from the standpoint of the two sources of error noted in the previous section--the seasonality of the collections and the aggregate forecast.

Monthly variations in the revenue collection pattern were examined for stable seasonality by applying the Bureau of Labor Statistics (BLS) seasonal adjustment and analytical software program to a data set consisting of 48 months of state revenue receipts. The analysis revealed a highly stable seasonal collection pattern, and the seasonally adjusted monthly factors estimated using the BLS technique differed somewhat from the factors used by the VDHT Budget Division. These seasonally adjusted distribution factors are given in Table 1.

TABLE 1 Seasonal Factors for State Revenue and Contract Maintenance

Month	Revenue	Maintenance
January	0.0785	0.017
February	0.0845	0.012
March	0.0995	0.004
April	0.0816	0.005
May	0.0909	0.023
June	0.1119	0.103
July	0.0521	0.124
August	0.0795	0.168
September	0.0828	0.168
October	0.0862	0.169
November	0.0795	0.147
December	0.0731	0.061

Note: Factors are based on 48 months of data.

With respect to the aggregate estimate of revenue to which the seasonal factors are applied, the law requires that the official forecast serve as the basis for the department's budget and as the basis of geographic allocations. Nevertheless, for contingency planning in the context of the programming, scheduling, and advertisement of construction projects, some effort should be made to determine the extent to which the near-term official revenue forecast is likely to target actual revenue collections. Such an effort would give an early test, in the current fiscal year, of the reliability of the official forecast that has been made for the following fiscal year in advance of official updates, which typically are made as often as quarterly. A technique that is well suited to such an early testing effort is based on the finding that actual state revenue collections in the third quarter of a fiscal year (January, February, and March) exhibit a highly stable proportion of actual collections in the following fiscal year. Since FY 1978 this proportion has averaged 24.835 percent and its standard error has been 1.02 percent.

Results from applying this test technique as a planning tool show that over the 7 fiscal years beginning in 1978, the estimation error averaged 2.85 percent of actual collections. The underestimates averaged from $580,000 to $2.0 million per month, and the overestimates from $1.0 million to $2.4 million per month. For the last 3 fiscal years for which official forecasts from the Secretary's Office of the VDHT are readily available, that error averaged 6.5 percent of actual collections, was an overestimate in FY 1982 ($37.5 million), an underestimate in FY 1983 ($16.7 million), and an underestimate in FY 1984 ($63.6 million) even though the FY 1982 forecast was revised in February 1982, the FY 1983 forecast was revised in September 1982 and April 1983, and the FY 1984 forecast was revised in December 1983 and April 1984.

Clearly, official forecasts need to be updated; but, just as clearly, contingency planning in the form of early tests of the potential of actual revenue being significantly different from the official forecast is a prudent contingency planning exercise. In this context it is interesting to note that an FY 1985 forecast of state revenue based on collections in January through March of 1984 (the new contingency planning technique) yielded an estimate of $728.0 million. The official forecast updated in March 1984 was $709.1 million. It was updated again in August 1984 to $723.772 million, an amount only slightly less than the estimate yielded by the third-quarter collections technique.

Multiple regression and correlation analyses were employed on a data set consisting of the latest 24 months' revenues as a way of testing the forecasting accuracy that can be expected from the application of the monthly distribution factors derived from the BLS seasonal adjustment program to aggregate revenue estimates derived from both the official forecasts (including updates) and the third-quarter collections technique. The results are noted in the items that follow.

1. Using the monthly factors employed by the VDHT Budget Division and the updates to the official forecasts during the 24-month test period, monthly estimates explained 84 percent of the variation in actual collections and had a standard error of $4.32 million per month. The cumulative error was $25.4 million and this was exhibited for much of the period. It should also be noted that this degree of accuracy was afforded only by frequent updates of the official forecast.

2. Using the seasonally adjusted distribution factors derived in this work applied to a forecast based on third-quarter collections, monthly estimates were within 1 percent of actual collections, explained 84 percent of the monthly variation, and exhibited a standard error of $3.75 million per month. The cumulative error was $15.0 million but was removed in 4 months and remained under $5.0 million for the balance of the test period.

3. Even if the aggregate forecast is perfect, the standard error of estimated monthly collections can be, at best, in the neighborhood of $3.67 million per month.

Forecast Employing Proposed Techniques

In this section is presented a comparison of actual collections for January to July 1984 with the results of forecasting state revenues by the techniques available to the budget division before December 1983 and under the third-quarter forecasting technique using seasonally adjusted monthly factors. For purposes of identification, the techniques in use by the VDHT Budget Division have been denoted by "23 MNTH.," a name taken from the department's previous 23-month construction payout forecasting method. The proposed techniques are labeled "MNTH. FACTORS," representing a monthly factors distribution technique. When examining Figures 1 and 2, the reader should note that the forecast could have been prepared as early as April 1983, 9 months before the beginning of the forecast period and 8 months before the last official forecast revision before the beginning of the forecast period.

Notwithstanding that the official forecast was revised in December 1983, Figures 1 and 2 show that the proposed techniques perform much better than the 23-month payout. Over the 7-month period, the 23-month technique consistently underestimated monthly revenue. Errors ranged from $2.0 million to $22.7 million. The monthly factors forecast error ranged from $0.7 million to $6.3 million.

Federal Aid Reimbursements

Recent Forecast Performance

Forecasting federal aid reimbursements has been and likely will continue to be among the most difficult tasks of the monthly cash flow estimation process. The budget division forecast for April 1982 through December 1983 captured only 5 percent of the monthly variation in federal aid reimbursements and exhibited a cumulative overestimation error in excess of $100.0 million. That forecast was based on an estimate of aggregate construction payout in the federal aid category, an assumed average federal participation rate, and a 1-month lag between payout and reimbursement. The overly optimistic reimbursement forecast can be traced to the inaccuracy of the contract construction forecast technique that was in use in 1982 (1).

In January 1984, the budget division implemented a new contract construction payout forecasting technique as a result of work completed in an earlier phase of this study (1). Concurrently, a new federal aid forecasting technique was implemented. Because federal aid reimbursements are a direct function of the federal aid portion of the construction program, the current forecast is estimated as the multiplicative product of the expected monthly payout for each construction contract and its specific participation rate summed over all federal aid projects. Reimbursements are estimated to lag payout by 1 month. Figure 3 shows the performance of the new forecasting technique implemented in January 1984. In comparison with the 23-month payout technique used before that time, the monthly factors model appears to perform well. For the first 7 months of 1984, the cumulative error in the new forecast was $13.0 million. The error using the former technique was $49.7 million. Through September 1984 these cumulative overestimates had grown to $30.7 million for the new technique and $85.6 million for the former method.

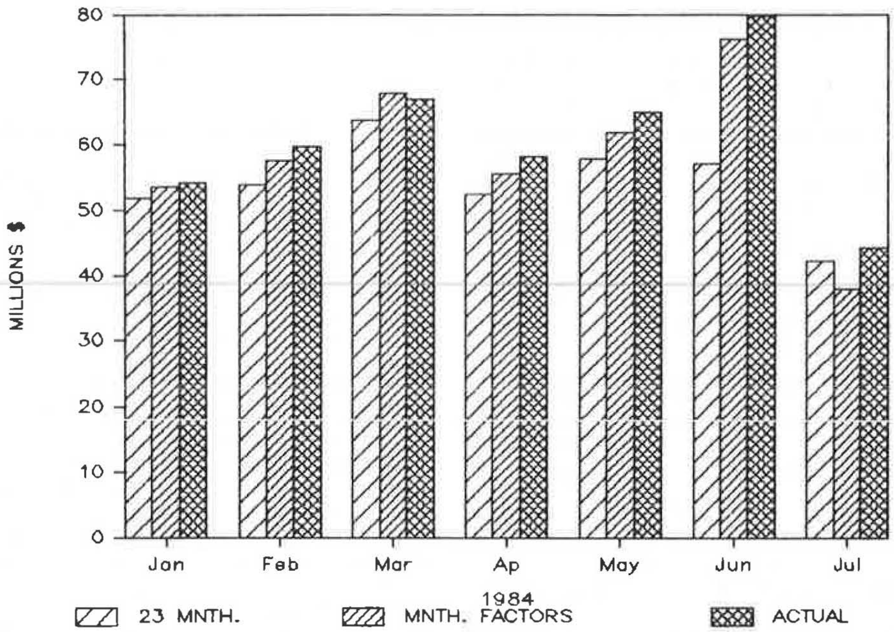

FIGURE 1 Estimated state revenue, January 1984.

Notwithstanding that errors that result from the monthly factors technique are likely to be significantly smaller than those under the formerly used 23-month payout model, the tendency of the forecast to consistently overestimate actual reimbursements is not desirable should it be found to persist. It is quite reasonable to hypothesize that the difficulty in estimating reimbursements stems largely from the fact that the lag structure, which typically applies to federal aid receipts (around 39 days), is made significantly longer and highly variable by reimbursements that fall into three "adjustment" categories: (a) charges to projects for which no federal aid agreement exists, such as advance construction; (b) charges the appropriateness of which has been questioned by the FHWA and for which the VDHT has returned federal funds while the matter is reviewed; and (c) cost overruns not covered by an existing federal aid agreement and for which a modified agreement must be negotiated. When a charge falls into one of these categories, several months to several years may elapse before reimbursement is received. The best information available to the author indicates that as much as $15.0 million to $20.0 million falls into the cost overrun category at any point in time and that much of this money is not reimbursed until the final FHWA audit 2 years after project completion.

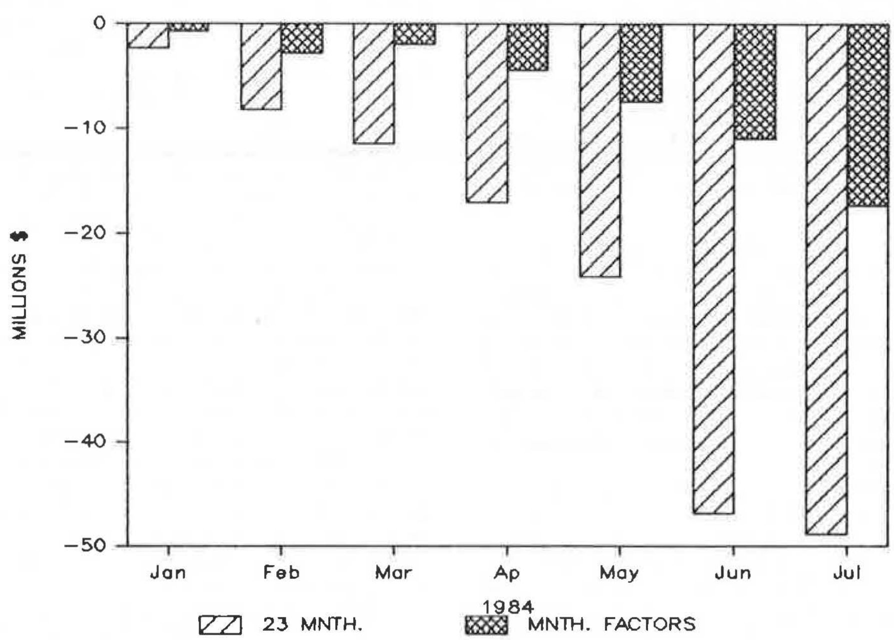

FIGURE 2 Cumulative state revenue error, January 1984.

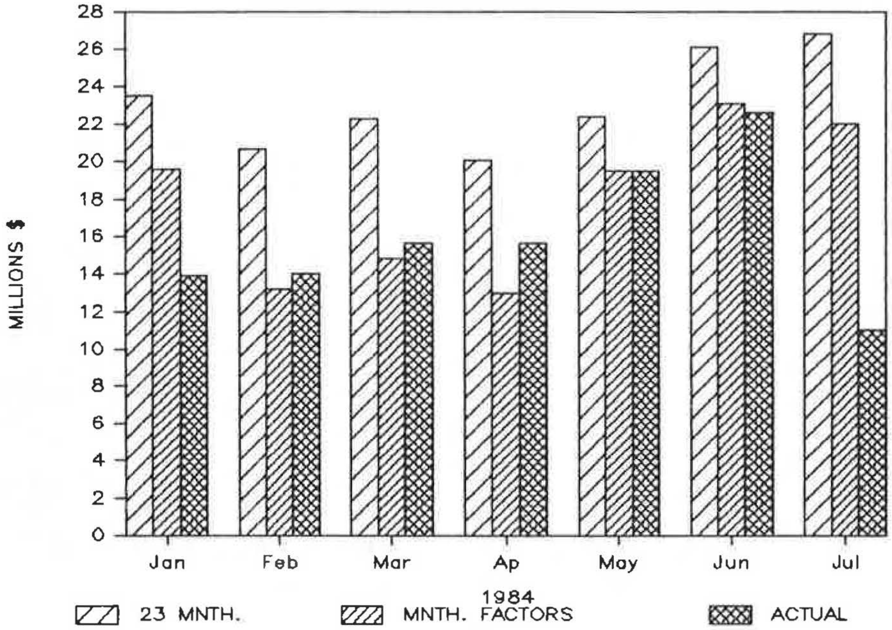

FIGURE 3 Estimated federal aid, January 1984.

Proposed Improvements

Consistent overestimation is an undesirable characteristic of the federal aid forecast. Two alternatives are proposed here as avenues for correcting this tendency. The first relates to the currently used monthly factors technique and the second to a technique based on federal aid apportionments.

Logic strongly suggests that the monthly factors technique currently being used by the VDHT Budget Division (1) should produce an accurate forecast. Nevertheless, the tendency of the technique to overestimate might be corrected somewhat by two adjustments. The first relates to cost overruns. In the monthly factors construction payout technique developed in the first phase of this study, disbursements are based on a final contract estimate that includes an estimate of cost overruns. Because cost overruns are typically not part of negotiated federal aid agreements, the federal aid monthly factors model should be adjusted so that contract participation rates are multiplied by a contract estimate that excludes the estimate of cost overruns. The second adjustment relates to those instances in which the VDHT initiates and designates a construction project as a federal aid participating project in advance of the approval of a negotiated federal agreement. Such projects should be included in the estimation pool for federal aid reimbursement only after the negotiated agreement has been approved.

A second technique that offers potential for improving the federal aid forecast should be employed in addition to the monthly factors technique now in use until the latter can be tested over a longer period of time. This technique is predicated on the assumption that the VDHT will continue to obligate all available federal aid and on the recognition that reimbursements received in a particular fiscal year stem from apportionments and obligation authority spanning 5 years (3). This trickle of reimbursements begins with the apportionment announcement and ends 4 or 5 years later when the last charges to a construction project have been submitted, approved, and reimbursed. The proposed technique consists of the following steps:

1. Reimbursement in each month is assumed to consist of a seasonally stable percentage of the apportionment in the current and previous 4 fiscal years.
2. Monthly distribution factors are derived by applying the BLS statistical package (2) to a data set consisting of actual federal aid reimbursements. Because reimbursement in a particular month is comprised of obligation authority available over a 5-year period, the estimated monthly factors are divided by 5. The resulting factors are given in Table 2.
3. Preliminary estimates of monthly federal aid for a particular year are derived by summing the apportionment bundles for that year and the previous 4 fiscal years and multiplying the sum by the factor given in Table 2 for the month in question.

TABLE 2 Monthly Factors for 5-Year Federal Aid Reimbursement Estimation

Month	Factor	Month	Factor
October	0.0272	April	0.0168
November	0.0208	May	0.0148
December	0.0184	June	0.0192
January	0.0160	July	0.0198
February	0.0120	August	0.0110
March	0.0102	September	0.0138

4. Final monthly estimates of federal aid are derived by using the equation:

Final estimate = 1.06 (preliminary estimate) − 5.18

This equation was developed with the aid of multiple regression analysis, explains 67 percent of the variation in monthly federal aid for the 28-month period beginning in November 1981, and has a standard regression error of $3.51 million per month.

Employing Steps 1 through 4 results in a forecast

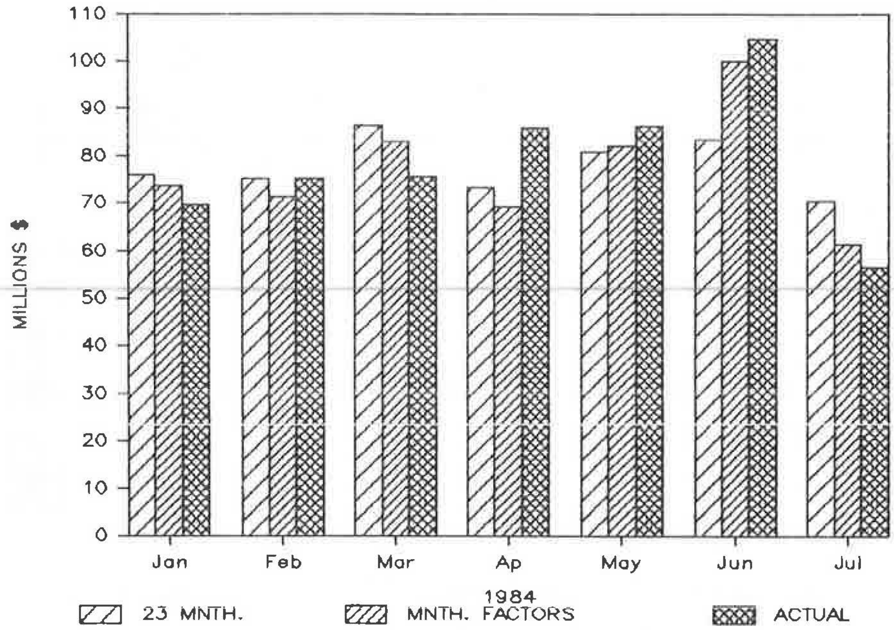

FIGURE 4 Estimated total revenue, January 1984.

for January through September 1984 that cumulatively underestimates federal aid collections by $7.9 million.

Total Revenues

The results of using the techniques proposed for forecasting state revenue and federal aid are shown in Figure 4. The errors in estimating total revenues are much smaller under the proposed techniques than under techniques used by the VDHT before December 1983. The average error for the previously used techniques is $10.11 million with a standard error of $6.84 million per month. Under the proposed techniques, the average error is $6.56 million with a standard error of $4.6 million per month.

FORECASTING CONTRACT CONSTRUCTION

As a result of an earlier phase of this study (1), the VDHT Budget Division implemented a new forecasting technique for estimating contract construction payouts. This technique, called the "monthly factors model," has been the basis of the construction payout forecast since January 1984 and has performed extremely well.

Performance of the forecast is shown in Figure 5. Through July 1984, the monthly factors model over-

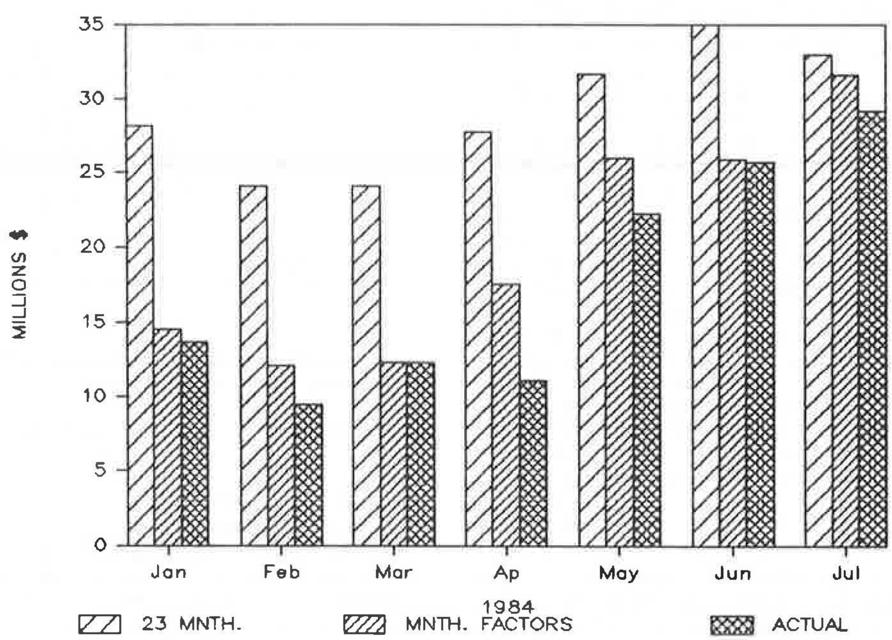

FIGURE 5 Estimated construction, January 1984.

estimated payout by an average of $2.31 million per month. The standard error was $2.25 million and the cumulative error $16.2 million. The technique used previously overestimated actual payout by $11.46 million per month and resulted in a cumulative overestimate of $80.2 million. As of the end of September 1985, the monthly factors model showed a cumulative error of $13.2 million. Clearly, the monthly factors model is exhibiting excellent performance.

FORECASTING PAYMENTS TO LOCALITIES, OTHER AGENCIES, AND TRANSIT PROPERTIES AND EXPENDITURES ON SALARIES, WAGES, EQUIPMENT, AND RIGHT-OF-WAY

The budget division forecasts for a number of line items in the cash forecast have performed well and require no change. These are

1. Payments to the counties of Arlington and Henrico,
2. Payments to cities for street maintenance,
3. Payments to other state agencies,
4. Payments to transit properties,
5. Expenditures on salaries and wages,
6. Expenditures on equipment, and
7. Expenditures on right-of-way.

FORECASTING MAINTENANCE CONTRACTS

Performance of Current Technique

Contract maintenance is not a line item in the department's budget, although it is a line item in the cash forecast. Over the past 3 fiscal years, the budget division has based estimates of monthly payout for maintenance contracts on figures provided by the maintenance division. These estimates have consistently been overly optimistic in terms of the amount of maintenance that would be performed under contract, and in the first 7 months of 1984 payouts were overestimated by $11.2 million.

Proposed Improvements

The BLS seasonal adjustment program (2) was used to analyze historical data on contract maintenance payout. The analysis revealed that payout exhibits a highly stable seasonal pattern. Monthly factors that can be applied to the total estimate of contract maintenance were given in Table 2.

The historical pattern of contract maintenance serves as an appropriate technique for arriving at an aggregate estimate of payout for a particular fiscal year. In FY 1984 contract maintenance was 24.3 percent of the maintenance budget; from FY 1979 to FY 1984, excluding flood damage, the average was 26.1 percent. Until such time as the maintenance division can provide estimates that do not tend to be overly optimistic, averaged historical payout can serve as a reasonable aggregate estimating technique. Applying an estimate of 27 percent of the maintenance budget results in total payout estimates of $75.53 million for FY 1984 and $81.98 million for FY 1985. The results of a forecast using the monthly factors given in Table 2 are shown in Figure 6. Over the forecast period, the cumulative error of this proposed technique is a $1.7 million underestimate. As of September 1984 the forecast exhibited an overestimate of only $100,000.

FORECASTING CONSULTANT CONTRACTS, MISCELLANEOUS CONTRACTS, AND OTHER EXPENDITURES

Performance of Current Technique

In addition to contract maintenance, several other line items in the cash forecast do not correspond to line items in the VDHT program budget. Among these are the line items "consultants," "miscellaneous contracts," and "other expenditures."

Obtaining data with which to develop a forecasting method for these line items proved impossible, partly because the historical data lacked continuity. Verification of the "consultant" line item presented an additional complication because the reported expenditures for accounting object codes,

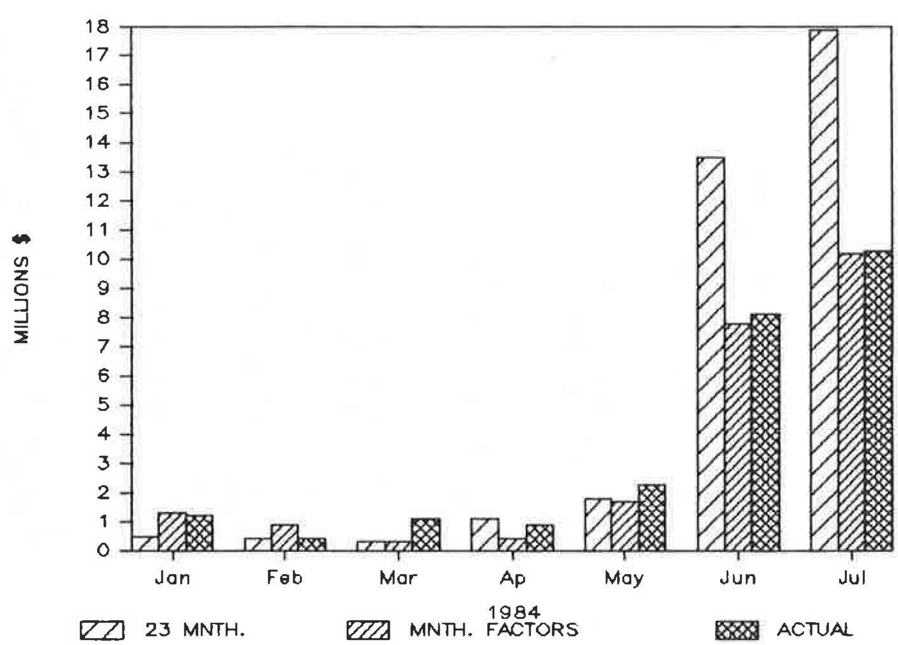

FIGURE 6 Estimated maintenance contracts, January 1984.

which presumably correspond to expenditures for consultants, average about $300,000 per month, an amount significantly less than the $2.8 million per month average indicated by the July 1982 through December 1983 cash balance reports prepared by the fiscal division. Finally, the line item "other expenditures" frequently contains negative entries.

Proposed Improvements

Because consultant contracts, miscellaneous contracts, and other expenditures appear to lack a seasonal pattern and because of the inclusion of negative entries for other expenditures, the cash forecast could be simplified by combining these three line items into one item, estimating the aggregate fiscal year payout as equal to from 5.5 to 6.5 percent of the arithmetic sum of state revenue and "other" revenue, and distributing the payout in equal proportions throughout the months of the fiscal year.

FORECASTING EXPENDITURES ON MATERIALS AND SUPPLIES

Performance of Current Technique

Examination of the forecast of expenditures on materials and supplies for January through July 1984 revealed that the monthly estimate always exceeded the payout, in some months by as much as $10.0 million.

Purchase of materials and supplies is a line item in the department's program budget, and the cash forecast of the payout on materials and supplies historically has been derived by distributing the budgeted amount proportionately throughout each month of the fiscal year. From January 1984 through June 1984, the forecast payout was $97.8 million; payout for this period was, however, only $39.6 million.

Proposed Improvements

Using budget figures provided by the VDHT Administrative Services Division as the basis for forecasting payout on materials and supplies appears to be quite reasonable. Nevertheless, this approach shows an apparent tendency to overestimate actual expenditures. It is not clear that the budgeted amount is the cause of this tendency. Several changes have been made in the format of the monthly expenditures and cash balances report during the past 2 years and these may have been responsible for the fact that, since July 1982, reported expenditures do not track recorded purchases of materials and supplies even if reasonable time lags are allowed between purchase dates and payment dates.

Two options are available to improve the forecast. The first, which has been initiated in the VDHT's latest cash forecast, is to somewhat reduce the budgeted amount for materials purchases for purposes of cash payout forecasting. This option was pursued for testing purposes and the results are shown in Figure 7. When the reduction in the materials budget was incorporated into the total payout forecast (shown in Figure 7), the outcome was encouraging: total payout through July 1984 is overestimated by $2.7 million and data collected through September 1984 showed an overestimate of $6.2 million for the forecast period beginning in January 1984. The second option for improvement is for the fiscal, administrative services, and budget divisions to cooperate in identifying the cause of the disparity between reported purchases and reported expenditures on materials and supplies.

CASH BALANCES

January 1984 to July 1984

The techniques proposed in the previous sections, including the adjustment for materials purchases, were applied to derive a cash balance forecast for January 1984 to July 1984. The accuracy of this forecast is shown graphically in Figure 8. Data available through September 1984 showed the cumulative error to be approximately $20.0 million, most of which resulted from overestimates of federal aid ($18.3 million) in September. For the forecast pe-

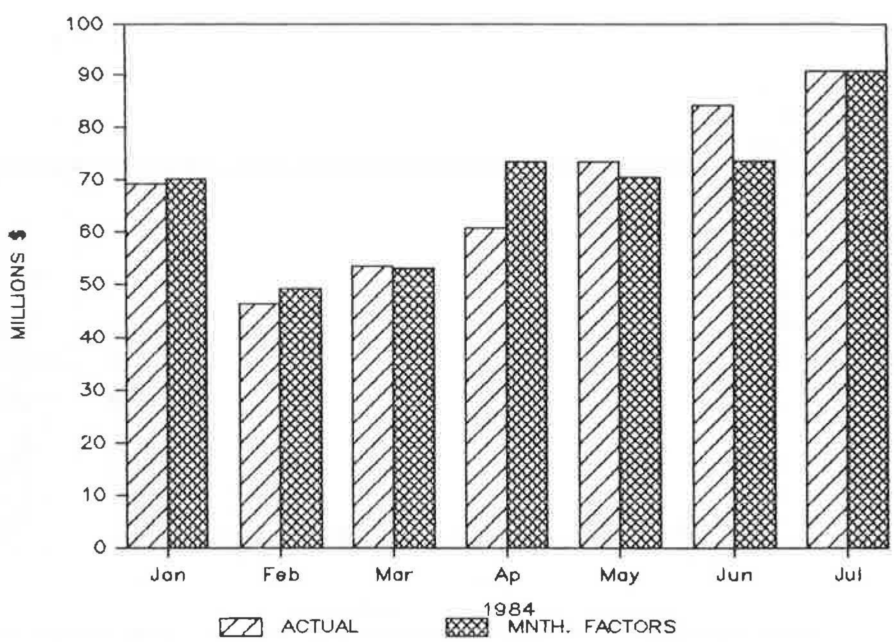

FIGURE 7 Total versus material-adjusted payout, January 1984.

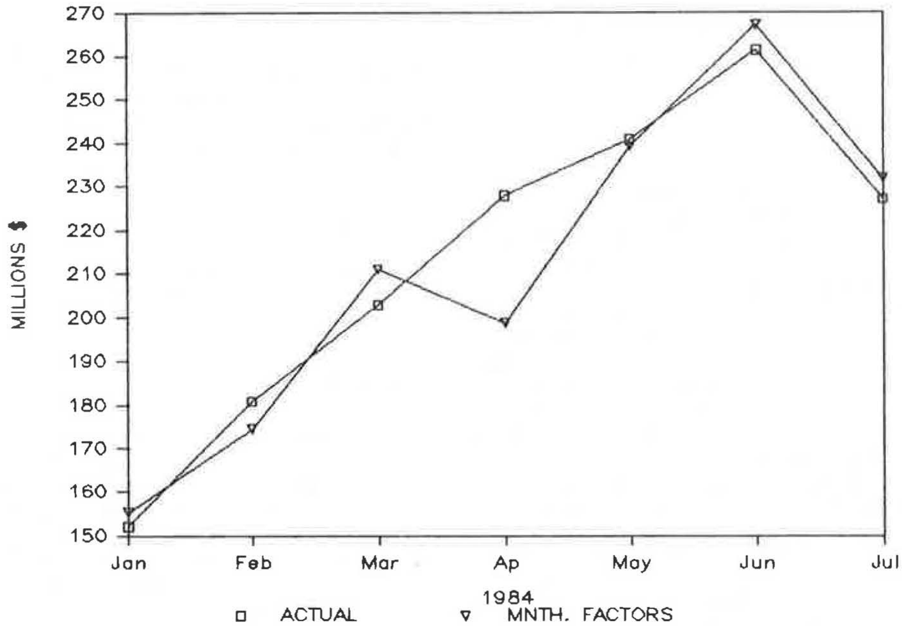

FIGURE 8 Cash balance, January 1984.

riod, the error averaged ±$8.3 million per month and had a standard deviation of $9.1 million.

FY 1985 and FY 1986

The techniques proposed in this paper offer the potential for much more accurate forecasts than have been the case in the past. For the forecast period from July 1984 through June 1986 cash balances should be significantly above levels predicted by the techniques previously used by the VDHT. This forecast is shown in Figure 9. The following can be expected for the forecast period:

- Under the techniques formerly used, federal aid is estimated to be $992.0 million. The estimate is $756.0 million under that obtained with the proposed techniques.
- Under the techniques formerly used, contract construction payout is estimated to be $1.1 billion. The estimate is $801.0 million under that obtained with the proposed techniques. Through December 1985, this forecast was within 4 percent of actual payout.
- Under the techniques formerly used, total payout is estimated to be $1.953 billion. The estimate is $1.860 billion under the proposed techniques.
- Under the techniques formerly used, the cash balance is not expected to be less than $145.0 million. Under the proposed techniques the balance is expected to remain substantially higher, peaking at close to $300.0 million.

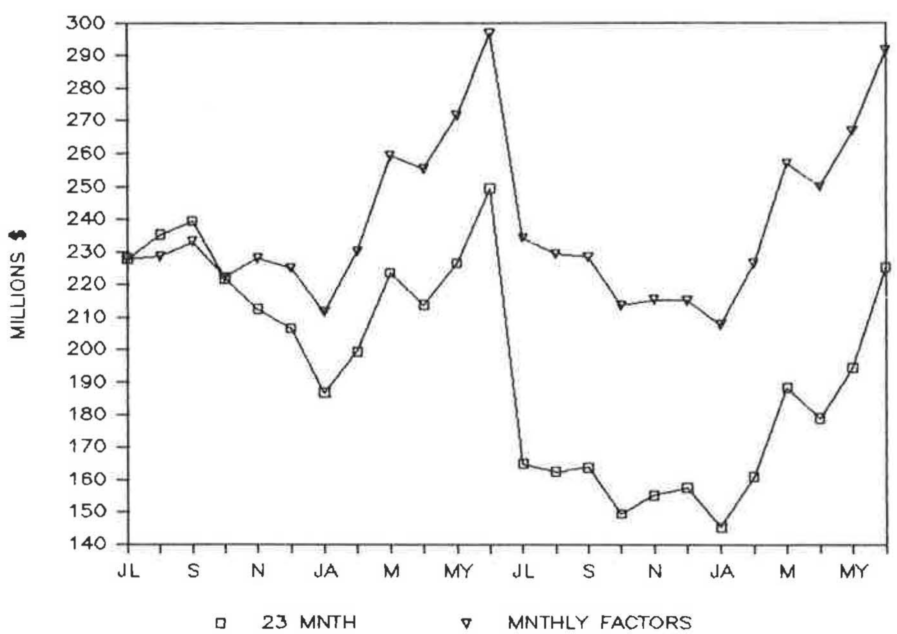

FIGURE 9 Cash balance July 1984 to June 1986, payout curve versus monthly factors.

• As of the date of writing, data reveal that through December 1985 the forecast made in January 1984 is within $11.0 million of the actual cash balance.

What Are Reasonable Cash Balances?

In addition to maintaining a contingency to take advantage of unanticipated federal aid, another criterion by which to gauge the reasonableness of cash balances for contingency purposes is stability in the pattern of the periods during which expenditures exceed monthly revenues. Since July 1980, expenditures have exceeded revenues for the months of July, August, September, and October. Revenues have exceeded expenditures for the months of November through June. Thus it may be reasonable to design the programming and scheduling of the construction program to ensure that the cash balance accumulated on June 30 of each fiscal year approximates, with a reasonable margin of error, the expected excess of expenditures over revenues for the following months of July through October. Approximately $70.0 million might have been a reasonable balance for this purpose for June 30, 1984. Approximately $90.0 million to $100.0 million may not be excessive for June 30, 1985, assuming the proposed advertisement schedule proceeds on target and the seasonality of revenue follows its historical pattern. Additional amounts would be necessary for a federal aid contingency.

Maintaining cash balances at reasonable contingency levels is consistent with maximizing the benefits from revenues available from user taxes, and establishing mechanisms to ensure the implementation of a construction program consistent with maintaining such balances is an appropriate goal to be achieved through the finance, programming, and scheduling functions of the department. However, extreme caution must be exercised in proposing, at a glance, that balances are too high or too low. Nevertheless, with the aid of the forecasting techniques proposed in this study, "what if" scenarios can be developed to determine the extent to which changes in the construction program result in unacceptably low or high cash balances.

ACKNOWLEDGMENTS

The research reported here was financed from Highway Planning and Research funds administered through the Federal Highway Administration.

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The opinions, findings, and conclusions are those of the author and not necessarily those of the sponsoring agencies.

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

Computational Method for Performance-Oriented Statewide Highway Needs Analysis

GEORGE MENDELL, THOMAS GAUL, and JACK SHAMBAUGH

ABSTRACT

Existing statewide needs studies, previously used in Arizona and currently used in most states, are driven by a minimum tolerable standard, which, typically, cannot be directly related to the performance of the highway system. A revised process, developed in Arizona, is performance driven. The computational procedures select capacity, physical condition, and safety needs in response to performance standards set by the user and test the selected needs against seven performance measures. The results obtained in Arizona have yielded significant differences in costs and performance among the tested performance alternatives.

The revised process for conducting a statewide needs study in Arizona, developed in 1984, represents a significant advance in the state of the art of statewide needs study methodologies.

Existing statewide needs studies, as previously used in Arizona and as currently used in most states, are driven by a minimum tolerable standard, which, typically, cannot be directly related to the performance of the highway system. In other words, there is not a clear relationship between changes in the minimum tolerable standard and performance. Consequently, there is little capability to predict how much improvement in performance is "purchased" for a given level of improvement.

The revised process is performance driven: To initiate the process, a target performance (measured in terms of capacity, physical condition, and safety) is set. Improvements required to realize the target levels of performance are selected. Finally, each set of selected improvements (or needs) is tested for actual performance against the three target measures used to trigger improvements as well as against four additional economic and environmental measures. The performance targets may be varied, resulting in the selection of different improvements, and relationships between differing levels of needs and performance may be compared.

In the revised needs study, needs are triggered by one or more of the following performance measures:

1. Capacity (measured in terms of level of service),
2. Physical condition (measured in terms of pavement ride quality and distress), and
3. Safety (measured in terms of number of high-accident locations or rail crossing hazard index).

Five program modules compute the needs triggered by the three performance standards:

1. Capacity needs on highway links are computed over a 20-year design horizon. For urban links, the program selects from a sequential menu of transportation system management improvements, spot widenings, and full widenings. Improvements are limited by available right-of-way. For rural highway links, the program selects from a menu of widening and relocation options.
2. Physical condition needs on highway links are selected on the basis of optimized pavement management strategies developed in the Arizona Department of Transportation pavement management system.
3. Safety needs for highway links and structures are obtained by computing the cost of reducing the number of high-accident locations in the state to target levels.
4. Capacity, physical condition, and safety feature needs for bridge structures are obtained by selecting, on the basis of a decision-tree algorithm, from a sequential menu of structural widenings, rehabilitations, and replacements.
5. Safety needs for railroad crossings are derived by computing the number of improvements needed to reduce the hazard index at railroad at-grade crossings to target levels.

Once selected, each set of needs is further tested against seven performance measures: the three initially used to trigger improvements (capacity, physical condition, and safety) and four additional measures: financial, aggregate volume-to-capacity ratio, vehicle hours of travel, and environmental.

These elements are packaged in a single computer jobstream from which a variety of worksheets and reports is produced.

PERFORMANCE STANDARDS

Capacity Performance Standard

The target capacity performance standard is defined as the peak-hour, peak-direction volume-to-capacity (v/c) ratio above which a need is said to exist. The program will attempt to select improvements to maintain the v/c ratio at a level lower (better) than the capacity performance standard for any highway link that fails to meet the standard. The program will also determine the need for any bridge structure widenings along each highway link for which a capacity improvement is selected. For example, if the target capacity performance standard is set at a peak-hour, peak-direction v/c ratio of 0.85, or level of service (LOS) D, an improvement will be selected for each link (and the structures contained

G. Mendell and J. Shambaugh, Arizona Department of Transportation, 206 South 17th Avenue, Phoenix, Ariz. 85007. T. Gaul, PRC Engineering, 1500 Planning Research Drive, McLean, Va. 22102.

therein) with a calculated peak v/c ratio of 0.86 or worse.

The capacity performance standard can be set to reflect whatever policy alternative the user desires to test. Capacity standards set for the 1985 Arizona needs study ranged from 0.75 (LOS C), under a performance alternative that called for significant improvement in capacity, to 1.05 (LOS F), under an alternative that allowed capacity performance to decline.

Physical Condition Performance Standard

Physical condition needs for highway links are selected on the basis of two measures: pavement ride quality (or roughness) and pavement cracking (or distress). The standards for both ride quality and cracking are defined as the percentage of pavement area in good condition versus the percentage in adequate and poor condition, and the number of years into the future at which the standards are to be met. "Good" and "poor" are defined as follows:

	Pavement Ride Quality	Pavement Cracking (%)
Good	≤ 165 in. axle deflection/mile	≤ 10
Poor	> 255 in. axle deflection/mile	> 30

Note that axle deflection is measured using standard ridemeter techniques.

Three of the physical condition standards used in the 1985 Arizona needs study were set on the basis of the current percentage of pavement in good and poor condition for both ride quality and cracking within each administrative category (state, county, and city): (a) maintaining exactly the current levels of good and poor, (b) a 5 percent decrease in the amount of pavement in poor condition and a 5 percent increase in the amount in good condition under improving performance alternatives, and (c) vice versa under declining performance alternatives. A fourth physical condition standard involved degradation of pavements to the lower limit of public acceptance (80 percent poor). These standards were to be met by the fifth year into the future, after which they were to be main- tained in a steady state.

Variable physical condition performance standards are not set for bridge structures. Structural condition needs are selected through a decision-tree algorithm that remains constant under all performance scenarios.

Safety Performance Standard

The performance standard for safety on highway links and structures is set in two parts: the percentage reduction or growth to be achieved or allowed in the total number of high-accident locations (HALs) in the state and the number of years into the future at which the standard is to be met. A HAL is defined as any intersection with a rate of one or more accidents per million vehicles or any road segment or structure with a priority index (a composite measure incorporating accident rates and severities) of 5.0 or greater. This definition is adopted from the Arizona Department of Transportation (ADOT) highway safety improvement program.

The performance standard for safety at railroad at-grade crossings is stated in terms of a permissible hazard index, which is defined as the annual average number of accidents per rail crossing. The program will attempt to select an improvement for any at-grade crossing at which the calculated hazard index exceeds the standard.

The safety standards set for highway links in the 1985 Arizona needs study ranged from a "do-nothing" level (allowing the number of HALs to increase unchecked) to a 15 percent reduction in HALs across the state by 10 years into the future. Railroad safety standards ranged from a hazard index of 1.00 to a hazard index of 0.05.

COMPUTATION OF NEEDS

Highway Link Capacity Needs

The computation of capacity needs for highway links is performed link-by-link. For each highway link, the needs study computer program conducts the following procedure.

Traffic Forecasts

The needs study program determines the base year average daily traffic (ADT) volume and average annual ADT growth rate for automobiles, medium trucks, and heavy trucks on each link through one of three methods. Where recent traffic counts and future projections from either the ADOT state highway traffic forecasting program or local government planning agencies are available, these are used. If recent traffic counts are known but future projections are unavailable, the program will estimate future traffic growth through the application of projected population growth rates for each jurisdiction. Finally, if there are no traffic data available for the link, the program will fill in the gap by extrapolating ADT and traffic growth rate data from adjacent links.

ADTs by vehicle type for each future year under study are calculated from the base year ADTs and the projected average annual ADT growth rate. The yearly link peak-hour, peak-direction volumes are then determined through the application of peak-hour directional factors derived from historical data for highways within the state of Arizona.

Daily and peak-hour, peak-direction vehicle miles of travel (VMT) by vehicle type are calculated for each year by multiplying the yearly ADTs and peak-hour direction volumes, respectively, with the length of the link.

Each of the various types of calculated traffic data (daily and peak volumes, and daily and peak VMTs, each by three-way vehicle split) are used at various locations throughout the remaining procedures for the link.

Capacity Circulation

The peak-hour, peak-direction capacity of each link, as calculated by the program, is dependent on a number of variables. The equations used are

Rural two-lane undivided highway

$$C = 2000 \cdot W \cdot T \cdot 0.55$$

where

C = one-way hourly capacity,
W = lane width and lateral clearance factor, and
T = truck factor.

Freeways, rural divided highways, and rural multilane undivided highways

$$C = 2000 \cdot W \cdot T \cdot L$$

where

C = one-way hourly capacity,
W = lane width and lateral clearance factor,
T = truck factor, and
L = number of lanes in peak direction.

The capacity calculation methodologies used for these types of highways, along with the various lane width and lateral clearance factors and truck factors, were adopted from those described in the 1965 Highway Capacity Manual (1). The lane widths and lateral clearances for each link are calculated from roadway geometric data stored in the needs study data base. Truck percentages are calculated from the previously determined traffic volumes by vehicle type.

The capacity calculation methodology for urban links other than freeways was developed on the theory that urban link capacity will be controlled by intersection capacities, resulting in the equation:

$$C = B \cdot T \cdot G/100$$

where

C = one-way hourly capacity,
B = base capacity dependent on number of lanes and intersection lane configuration,
T = truck factor, and
G = percentage green time.

The base capacity for the link is derived from the following table:

No. of Peak-Direction Lanes	Base Capacity for One-Way Street	Base Capacity for Two-Way Street With Left-Turn Lanes	Base Capacity for Two-Way Street Without Left-Turn Lanes
1	1,700	1,700	1,190
2	3,400	3,400	2,720
3	5,100	5,100	4,335
4	6,800	6,800	6,035
5	8,500	8,500	7,735
6	10,200		

The truck factors were adopted from the 1965 Highway Capacity Manual (1), and the truck percentages were calculated from the previously determined traffic volumes by vehicle type.

Volume-to-Capacity Ratio

The unimproved peak-hour, peak-direction v/c ratios for the base year and for 5, 10, and 20 years into the future are calculated by dividing the peak capacity into the total peak traffic volumes for each of the years.

Capacity Needs

The link v/c ratio at 20 years from the present is compared with the capacity performance standard. If the ratio is lower than the standard, the program does not select any capacity-driven needs for the link. If, however, the ratio is higher than the standard, the capacity-driven needs selection process is triggered.

The first step in the capacity-driven needs selection process is to determine the first year in which the link fails to meet the standard, because this will be the year in which any selected improvement will be made and the year in which improvement costs will be assigned as a need. The design year for the improvement is defined as the first year of failure plus 20 years (i.e., a 20-year design horizon). Using the design year peak traffic volumes, the program then calculates the peak capacity that will be required to maintain the capacity standard in the design year.

Selection of the most cost-effective capacity improvement occurs by iteratively searching through a sequential menu of improvements and calculating the peak capacity for each improvement category within the menu until either the required design year capacity is attained or a terminal condition is reached. Terminal conditions include the availability of right-of-way (in urban areas) and the total permissible number of through lanes (in both urban and rural areas) and in some instances may constrain the selected improvement to one that will not attain the desired capacity.

The choice of improvement menu used for urban links depends on the functional class; the presence of left-turn lanes or medians, or both; and the surface type (paved versus unpaved). The choice of menu used for rural links depends on the functional class, the vertical and horizontal alignment adequacies, the surface type (paved versus unpaved), and whether the link is divided or undivided. Urban improvement menus may include transportation system management (TSM) actions, continuous left-turn lanes, spot widenings, and full widenings; rural menus include a combination of widening and relocation options. Table 1 gives a sample improvement menu developed for the Arizona needs study.

As the sample improvement menu indicates, improvements may be selected that have two or more stages spaced over the 20-year design horizon. In these situations, the program will determine the appropriate year for each improvement stage by comparing the improved capacity of each stage with the traffic volumes and the capacity required to maintain the performance standard over time. This process is graphically shown in Figure 1.

When the improvement has been selected, the cost is calculated by multiplying the link length with various per mile unit costs appropriate to the improvement type. These costs may include the cost of additional right-of-way, additional pavement, roadway striping, engineering and design, TSM actions, and so forth. The unit costs are based on the Arizona construction cost index, which is developed from recent construction project costs throughout the state. All improvements are designed to meet ADOT lane width, shoulder width, and median width design standards.

The program then stores the cost, year, action type, and improved peak capacity for each improvement stage selected for the link for purposes of performance calculation and reporting.

The capability to override the entire capacity-driven needs selection process for any particular link is provided within the program. This feature enables the user both to stipulate known future improvements to existing links and to suppress the selection of improvements where none are desired for reasons external to the program. In a similar manner, known future new highway facilities can be input into the process as "survey routes."

Physical Condition Needs

Physical condition needs for all highway links, with the exception of unpaved and portland cement con-

TABLE 1 Sample Capacity Improvement Menu (urban minor arterial, paved, no left-turn lanes or raised medians)

Improvement Category	No. of Stages Within Category	Capacity Improvement	Consumed Right-of-Way (ft)	Additional Pavement Width (ft)	Additional Through Lanes	Left-Turn Lane Status
1	1	Transportation system management (TSM)	0	0	0	No
2	2	TSM actions	0	0	0	No
		Add continuous left-turn lane	11	Existing deficiency plus 11	0	Yes
3	2	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24[a]	2[b]	No
4	3	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24[a]	2[b]	No
		Add continuous left-turn lane	11	11	0	Yes
5	3	TSM actions	0	0	0	No
		Spot widen by two lanes at intersections	12	Existing deficiency plus 24[a]	2[b]	No
		Widen by two lanes and add continuous left-turn lane	35	35	2	Yes
6	3	TSM actions	0	0	0	No
		Widen by two lanes and add continuous left-turn lane	35	Existing deficiency plus 35	2	Yes
		Widen by four lanes	48	48	4	Yes

[a]Plus 24 ft at intersections, plus 0 ft between intersections.
[b]At intersections.

crete (PCC) links, are selected through the application of the ADOT pavement management system (PMS).

The PMS is a network optimization system, developed and implemented by the ADOT Materials Section, that optimizes the design, maintenance, and preservation of pavements. Using a probabilistic model of deterioration, PMS predicts the future ride and cracking condition for asphaltic concrete pavements, depending on their initial condition. PMS determines the most cost-effective rehabilitation actions over time to achieve and maintain desired performance standards for different roadways in the state and calculates the yearly pavement maintenance and construction costs associated with these actions. Actions are selected from a menu that includes a variety of overlays and seal coats.

The PMS system divides all highways within the state into 36 possible problem groups, each of which has different characteristics in regard to pavement condition needs. The PMS problem groups are stratified as

- Four administrative systems (Interstate, state, county, and city);
- Three ADT groups ($\leq$2,000, 2,001 to 10,000, and > 10,000; and
- Three regional types (desert, transitional, and mountainous).

The PMS network optimizing program is run for each PMS problem group of interest (some of the groups have little or no mileage within them and thus are not run) with the physical condition performance standards as inputs. Each PMS run yields the total optimized pavement maintenance and construction costs in each of the next 10 years for all highways within that problem group.

The needs study program takes the results from each of the PMS runs as inputs. As the link-by-link analysis is being performed, the program determines which of the PMS groups the link belongs in and apportions the yearly pavement maintenance and construction costs to the link based on that link's share of the total square yards of pavement in the entire PMS group. A factor representing engineering and design overhead costs is then applied to the link pavement construction costs.

Physical condition needs for unpaved and PCC links are handled separately because they are not presently included within the PMS program. Unpaved maintenance needs are calculated by applying an annual unit cost of grading and spraying to the surface area of the link. PCC needs are calculated by multiplying annual unit costs for PCC pavement maintenance and construction with the link pavement area. Both unpaved and PCC unit costs are stratified by region type and were developed from recent ADOT project costs.

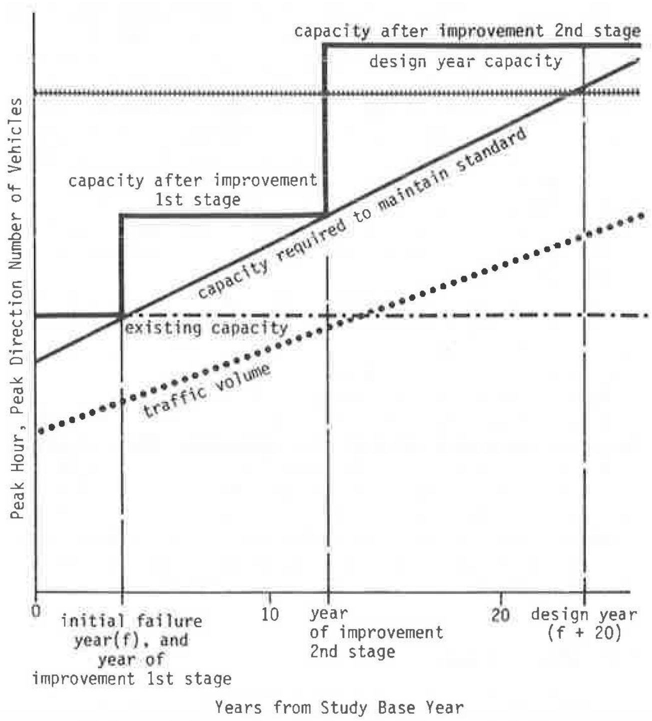

FIGURE 1 Determination of capacity improvement years.

Highway Link Safety Needs

The needs study program projects the future number of HALs in the state by assuming that the number will grow in direct proportion to the increase in daily VMT on substandard roads statewide (a substandard road for this purpose is one with either poor horizontal or vertical alignments, or lane widths or lateral clearances that are below design standards). The target number of HALs required each year to meet the highway safety performance standard by the target year is determined with the difference between the target and projected numbers representing the amount to be improved. A portion of the number of HALs to be improved, related to the proportion of substandard road VMT for which highway capacity improvements were selected, is presumed to have been improved as a consequence of capacity improvement (capacity improvements by definition are designed to meet design standards).

The remaining HALs to be improved are divided into two groups based on proportions provided by the ADOT highway safety improvement program: those requiring major reconstruction and those requiring a minor improvement. An average improvement cost for each type, based on recent experience within Arizona, is applied to the two groups to determine total yearly highway safety needs.

Bridge Structure Capacity, Condition, and Safety Feature Needs

Bridge structure needs for each structure on a particular highway link are calculated after the needs selection process for the link itself has been completed. The methodology employed depends on whether the structure carries or passes over the link. Data for the structures methodology were obtained from the structures inventory data base maintained by the ADOT Structures Division based on FHWA National Bridge Inventory Project procedures (2).

The need for physical condition or safety improvements to structures carrying links is determined through a series of checks on present structural and deck conditions, safe load, inventory rating, and status of traffic safety features (including railings, approach guardrails, and transitions). If a capacity improvement has been selected for the link, the structure is also checked to determine whether the present structure is wide enough to accommodate the link improvement (Table 2). Depending on the result of these checks, the program will select an action ranging from no improvement to structural replacement with a wider cross section. These checks and resulting improvements are calculated from unit costs provided by the ADOT Structures Division.

The vertical underclearance provided by any structure that passes over a link is compared with a standard of 16 ft to determine if it is adequate. If a capacity improvement has been selected for the link under the structure, the structure is also checked to determine whether the present lateral underclearance is sufficient to allow the link improvement. If either or both of these tests are failed, the program flags the structure for a later manual analysis because the necessary improvements and costs required to correct these types of deficiencies are highly dependent on the particular location and cannot be calculated by a generalized program.

Railroad At-Grade Crossing Safety Needs

The methodology employed by the program to estimate safety needs at railroad at-grade crossings is based on the rail crossing hazard index and uses rail crossing data obtained from a data base maintained by the ADOT safety program. The hazard index is a measure composed of the daily train volume, a traffic coefficient dependent on ADT, and a device coefficient dependent on the type of protective device (crossbucks, flashers, or gates) and is calculated using a modification of the New Hampshire method.

The program determines the hazard index for each year and compares it with the hazard index standard previously set by the user. If the standard is met, no improvement is selected and the program proceeds to the next year. If the standard is not met, however, the program selects an improvement based on the existing device type:

Existing Device Type	Selected Improvements
Gates	None
Flashers	Gates
Crossbucks	Flashers or gates

When there is a choice of flashers or gates, the most cost-effective improvement, determined by comparing the estimated hazard index decrease for each improvement divided by the improvement cost, is selected. Unit costs for installation of flashers and gates are obtained from the Arizona Construction Cost Index, and are assigned to the improvement (if selected) for the year in which the standard was not met.

Needs Summaries

The improvement costs calculated during needs selection are aggregated by the program and summarized in three reports. The first reports the needs for each local jurisdiction, stratified by need type (capac-

TABLE 2 Bridge Structure Improvement Selection Decision-Tree

Safe Load	Inventory Rating	Structural Condition	Deck Condition	Traffic Safety Features	Selected Improvement Action	Selected Improvement Action if Link on Bridge to be Widened
Pass		Pass	Pass	Pass	No improvements	Widen bridge
Pass		Pass	Pass	Fail	Safety improvements	Widen bridge
Pass		Pass	Fail (R)		Rebuild deck	Rebuild deck wider
Pass		Pass	Fail (N)		Replace deck[a]	Replace deck wider[a]
Pass		Pass	Fail (N)		Replace bridge[b]	Replace bridge wider[b]
Pass		Fail (R)	Pass		Repair bridge	Replace bridge wider
Pass		Fail (R)	Fail		Replace bridge	Replace bridge wider
Pass		Fail (N)			Replace bridge	Replace bridge wider
Fail (R)	Pass	Pass	Pass		Strengthen bridge	Replace bridge wider
Fail (R)	Pass	Pass	Fail		Replace bridge	Replace bridge wider
Fail (R)	Pass	Fail			Replace bridge	Replace bridge wider
Fail (R)	Fail				Replace bridge	Replace bridge wider
Fail (N)					Replace bridge	Replace bridge wider

Notes: R = repairable failure and N = nonrepairable failure.

[a]Structure design allows replacement of deck.
[b]Structure design does not allow replacement of deck.

ity, physical condition, structure, and rail crossing) and administrative system (state, county, and city). The second summarizes the statewide needs by need type, administrative system, and functional class; and the third reports the safety needs for the entire highway system. Each report is produced for 5-, 10-, and 20-year cumulative needs.

PERFORMANCE MEASURES

After the needs selection process has determined highway, structural, and rail crossing needs in reaction to the performance standards, the following measures are calculated to test the resulting performance. Each of the performance measures, with the exception of the 20-year earnings-to-cost ratio (which is calculated for the 20-year period only), is calculated for the base year and for 5 and 10 years into the future.

Capacity Performance Measure

The improved capacities resulting from the capacity improvement selection process for the link are divided into the link traffic volumes to determine the improved peak-hour, peak-direction v/c ratios for each year.

The program reports the number of miles in each capacity LOS category stratified by administrative system and functional class, where the LOS categories are defined as follows:

LOS	v/c Ratio Range
A/B	$\leq$ 0.70
C	0.71-0.80
D	0.81-0.90
E	0.91-1.00
F	1.01-1.20
FF	> 1.20

Physical Condition Performance Measure

As a result of the use of optimization in the PMS for the determination of highway physical condition needs, the percentage of highway pavement area in good condition versus the percentage in poor condition for both pavement ride quality and pavement distress or cracking resulting from the selected physical condition needs equates precisely to the standards that were set and therefore does not require any further calculation by the program.

Safety Performance Measure

The safety performance measure for highway links and structures is defined as the total number of improved HALs on the entire highway system. The rail safety performance measure is reported as the number of selected rail crossing improvement projects of each type (flashers or gates) stratified by administrative system and functional class.

Financial Performance Measure

Two measures are included in the financial performance measure. The capacity benefit-to-cost ratio is designed to compare the relative cost-effectiveness of the capacity improvements selected for individual links and is defined as the net decrease in link v/c ratio (weighted by the link length) in the year of interest divided by the link capacity improvement costs up to that year. The program produces a listing of all selected capacity improvement project locations and costs, ranked in descending order by benefit-to-cost ratio.

The 20-year earnings-to-cost ratio measures the ability of a roadway to generate user revenue in excess of its improvement costs. The yearly earnings generated by each link are calculated through the application of annual commercial and noncommercial earnings factors to the link daily VMTs and are summed over the next 20 years. The link earnings are then divided by the link total calculated costs over 20 years, including the costs of structural and rail crossing improvements on the link, to yield the 20-year earnings-to-cost ratio. The earnings factors used were derived from highway revenue projections provided by the ADOT Administrative Services Division. The program reports 20-year aggregate earnings-to-cost ratios by administrative system and functional class for each jurisdiction.

Peak-Hour Aggregate Volume-to-Capacity Ratio Performance Measure

The peak-hour, peak-direction aggregate v/c ratio is a measure designed to reflect the aggregate level of congestion within a given jurisdiction or administrative system. It is calculated by summing the product of the peak-hour v/c ratio and VMT for each link and dividing this sum by the summed link VMTs (thus weighting the measure by peak-hour VMT).

The program reports the weighted aggregate peak-hour v/c ratio, stratified by administrative system and functional class, for each jurisdiction.

Peak-Hour Vehicle Hours of Travel Performance Measure

The program calculates the link peak-hour, peak-direction average travel speed from the improved v/c ratio using the appropriate relationship (rural or urban) shown in Figure 2. The peak-hour, peak-direction vehicle hours traveled (VHT) is calculated by dividing the link average speed into the peak VMT.

The program reports VHTs summed by administrative system and functional class. Comparison of the differing levels of VHT under varying performance alternatives yields the relative amount of vehicular delay experienced with different calculated needs.

Environmental Performance Measure

Peak-hour vehicle emissions and fuel consumption on urban links are calculated using equations and factors adopted from the FHWA report "A Method for Estimating Fuel Consumption and Vehicle Emissions on Urban Arterials and Networks" (3). Emissions are determined by multiplying link peak VMTs with an emission factor dependent on ambient temperature, altitude, and link average speed. Fuel consumption is calculated separately for automobiles, medium trucks, and heavy trucks, using equations dependent on the average speed and VMT, and is summed to yield the link total.

The program reports urban peak-hour fuel consumption and HC, CO, and NOX vehicle emissions, stratified by administrative system and functional class, summed over all links.

It should be noted that the calculation of estimated vehicle emissions by the needs study program is not intended to be an overall analysis of air quality impacts, which would require extensive analysis of local meteorology, climate, and other fac-

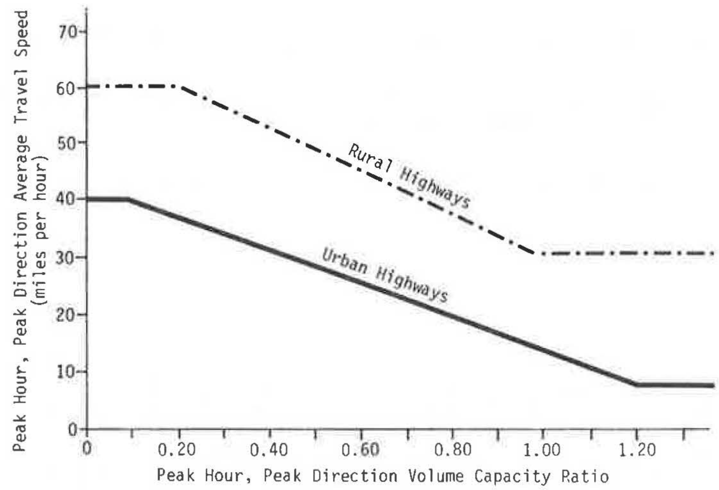

FIGURE 2 Relationship of peak-hour travel speed and v/c ratio.

tors, but rather is meant to provide some insight into the comparative effects of varying performance alternatives on air quality.

CONCLUSIONS

The computational procedures described for the revised highway needs study process select capacity, physical condition, and safety needs in response to performance standards set by the user and test the selected needs against seven performance measures. The process gives the user the capability to test any desired number of different performance alternatives rapidly and efficiently, covering a range of scenarios from "minimum tolerable" to "free-flow, like-new." In this way, the performance of the highway system resulting from different needs levels can be analyzed and compared.

The results obtained in Arizona from the revised process have yielded significant differences in costs and performance among the tested performance alternatives.

Devising performance alternatives is simple because all that is required to specify an alternative are the standards for the three "trigger" performance measures: capacity, physical condition, and safety. Less than one-half of a man-day is required to input new standards and run the needs program for a new alternative, and experience in Arizona indicates that as many as five different alternatives can be batched and run in a single day. The revised needs study process is flexible, efficient, and easy to use.

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

Development and Implementation of a Performance-Based State Transit Subsidy Allocation Formula for Indiana

KUMARES C. SINHA, JOHN N. PARSONS, DAROLD T. BARNUM, and ESSAM A. SHARAF

ABSTRACT

In this paper are presented the findings of a study to develop and evaluate an equitable procedure for allocating Public Mass Transportation Fund (PMTF) monies in Indiana. Background information, the pre-1985 allocation method, the recommended formula, and the strategy for implementation of the formula are described. The recommended formula allocates 50 percent of the funds on the basis of a sustenance criterion and the other 50 percent according to performance criteria. The sustenance funds are distributed in proportion to service area population. The performance funds are allocated using a two-step process. First, all systems are clustered into four groups, and funds are allocated to the groups according to each group's proportion of the total deficit. Second, a group's funds are allocated to each system within the group on the basis of its operating ratio, passengers per capita, and passengers per revenue vehicle-mile. Each of the three performance factors is weighted by the ratio of the system's locally derived income to the group total locally derived income. The recommended formula was adopted by the Indiana Department of Transportation (IDOT) and became effective July 1, 1985. The study was strongly oriented to implementation and therefore emphasized a close interaction with transit operators at every phase. The key elements of the formula are system clustering, use of performance indicators, and consideration of locally derived income.

As of 1984 there were a total of 30 publicly assisted transit systems in Indiana, including 29 fixed-route or demand-responsive systems and 1 commuter rail system, the Northern Indiana Commuter Transportation District (NICTD). Five of these systems serve areas with populations above 200,000, 12 are in areas with between 50,000 and 200,000 people, and another 13 are in areas with populations below 50,000. NICTD provides commuter service to Lake, Porter, LaPorte, and St. Joseph Counties along the northern corridor of the state. A new system, which provides demand-responsive service in Madison County, was added in 1985. Four of the bus systems now essentially serve counties, and the remaining 26 serve various cities and some surrounding areas.

In 1984 provision of public transit service in Indiana cost a total of $55.5 million, an increase of 0.8 percent over 1983 levels. The cost of providing a vehicle-mile of service in 1984 increased from $2.85 to $2.94 while the cost per passenger declined from $1.59 to $1.57. The statewide fare recovery ratio, which remained unchanged from 1982 to 1983, increased from 0.34 to 0.35. The average fare revenue collected per passenger, however, remained constant at $0.54 (1). In 1984 federal operating assistance increased slightly to $16.8 million while state funding at $10.3 million fell slightly from 1983 levels. The operating subsidy per passenger dropped from $0.98 to $0.90 from 1983 to 1984, while the subsidy per revenue-mile increased from $1.75 to $1.77.

K.C. Sinha, School of Civil Engineering, Purdue University, West Lafayette, Ind. 47907. J.N. Parsons, Indiana Department of Transportation, State Office Building, 100 North Senate Avenue, Indianapolis, Ind. 46204. D.T. Barnum, Department of Management, University of Illinois at Chicago, 601 South Morgan Street, Chicago, Ill. 60680. E.A. Sharaf, Public Works Department, Cairo University, Giza, Egypt.

DESCRIPTION OF THE PMTF

The Public Mass Transportation Fund (PMTF) is a special revenue fund created by the 1980 Indiana General Assembly to assist public transportation in the state. The PMTF evolved from a state grant program established by the legislature in 1975. Part of the 1975 program called for annual general fund appropriations designed to aid local units of government in matching public transportation grants provided under the federal Urban Mass Transportation Act of 1964, as amended. It was strictly a program to augment local matching funds at a time when municipalities were under financial constraints imposed by a property tax control program.

In creating the PMTF in 1980, the Indiana General Assembly changed the funding source from a general fund appropriation to a dedicated 0.76 percent of the state's 5 percent general sales and use tax. In addition to creating a dedicated source of funds, the General Assembly also increased the state's maximum proportion of the local share of a federal grant from 1/2 to 2/3. (It should be noted that the PMTF was originally set at 0.95 percent of the 4 percent general sales and use tax; 100 percent of the 1983 penny increase in the sales tax was dedicated to the state's general fund. This required the PMTF percentage to drop from 0.95 to 0.76 percent.)

The PMTF allows any municipal corporation that receives a federal mass transit grant to apply for state assistance. Until mid-1985, the Indiana Department of Transportation (IDOT) used an annual list of proposed projects to gauge total demand for state assistance and made actual allocations on the basis of the grant recipient's service area population. Service area population was defined either as the population within the municipal corporation's taxing unit or as the urbanized area as defined by the Census Bureau in the current decennial census.

State assistance can be used for both capital and operating purposes. However, because state funds are limited and localities can bond for the local share of capital projects, most systems opt to use their state assistance to offset operating costs. For example, in FY 1983 only about 0.3 percent of available state funds was used to match federal capital grants (1).

PROBLEMS WITH THE POPULATION-BASED FORMULA

When the state program began in 1975, service area population appeared to be the only generally agreed on basis for allocating state funds. However, IDOT found that a primary attribute of this factor, stability, is also its major drawback. Using a formula that relies solely on population rendered the IDOT unable to respond to changes in the operation and financing of local transit service.

One of the most significant changes was the influence of federal transit assistance. What started out as a federal formula program that provided modest capital and operating assistance grants to Indiana's larger urban transit systems grew into a $30 million annual federal appropriation that now includes the state's small urban and rural transit systems.

When, in 1978, Congress made federal assistance available to small urban and rural transit systems and increased assistance to larger systems, the state began to experience increasing demand for state assistance. This growth in federal assistance caused the state program to expand from 14 to 30 systems within a 5-year period. These "new" systems lacked the characteristics shared by the earlier recipients. This new group consisted of rural counties and smaller cities providing demand-responsive and low-frequency, fixed-route transit service. Lacking a suitable alternative for allocating state funds to the new transit systems, the IDOT applied the same state allocation formula, service area population. Under the formula, numerous small systems were allocated funds they could not use or legally spend because their allocations were in excess of the 2/3 match limitation imposed by state statute. On the other hand, other systems, especially the largest ones, experienced immediate shortfalls.

In 1982 Congress voiced its concern over escalating operating costs by cutting operating assistance to pre-1982 levels. This meant that many systems were forced for the first time to look more closely at their costs and revenues. To accommodate the cuts, most of the state's transit systems raised their fares and reduced service. Others attempted more sophisticated marketing and service strategies to increase ridership and maintain control over escalating costs.

In both cases the population-based state allocation method failed to address the changes occurring locally as a result of reductions in federal operating assistance. Because it merely compared each system with every other system on the basis of service area population, the state formula did not encourage systems to improve their performance. The population-based formula perpetuated the role of the state as a passive funding agent instead of an active participant in defining state objectives that could lead to improvements in transit performance. Contributing to the magnitude of this problem was the growing importance of state funding in local transit budgets. When the state program changed from a general fund appropriation to a dedicated fund, annual receipts jumped from $4.25 million to $9.5 million. After the change, state participation grew to the point where in 1983 state funds provided 19.4 percent of total operating revenue, eclipsing local tax revenue by 27.9 percent. These developments, coupled with diminishing federal operating funds, created a unique opportunity for the state to use its resources to leverage improvements in local productivity and play a more significant role in the provision of public transit service.

Because of the problems associated with a 100 percent population-based formula, a study was undertaken to examine alternative allocation strategies. The purpose of the study was to identify an allocation method that would

- Provide an incentive for systems to improve performance,
- Encourage local governments to increase their financial assistance to transit,
- Improve the efficiency of the allocation process by reducing the need to administratively reallocate funds from systems that could not use the money to those that could, and
- Provide some minimal level of support to all systems.

STUDY METHODOLOGY

In the study, particular emphasis was placed on interacting with transit systems at every phase of the research. Figure 1 shows the major elements of the study and the points of interaction with transit operators.

At the initiation of the study an organizational meeting was held with representatives from IDOT and general managers and other representatives of transit systems in Indiana. In this meeting issues involving the state transit subsidy and possible approaches to an equitable allocation scheme were discussed. The objectives underlying the Indiana PMTF were reviewed and the need for increased transit performance and accountability was emphasized. The general agreement was that the current state transit subsidy allocation procedure was not related to either need or performance. It was believed that an improved procedure would be desirable; however, the procedure had to be equitable.

The next phase of the study involved an examination of the current subsidy allocation procedures at state and federal levels. A review was also made of possible approaches that Indiana could adopt in allocating state transit funds, including the incorporation of a range of performance indicators.

A questionnaire survey of the transit operators in Indiana was then conducted over the telephone. The basic purpose of this survey was to identify the perception of transit managers concerning the missions, goals, and objectives of their systems as well as to determine their thoughts about the effectiveness of the current allocation procedures and the possible inclusion of performance measures in allocation formulas.

The next phase consisted of the development of a set of criteria along with the identification of appropriate operating characteristics that could be used in an allocation scheme. A set of fund allocation formulas based on the information collected in this phase was developed so that the effects of various combinations of factors in the allocation formulas could be evaluated.

Also considered in this phase was the stratification of transit operators. A major difficulty in using a performance-based fund allocation scheme is

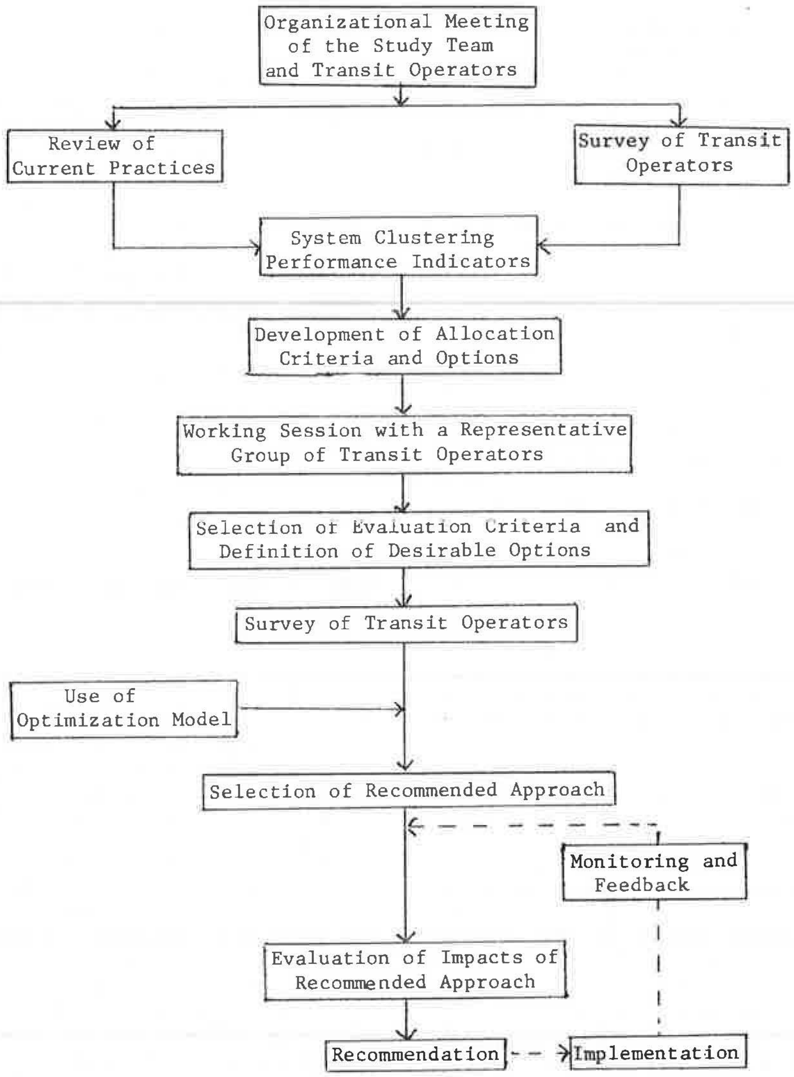

FIGURE 1 Schematic diagram of the major elements of the study.

that the operating performance of one system cannot be directly compared with that of other systems. There are certain biases that are inherent in transit performance measurements because of the effect of several environmental variables beyond the control of transit operators. Therefore a statistical analysis was employed to subdivide transit systems into a number of groups so that the systems within a group would have substantially similar operating environments.

A large number of possible options were developed and evaluated in consultation with the personnel of the IDOT. A set of 14 options and the list of possible evaluation criteria were then presented to a working committee comprised of IDOT personnel, the study team, and a representative group of transit managers. The committee reviewed the proposed options and developed an evaluation procedure that could be used to select a formula for adoption. A ranking procedure based on an iterative Delphi approach was used to determine the specific evaluation criteria to be included and their weights. The committee reduced the number of feasible options to four. It was decided to survey all of the transit systems about the relative desirability of the four options.

A mail-back questionnaire survey of transit systems, in which they were asked to evaluate the relative merit of four selected options according to the list of evaluation criteria, was conducted. The transit systems were also encouraged to provide comments and suggestions about the proposed options.

A modeling framework based on goal programming was simultaneously developed to create an optimization approach to subsidy allocation. The model's objective was to determine how much to allocate to each transit system, given the constraints of available resources and the need to satisfy stated subsidy allocation goals. The results of the optimization program were also used to evaluate the four options.

On the basis of the responses of the transit systems and other input, one option was selected. A set of guidelines was developed, including the criteria, data type, system grouping procedure, and allocation scheme. The recommended approach was presented to the IDOT and then to the Indiana Transportation Coordinating Board (TCB). The TCB approved the recommended approach at its meeting of April 11, 1985, and the new formula took effect on July 1, 1985. The rest of this paper provides more details on various aspects of the preceding overview of the development process.

STATE TRANSIT SUBSIDY ALLOCATION METHODOLOGIES

There is little uniformity among the states in methods used to allocate transit funds. Judd and Spies (2) provide a summary of the state transit aid allocation methodologies. In general, state capital assistance based on a proportion of the nonfederal share, a proportion of total costs, or both, is given to transit systems. Methods of allocating operating assistance can be grouped into four major categories: (a) deficit based--a proportion of costs remaining after revenue and nonstate aid; (b) cost based--a flat proportion of costs, usually disregarding other aid; (c) multiple factor based--formula using population, ridership, costs, and so on; and (d) discretionary.

A few states have either used or recently considered using transit performance as one of the factors in subsidy allocation. In California, transit operators that use state funds made available under the California Transportation Development Act (TDA) of 1971 are required to have mandated triennial performance audits, but no penalties or bonuses are involved (3). In 1980 Pennsylvania enacted legislation (Act 101) that established a state funding formula that incorporates financial need and system performance (4). The key performance indicators include ridership increase, revenue increase, cost increase, and the revenue-to-expense ratio. These system performance indicators are not evaluated by peer group analyses but by annual changes in performance of individual transit systems. In Iowa a performance-based allocation formula was adopted in February 1982 (5). This formula is a modification of the proposed formula developed in 1978 using ridership and revenue-miles as the basis for transit fund allocation (6). New York started monitoring the performance of local transit systems in 1979 to carry out a legislative mandate that required economy, efficiency, and effectiveness on the part of local transit operators receiving state assistance (7).

There are several other states that include some system performance factors in state transit fund allocation formulas (1). However, the current state of the practice of transit subsidy allocation relies heavily on population-based criteria. Few states include performance as a criterion for subsidy allocation. Most states that do consider performance allocate only a small portion of their funds on this basis. The major obstacles to the use of performance as a criterion are the lack of consensus about the type of indicators to be used, data reliability, and the problem of comparability of performance of systems in diverse operating environments.

FACTORS CONSIDERED

A review of the various allocation criteria indicated that the two major considerations in the development of an effective allocation formula that were most applicable to the situation in Indiana were sustenance and performance. Sustenance refers to the broad objective of the state PMTF to provide sufficient support to individual systems to allow them to maintain a reasonable level of service. On the other hand, the criterion of performance includes service efficiency, effectiveness, and equity considerations. The way these two major factors are combined in a formula determines the extent of incentive and innovation that a subsidy allocation procedure encourages.

The size of a service area population, in an aggregated sense, indicates the volume of total service in an area and recognizes the obligation each system has to serve the residents within its tax base. Furthermore, service area population can be easily computed on the basis of census data. Therefore service area population can be used as a reasonable indicator of the sustenance criterion.

Much work has already been done on system performance. Fielding et al. (8), Sinha et al. (9), and Gleason and Barnum (10) have conducted extensive research on definition and measurement of transit system performance. Several studies have also been conducted on the use of performance measures in subsidy allocation. The studies done by Drosdat (11), Keck and Schneider (12), Miller (4), Underwood (13), Fielding and Glauthier (3), Forkenbrock (14), Crider and Sinha (15), and Barnum and Gleason (16) are examples of some of these efforts.

After a series of discussions and evaluations in consultation with IDOT personnel and representatives of transit operators, the following three performance indicators were selected:

1. Operating ratio,
2. Passengers per capita, and
3. Passengers per revenue vehicle-mile.

The operating ratio is the ratio of locally derived income to operating expense. Locally derived income consists of operating revenue and local assistance including both local government subsidy and private sector assistance, if any. This factor indicates the self-sufficiency of a system as well as the extent of local commitment to the provision of transit service.

Passengers per capita is a factor that measures the degree to which residents in a particular area patronize their transit service. It also reveals the quality of service in the sense that a higher per capita ridership is an indicator of effective delivery of service.

The third factor, passengers per revenue vehicle-mile, measures service utilization more specifically. It also represents the efficiency of the operation because it indicates passenger utilization throughout the system.

All data needed to compute these factors are included in the current data reporting system. Operating revenue and expense data are directly auditable, and the reliability of the ridership and vehicle-mile data can be readily checked against historical records and records of on-site inspection, and by cross-checking with other financial data.

CLUSTERING OF SYSTEMS

Indiana has a diverse group of transit systems that range from a regional commuter railroad to many small demand-responsive systems. The operating characteristics of these systems are widely different. The environment in which these systems operate also varies greatly in terms of land use, street network, existence of large traffic generators, and other factors. These factors are mostly beyond the control of transit management. Obviously, all 30 constituent systems cannot be treated as a single group for performance evaluation. An effort was therefore made to subdivide the systems into a number of groups of systems with similar characteristics. Such a stratification scheme would allow systems of similar types to be compared with each other.

The clustering or grouping of the systems was done by a statistical correlation matrix analysis (9,17). The objective of this analysis was to group the transit systems into clusters such that elements within a cluster would be homogeneous (similar) and elements between clusters would be heterogeneous (dissimilar). The variables considered in the clustering analysis include type of service, service area population, peak-hour fleet size, average system speed, and employee wage rate.

On the basis of the clustering analysis a stratification scheme consisting of four groups was achieved. Group 1 includes the relatively large systems in Indiana. Group 2 consists of medium-sized systems, and Group 3 is a collection of small fixed-route, fixed-schedule systems. Group 4 is made up of all demand-responsive systems, some of which are countywide and serve primarily elderly and handicapped passengers.

ALTERNATIVE ALLOCATION FORMULAS

The approach used in developing alternative allocation formulas was to incorporate population and performance factors in several combinations. Another dimension of these combinations was clustering; that is, several alternatives were developed with clusters and without clusters. In addition, factors such as deficit, passenger trips, locally derived income, or population, used to allocate funds among four clusters, provided yet another dimension. Furthermore, several alternative formulas were developed with factors such as population density as well as with various weights for each of the factors considered. Again, some alternatives included different definitions of deficit, locally derived income, and operating ratio. These combinations produced a large number of alternatives that were screened for reasonableness. The primary parameter used to do the first screening was the deviation of the individual system's allocations from that which resulted from the population-based allocation formula. In addition, the resulting group total of allocations by cluster was also used as a control for assessing the reasonableness of an alternative. Another consideration was total allocation by geographic area, particularly for the six systems located in northwestern Indiana.

EVALUATION OF PROPOSED OPTIONS

A mail-back questionnaire survey of transit operators was conducted to assess the evaluation of the four final options. Each system was requested to complete a separate evaluation form for each of the four options. There were 22 responses received from the 30 operators in the study, a sample of about 70 percent. The respondents were asked to score each option as "desirable," "neutral," or "undesirable" on the basis of the following criteria:

1. Sustenance: The higher the proportion of subsidy that is based on population, the higher the guaranteed amount;
2. Administrative practicality: An option's impact on data collection costs for the systems, administrative costs for the state, auditing costs, clarity and consistency of variable definitions, clarity of the procedure for collecting the data, and simplicity of the formula;
3. Fund reallocation: The present formula requires a high degree of fund reallocation because it is not closely related to the needs of the systems;
4. Comparability: The extent to which similar systems are grouped together;
5. Controllability: The degree to which system-related variables in performance factors are controllable by the system or local government;
6. Subsidy predictability and variability: The ease of predicting future funding levels and potential fluctuations in the annual subsidy;
7. Impact on service: Possible impact of an option on such variables as passenger trips, passenger-miles, percentage of population served, revenue vehicle-miles, maintenance of fare levels, and service to the transportation disadvantaged;
8. Operational efficiency: Possible impact on such ratios as cost per passenger trip, cost per passenger-mile, cost per revenue vehicle-mile, operating ratio, and cost per transportation-disadvantaged trip; and
9. Equity: The fairness of the allocation of state funds, considering measures of equity such as subsidy per passenger trip, subsidy per revenue vehicle-mile, (state subsidy)/(local subsidy + operating revenue), and subsidy per capita.

A detailed statistical analysis of the responses was performed. The appropriate tests used were the distribution-free test and the distribution-free multiple comparisons based on Friedman rank sums (17,18). The favored option involved allocating 50 percent of the funds on the basis of population before clustering and the rest on the basis of performance factors after clustering the systems. Under this option, group amounts would be determined according to total group need measured in terms of the difference between operating expense and operating revenue. After analyzing the responses and further evaluation of the options in terms of the stated criteria, the option discussed in the following section was considered the optimal solution.

RECOMMENDED FORMULA

The following approach was recommended for distribution of PMTF funds among constituent systems:

1. Distribute 50 percent of the total available PMTF funds directly to each transit system according to the service area population of each system.
2. Divide the remaining 50 percent of the funds into four group amounts according to the subsidy needs of each group in relation to the total statewide subsidy requirement (measured by the group summation of operating expense minus operating revenue):

$$\text{Group allocation} = 0.5 \times \text{PMTF} \times (\text{Group deficit}/\text{Total statewide deficit})$$

3. Suballocate each group amount among constituent systems within a group equally in proportion to the following three factors:

$$(\text{OR} \times \text{LDI})/\sum_{n}(\text{OR} \times \text{LDI})$$

$$(\text{PC} \times \text{LDI})/\sum_{n}(\text{PC} \times \text{LDI})$$

$$(\text{PRVM} \times \text{LDI})/\sum_{n}(\text{PRVM} \times \text{LDI})$$

where

OR = operating ratio = locally derived income ÷ operating expense,
LDI = locally derived income = operating revenue + local government assistance + private contribution,
PC = unlinked passenger trips per capita of service area population,
PRVM = unlinked passenger trips per revenue vehicle-mile of operation, and

n = number of systems included in a particular group.

4. The total subsidy to be received by a system is then the summation of the amount derived in Step 1 and that obtained from Step 3.

RESULTS OF RECOMMENDED APPROACH

Because the 1984 operating data were available in May 1985, the recommended approach was applied to allocate PMTF funds for FY 1986 ($12,399,870) on the basis of the 1984 data. The input variables for each system are given in Table 1. Service area populations were determined by examining the actual area served by a system. Other information was obtained from the 1984 Annual Report of the IDOT (19). A new transit system in Madison County was initiated in 1985. Because no operating data were available, only service area population was used to allocate FY 1986 funds for this system.

The results of the application of the recommended approach to 1986 PMTF allocation are given in Table 2. In addition to the total allocated amounts, the percentage of funds assigned to each system on the basis of population and performance indicators is also presented. For example, in FY 1986, the total allocation for Indianapolis is $3,784,814 of which $1,742,907 (46 percent) is derived on the basis of population and $2,041,907 (54 percent) is the result of performance. On the other hand, only 36 percent of Gary's total allocation of $1,027,107 is derived on the basis of population and 64 percent results from performance.

In Table 3 are given the equity values that result from the recommended formula. It can be seen that the recommended formula succeeds in achieving an overall parity in equity factors within each group. Although there are still some discrepancies, the wide variation that existed earlier has been significantly reduced.

In 1986 the systems in Group 1 will receive 62

TABLE 1 Transit System Characteristics, 1984

System	Population	Passenger Trips	Revenue Vehicle-Miles	Passenger Trips per Capita	Passenger Trips per RVM	Operating Ratio	Local Assistance ($)	Fare Box + Other Revenue ($)	Locally Derived Income ($)	Deficit ($)	Total Operating Expense ($)
Group 1											
Fort Wayne	236,479	1,770,200	1,245,551	7.490	1.421	0.520	1,161,676	1,040,017	2,210,693	3,191,561	4,231,574
Gary	151,953	3,823,782	1,492,864	25.160	2.561	0.650	321,132	2,708,798	3,029,930	1,926,797	4,635,595
Indianapolis	711,539	15,493,382	6,204,178	21.770	2.497	0.570	1,874,497	8,567,417	10,441,914	9,708,994	18,276,411
South Bend	149,928	4,456,216	1,727,939	29.720	2.579	0.520	1,239,933	1,222,910	2,462,843	3,527,343	4,750,253
NICTD	171,371	2,248,795	1,526,032	13.120	1.474	0.530	0	5,472,680	5,472,680	4,780,746	10,253,426
Group total	1,421,270	27,792,375	12,196,564				4,597,238	19,011,822	23,609,060	23,135,441	42,147,263
Group average	284,254	5,558,475	2,439,313	19.560	2.279	0.560	919,448	3,802,364	4,721,812	4,627,088	8,429,453
Group 2											
Anderson	66,910	339,185	359,285	5.070	0.944	0.280	181,325	99,480	280,805	886,650	986,130
Bloomington	52,044	308,455	282,324	5.930	1.093	0.440	234,660	114,653	349,313	684,718	799,371
Evansville	130,496	1,540,797	687,678	11.810	2.241	0.490	135,423	510,176	645,599	812 541	1,322,717
Lafayette	91,380	1,147,401	858,369	12.560	1.337	0.460	326,326	425,350	751,676	1,219,968	1,645,318
Muncie	77,216	1,376,901	721,978	17.830	1.907	0.500	374,726	500,718	875,444	1,260,887	1,761,605
Terre Haute	63,931	500,360	492,887	7.830	1.015	0.370	104,689	198,024	302,713	624,244	822,268
Hammond	93,714	355,822	297,198	3.800	1.197	0.310	142,918	130,018	272,936	746,248	876,266
Southern Indiana	73,487	184,165	182,325	2.510	1.010	0.270	87,982	71,057	159,039	527,890	598,947
Group total	649,178	5,753,086	3,882,044				1,588,049	2,049,476	3,637,525	6,763,146	8,812,622
Group average	81,147	719,136	485,256	8.860	1.482	0.410	198,506	256,185	454,691	845,393	1,101,578
Group 3											
Columbus	30,614	179,264	233,483	5.860	0.768	0.320	36,935	49,889	86,824	221,607	271,496
East Chicago	39,787	409,252	149,219	10.290	2.743	0.170	98,870	0	98,870	593,223	593,223
LaPorte	21,796	113,826	211,831	5.220	0.537	0.350	38,468	65,279	103,747	230,808	296,087
Marion	35,874	134,923	142,580	3.760	0.946	0.270	40,677	34,104	74,781	244,062	278,166
Michigan City	36,850	219,150	176,818	5.950	1.239	0.330	48,631	71,074	119,705	291,788	362,862
Richmond	41,349	164,647	218,747	3.980	0.753	0.440	32,662	95,178	127,840	195,972	291,150
Washington	11,325	24,481	32,223	2.160	0.760	0.390	3,707	8,071	11,778	22,241	30,312
New Castle	20,056	98,138	122,545	4.890	0.801	0.240	45,073	26,440	71,513	270,440	296,880
Bedford	14,410	35,591	90,940	2.260	0.358	0.250	21,489	14,220	35,709	128,936	143,156
Group total	252,061	1,376,272	1,378,386				366,512	364,255	730,767	2,199,077	2,563,332
Group average	28,006	152,919	153,154	5.460	0.998	0.290	40,724	40,473	81,196	244,342	284,815
Group 4											
Goshen	19,665	8,812	21,763	0.450	0.405	0.360	3,212	5,979	9,191	19,272	25,251
Kosciusko	29,778	77,051	140,028	2.590	0.550	0.290	47,094	46,940	94,034	282,565	329,505
LCEOC	25,711	161,732	481,552	6.290	0.336	0.370	64,985	178,471	243,456	486,135	664,606
Monroe County	25,557	38,229	163,196	1.500	0.234	0.220	43,354	18,947	62,301	260,122	279,069
Trade Winds	25,711	108,861	367,057	4.230	0.297	0.230	20,609	70,610	91,219	318,105	388,715
KIRPC	38,119	56,640	197,864	1.490	0.286	0.230	49,048	26,120	75,168	294,288	320,408
Union County	3,430	9,508	34,857	2.770	0.273	0.240	8,731	4,912	13,643	52,384	57,296
Mitchell	4,641	9,004	13,681	1.940	0.658	0.250	6,140	4,239	10,379	36,843	41,082
Madison County	36,213										
Group total	208,825	469,837	1,419,998				243,173	356,218	599,391	1,749,714	2,105,932
Group average	23,203	58,730	177,500	2.53	0.331	0.280	30,397	44,527	74,924	218,714	263,242
Grand total	2,531,334	35,391,570	18,876,992				6,794,972	21,781,771	28,576,743	33,847,378	55,629,149
Grand average	81,656	1,179,719	629,233	14.450	1.875	0.460	226,499	726,059	952,258	1,128,246	1,854,305

TABLE 2 1986 PMTF Allocations Using the Recommended Formula

	1986 PMTF		Distribution of PMTF by				
				Performance			
	Allocation ($)	Percentage	Population (%)	OR (%)	PT/Capita (%)	PT/RVM (%)	Total Performance (%)
Group 1							
Fort Wayne	837,403	6.75	69.17	14.58	5.98	10.27	30.83
Gary	1,027,107	8.25	36.24	20.45	22.55	20.77	63.76
Indianapolis	3,784,814	30.52	46.05	16.77	18.24	18.94	53.95
South Bend	900,731	7.26	40.77	15.16	24.68	19.39	59.23
NICTD	1,168,897	9.43	35.91	26.46	18.66	18.97	64.09
Group total (average)	7,718,897	62.22	(45.10)	(18.30)	(18.30)	(18.30)	(54.90)
Group 2							
Anderson	218,926	1.77	74.86	9.44	6.72	8.99	25.14
Bloomington	217,582	1.75	58.59	18.56	9.83	13.02	41.41
Evansville	588,883	4.75	54.28	14.11	13.37	18.24	45.72
Lafayette	486,779	3.93	45.98	18.66	20.03	15.32	54.02
Muncie	589,314	4.75	32.09	19.51	27.36	21.03	67.91
Terre Haute	233,310	1.88	67.11	12.61	10.49	9.78	32.89
Hammond	286,736	2.31	80.05	7.75	3.74	8.46	19.95
Southern Indiana	207,322	1.67	86.82	5.44	1.99	5.75	13.18
Group total (average)	2,828,853	22.82	(56.20)	(14.60)	(14.60)	(14.60)	(43.80)
Group 3							
Columbus	119,707	0.97	62.64	13.70	14.18	9.49	37.36
East Chicago	187,509	1.51	51.97	5.29	18.10	24.64	48.03
LaPorte	102,375	0.83	52.15	20.93	17.64	9.28	47.85
Marion	121,218	0.98	72.49	9.83	7.74	9.95	27.51
Michigan City	162,605	1.31	55.51	14.34	14.61	15.55	44.49
Richmond	167,837	1.35	60.34	19.78	10.11	9.77	39.66
Washington	32,822	0.26	84.51	8.26	2.59	4.65	15.49
New Castle	80,674	0.65	60.89	12.55	14.46	12.10	39.11
Bedford	45,435	0.37	77.68	11.60	5.92	4.80	22.32
Group total (average)	1,020,183	8.24	(60.04)	(13.32)	(13.32)	(13.32)	(39.96)
Group 4							
Goshen	52,212	0.42	92.25	3.79	0.35	3.61	7.75
Kosciusko	126,176	1.02	57.80	12.94	8.49	20.77	42.20
LCEOC	225,669	1.82	27.91	23.89	29.85	18.35	72.09
Monroe County	82,302	0.66	76.06	9.97	5.00	8.98	23.94
Trade Winds	106,208	0.86	59.29	11.82	15.98	12.90	40.71
KIRPC	119,537	0.96	78.11	8.66	4.12	9.12	21.89
Union County	13,908	0.11	60.40	14.09	11.95	13.55	39.60
Mitchell	17,265	0.14	65.84	8.99	5.13	20.04	34.16
Madison	88,696	0.72	100.00	0	0	0	0
Group total (average)	831,974	6.72	(61.84)	(12.84)	(12.84)	(12.84)	(38.52)
All groups (average)	12,399,870	100.00	(50.00)	(16.67)	(16.67)	(16.67)	(50.00)

percent of the total funds, and the systems in Groups 2, 3, and 4 will receive 23, 8, and 7 percent, respectively. The allocation using only population figures for Groups 1, 2, 3, and 4 would have been 56, 26, 10, and 8 percent, respectively. The use of performance measures thus would move about 6 percent of the total funds from medium-sized and small urban and rural systems (Groups 2, 3, and 4) to the state's five largest systems (Group 1). It should be recognized, however, that many of the smaller systems could not use their full allocation in the past because of lack of need or because they reached the maximum 2/3 limitation on PMTF participation.

Although the recent removal of the 2/3 maximum limitation by P.L. 372 of the 1985 Acts of the Indiana General Assembly coincided with the completion of the study, the new formula would have greatly limited reallocation needs. However, the most important aspect of the new formula is that the PMTF allocation is now tied to actual needs and system performance.

The new formula satisfies the state objective of providing a minimum level of sustenance while encouraging performance improvements. Furthermore, by placing added emphasis on locally derived income within the formula, the new formula should have a positive effect on reversing the recent trend of declining local participation in operating costs and on encouraging transit systems to seek out private-sector involvement.

IMPLEMENTATION

The recommended formula was presented to the Indiana Transportation Coordinating Board on February 14, 1985. The board approved the formula at its meeting on April 11, 1985. The study team, in cooperation with the IDOT, held a 1-day workshop on May 22, 1985, for transit operators and local transportation officials to disseminate the essential elements of the study and to discuss the details of the recommended formula and how it would be implemented. Discussion was also held on what transit systems can do to maximize their shares of state subsidy as well as to optimize their overall financial situation.

The IDOT intends to use the approved formula to allocate PMTF funds received after July 1, 1985. The formula would incorporate operating and financial data from the most recently completed calendar year. Under the IDOT's current reporting system, each transit system is required to complete a detailed annual report questionnaire by February 13. In most cases, the annual report is based on unaudited information. However, each report is subjected to a comprehensive review and any significant variations

TABLE 3 Equity Values Resulting from the Recommended Formula, 1986

	Equity Factor[a]				
	1	2	3	4	5
Group 1					
Fort Wayne	0.4731	0.6723	0.6026	0.1979	3.5411
Gary	0.2686	0.6880	0.6290	0.2216	6.7594
Indianapolis	0.2443	0.6100	0.5793	0.2071	5.3192
South Bend	0.2021	0.5213	0.4974	0.1896	6.0078
NICTD	0.5198	0.7659	0.7326	0.1140	6.8205
Group 2					
Anderson	0.6454	0.6093	0.5351	0.2220	3.2719
Bloomington	0.7054	0.7707	0.7371	0.2722	4.1807
Evansville	0.3822	0.8563	0.8458	0.4452	4.5127
Lafayette	0.4242	0.5671	0.5630	0.2959	5.3270
Muncie	0.4280	0.8162	0.8012	0.3345	7.6320
Terre Haute	0.4663	0.4734	0.4231	0.2837	3.6494
Hammond	0.8058	0.9648	0.8683	0.3272	3.0597
Southern Indiana	1.1257	1.1371	1.0826	0.3461	2.8212
Group 3					
Columbus	0.6678	0.5127	0.5006	0.4409	3.9102
East Chicago	0.4582	1.2566	1.1596	0.3161	4.7128
LaPorte	0.8994	0.4833	0.4742	0.3458	4.6970
Marion	0.8985	0.8502	0.8264	0.4358	3.3970
Michigan City	0.7420	0.9196	0.9024	0.4481	4.4126
Richmond	1.0194	0.7673	0.7513	0.5765	4.0590
Washington	1.3407	1.0186	1.0186	1.0828	2.8982
New Castle	0.8220	0.6583	0.6384	0.2717	4.0224
Bedford	1.3941	0.4996	0.4955	0.3174	3.1530
Group 4					
Goshen	5.9251	2.3991	2.3991	2.0677	2.6551
Kosciusko	1.6376	0.9011	0.5853	0.3829	4.2372
LCEOC	1.3953	0.4686	0.4532	0.3396	8.7771
Monroe County	2.1529	0.5043	0.4236	0.2949	3.2203
Trade Winds	0.9756	0.2893	0.2604	0.2732	4.1308
KIRPC	2.1105	0.6041	0.5093	0.3731	3.1359
Union County	1.4628	0.3990	0.2930	0.2427	4.0548
Mitchell	1.9175	1.2620	1.2464	0.4203	3.7202

[a]Equity factors: 1 = state subsidy per unlinked passenger trip, 2 = state subsidy per revenue vehicle-mile, 3 = state subsidy per revenue vehicle-hour, 4 = state subsidy/total revenue, and 5 = state subsidy per capita.

between current and past reports and any significant inconsistencies within the report are noted and resolved with the transit system.

IDOT would make the actual allocation no less than 1 month before the beginning of the affected state fiscal year. Each system would have the option of using its allocation for capital or operating purposes. However, to maintain the integrity of the performance allocation, any excess funding available for reallocation would not be made available for operating purposes.

Because the recommended formula represents a significant departure from the existing method, the IDOT will conduct an evaluation before allocating state FY 1987 funds. This will enable the IDOT to gauge the relative effect of any major changes in the formula's data inputs on the allocation process and, if necessary, propose formula modifications to the Transportation Coordinating Board. Particular attention will be given to the group allocation of the PMTF. If the deficit figures show fluctuations, alternative procedures will be examined to determine the group amounts, including the assignments of group percentages, on an administrative basis.

CONCLUSIONS

The recommended formula became effective July 1, 1985. A successful implementation will require efforts from both the IDOT and the individual operators. The IDOT needs to develop an improved procedure to check the reliability of the reported annual operating data. For that, each variable must be uniformly defined and measured. There exist sufficient historical data to perform longitudinal analysis of an individual system's reported data for a particular year. Nevertheless, it may be desirable to actually audit individual systems.

The IDOT must also carefully monitor the impact of the recommended formula. If the results do not indicate that the intended objectives are being achieved, necessary modifications should be made. An important aspect of this monitoring process should be an evaluation of what adjustments individual systems undertake to achieve greater operating performance and to seek out increased local assistance.

The IDOT should provide technical assistance to individual systems in their efforts to improve their operation. Much help can be rendered, particularly to small systems that generally do not have access to a variety of management tools that can be used in making decisions on operating improvements.

The individual systems should, at the same time, seize the opportunity offered by the change in the state subsidy allocation formula to improve their operation. Much can be achieved in the area of service innovation, and transit systems must seek out alternative ways to improve service and reduce costs. Private-sector participation in transit service delivery may be one such possibility. Most important, management decisions must be evaluated in terms of sound financial considerations and the goal of being as self-sufficient as possible must be set.

With continuation of the mutual cooperation that has existed between the IDOT and individual transit operators in Indiana during the past decade, it can only be expected that the recommended change in the state subsidy allocation procedure will point a positive direction for the transit industry in Indiana. In addition to achieving the intended objectives of improved transit service and increased financial efficiency, an important effect of the new subsidy allocation procedure should be to make the Indiana transit subsidy program more accountable and thus in the long run legislatively more viable.

ACKNOWLEDGMENT

This paper is part of a study conducted with financial support from the Indiana Department of Transportation. The authors are, however, solely responsible for the content of this paper.

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Publication of this paper sponsored by Committee on Local Transportation Finance.

Ten Years of Research Implementation and Technology Transfer for Local Agencies in Minnesota

E. L. SKOK, Jr., G. S. BODOCZY, and P. J. DIETHELM

ABSTRACT

The Minnesota Local Road Research Board has sponsored a Research Implementation Project for the past 10 years to help put research into practice for city and county engineers and other administrators of low-volume roads. The project was developed by (a) establishing an advisory panel or committee, (b) developing a prospectus that included goals and guidelines, (c) engaging a consultant, (d) presenting proposals including subject background to the advisory panel, and (e) ranking the projects selected by the panel in priority order. Implementation of each project included (a) obtaining an idea from the panel or staff, (b) gathering background information, and (c) developing an implementation plan that might include some or all of the following: slide tapes or videotapes, technical advisories, and memos. Implementation packages have been developed for pavement management (surface condition, rideability, calculation of equivalent 18,000-lb single axle loads, pavement strength, and a summary presentation); water quality; sprinkle treatments; load effects on pavements; statistics for end-result specifications; pavement recycling; use of geotextiles in road construction; research summaries; snow and ice control; and bituminous pavement repair techniques. Presentations and publications on these subjects have been made available around the state and throughout the country. The project staff has also been working with the various technology transfer centers in the upper midwest to help distribute more research information.

From the beginning there has been concern about how the new ideas and materials that result from research can be put to use. Researchers themselves usually are familiar with the materials they are working with and assume that practitioners will easily see the benefits of the new concepts or materials and immediately carry through with their application. Unfortunately, because of lack of time, interest, or follow-through for verification, many worthwhile new ideas are not used as soon as they could be. This problem exists in the transportation field as it does in many other fields of technology.

In Minnesota the Local Road Research Board saw a need for this step in the application of research to practice for local roads. They therefore set up a project to accomplish this. This research implementation project has now been operating for more than 10 years and has used many different approaches to developing new concepts and procedures:

1. To make local city and county engineers aware of a rating scheme for bituminous pavement surfaces, a slide show was developed and presented at seminars around the state. After the presentations, those attending the seminars practiced rating the surface condition of some local pavements. This same approach was used for rating the rideability and strength of pavements. Many users have documented large monetary savings by avoiding unnecessary work using this rating scheme.

2. Sprinkle treatment of bituminous pavements is an interesting method of obtaining a good surface. This procedure was suggested and developed as a demonstration project by the FHWA (1). Information on this procedure was gathered in Minnesota and sent to all city and county engineers by memo to generate interest in this process.

3. To make Minnesota local engineers aware of and able to design using geotextiles, an expert, the late T. Allen Haliburton, was asked to teach some seminars around the state. Then demonstration projects were set up and monitored. Research implementation pamphlets called "The Research Implementation Series" have been developed to briefly present the concepts of geotextile technology and how geotextiles can be designed into various types of projects. Situations in which geotextiles can be used as an economic alternative are also presented. Such pamphlets are advertised as available and are sent to anyone who wants them.

4. In 1980 10-ton routes were proposed in many locations around the state of Minnesota. There were even some proposals to have all routes increased in rated capacity to 10-ton routes. The staff of the Research Implementation Project were asked to gather information on this for the city and county engineers. A slide-tape presentation was developed and shown to technical, nontechnical, and political groups not only around Minnesota and in this country but internationally. This slide tape is an example of how relatively new technology can be disseminated in useful form to let the public know what the effect of higher axle loads would be. For such diverse audiences, extreme care must be exercised to make presentations as nontechnical as possible.

These are a few examples of how research has been implemented in Minnesota during the past 10 years with the Research Implementation Project. In this paper are discussed the development of the project,

E.L. Skok, Midwest Pavement Management, Inc., 1404 Concordia Avenue, St. Paul, Minn. 55104. G.S. Bodoczy and P.J. Diethelm, Minnesota Department of Transportation, Transportation Building, John Ireland Boulevard, St. Paul, Minn. 55155.

how it is funded, how it is administered, and the steps that are necessary to carry out an effective research implementation program. Above all, it is shown that the cooperation of many people from experts to laborers is required to effectively implement new topics and materials.

MINNESOTA LOCAL ROAD RESEARCH BOARD

Minnesota has had a Local Road Research Board for more than 25 years. This group has funded more than 50 useful projects and conducted and administered these through the Office of Research and Development of the Minnesota Department of Transportation (previously the Minnesota Highway Department). These projects cover many aspects of road design, construction, and maintenance.

Lukanen and Skok (2) have compiled a compendium of reports on projects funded by the Minnesota Local Road Research Board (LRRB). Also included are annotations and the implementation status of each project. The information contained in this work is of interest and use to Minnesota's local roads engineers. The topics covered include

1. Bridges,
2. Ice removal and salt,
3. Literature and research reviews,
4. Load capacity,
5. Miscellaneous,
6. Pavements,
7. Quality control and laboratory tests,
8. Specifications and standards,
9. Subgrade and base materials,
10. Surface treatments and crack sealing,
11. Trench studies, and
12. Vegetation and erosion control.

The Minnesota LRRB was formed in 1960 by the Minnesota Legislature and is funded with up to 1/4 of 1 percent of all municipal and county state-aid funds. This amounts to about $300,000 per year at present funding levels. Research is administered through the Office of Research and Development of the Minnesota DOT. Some research is conducted by that office and other projects are carried out by other public and private research agencies. As can be seen (2), through the years much good research has been completed, reported, and used by most state and local agencies in Minnesota. Much of this work has also been used in other states. Minnesota has also received the benefit of work done in the other states through similar exchanges of information. This work can be shared by the states through such forums as the Transportation Research Board (TRB), the American Association of State Highway and Transportation Officials (AASHTO), the Federal Highway Administration (FHWA), the American Society of Civil Engineers (ASCE), the American Concrete Institute (ACI), the Association of Asphalt Paving Technologists (AAPT), the American Public Works Association (APWA), and the National Association of County Engineers (NACE). By participating in these organizations and attending meetings, researchers and practicing engineers can exchange ideas and interact with people doing design, construction, and maintenance work on roads. The people conducting the research must know what the real problems are before the work is started and, when the research is completed, the results must be presented in such a way as to be most usable to the practicing engineer.

The Minnesota LRRB helps in the first function by recommending and funding projects. In 1974 the Minnesota LRRB decided to sponsor a research implementation project (Investigation 645) so that new research work and concepts developed here and elsewhere could be made more directly usable by local and state agencies.

ADMINISTRATION OF THE MINNESOTA RESEARCH IMPLEMENTATION PROJECT

Research implementation and technology transfer have been helped by the Minnesota LRRB, which has initiated a project specifically aimed at implementation of research findings. The project was organized as follows:

1. An advisory panel was established and appointed by the Chairman of the LRRB. This panel consists of two county engineers, two engineers working for municipalities, a Minnesota DOT state-aid engineer, and two staff engineers from the Office of Research and Development.
2. The advisory panel was used to develop a project prospectus that included a definition of goals and some general guidelines for conducting the project.
3. A consultant was engaged to conduct the research implementation. The initial contractor was St. Paul Technical Vocational Institute. It was believed that an educational institution would be appropriate for this because they had access to audiovisual equipment and staff members would have expertise in various functions needed for the individual implementation packages. The consultant, after some study, developed a proposed set of implementations based on the advice of the project advisory panel. The project has been conducted by a private consultant (Midwest Pavement Management, Inc.) for the past 3 years.
4. The implementation proposals included subject background, technical subject, and proposed method of presentation. In some cases during the 10-year period, memos were sent to all city and county engineers to inquire what subjects they were interested in.
5. The project advisory panel then made a final selection of implementations and ranked the project activities in priority order for the staff.

SUMMARY OF IMPLEMENTATION

Many subjects and research activities have been covered during the course of this project. The form of the presentations has ranged from memos to city and county engineers to slide-tape shows, videotapes, and workshops with demonstrations. In this section the various research areas are summarized along with the type of implementation packages developed for each subject. In some cases there have been a number of different presentations made on the same subject to encourage use of the concepts.

Process

The implementation process has taken many forms. In some cases memos have been sent out informing local engineers of some new concept or material available. The feedback has then been analyzed.

The general implementation process has usually taken the following five steps:

1. An idea for a topic is presented. Ideas have come from many sources. The most important has been the project panel. Ideas have also been obtained from contact with Minnesota DOT and local engineers. Reports and attendance at national meetings are also

sources of useful new concepts. Project personnel also attend many local meetings so that they can find out from local engineers what types of problems they need solved or what new materials they are using or work they are doing that might be of interest to others. Being available to individual local engineers is an important step in implementation.

2. After ideas are generated, background information is gathered. This can be obtained by making a synthesis of publications, journals, or research reports on the subject. In some cases reports and other presentations have already been developed and only have to be modified for Minnesota conditions. An important part of this step is to contact a resource person who is an expert on the subject. Resource people have been Minnesota DOT employees such as Roger Olson, Richard Wolters, Dennis Luoto, and Rudy Ford; industry people such as Timothy O'Connell and Roy Boone; and national experts such as T.A. Haliburton (deceased), David Anderson, Herbert Southgate, and John Barron.

3. After the background material and resources are gathered, an implementation plan is developed. Various methods are considered. In some cases memos are sent out asking if there is more information available and if the subject is of general interest. If there is significant interest, a workshop may be set up. The workshop includes experts to discuss and give up-to-date background material on the topic. For instance, T.A. Haliburton and John Barron have come from Oklahoma to present a condensed version of a short course that was prepared for the FHWA. The short course was discovered in discussions at a planning committee meeting for the Third International Conference on Low-Volume Roads.

4. Visual aids including slide tapes, videotapes, or other types of training aids may be developed. At the workshops general applications are usually presented, whereas, for implementation in Minnesota, examples are developed that conformed to local uses and materials.

Technical advisories have been prepared to disseminate information on subjects that are considered particularly useful and implementable. These items and announcements have been sent to all city and county engineers in the state. Questionnaires have been included to find out how many have been using the new concepts.

5. The tying together of methods and the sequence of implementation are not always the same. How they have been carried out depends on the subject matter covered; how far the given subject has been developed; and, to some extent, what packages may be in existence from other sources.

For most of the subjects some type of presentation has been developed; these are listed in the Appendix. These are sent to each district state-aid engineer or made available through the Minnesota DOT Research Office. The marketing of these is done through meetings, announcements, and personal contact. Project personnel are available to local engineers for discussions on how best to use the new ideas, and engineers are also referred to local experts who can best help with the work. Eventually, project personnel will mostly refer local engineers to appropriate experts in the field for advice about proper use of a new procedure. However, periodic updating may be necessary.

The marketing strategy for each of the packages relies on contact with potential users of the information. This includes sending memos and announcements; attending city, county, and speciality conferences; and making presentations to make people aware of the research implementation effort and let them know what is available.

Implementation Packages

Since the Research Implementation Project started, there have been a number of packages developed. There have also been many informal and personal contacts made as part of the project. The major areas of effort have been in pavement management, water quality, sprinkle treatments, load effects on pavements, pavement recycling, geotextiles in road construction, end-result statistically based specifications, Minnesota research summaries, snow and ice control, and bituminous pavement repair techniques. Each of these areas has been approached in a different way, and the audience for each has been different. For instance, the research summaries are mostly for the engineers, whereas the snow and ice control slide tapes are for snowplow operators. In this section the packages are summarized and the methods used for presenting and selling the concepts are discussed.

Pavement Management

Slide shows with scripts were developed for surface condition rating of a pavement system, determination of the rideability of a pavement, calculation of the traffic factor (N18) on a pavement section for design purposes, and determination of the strength of a pavement section using the Benkelman beam device.

For the surface condition rating system a booklet was developed to illustrate the various conditions to be rated and the slide presentation was put into a slide-tape format. The slide show was originally developed in 1975 and was updated to the slide-tape show in 1983. This procedure has been used by some engineers in the area for determining when a pavement needs surfacing, whether it be a seal coat or overlay. The slide set was presented in workshops 10 times around Minnesota. The presentation was supplemented by practice rating sessions for the city and county engineers and maintenance people. More than 300 people attended these sessions.

The rideability slide set describes the use of the present serviceability rating for determining the rideability of pavement sections. Methods were presented whereby local agencies could determine the rideability with a panel or by measuring it using either the PCA roadmeter or the Maysmeter. This slide series was also presented in seminars around the state.

A slide set describing a method for predicting and calculating the load effect of traffic on a pavement section was developed. The equivalent load concept is presented and methods of estimating total traffic, truck distribution, and weight distribution of trucks in Minnesota are presented. A worksheet is used for making calculations and some problems are worked out during the seminars to help local engineers make the calculations.

Methods of determining the strength of pavements using the Benkelman beam deflection test in Minnesota were presented in the slide series on pavement strength. The Benkelman beam was the device available to measure the strength of a pavement section in 1976. The proper method of running the Benkelman beam test was presented along with the method developed by the Minnesota DOT to determine the allowable loading for a pavement section during the critical spring period. The appropriate factors to use to convert deflections during any period of the year to the critical spring deflections were presented along with temperature corrections and other factors necessary to appropriately determine pavement strength.

These four factors, surface condition, rideability, traffic, and strength, were combined in a summary report that was made available to all city and county engineers around the state. Examples were presented to show how city and county engineers could use the information to make appropriate decisions about when maintenance is required on their pavements and what maintenance procedure would be most appropriate for a pavement with particular conditions and traffic level. This set of slide shows and seminars was the primary effort of the Research Implementation Project staff for the first 2 1/2 to 3 years of the project. This early (1976) synthesis of relevant information was the first pavement management effort in Minnesota.

Water Quality

Water quality was of concern to both the Minnesota DOT staff engineers and to the city and county engineers in the mid to late 1970s because of increasing concern with the environment. Various references were obtained on the latest procedures and rules to follow for assuring continued good water quality during and after construction of both state and local roads. A memo was developed to alert local engineers to some of the newest developments in this area. The memo also gave a list of expert people to contact for help in evaluating these conditions.

Use of Sprinkle Treatments

In 1976 and 1977 the FHWA had developed as one of its demonstration projects the use of sprinkle treatments of aggregates on asphalt pavements. A number of sprinkle treatment installations had been made in Virginia, in Iowa, and in other states. This is a method of applying a high-quality rock to a soft asphalt surface and rolling the rock into the surface. A high-quality, skid-resistant surface results without using the high-quality rock throughout the total asphalt mix. Information and specifications were gathered and put into a memo on sprinkle treatments, which was distributed to the city and county engineers of Minnesota. An offer was made to help design and construct some pavements using this procedure. There was not a great deal of interest in this subject in Minnesota because in most areas good aggregate is available.

Load Effects on Pavement

One of the primary problems that Minnesota city and county engineers have with their pavements is determining what the allowable load capacity should be for a given route. In Minnesota this has been studied for almost 40 years using the flexible pavement design procedure, the plate load test, the Benkelman beam test, the Road Rater, and the falling weight deflectometer. These devices have not been available to the city and county engineers until lately. There were two projects that came under the general category of load effects on pavements.

One of these was brought about by Northern States Power Co. (NSP) because they wished to move some 375,000-lb. transformers over roadways between North Branch, Minnesota, and a location 5 mi to the south. As part of the research implementation work, an evaluation was made of the pavement proposed for the moves on the basis of surface condition, rideability, and structure. The structure was evaluated in terms of its condition and strength was measured with the Benkelman beam deflection device.

NSP rented a trailer with 92 wheels that had a hydraulically controlled suspension system. This suspension system kept an equal weight on each wheel and thus kept the individual loads within design limits. However, the total stress bulb under the large load was greater than for most loads. Evaluation of the pavement section and condition after the move showed that there was no measurable deterioration of the roadway due to the move of the five 375,000-lb transformers. This information was documented with slides and in report form and made available to the city and county engineers. It was presented at a number of conferences around the state.

In 1980 proposals were being made to increase the allowable load limit on single axles of trucks to 10 tons (20,000 lb). The effect of this increase would not necessarily show up as a dramatic decrease in serviceability or increase in cracking and rutting of pavements, especially on low-volume roads, but there would be a fatigue effect over a period of time. A slide-tape show was developed to bring out what some of the consequences would be of increasing allowable axle loads. This slide-tape show presented the equivalent load concept as a fatigue effect on pavement sections. The slide tape was developed so that city and county engineers could present it to truckers, city councils, legislators, and so forth, to point out the decrease in pavement life that would occur if the axle loads were increased. This slide-tape show was presented at many town councils and the state legislature. It has been distributed to all nine districts of Minnesota DOT and to many state DOTs around the country. It has also been translated into Spanish and used by the World Bank.

A publication was put together based on the slide-tape show on load effects on pavements. This report was also distributed to all city and county engineers in the state of Minnesota and to selected other engineers throughout the country.

Pavement Recycling

Pavement recycling has been used successfully in Minnesota since 1978. The first hot mix recycling research project was performed in 1976 in Maplewood. Minnesota DOT and many of the cities and counties have used the concept of recycling as an alternative to pavement rehabilitation since about that time. Hot recycling especially has become a good, usable tool for the stabilization of base courses. Many of the city and county engineers were not aware of how this procedure and concept could be used. Therefore, a slide-tape show was developed for showing at the state-aid engineers' meetings. This makes the city and county engineers aware of the recycling specification available from Minnesota DOT. It also warns the local engineers that proper design and construction procedures must be followed. A recycling job must be watched more carefully than a job using only new materials. The important parts of Minnesota DOT recycling specification 2332 were presented and it was indicated that this could be used as an alternative to standard reconstruction or stabilization procedures. A reference file has also been developed so that the project staff can respond to city and county engineers if they have problems with hot recycling projects.

In the past 3 years the concept of cold recycling has been developed. Cold recycling can be done essentially as base stabilization by grinding up the in-place material and spraying liquid asphalt emulsion or some other appropriate asphalt material into the recycled material. This procedure, along with crack and pothole repair, was covered in a bituminous repair workshop held in April 1984. Local staff put on the workshop and other experts were brought in from Canada, Pennsylvania, and other parts of the United States to present the updated procedures that are currently being used for each of these three processes. At the workshop the attendees were asked if they would be interested in participating in a demonstration project in the field. Allen Goodman, the Lake County engineer, stated that he would like to work further on this project. After some developmental work, pavement sections near Knife River were selected for cold recycling. A BROS reclaimer machine was used to grind up and mix asphalt emulsion into the existing ground-up pavement structure. This was a cooperative effort among Lake County, Minnesota DOT, Koch Asphalt Co., and the Research Implementation Project staff. This project showed that the cold recycling concept can be used for low-volume road applications. The project was done in August 1984 and is performing quite well considering the type of construction used. In 1985 more cold recycling projects were done in Winona and Sibley Counties, Minnesota.

A research implementation series publication is planned to review the concept of cold recycling and how it can be economically used in Minnesota. Some drawbacks and precautions are also presented so that city and county engineers will have a good idea of both what can and what cannot be done with cold recycling.

Geotextiles in Road Construction

During the past 10 years there have been many projects done around the country using engineering fabrics or geotextiles to aid in the construction of road and other embankment-type construction. Geotextiles have been valuable in helping stabilize very weak subgrade soils such as those in swamp and beach areas. They also work well as a separation layer between granular materials and fine-grained soils. They can be used in erosion control as silt fences and have been used with some mixed success as interlayers in pavement sections. Many engineers saw the application of geotextiles as a save-all procedure under just about any conditions. Manufacturers also saw geotextiles as solutions to just about any type of construction problem. Geotextiles had worked well beyond the imagination on some projects with little analysis or documentation of properties or construction conditions. The U.S. Army Corps of Engineers and the FHWA cooperated to categorize the use of geotextiles and document what types of geotextiles are appropriate for given applications.

A manual was written by the late T. Allen Haliburton et al. (3). He and his associates wrote a complete manual on the design and construction of projects with geotextiles. They developed slides and set up a 4-day school for presentation of this material to engineers throughout the country. This project, sponsored by the FHWA, was done for the purpose of presenting the most up-to-date material on geotextile technology. In 1981 geotextile technology was one subject that the Research Implementation Project advisory panel thought was critical and, therefore, the project staff began looking for ways to make this information available directly to Minnesota engineers. The FHWA was contacted and gave permission to have the geotextiles manual (3) reprinted and distributed to all of the city and county engineers in Minnesota. Haliburton was contacted and, in the winter and spring of 1982, presented four 2-day schools in Minnesota. These were in Brooklyn Park, Mankato, Brainerd, and Maplewood.

At these schools slides were used to supplement Haliburton's presentation and discussion and there were some problems actually worked out by the attendees. A total of 240 people attended these workshops.

Questionnaires were handed out at the workshops and the attendees were asked how they could most effectively use the concepts that were presented. They were asked if they would be willing to put in some trial geotextile sections in their own county or city areas. A number of them responded positively, and many people believed that follow-up workshops, in which more specific design information could be presented, should be held. The original workshops in Minnesota were 2-day condensations of the 4-day workshop that had been developed for the FHWA. Many of the design problems that were to have been worked by the attendees were omitted due to lack of time. Haliburton passed away in the fall of 1982 and, therefore, one of his associates, John Barron, was contacted to put on a number of schools that would include design examples using geotextiles. Four schools were again put on, two in the Twin Cities area, one in Marshall, and one in Park Rapids. At these schools much of the same general material was summarized and then there was time available for the attendees to work out some design problems. A total of 180 people attended these four workshop sessions.

Minnesota DOT had been using geotextiles in various types of construction for a number of years. These applications included stabilization of embankments, erosion control, and pavement interlayers. A number of counties decided to try the various applications of geotextiles. There follow a few examples of these.

1. Wright County constructed a road in a swamp section using geotextiles as stabilization. This was done in 1977 and is an example of successful use of geotextiles in Minnesota. This project had been well documented by the Wright County Engineering Department and was discussed in a paper at the 1983 TRB Low-Volume Road Conference. Similar projects were also built in Cass County and Pine County. These projects have been well documented by the respective county engineering departments and are used as examples of how to properly use geotextiles for embankment construction.
2. St. Louis County has been using geotextiles as separation layers between clay-type soils and granular base materials. Installations of these have been in service now for more than 5 years. Areas of frost boils and soft spots have been successfully rehabilitated with these procedures.
3. As mentioned, Minnesota DOT has two projects in which they are evaluating the use of geotextiles as pavement interlayers. So far these have met with mixed success and a well-documented design procedure has not been developed. This continues to be studied and materials such as geogrids may be available in the near future for this use.

Implementation of the use of geotextiles in Minnesota has been carried out for this project by reviewing as much literature as possible on the subject and talking with experts within Minnesota, such as Graham R. Ford of the Soils and Geology Section, and some local suppliers. National experts were contacted to help generate more interest and to educate Minnesota engineers about what geotextiles can and cannot do and how to design engineering structures. Installations were encouraged and documented after the schools were completed. Research Implementation Series publications have covered the various applications of geotextiles and how to property set up and use them. As more information becomes available on this subject, the staff of the Research Implementation Project will try to document and make available this more up-to-date design and construction information.

End-Result Statistically Based Specifications

In 1977 the Minnesota DOT started using statistically based specifications. The FHWA sponsored the development of a short course at the Pennsylvania State University to help practicing engineers and technicians see how to apply statistics to the materials used for highway construction. This 2 1/2-day short course was taught in each of the nine districts of Minnesota DOT. It was available to all interested Minnesota DOT, city, and county engineers and technicians. A total of 180 people participated. The workbook developed under the sponsorship of FHWA (4) was distributed to each of the attendees.

Minnesota Research Summaries

The Research Implementation Project panel believed that it would be useful to have a listing of all research projects that had been conducted over the years by the Office of Research and Development at Minnesota DOT. There have been projects sponsored directly by Minnesota DOT, the LRRB, or the FHWA and in cooperation with other states and national organizations. These projects were classified as investigations, special studies, and local documentations. In some cases the findings have been fully implemented and in others only partly. In some cases the projects have not received much attention since they were completed. Occasionally new products and projects have been proposed when there had been similar work done in the not-too-recent past. Therefore a listing of projects including a statement on how they had been implemented was considered useful. Two of the three planned research implementation summaries have been completed.

The first research review (2) covers the implementation status of research projects that have been sponsored wholly or in part by the Minnesota LRRB since 1959. These projects cover a wide variety of subjects including geometric standards, pavement design and evaluation, materials evaluation, and roadside turf establishment. Much of the information from these projects has been of value to all city and county engineers as well as Minnesota DOT engineers and industry. In addition to a statement indicating how each of the projects is being implemented, recommendations are included regarding further implementation. As more implementation or changes in the status of the projects occur, updated pages will be prepared and distributed. For particularly significant projects, a Research Implementation Series pamphlet is produced. The projects have been put in the categories of bridges, ice removal and salt, literature and research reviews, load capacity, miscellaneous, pavements, quality control and laboratory tests, specifications and standards, subgrade and base materials, surface treatments and crack sealing, trench studies, vegetation, and erosion control.

A second implementation review publication (5) has been completed and includes a listing and review of all investigations conducted by the Office of Research and Development. Some of these were sponsored by Minnesota DOT and some by the FHWA.

A third compendium of research and implementation summaries is planned to cover the various special studies that have been conducted by the Office of Research and Development.

Snow and Ice Control

The project implementation panel believed that the subject of snow and ice control is of great interest to all city and county engineers and maintenance personnel, and that there had been much new information and many new procedures developed on this subject in the past few years. Also, there have been many retirements of maintenance personnel and it would be good to have some type of videotape or other presentation available to show new personnel. The project staff contacted Pat Chandler, retired maintenance engineer from the Golden Valley Minnesota DOT district office, who gave technical assistance and coordinated presentations on snow and ice control. With the cooperation of the maintenance sections of both the Oakdale (District 9) and the Golden Valley (District 5) offices of Minnesota DOT, videotapes were prepared on truck preparation, snowplow attachment, and the general concepts of snowplowing.

The presentation on truck preparation shows the proper check-out procedure that each driver should go through daily before using the truck. The snowplow attachment videotape shows the attachment procedure used on Minnesota DOT Type-33 trucks. In this way the attachment procedure can be shown without having to have a truck available.

The general videotape, entitled "The Snowfighters," describes general snow removal techniques and the importance of the job. It can be shown to new employees to make them aware of the great importance of the job and some general procedures that will help them carry the job out properly. Making this videotape required much time to obtain good shots of actual snow removal operations in the field.

It is hoped that by preparing these videotapes the research implementation staff has encouraged the training section of Minnesota DOT and the various other sections to develop similar training aids and other publications to help train in-service and new employees.

Bituminous Pavement Repair Techniques

One of the great needs of the past few years has been to develop and use proper techniques for repairing pavements. There have been more than 100,000 mi of pavements constructed in Minnesota during the past 50 to 60 years, and to keep these in serviceable condition will require continual maintenance and rehabilitation work. It has been found that the most economical way to maintain a pavement is to make the repair as permanent as possible so that a particular location does not have to be repaired repeatedly. If pavements are deteriorating during the cold wet seasons, it is not always possible to go through the proper procedures and more emergency-type measures must be used. Repairs made under emergency conditions should be replaced with more permanent repairs during the summer season.

Work in this field was reviewed by the project staff and it was decided to sponsor a pavement repair conference at which local experts and others from around the country would be asked to present some state-of-the-art knowledge on this subject. In April 1984 a conference was held in St. Paul. The conference covered the latest information on pothole repair techniques, crack repair and filling methods, and seal coat and surface treatment procedures. The Office of Research and Development participated in this conference by making the attendees aware of projects that have been conducted by Minnesota DOT along with the status of these projects. There were 135 attendees at this conference including county engineers, city engineers, and maintenance supervisors.

As a follow-up to this conference it was believed that workshops should be presented at which there could be demonstrations of the procedures presented. In 1985 five workshops were developed and presented. At these workshops Minnesota DOT engineers reviewed projects and procedures that are appropriate for crack, pothole, and surface repair. Local crews and some manufacturers provided equipment and materials to conduct field demonstrations of the procedures. There were between 45 and 55 attendees at each of these workshops, which were held at Marshall, Normandale Community College in Bloomington (2), Detroit Lakes, and Virginia. The benefits of these workshops have been ascertained from the evaluation sheets. Just about all subjects were well received. Workshops like these make it possible for people to get together and have presentations and discussions on the various aspects of proposed new techniques.

A slide show on causes of and proper repair techniques for potholes was prepared by the Pennsylvania DOT. This show has been adopted to cover Minnesota conditions and has been distributed around Minnesota.

Each of these projects has required the cooperation of many people, in particular the staff of the Office of Research and Development of Minnesota DOT. These include Gabriel Bodoczy, Roger Olson, Ronald Cassellius, Donald Caswell, and Ronald Canner.

As can be seen from the review of the projects conducted for the Research Implementation Study, there have been various procedures used. These procedures have been categorized as

1. Research Implementation Series (RIS),
2. Slide show (SS),
3. Slide tape (ST),
4. Research Implementation publication (RIP),
5. Videotape (VT),
6. Memo (M),
7. Workshop (WS),
8. Seminar (SM), and
9. Demonstration project (DP).

The following listing shows which of these procedures or methods were used for the implementation subjects.

Pavement management	
Surface condition rating	SS, ST, RIP, SM
Traffic--18,000-lb single axle	
Equivalent load calculation	SS, RIP, SM
Rideability	SS, RIP, SM
Pavement strength	SS, RIP, SM
Summary presentation	SS, RIP, SM
Water quality	M
Sprinkle treatment	M
Statistically based specifications	RIP, WS
Load effects	
Transformer moves	RIP, DP
Truck effects on pavements	ST, RIP, SM
Recycling	ST, RIP, SM, WS, DP
Use of fabrics in road construction	M, SM, WS, DP, RIS
Minnesota research summaries	RIP (3)
Snow and ice control	M, VT
Pavement repair and maintenance	VT, SM, WS, DP

As can be seen from this list, the subject and available information dictate the type of research implementation package to use for a particular topic.

Interaction with Technology Transfer Centers

The FHWA has sponsored technology transfer centers, which have as part of their operation research implementation work throughout the country. In the upper Midwest, centers are located at the North Dakota State University in Fargo, the University of Wisconsin in Madison, and Iowa State University in Ames. The center at North Dakota State University has as part of its responsibility serving the state of Minnesota. The purpose of these technology transfer centers is to convey new technology to the county, city, and township engineers and other people responsible for the design and maintenance of transportation systems. The technology transfer centers have, in addition to research implementation, the task of training maintenance and other highway personnel. They are involved with the setting up and distribution of slide-tape shows and videotapes, conducting workshops, and publishing newsletters. The staff of the Minnesota Research Implementation Project has cooperated with the North Dakota State University staff in putting on a transportation conference in Fargo. Other areas of cooperation are also being developed.

SUMMARY

Minnesota has had a Research Implementation Project for more than 10 years. During this 10-year period the project has resulted in many research implementation packages. The written reports and various other presentations are listed in the Appendix of this paper. As can be seen from the Appendix and the previous list, there are many different approaches that can be taken to developing research implementation packages. The one chosen depends on the audience to be served and the subject matter being considered.

The Minnesota LRRB, which was created in 1959, has sponsored many research projects for local application in Minnesota since that time. The Research Implementation Project has been administered by an advisory panel appointed by the chairman of the Minnesota LRRB. The steps required to conduct the project and develop research implementation packages are

1. Establish an advisory panel;
2. Develop a project prospectus including a definition of the goals of the project and some general guidelines for conducting the project;
3. Engage a consultant to conduct the research implementation; the consultant, after some study, should develop a proposed set of implementations to present to the advisory panel;
4. Present proposals including subject background and technical support to the advisory panel; and
5. Select implementation packages by ranking the project activities in priority order for the staff.

The implementation packages have consisted of slides, narrations, slide shows, slide tapes, publications, videotapes, memos, workshops, seminars, and demonstration projects. The 10 or more implementation areas that have been worked on are discussed in this paper and various forms of implementation have been used within each of the general areas as deemed appropriate. The implementation process has generally included the following steps:

1. Obtaining an idea from the panel or staff;
2. Gathering background information; and
3. Developing an implementation plan that can include some or all of the following: (a) visual

aids such as slide tapes or video tapes, (b) technical advisories, and (c) memos.

The 10 areas are pavement management, water quality, sprinkle treatments of asphalt pavements, statistics for end-result specifications, load effects on pavements, pavement recycling, use of geotextiles in road construction, Minnesota research summaries, snow and ice control, and bituminous pavement repair techniques. Presentations and publications on these various activities have been presented around the state and are being used by many local city and county engineers throughout Minnesota. Some have been distributed around the country as well as internationally.

The project staff is now cooperating with the technology transfer centers sponsored by the FHWA to help further develop and disseminate implementation packages.

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APPENDIX--PUBLICATIONS AND PRESENTATIONS OF THE RESEARCH IMPLEMENTATION PROJECT

Publications

1. Surface Condition Rating System
2. Rideability
3. Calculation of Equivalent 18,000-lb Axle Loads
4. Determination of Strength with the Benkelman Beam Deflection Test
5. Summary Report on Measurement of Pavement Conditions and Evaluation Techniques
6. Statistical Calculations for Highway Material End-Results Specifications
7. Load Effects on Highway Pavements
8. Use of Nonspecification Fine Aggregate Asphalt Hot Mix Materials--Research Implementation Series No. 1
9. Research Review, Vol. 1: Minnesota LRRB Projects
10. Research Review, Vol. 2: Minnesota DOT Investigation Report Summaries
11. Research Review, Vol. 3: Summary of Special Reports
12. Summary of Geotextile Usage--Minnesota Research Implementation Series No. 2
13. Use of Geotextiles for Roadway Embankment Construction--Minnesota Research Implementation Series No. 3
14. Use of Geotextiles as Separation Layers--Minnesota Research Implementation Series No. 4

Audiovisual Presentations

1. Surface Condition Rating System: slide show with written narration
2. Rideability: slide show with written narration
3. Calculation of Equivalent 18,000-lb Single Axle Loads: slide show with written narration
4. Measurement of Strength with the Benkelman Beam Deflection Test: slide show with written narration
5. Summary of Pavement Conditions: slide show and report
6. Load Effects on Highway Pavements: slide-tape show
7. The Use of Recycled Materials in Minnesota: slide-tape show
8. Surface Condition Rating System: slide-tape show
9. Pothole Repair Techniques: slide-tape show
10. Inspection of Minnesota DOT Type-33 Truck: videotape
11. Attachment of Standard Minnesota DOT Snowplow: videotape
12. The Snowfighters--A General Guide for Snowplowing: videotape

Publication of this paper sponsored by Committee on Conduct of Research.

Planning for Effective Technological Innovation: Recent Experience of Transport Canada

R. T. LEWIS, W. F. JOHNSON, and R. R. MAYES

ABSTRACT

A methodology for strategic planning of technological research and development (R&D) for transportation at the national level is presented. The methodology is based on recent Canadian experience with strategic planning in R&D. The methodology involves technology assessments, identification of issues, setting of R&D objectives, consultation with industry and provinces, and development of strategic options and strategy plans by sector. A successful application of the methodology to strategic planning of R&D for railroad transportation is outlined. The current application of the methodology to Canadian highway transportation is described with reference to achievements to date and future activities.

In this paper the strategic research and development (R&D) planning mechanism developed by Transport Canada for technological innovation is described, and two examples of its application are presented. The first example, rail freight, is a recent successful application of the methodology, and the second example, highway transportation, is currently in progress.

BACKGROUND

The department has designed its R&D efforts to support the attainment of transportation objectives, whether these be improved effectiveness of the department's ice-breaking services or related to the railways' concerns about improved productivity. This "demand-pull" orientation provides the justification for more than 85 percent of the department's R&D efforts. However, R&D programs also have to provide for the dynamism of technology. Flexibility must be provided in the department's R&D programs to accommodate longer term, higher risk efforts that cannot be justified solely on the basis of demand-pull. The department's support of exploratory research in such fields as materials technology, laser and fiber optics, combustion technology, magnetic levitation, and fifth-generation computers are examples of initiatives in this area, sometimes known as "technology-push."

The bulk of the department's R&D resources are, however, dedicated to objectives in the following areas:

- Policy decision making: R&D can provide the essential knowledge base on which informed decisions can be made. An obvious example is rail electrification. Most recently, a program was supported that, although it has real application to moving coal from Tumbler Ridge to the British Columbia Railway's main line, is also designed to collect data on the feasibility and performance of rail electrification technology under Canadian conditions.
- Support of safety regulation: This essential function of government affects both transportation safety and costs. For example, technological performance standards that can be set for the safe transportation of dangerous goods need to be known. Furthermore, in the Arctic and off the East Coast, technological standards that are required to permit safe and economic transportation in these hostile marine environments need to be known.
- Government transportation services: The federal government operates or supports the operation of major elements of Canada's marine and air transportation infrastructure. The provinces build and operate roads, sometimes with federal support, and the provinces and municipalities provide urban transportation services. R&D activities are key elements of the efforts required to improve the efficiency of these services and, of course, are also a key element of strategies to develop specifications for medium-term and longer term equipment procurements.
- Support of industry: Part of the role of Transport Canada is to act as a clearinghouse for information on transportation technology trends and related R&D programs. In many areas, Transport Canada has mounted, and will continue to mount, cooperative R&D programs with the transport industry to meet common objectives.

The resources available to achieve overall transportation R&D objectives are not limited to departmental or even federal sources. An important goal is to maximize the effectiveness of departmental R&D expenditures by complementary expenditures by other federal departments and external R&D participants. The distribution of transportation R&D expenditures (1) in Canada is given in Table 1.

At the federal level, policy development and planning for transportation R&D are coordinated and guided interdepartmentally through a panel led by Transport Canada. At the program level, departmental R&D mandates are limited, although there is good coverage across the technology innovation cycle. The steps in this cycle are given in Table 2 with the R&D participants listed under each step.

Some interesting issues arise from these patterns of expenditures and participation:

- The federal government as a whole spends a considerable sum of money on transportation R&D, but

Transport Canada, Place de Ville, Ottawa, Ontario K1A 0N5, Canada.

TABLE 1 Distribution of Transportation R&D Expenditures (*1*)

	Funding Source			
Mode	Federal	Provincial	Industry	University
Air	38	0	243	0.7
Marine	41	0	5	0.5
Rail	4	1	10	0.7
Road	16	10	6	0.3
Other	5	0	1	1.3
Subtotal	105	11	265	3.5
Total	384			

Transport Canada spends only $26 million or one-quarter of federal expenditures. More than 95 percent of this amount is contracted out either to private industry or to university research centers.

• Transport Canada is but one actor in stimulating technological innovation. To be successful across all modes, it must rely extensively on the efforts of others. To do so, it must engage in a process designed to build consensus on R&D objectives and priorities and on appropriate strategies.

These considerations have led to development of a logical and consistent process for planning and programming R&D. This process is designed to permit technology innovation to make its contribution to broader transportation and other sectoral needs and opportunities. It is also designed to be flexible to cope with the dynamics of both the environment and the technologies themselves. It addresses the need for focused R&D planning and for concerted programming, the lack of which was clearly identified in the assessments of Canadian transportation R&D activities carried out in the 1970s.

PLANNING FRAMEWORK

What follows is a straight-line description of a logical approach designed to produce consensus on what R&D is required to address transportation needs for technology innovation and to produce a strategic plan for transportation R&D (2). There are two stages the first of which is to develop a quantitative assessment of the technology innovations required to address transportation needs. The product of this stage is a set of objectives for innovation.

The second stage is designed to establish strategies for implementation, jointly or separately by members of the transportation community, of R&D programs that will meet these innovation objectives. The objectives are further ranked by priority in relation to the impact that transportation R&D has on other sectors of the economy.

There follows a brief outline of the framework used to establish technology innovation objectives and priorities, which, in turn, are used to develop strategic R&D plans to achieve these objectives and priorities. The flow of logic of the two-stage process is shown in Figure 1.

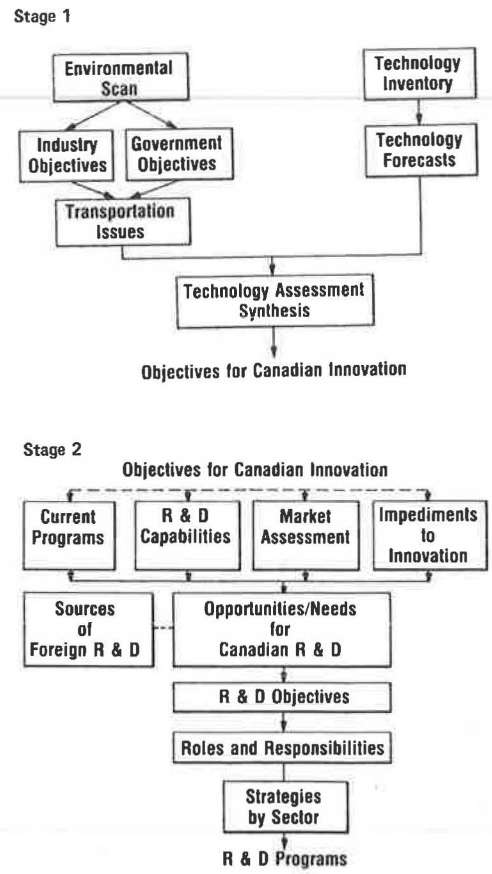

FIGURE 1 Transportation R&D strategic planning framework.

Stage 1

• To establish quantified targets for innovation in the short, medium, and long term: In analytical terms, this requires socioeconomic assessments of transportation systems to define the issues (for example, escalating highway maintenance costs) and the degree to which current technology constrains system safety and efficiency. In parallel, technology forecasts are developed to establish the improvements that can be achieved by innovation in vehicles, ways,

TABLE 2 Technology Innovation Cycle

Basic Research	Applied Research	Product Development	Demonstration	Deployment
National Research Council Universities	Transport Canada Carriers Provinces Other Federal Energy, mines, and resources Environment Fisheries Oceans U.S. and foreign (joint research)	Regional Industrial Expansion	Transport Canada Provinces	Transport Canada Provinces

and terminal technology and in related operating procedures.

Stage 2

• A review of existing R&D programs to define gaps and impediments to technology innovation: This review is extensive because it considers transportation R&D programs at all levels of government, in industry, and in the universities in Canada, the United States, and abroad. It requires assessment both of Canadian capability to work effectively in a particular field and of the degree to which such efforts can be justified, not only in transportation terms, but also in terms of the impact of R&D on objectives in related fields (such as energy, industrial and regional development, national defense, and environmental protection). This review results in the identification of strategic objectives for Canadian transportation R&D, which reflect both the need for technology innovation in a particular mode (or perhaps across modes) and the capability resident in Canada (or which could be developed in Canada) to meet the objectives.

• A review of the roles and responsibilities of federal and provincial governments, industry, and universities designed to define what part each of these could play in developing operational plans and programs to meet Canadian strategic transportation R&D objectives: This results in the identification of areas in which individual or joint R&D programs could be developed to meet the objectives.

This process, even in the simplified form described here, is time consuming. The pay-offs, however, in the rail freight case cited later in this paper, have proven to warrant the effort. It must be remembered that the process is designed to ensure not only that technology innovation needs are met but that they are achieved through integrated R&D planning and programming. Only in this way can success be achieved and the severe financial and human resource constraints that exist overcome.

RAIL FREIGHT R&D

In this section is outlined the application of the strategic planning approach to develop a rail freight R&D plan. This was one of seven areas of transportation R&D identified as high priority in a 1980 federal assessment. To leap forward to 1985, the results demonstrate how government and industry, through collective planning and individual and joint R&D programming, were able to maximize achievement of their R&D objectives through a commitment to work together (3). The results, aside from those directly related to transportation productivity and safety, have or will have significant impacts on such related concerns as energy and industrial development. It should also be noted that, although the initiative to develop this plan came from Transport Canada, its implementation and indeed its current shape would not have been possible without the efforts of all of the other participants.

Stage 1 Results

In 1981 the world economic outlook was still dominated by the energy crisis and slow economic growth. The railway industry in Canada was investing a minimal amount in R&D. There were concerns about medium- and long-term prospects for industrial growth based on a healthy and innovative rail sector. The strategic R&D objectives of the industry were

• To improve productivity and efficiency in order to recover profitability and
• To maintain and improve safety and reduce losses due to accidents.

The strategic R&D objectives of the government were

• To establish self-reliance in energy;
• To improve rail safety, in particular with respect to the transport of dangerous goods;
• To improve rail productivity and efficiency; and
• To reduce environmental impacts.

In 1981 four main rail freight sector issues, which provided targets for technological innovation, were defined:

1. Rail capacity: Rail investment in the 1980s was projected to be some $14 billion split almost equally between investments in locomotives and rolling stock and in infrastructure. In assessing this issue, it was found that capital investment economies could be attained by concentrating on the application of advanced technologies to improve the use of existing infrastructure as an alternative to traditional methods of expanding capacity, such as providing new sidings or double tracking. Among other things, this was the genesis of the Advanced Train Control R&D Program, which is currently being pursued jointly by the Railway Association of Canada and the American Association of Railroads.
2. Rail productivity: During the 1960s and the early 1970s the productivity of railway capital and labor increased annually at between 6.4 and 7.8 percent. During the remainder of the 1970s, and into the 1980s, this growth declined dramatically to between 0.7 and 2.0 percent annually. This resulted in an upward pressure on rail freight rates precisely at a time when increases in domestic inflation and the state of competitiveness of Canadian exports were emerging as major national issues.
3. Energy: Although to some extent the energy crisis appears to have abated, there remain continuing concerns about the price and availability of quality diesel fuel.
4. Safety: A time-series analysis of railway accidents shows that 31 percent resulted from track problems, 24 percent from employee mistakes, 18 percent from equipment failures, and the remainder from a combination of these or nonrailway concerns.

A sector profile was developed that identified the technologies relevant to railway system development. This consisted of an inventory of rail technologies with measures of their current effectiveness and forecasts of future technological developments.

The technological assessment process established five main thrust areas for innovation in rail freight: motive power, freight cars, intermodal systems, infrastructure and maintenance, and communication control and automation. This assessment was based on consideration of all possibilities for innovation not just those that might be developed in Canada. Within each thrust area, individual projects were assessed and rank ordered.

The relationship, in general terms, that was established between the top-down assessments of issues and the bottom-up forecasts of the ability of technology to resolve these issues is given in Table 3.

Stage 2 Results

In this section are summarized the main factors that led to the definition of a rail freight R&D program strategy.

TABLE 3 Relationship Between Assessments of Issues and Forecasts of Ability to Resolve Them

	Rail System Issues			
	Capacity	Productivity	Energy	Safety
Motive power				
Engine design	X	X	X	
Fuel alternatives			X	
Lower grade fuels		X	X	
Electrification	X	X	X	
Freight cars				
Materials	X		X	
Design	X	X	X	X
Smart cars		X	X	X
Track and train dynamics			X	X
Braking systems		X		X
Diagnostics				X
Displays				X
Hazardous commodities				X
Intermodal systems, infrastructure, and maintenance	X	X	X	
Equipment	X	X		
Procedures	X	X		
Roadbed	X	X		X
Wheel and rail wear	X	X	X	X
Grade crossings				X
Speed control			X	
Communication, control, and automation (location, routing, scheduling, and control)	X	X	X	

In 1981 federal and industry expenditures on rail freight R&D were on the order of $5.5 million annually. The objectives were technically feasible and desirable; the need was for new commitment to fill in the gaps and expand the total effort.

It was generally found that Canadian rail research facilities could potentially perform almost all of the required R&D. Subject to market opportunity and foreign competition, they might be expected to produce competitive products in a number of areas. The analysis also showed the need for development of certain new facilities. This supported the Canadian National Research Council's recent investment in a controlled-climate testing facility for railway rolling stock.

Arising from this were assessments of the ability of Canadian products both to serve domestic markets and replace imports and to potentially penetrate North American and other foreign markets. For example, it was estimated that, as an outcome of enriched rail freight R&D, exports of Canadian products could grow from $150 million in 1976 to more than $500 million by the mid to late 1980s.

At the outset of the planning process, it was apparent that governments and industry had differing perceptions of needs and opportunities and of what needed to be done to meet them. It was also apparent that the relationship of Canadian railways and Canadian equipment manufacturers had resulted in short-term and discontinuous production. Both of these factors were at odds with maintenance of a viable manufacturing industry, let alone maintenance of a long-term commitment to R&D by that industry.

In view of the continental nature of North American rail systems, needs and opportunities for joint research with U.S. railroads and the Federal Railroad Administration were also identified.

An assessment of the roles of each level of government, industry, and academia, and of the options open to the federal government in relation to attainment of the strategic R&D opportunities, is reflected in the strategy outlined hereafter.

Canadian Rail Freight R&D Strategy

In light of government-industry awareness of strategic objectives and priorities, the following strategy was developed and subsequently implemented:

- The railways would conduct R&D to satisfy their operating strategies, system requirements, and needs for equipment specifications;
- The supply industry would conduct the R&D required for hardware and production systems to meet domestic and foreign market opportunities; and
- The federal government would work to overcome impediments to technological innovation and to create an environment for a viable rail freight R&D program in Canada.

In concrete terms, the federal government also augmented its contribution to rail freight R&D programs from some $1 million annually to between $3 million and $4 million annually. Despite the recession, industry, principally the railways, also augmented its commitment to research and development, and, by 1983-1984, total rail R&D expenditures had quadrupled to more than $20 million annually.

Summary

Much has resulted since this strategy was approved in 1981 and augmented resources for federal rail freight R&D programs were provided. Where federal technical regulation is involved, such as in the transportation of dangerous goods, the required R&D is funded by the department and work is carried out cooperatively with industry; for example, tank car explosion suppression technologies. To meet federal policy objectives, the potential for rail electrification is being thoroughly explored under Canadian conditions.

Where industry objectives for productivity dominate, the required R&D has been carried out on a shared-cost basis. Collaborative projects between Transport Canada and industry have resulted in new designs for a train location, identification, and control system; an end-of-train monitoring system; steerable trucks; a rail-reprofiling technique; a single-cylinder test engine; and a transponder for use in automatic rail car identification systems.

The most notable outcome of the rail freight R&D program is perhaps the current efforts of the Canadian railways not just to maintain but to expand on their commitment to R&D. Rail freight technological innovation is both making the railways safer and more productive and achieving some spin-off benefits for other sectors of the economy that reflect the significant role played by the railways in Canada. Finally, a new, augmented federal rail freight R&D program is in the planning stage.

HIGHWAY TRANSPORTATION R&D

Currently, some $34 billion is expended annually in Canada on highway transportation. In contrast, the combined expenditures on air and rail transportation are some $12 billion annually. However, R&D expenditures in air and rail amount to some $310 million annually, while those by all levels of government and industry for highway R&D amount to only $29 million. Some of the reasons for this are the high percentage of imported vehicles in use in the highway mode; a perceived lack of alternatives to current methods of building, operating, and maintaining highways; and attitudinal barriers that arise from an absence of thinking about what technology should and could be doing to resolve highway transportation problems. Certainly, the low level of expenditures on highway transportation R&D compared with other modes does not in itself justify increasing the level to conform to that of other modes. It does, however, signal the need to assess in hard terms what could and should be done in highway transportation R&D as has, for example, been initiated in the United States.

The Highway Advisory Board Plan of 1981 identified nine thrust areas for national highway transportation R&D planning. At that time R&D planning was dominated by the continuing world energy crisis, the urgent need to improve productivity of transportation, rising expectations for improved safety, and shrinking resource allocations for research activities. These concerns were common to all North American highway transportation jurisdictions. Needs for R&D were identified in the following areas:

- Highway data base,
- Traffic mix,
- Heavy vehicles,
- Infrastructure,
- Energy,
- Data-gathering devices,
- Special cold weather requirements,
- Urban highway-related needs, and
- Intermodal needs.

Stage 1 Results

Since early 1984, an analysis of highway transportation similar to that of Stage 1 outlined in the planning framework has been in progress within the federal government (4). By adopting the perspective of "highway transportation," the analysis sought to develop a global assessment that would encompass both infrastructure and vehicle systems. The results of this federal initiative were discussed with provinces, industry, and universities. One substantial outcome of these discussions has been to raise awareness of opportunities and needs for highway transportation R&D and to set in motion planning activities as a prelude to action.

The strategic objectives of Transport Canada for highway transportation relate first of all to its responsibility for regulation of motor vehicle construction standards under the Motor Vehicle Safety Act. Second, the department supports the national goal of a productive and safe highway transportation system. Third, the department is involved in financial assistance for selected elements of the national highway system and in these cases has an interest in improving efficiency and effectiveness through R&D.

The strategic objectives of the provincial governments relate directly to improving the efficiency and effectiveness of their expenditures on highway construction and maintenance and to reducing losses due to accidents. The strategic objectives of the highway transportation industry are defined collectively by vehicle operators, shippers and users, and firms involved in construction and maintenance of the system. These objectives are related to maintaining an economically viable transportation system that continues to provide employment and return on invested capital.

A short list of the seven main issues that impinge on highway transportation includes

- Productivity improvements;
- Safety, including transport of dangerous goods;
- Accessibility for elderly and handicapped persons;
- Energy, including conservation and alternative fuels;
- Human resources, training and development;
- Industrial and economic development; and
- Environmental protection.

The candidates for innovation activity were assessed on the basis of the following criteria. At the outset, the major potential impacts in the areas of productivity, safety, and accessibility were weighted uniformly in assessing research priorities. The remaining criteria (i.e., energy, human resources, industrial and economic development, and environmental impacts) were also assigned equal weights within their own category. Further assessments were based on a sensitivity test that involved ranking the issues in the order in which they have been enumerated.

After this analysis was completed, priority innovation targets were identified in three thrust areas: vehicles and systems, infrastructure, and management. A summary of the priority thrust areas and their component subgroups is given in Table 4. Because the process of consultation is incomplete, these thrusts are subject to modification before final acceptance by the highway transportation R&D community.

Stage 2 Results

The strategic planning activities related to Stage 2 of the planning framework for highway transportation R&D are now in progress. The largest single highway-related R&D project currently under way in Canada is the heavy vehicle weights and dimensions project. This is a cooperative project of the federal government, the provinces, and industry. Preliminary results are due in mid-1986.

In addition, federal responsibilities for road

TABLE 4 Priority Thrust Areas

Vehicles and Systems	Infrastructure	Management
Freight safety (including transport of dangerous goods), productivity, and efficiency (including energy efficiency)	Pavement performance, rehabilitation, maintenance, cold climate pavement technology	Physical distribution efficiency
Passenger safety (automobile, light panel truck, other vehicles) and efficiency (including fuel economy)	Protection from weather and salts Maintenance system efficiency and effectiveness	Technology and information to support regulations and/or regulatory reforms
Highway bus safety, productivity, and access for elderly and handicapped persons	Efficient use of existing facilities	
	Safety and energy efficiency of infrastructure: design, maintenance, operation	Expert systems technology to improve skilled labor productivity
	Access for elderly and handicapped persons at terminals	Technology transfer

safety have resulted in the preliminary identification of federal R&D program needs. These include occupant restraint and crash assistance research, statistical and behavioral research in such areas as the magnitude and nature of impaired driving, safety enhancements that could be obtained from improvements to driver communication systems, and improved vehicle safety standards. R&D is also being proposed to provide operators with improved problem-sensing devices, to provide safer containers for hazardous goods, and to minimize the risk of spills when transporting dangerous goods.

The provincial highway and transportation departments have well-established R&D programs, particularly in the areas of pavement performance and structures. The provincial research laboratories, together with the federal Motor Vehicle Test Centre, the National Research Council laboratories, and industry-operated laboratories form an effective network both to facilitate the transfer of new technology to Canada and to develop solutions to unique Canadian problems.

An important influence on deliberations in Canada at this stage is the existence of a major highway research initiative in the United States. The American Association of State Highway and Transportation Officials is now in the process of developing a 5-year, $150 million R&D program entitled "Strategic Highway Research Program" (5). It is essential that any strategic R&D plans developed in Canada for highway transportation recognize the impact of this program. The program has identified the following six areas as having high payoffs:

- Asphaltic materials,
- Long-term pavement performance,
- Maintenance cost-effectiveness,
- Protection of concrete bridge components,
- Cement and concrete in highway pavements and structures, and
- Chemical control of snow and ice.

In each of these areas, a Canadian interest has been or can be defined. Although many of the issues faced by U.S. agencies are different, either in terms of the urgency for a solution or the nature of the problem, this U.S. effort, both in its definition of problem areas and in the proposed R&D solutions, provides guidance for targeting complementary Canadian efforts.

Roles and Responsibilities

It was realized early in the planning process that an appropriate national forum would be required for R&D program definition to proceed successfully. Recently such a forum came into existence with the merger of the Highway Advisory Board, mentioned earlier, and the Council on Cooperative Research of the Roads and Transportation Association of Canada. The outcome of this revised institutional framework is a Council on Highway Transportation Research and Development. This council combines the R&D policy advice function of the Highway Advisory Board and the R&D programming function of the Council on Cooperative Research. The organizations involved in the new council are shown in Figure 2.

Proposed Strategies

At present, a number of R&D program options are under active consideration. One proposal is to extend the vehicle weights and dimensions project. The Council on Highway Transportation R&D, which manages the current project, will develop a plan for further work in cooperation with Transport Canada.

Another proposal of the council is for the Roads and Transportation Association of Canada to develop a Canadian program complementary to the AASHTO Strategic Highway Research Program (6). This proposal, known as C-SHRP, would consist of three main thrusts:

- Integrated program elements in which Canadian agencies would be directly involved as integral elements of the U.S. program; for example, to contribute test sites to the long-range pavement performance evaluation program.
- Complementary Canadian research efforts in which Canadian R&D programs would be undertaken to cover problems complementary to but not being carried out under the U.S. program and unique Canadian problems.
- Monitoring SHRP to keep informed of what is happening in the program and to disseminate that information to appropriate agencies and individuals in Canada.

The effectiveness of a strategic planning process for R&D is measured by its success in achieving commitment to programs for action. By this measure, the

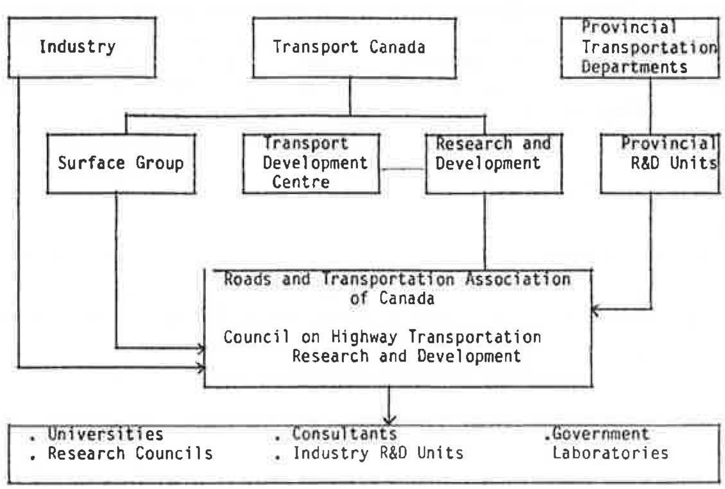

FIGURE 2 The national cooperative model.

strategic highway transportation R&D planning process pursued and supported by Transport Canada during the last 2 years is beginning to bear fruit. The department's role has been modest, but, through the catalytic action of its Highway Advisory Board, analysis of innovation needs, participation in institutional reform, and support for cooperative research with the United States, substantial and effective national highway transportation R&D plans are emerging to the collective credit of all concerned.

SUMMARY

Strategic planning for effective innovation in transportation is a lengthy and complicated task. When it has been completed the first time, subsequent rounds become easier, if only because the process builds a common understanding of problems and a common appreciation of how technology can be used to meet challenges. Its effectiveness, however, is only as good as the commitment those involved make to developing the plans, to committing resources to carry out R&D, and to following through to complete the innovation cycle. No one level of government, industry, or academia has the resources to carry out all of the required R&D or all of the steps of the innovation cycle. Success can be achieved provided that plans are flexible and modified to meet changing circumstances. If there is one lesson to be learned from the experience of the past 5 years in developing and implementing these plans, it is that no one has all the answers but that, by working together, the answers can be developed and R&D programs implemented to meet Canadian needs.

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Publication of this paper sponsored by Committee on Conduct of Research.

Application of Three Plan Evaluation Procedures to a Highway Alignment Problem

BRYAN H. MASSAM and IAN SKELTON

ABSTRACT

In this paper is offered a comparison of three formal methods of assessing alternate highway alignments. The methods are probabilistic linear vector analysis, a multiattribute trade-off system, and concordance analysis. Data for testing the methods are taken from a study of the evaluation of eight proposed alignments for I-75 north of Atlanta, Georgia. Scores for a set of six variables for each alignment are used. Sensitivity tests are incorporated in the analyses. The need for a policy-making environment in which formal methods are used to improve decision making is stressed.

Currently there is available a variety of formal procedures that can be used to evaluate alternate plans using multiple criteria. These procedures use as basic input data information on the relative merits of alternate plans for a set of criteria. The evaluations can be considered from the point of view of different interest groups. The information can be characterized by a three-dimensional matrix of the style shown in Figure 1. Recently Voogd (1) has suggested that it is appropriate for planners to compare the merits of different procedures, and to this end he has undertaken a comparative study of cardinal and qualitative techniques. A Monte Carlo analysis of more than 30 techniques was undertaken, and Voogd notes (1,p.209) that

> In general it can be concluded that there is a minimum of a 40 percent chance that a technique results in a different ranking [of the alternate plans] from any other technique.

Clearly, it is difficult to recommend a specific procedure to be used to tackle a precise plan evaluation problem; however, the present authors subscribe to the view offered by Midgley and Piachaud (2,p.6) that

> Although it is recognized that planning techniques have many limitations . . . we believe that they are helpful aids to policy-making which enhance objectivity and efficiency. To reject their use is to deny the need for greater rationality in decision-making.

In this paper three specific procedures will be applied to a plan evaluation problem. The data are drawn from a practical study that involved the comparison of alternate alignments for an Interstate highway in the United States.

The three procedures are

1. Probabilistic linear vector analysis (PLVA) (3),
2. Multiattribute trade-off system (MATS) (4), and
3. Concordance analysis (CAS) (5).

The technical details of these procedures will not be given here; they are available in the cited references. This project complements recent studies that offer a critical comparison of CAS with the following procedures:

- Structural mapping,
- Utility scores,
- Lexicographic ordering (6),
- Factor analysis,
- Electre III,
- Keeney-Raiffa approach (7), and
- Additive utility models (8).

It is suggested that CAS appears to provide planners and policy makers with a procedure that can assist in the systematic collection and analysis of

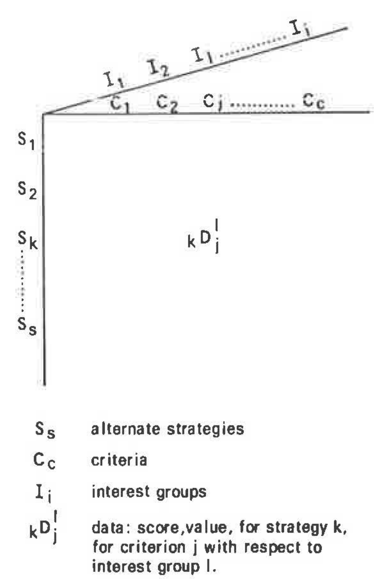

FIGURE 1 A three-dimensional plan evaluation matrix.

Department of Geography, York University, 4700 Keele Street, North York, Ontario M3J 1P3, Canada.

plan evaluation data. The technique is highly flexible and allows a number of different types of sensitivity analyses to be conducted. The authors suggest that CAS is a suitable multicriteria evaluation procedure for addressing a variety of practical planning problems.

DATA

The data have been abstracted from Zieman et al. (9). Their study examined eight alternate alignments for an extension to I-75 north of Atlanta, Georgia. A set of 56 variables was used to evaluate each proposed alignment. The variables addressed four areas of concern:

1. Economics and highway engineering,
2. Environment and land use,
3. Recreation, and
4. Social and human factors.

The study group selected weights that were assigned to each criterion. Using the full set of data and PLVA it was concluded that the alternatives could be classified in two distinct sets. The most attractive ones included routes G, G-1, T, and T-1. These codes are used following the designations in Zieman et al. (9) and Odum et al. (3). The four easterly alignments (F, F-1, O, and P) were clearly inferior. It should be noted that a preliminary study by the Georgia Department of Transportation had offered F as the preferred route. Protests by environmentalists and others caused a fuller set of data to be analyzed and this gave rise to the report by Zieman et al. (9). Using PLVA on the four better alignments allowed the authors to conclude that T-1 and G-1 were marginally better than G and T. However, the differences were not pronounced.

The study reported here uses the same set of eight routes, and a set of six variables has been selected. The weights from the original study have been preserved. The basic data are given in Table 1. Voogd (1) has offered arguments for restricting the number of criteria to about eight. For this reason and for ease of computation, the authors have opted to use a small set of data for comparing the three procedures.

RESULTS OF PROBABILITY LINEAR VECTOR ANALYSIS

In PLVA, scores are calculated for each alternative by adjusting raw scores and weights and then combining them. The selection of a standardization procedure depends on the nature and distribution of the raw scores. In the Zieman study, and in this one, raw values were standardized by dividing each by the largest value. The weights were standardized by dividing each one by the sum of all the weights to give the values given in Table 1.

The score for alignment j is calculated as follows:

$$I_j = \sum_{i=1}^{n} (w_i X_{ij} + e w_i X_{ij})$$

where

i_j = overall impact value or utility for alignment j,
w_i = scaled weight for criterion i,
X_{ij} = scaled weight for criterion i for alignment j,
e = random number between +0.5 and -0.5, and
n = number of criteria being considered.

For each alignment 20 simulations were run using a set of random numbers. The mean ($\bar{I}$) and the 95 percent confidence intervals were calculated. The results are shown in Figure 2 for both the full set of data and the small set. The overall results are quite similar for the $\bar{I}$-values, though the distinction between the two sets that is apparent when all of the variables are used tends to be lost when the group of six variables is used.

RESULTS OF MULTIATTRIBUTE TRADE-OFF SYSTEM

MATS allows the incorporation of different function forms into the calculation of the I-values. Whereas PLVA assumes a linear function between I_j and X_{ij}, MATS considers alternate shapes for the relationship. One of the critical and controversial aspects of MATS is surely the way in which the function forms are derived. Who is to be asked? How is the precise function to be determined? How reliable are the opinions and preferences of respondents? What is the level of comprehension of the respondents regarding technical terms such as "function form"? Instead of pursuing these issues, three alternate types of function that have general application are offered, and results of sensitivity tests are presented. The three general function forms used here are

1. $I_j = \Sigma w_i \pm 1\ (X_{ij})$,
2. $I_j = \Sigma w_i \pm 1\ (X_{ij})^{1/2}$, and
3. $I_j = \Sigma w_i \pm 1\{[1/(1 + e)\ (a - b)]\ (X_{ij})\}$

where a = 5 and b = 10.

The first equation represents a positive linear relationship between I-values and the attribute values. The second describes the situation of diminishing marginal utility for I as the value for an attribute increases. The third function form, the logistic

TABLE 1 Basic Data for Route Alignment Problem with Six Variables[a]

		Alignment							
	Weight[b]	G	G-1	T	T-1	F	F-1	P	O
Potential for economic development[b]	0.28	10	10	10	10	8	8	4	6
Total costs (x $10 million)	0.03	108	101	013	95	106	98	89	82
Area of water removed from right-of-way (acres)	0.05	17	27	23	33	22	32	52	19
Area affected by great noise (acres)	0.06	33	33	50	50	84	84	95	66
Visual disturbance[b]	0.02	-2	-3	-2	-3	-5	-6	-5	-2
No. of lives saved up to 1993	0.56	377	377	389	389	385	385	301	305

Note: The larger the number the more attractive the alignment.

[a]After Zieman et al. (9).
[b]Units not given in original report.

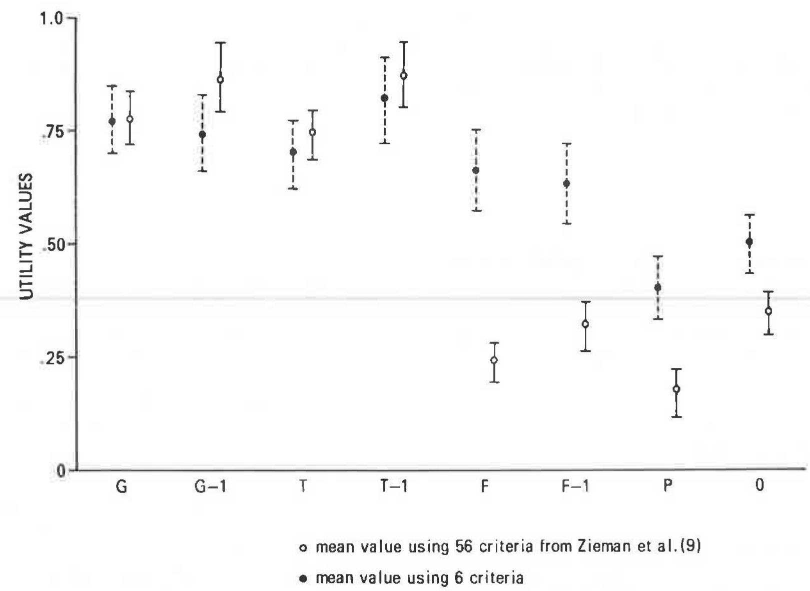

FIGURE 2 Probabilistic linear vector analysis: eight highway alignments, mean values, and 95 percent confidence limits.

curve, allows I to increase sharply for the lower range of values for an attribute, and later the marginal utility decreases. In this exercise the basic scores were scaled from zero (worst) to unity (best) before the application of the function forms.

A series of 21 experiments was undertaken using different weighting schemes for the criteria. In Weighting Scheme A, two criteria, the economic and environmental or the human pair, were assigned a weight of ±0.20, and the others ±0.15. Weighting Scheme B used ±0.30 and ±0.10, respectively. The results are given in Table 2. The first three experiments assume equal weight for all criteria. The values for I are highly stable for the different function forms.

The results suggest that Weighting Scheme A introduced some variation into the I-values, though the basic classification of the set of routes into two groups of better and worse remains stable. Weighting Scheme B produces less agreement with respect to the ordering of routes within the two categories. An overall classification of the routes can be derived by considering the I-values for the set of 21 experiments. These results are shown in Figure 3. The mean value for each alignment is given, and the 95 percent confidence intervals are indicated.

Overall, this analysis confirms that the westerly located alignments (G, G-1, T, and T-1) appear to be consistently superior to those in the east (F, F-1, P, and O).

TABLE 2 Results of Experiments Using Multiattribute Trade-Off System

Experiment No.	Weight	Scheme	Function Form[a]	Alignment G	G-1	T	T-1	F	F-1	P	O
1	Equal		L	0.81	0.76	0.79	0.75	0.49	0.45	0.16	0.63
2			S	0.82	0.67	0.69	0.60	0.44	0.40	0.10	0.63
3			E	0.82	0.81	0.81	0.82	0.49	0.46	0.16	0.59
4	Economic	A	L	0.77	0.75	0.77	0.75	0.48	0.46	0.18	0.63
5		A	S	0.78	0.66	0.68	0.60	0.44	0.41	0.11	0.65
6		A	E	0.79	0.78	0.78	0.81	0.48	0.47	0.19	0.59
7	Environmental	A	L	0.82	0.77	0.79	0.74	0.50	0.45	0.14	0.63
8		A	S	0.83	0.67	0.67	0.57	0.43	0.38	0.09	0.62
9		A	E	0.84	0.82	0.82	0.81	0.49	0.45	0.15	0.60
10	Human	A	L	0.82	0.76	0.81	0.76	0.50	0.46	0.16	0.62
11		A	S	0.83	0.67	0.72	0.61	0.45	0.41	0.09	0.63
12		A	E	0.84	0.82	0.83	0.83	0.49	0.46	0.15	0.58
13	Economic	B	L	0.68	0.71	0.71	0.75	0.44	0.48	0.24	0.64
14		B	S	0.69	0.63	0.63	0.61	0.44	0.45	0.15	0.69
15		B	E	0.69	0.70	0.69	0.79	0.46	0.49	0.28	0.58
16	Environmental	B	L	0.88	0.80	0.78	0.70	0.50	0.42	0.09	0.66
17		B	S	0.89	0.69	0.63	0.52	0.41	0.33	0.06	0.58
18		B	E	0.89	0.86	0.86	0.79	0.49	0.41	0.10	0.63
19	Human	B	L	0.85	0.78	0.87	0.80	0.53	0.46	0.14	0.58
20		B	S	0.87	0.68	0.81	0.66	0.49	0.43	0.08	0.62
21		B	E	0.89	0.86	0.88	0.87	0.50	0.47	0.11	0.55
	Mean			0.81	0.74	0.76	0.72	0.47	0.43	0.14	0.61
	Standard deviation			0.06	0.06	0.07	0.09	0.03	0.03	0.05	0.03
	Minimum 95 percent level			0.80	0.73	0.75	0.71	0.47	0.43	0.13	0.61
	Maximum 95 percent level			0.82	0.75	0.77	0.73	0.48	0.44	0.14	0.62

[a] L = linear, S = square root, and E = exponential.

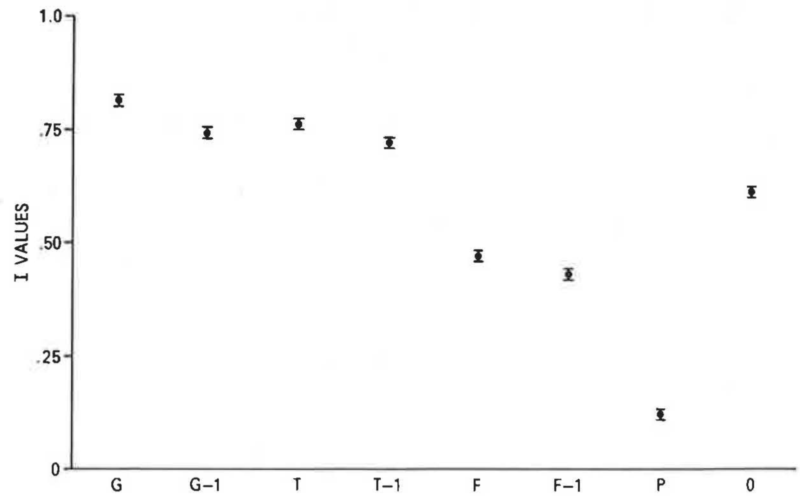

FIGURE 3 Multiattribute trade-off system: results of 21 experiments, mean values, and 95 percent confidence limits.

RESULTS OF CONCORDANCE ANALYSIS

The data given in Table 1 were examined using concordance analysis. A series of 28 experiments was defined using a variety of weighting schemes and four alternate just-noticeable-difference (JND) values. Concordance analysis is based on consideration of the scores for pairs of alternatives for each criterion. If JND = 100, any difference between scores for two alternatives for a criterion is sufficient to identify a preferred alternative. If JND = 95, a difference of less than 5 percent is judged to indicate that the alternatives are similar. The use of JND values allows the introduction of a systematic confidence level into the analysis. If there is absolute certainty that no errors exist in the basic data, JND = 100 can be used for each criterion. If there is less certainty about the accuracy of the impact scores, the JND values can be adjusted accordingly. For this analysis four different JND values were used: 100, 95, 90, and 85. These values were applied to all of the six criteria for each set of experiments.

Given eight alternate alignments, there are 56 pairwise comparisons. For each pair i and i′, for each criterion, three possible outcomes can be identified: i > i′, i = i′, or i < i′. Concordance analysis provides a way of combining this information as a concordance index (cii′) for alignments i and i′.

The index is defined as

$$cii' = [\Sigma w\ (i > i') + 1/2\ \Sigma w\ (i = i')]/\Sigma w$$

where

$\Sigma w\ (i > i')$ = the sum of the weights of the criteria for the cases in which i is preferred to i′,

$\Sigma w\ (i = i')$ = the sum of the weights for the criteria for the cases in which i is judged to be the same as i′,

Σw = the sum of the weights for all the criteria.

The value of cii′ ranges from zero to unity. It takes on the former value when i′ is preferred to i for all criteria. If i is preferred to i′ for all criteria, cii′ is unity.

Values for all cii′s for this problem can be summarized in an eight-by-eight square concordance matrix. By summing the values across each row, the alternatives can be ordered from highest to lowest values. An index of agreement (A) can be defined to measure the correspondence between this ordering and the information in the concordance matrix. If A = 1.0, the level of agreement is perfect. Full details of this index are given in Massam (5). The results for this set of experiments are given in Table 3. The A-values are consistently high.

The two sets of experiments that involve weighting the economic factors give rise to relatively high positions for alignment O. For all other experiments this alignment and F, F-1, and P are clearly inferior. There is a distinct classification of the eight alternatives into two sets. These results agree with those provided by PLVA and MATS.

OVERVIEW

In Table 4 a summary of the results for the three procedures is given. Although there is a certain level of consistency and identification of the best four is easy, beyond that the selection of the single best alignment depends on the specific procedure used.

There are two results that stem from this observation. First, the choice of an appropriate procedure can depend on the nature of the basic impact data. CAS can accommodate ordinal or interval scores, whereas MATS and PLVA require interval values. Second, formal techniques such as PLVA, MATS, or CAS can help in data collection and some basic analysis. For example, they can be used to undertake a series of experimental runs; however, the final choice for implementation must surely involve a choice procedure that is ot mechanistic. To this end the authors argue for the incorporation of the procedures into the general planning process. This begins with the identification of a need for an alignment study, through data collection and involvement of interest groups, before the final selection and implementation of a particular alternative. Formal methods surely have a useful role to play, but policy makers cannot rely solely on such methods for making decisions. The methods do not deserve to be rejected; instead policy-making environments within which formal procedures can play a role need to be designed.

TABLE 3 Results of Experiments Using Concordance Analysis

Experiment No.	Weight	Scheme	JND	A	Alignment G	G-1	T	T-1	F	F-1	P	O
1	Equal		100	0.96	2	4	1	3	6	7	8	5
2			95	1.0	1	3	2	4	6	7	8	5
3			90	1.0	1	3	2	4	6	7	8	5
4			85	1.0	1	3	2	4	6	7	8	5
5	Economic	A	100	0.91	2	3	4	5	7	8	6	1
6		A	95	0.91	2	4	3	5	7	8	6	1
7		A	90	0.96	1	4	3	5	6	8	7	2
8		A	85	0.91	1	4	3	5	6	8	7	2
9	Environmental	A	100	0.93	1	4	2	3	6	7	8	5
10		A	95	0.96	1	3	2	5	6	7	8	4
11		A	90	0.96	1	3	2	5	6	7	8	4
12		A	85	0.91	1	3	2	5	6	7	8	4
13	Human	A	100	0.96	2	5	1	3	6	7	8	4
14		A	95	0.96	1	3	2	4	6	7	8	5
15		A	90	0.96	1	3	2	4	6	7	8	5
16		A	85	0.98	1	3	2	4	6	7	8	5
17	Economic	B	100	0.84	4	2	5	3	6	7	8	1
18		B	95	0.86	3	5	4	2	8	7	6	1
19		B	90	0.88	1	5	3	4	7	8	6	2
20		B	85	0.84	1	4	2	5	6	7	8	3
21	Environmental	B	100	0.96	1	3	2	5	6	7	8	4
22		B	95	0.96	1	3	2	5	6	7	8	4
23		B	90	0.96	1	3	2	5	6	7	8	4
24		B	85	0.95	1	2	3	5	6	7	8	4
25	Human	B	100	0.93	3	5	1	2	6	7	8	4
26		B	95	0.96	1	3	2	4	6	7	8	5
27		B	90	0.96	1	3	2	4	6	7	8	5
28		B	85	0.98	1	3	2	4	6	7	8	5

Note: JND = just-noticable-difference value and A = index of agreement.

TABLE 4 Comparison of Results Using Probabilistic Linear Vector Analysis, Multiattribute Trade-off System, and Concordance Analysis

	Alignment G	G-1	T	T-1	F	F-1	P	O
PLVA	2	3	4	1	5	6	8	7[a]
MATS[b]	1	3	2	4	6	7	8	5
CAS	2	4	1	3	6	7	8	5[c]

[a]See Figure 2.
[b]These ranks were derived from the sum of the values calculated under the linear, square root, and exponential function forms given in Table 2.
[c]See Table 3.

ACKNOWLEDGMENT

This research was supported by awards to Bryan H. Massam from the Faculty of Arts, York University, Canada, and the Social Sciences and Humanities Research Council, Ottawa, Canada.

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Publication of this paper sponsored by Committee on Statewide Multimodal Transportation Planning.

Potential Applications of Knowledge-Based Expert Systems in Transportation Planning and Engineering

CHE-I YEH, STEPHEN G. RITCHIE, and JERRY B. SCHNEIDER

ABSTRACT

The objectives of this paper are to describe the characteristics of knowledge-based expert systems (KBES) and to suggest some applications that appear to have a high potential for development in the field of transportation planning and engineering. Such systems represent a rapidly developing branch of artificial intelligence (AI) and computer science that is already having significant impacts in many disciplines. KBES use interactive computer programs that seek to provide a level of performance and expertise that is matched by only a few human experts in a particular problem domain. An overview is provided of AI and KBES concepts and of existing KBES and their architecture. The current scope of expert systems is described in an attempt to identify high-potential applications in the fields of transportation planning and engineering. A number of these applications are identified and discussed. It is concluded that the potential appears high for KBES to become useful tools for practicing transportation planners and engineers.

Since the mid-1970s one of the most significant accomplishments in the field of artificial intelligence (AI) has been the development of knowledge-based expert systems (KBES). These systems are interactive computer programs that employ a collection of judgment, experience, rules-of-thumb, intuition, and other expertise in a particular field, coupled with inferential methods of applying this knowledge, to provide expert advice on the performance of a variety of tasks (1,2). Domain-independent reasoning techniques were given concentrated attention in the early history of AI. The General Problem Solver (GPS) (3), a classic example, could solve many puzzles and prove theorems. However, it was soon recognized that such universal AI programs could not handle very many real-world problems, so AI researchers have shifted their attention to the construction of expert systems with domain-dependent knowledge (4).

Many KBES are problem-solving programs designed to reach the level of performance of a human expert in a specific professional domain. Operational expert systems have already been developed in a number of disciplines. These include MYCIN for medical consultation (5), DIPMETER for oil well logging (6), PROSPECTOR for mineral exploration (7), and R1 for computer system configuration (8). The utility of these new computer programs has been proven in their short histories. For example, PROSPECTOR discovered a rich lode of molybdenum ore in eastern Washington State. Although this area had been explored by many experts since World War I, none had ever found the exact site of the ore. In the early 1980s PROSPECTOR was used to make inferences from data in a partly explored area and predicted ore in a particular location. Subsequent drilling confirmed predictions of where ore would and would not be found. The reason that PROSPECTOR could solve this difficult problem was that it not only incorporated the knowledge acquired from nine expert geologists but also had the advantages of the computer--high-speed operation and huge memory capabilities--that it employs during its inferencing activities. Human experts find it difficult to deal with more than four or five data elements at the same time although their knowledge in this field may be as good as that of PROSPECTOR (9).

KBES have high potential for solving problems that lack explicit algorithms (e.g., problems for which a numerical model does not exist). Currently, ill-defined problems can only be solved in a limited fashion by employing an algorithmic approach after extensive knowledge is summarized and a simple model created. However, there are generally some experts in every field who can solve such ill-structured problems using their past experience and knowledge. Many important real-world problems are ill-structured (e.g., designing an optimal transit route structure or making decisions about how to rehabilitate a major highway). Explicit and well-formulated algorithms do not exist in these domains. The transportation field, in particular, is full of such ill-structured problems in which human behavior, social and political considerations, and multiobjective decision making are involved.

In this paper an overview of expert systems is presented and some potential applications in the field of transportation are suggested. First, the basic concepts and structure of expert systems are introduced. The types and scope of expert systems are described. Criteria that can be used to ascertain when to apply expert systems are given, and the tasks and tools involved in building an expert system are discussed. After this overview of expert systems, some high-potential applications in transportation planning and engineering are identified and discussed.

C.-I Yeh, Institute of Transportation Studies, University of California, Irvine, Calif. 92717. S.G. Ritchie, Department of Civil Engineering and Institute of Transportation Studies, University of California, Irvine, Calif. 92717. J.B. Schneider, Department of Civil Engineering, University of Washington, Seattle, Wash. 98195.

TYPES AND SCOPE OF EXPERT SYSTEMS

Types

On the basis of the different functions they perform, expert systems can be divided into several types (10):

1. Diagnosis and debugging: inferring malfunctions from observed information;
2. Design: developing and configuring a process for a set of specific objectives that satisfy given constraints;
3. Planning: identifying a set of actions that will lead to the achievement of given objectives in the future;
4. Interpretation: explaining the characteristics of input and output data;
5. Forecasting: inferring likely future outcomes given a set of past trends;
6. Monitoring: observing and comparing observations with planned and desired system characteristics;
7. Repair: developing a plan to recover from a failure or malfunction; and
8. Control: a most complicated system that interprets the data, diagnoses the problem, predicts the future, formulates a plan, executes the plan, and monitors its implementation.

Many actual transportation problems are quite broad and involve aspects of several of these problem types. For example, typical transportation problems often involve the need to interpret incomplete and faulty data, predict ridership or population, diagnose traffic congestion, design new routes or reconstruct an existing network, monitor roadway traffic, and control network operations.

Scope

Not all problems are suitable candidates for the expert systems approach. A list of criteria that can be used to evaluate potential expert systems applications follows.

1. Algorithmic solutions are impractical because of complex physical, social, political, or judgmental components, which generally resist precise description and deterministic analysis.
2. Faulty or incomplete data will be encountered during the problem-solving activity.
3. Experts need technical tools (such as handbooks and computers) and reference resources to identify, make inferences, and analyze the problem because of the extensive basic and background knowledge requirements.
4. The problem-solving model must be changed to handle different types of problems or to adapt to dynamic conditions.
5. High-performance results are required in a short time, whereas a complete numerical solution could be obtained only after spending unreasonable or unacceptable amounts of time and money using traditional methods, and a reliable "short-cut" traditional method does not exist.
6. A failure by a faulty human expert cannot be tolerated.
7. Knowledge transfer from scarce human experts is too difficult or costly or may take too long.
8. A human expert is not available.
9. Public knowledge (books, papers) is not sufficient to allow most persons to reach an expert's level. Substantial private knowledge (expertise, heuristics) exists only in the minds of the experts.
10. The potential payoffs are high.

BASIC CONCEPTS

Expert Systems Versus Traditional Computer Programs

Most traditional computer programs involve the use of algorithmic procedures. These algorithmic programs can only follow step-by-step commands or procedures in searching for a solution to a problem. An existing model, usually a numerical model, is needed to support the operation of the search algorithm. The developer of the program must predetermine the sequence of problem-solving procedures and ensure that the set of commands can handle all possible combinations of problems or subproblems to obtain a unique and correct result. However, the knowledge pertinent to the problem and the process used to employ this knowledge are often interrelated (2). This produces some of the difficulties encountered with traditional programs:

1. An algorithm for solving the problem must exist. Many problems are impossible or impractical to deal with because the knowledge is difficult to represent in a numerical form and a sequence of steps that will produce a solution is unknown.
2. Only problems for which correct and complete data are available can be handled, otherwise an incorrect result will be obtained.
3. The maintenance and updating of a traditional program are difficult because the knowledge is dispersed throughout the entire program and intertwined with the algorithmic computation process.

Expert systems are designed to overcome these difficulties of traditional programs. A separate knowledge processor determines when, how, and where to apply every individual element of knowledge. An explicit problem-solving algorithm is not needed. Most expert systems can handle incomplete or faulty data by making inferences from their own knowledge base. Maintenance of knowledge is also more easily accomplished for expert systems because the knowledge base is separated from the control process, as discussed next.

Architecture of Expert Systems

In an expert system the program is divided into a knowledge base and a control process for applying and selecting knowledge (also known as an inference engine or inference machine). The general architecture of KBES is shown in Figure 1. Each component of the system (10-13) is described.

Knowledge Base

The knowledge base represents the power of the expert system. The knowledge base contains all relevant information, facts, or causal knowledge of the domain, and rules used for problem-solving activities to determine what actions will be executed if certain situations are met. There are various techniques for representing knowledge. The most widely used in current expert systems are rules, frames, and semantic nets (13). The most common method, particularly in transportation expert systems developed to date, involves production rules. These have an IF condition THEN action format. When the IF portion or premise of a rule is satisfied by the facts, the action specified by the THEN portion is performed. The rule is then said to "fire." For example, one rule in SCEPTRE (14), an expert system for pavement rehabilitation decision making, states:

IF Depth of rutting is greater than 3/4 in. and
Transverse cracking is the predominant type
of cracking

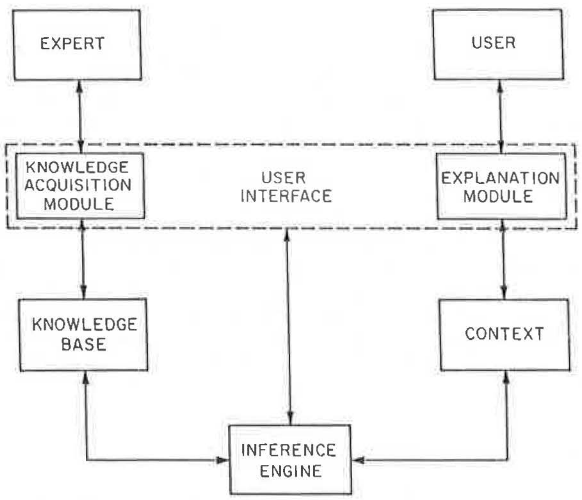

FIGURE 1 Architecture of a knowledge-based expert system.

THEN Mill and replace
or Prelevel and thin overlay
or Prelevel and medium overlay

Context

The context is the data level of an expert system. It contains all data, symbols, or facts that reflect the current status of the solution. This information may describe the problem being solved, the rules that are employed, and the facts that are true. The context is also called short-term memory.

Inference Machine

The inference machine (also called inference engine) is the control level of an expert system. The objective of the inference machine is to find a conclusion for a subgoal or the answer to an entire problem. It searches for facts through the knowledge base and identifies new facts for subsequent inferencing.

Explanation Module

Unlike a traditional program, which is often a "black box" to the user, an expert system has an explanation module that explains its problem-solving strategy to the user.

Knowledge Acquisition Module

Knowledge acquisition is often the bottleneck of the entire expert system development process. An automatic knowledge acquisition module can speed up the development of KBES. However, a system-independent knowledge acquisition module does not currently exist because each problem domain has its own knowledge structure.

User Interface

The user accesses the system through a user interface, which should be friendly so that man and machine can communicate directly and efficiently. Currently, actual language processors do not exist, so most user interfaces are implemented as a problem-oriented subset of English.

Building an Expert System and Associated Tools

The major task of building an expert system is to transfer the expertise and knowledge acquired from one or more experts to a computer program. The mission of expert systems developers (knowledge engineers) is to carry out such a transformation and to ensure that the performance of the resulting expert system can reach the desired level. The steps involved in constructing an expert system will vary depending on the characteristics of the problem, the objectives selected, and the development tools available. However, the following stages are normally encountered in the development of an expert system (10):

1. Identification: The first step in building an expert system is to identify the area, concepts, and characteristics of the problem and solution. In addition, the participants and resources (time, labor, and computing facilities) needed during development should be identified.
2. Conceptualization: The concepts needed to represent knowledge and the overall structure of knowledge-control strategies must be determined before a preliminary system design can be completed.
3. Formalization: This stage involves design of the formal organization of the knowledge consistent with the development tools or languages used. The detailed design of the system is formulated by the expert or experts and the knowledge engineer or engineers.
4. Implementation: In this stage the knowledge engineer turns the formalized knowledge into a working computer program.
5. Testing: The performance and behavior of the prototype expert system are iteratively evaluated through comparison with the human expert's abilities. Revisions of the system are then made by a knowledge engineer using additional advice from the human expert or experts.

In building expert systems, symbol-manipulation programming languages such as LISP and PROLOG have been widely used. These languages have been specially designed for artificial intelligence applications. However, a much faster route to system development can be to use a knowledge engineering toolkit or "shell," which comprises an inference engine, empty knowledge base and context structure, and support facilities such as a knowledge-base editor and user explanation facility. The system developer must then enter the rules (in a rule-based system) in the knowledge base. In recent years, a large number of commercial shells have become available for microcomputers. Many of these shells are also being coded in conventional programming languages such as C or PASCAL (for improved expert system execution speed), although knowledge-base creation and editing may still involve an English-language programming style.

POTENTIAL APPLICATIONS OF EXPERT SYSTEMS IN TRANSPORTATION

As discussed previously, KBES seek to provide a level of performance that is similar to that of an expert, or group of experts, in a particular problem domain. Such systems are primarily applicable to situations that require specialized knowledge, skill, experience, or judgment for determination of a solution or development of a solution strategy. In such cases, the problem is usually said to be ill-structured, in the sense that a numerical algorithmic solution is not available or is impractical. Because so many of the problems that transportation professionals face are of this kind, it can be said that, in general, the potential appears high for KBES to become useful tools for the practicing transportation planner and engineer. KBES can be envisaged as functioning as expert consultants, capable of explaining their reasoning and why they arrived at certain conclusions. Eventually, users may be able to learn from an expert system in the same way people can now learn from a dialogue with an expert consultant.

Recent applications of expert systems in civil engineering are described elsewhere (15), although none of the applications presented involve primarily transportation examples. Considerable research is now under way on developing expert systems in the transportation field, but comparatively little work has been reported to date. Some initial efforts include DELTA, a fault diagnosis expert system for troubleshooting diesel-electric locomotive maintenance problems (16); an automatic crew-scheduling expert system used by the National Aeronautic and Space Administration (NASA) for the space shuttle (2); DIRECTOR, an intelligent front-end expert system for an educational urban transportation decision-making simulation model; and identification of potential applications of expert systems in air traffic control (17). Recent operational prototype expert systems in transportation include SCEPTRE, for pavement rehabilitation decision making (18); CHINA, for acoustic design of highway noise barriers (19); TRALI, for traffic signal setting assistance (20); HERCULES, for postdisaster traffic recovery strategies (21); and EXPERT-UFOS, for multicriteria traffic network design (22).

Although a number of criteria for evaluating potential expert system applications have been outlined, it is still a difficult task to forecast developments and applications (without the aid of an expert system). Nevertheless, in this section of the paper, an attempt is made to identify a number of high-potential applications of KBES in the field of transportation planning and engineering.

Design

Facility Design

As in many other design problems, design of transportation facilities involves application of considerable expertise, experience, and heuristic expert knowledge. It is clearly a high-potential application area for an expert system. For example, a roadway design system could not only reduce design costs but could also provide a high-quality professional design service. Such a complete expert system would need to employ more complex AI techniques than are currently available. However, some subproblems could be examined using expert systems techniques to gradually develop the necessary overall capabilities.

In addition, well-designed intersections can enhance safety and reduce traffic delay and congestion. An expert system that could infer traffic demands and relate physical, environmental, and other design constraints to aid in the design of a high-quality intersection would be of substantial use to many smaller cities that cannot afford to hire expensive expert consultants.

An existing expert system in this general category is CHINA (19). CHINA addresses the problem of acoustically designing a highway noise barrier. It contains the expert knowledge of several specialists in the control of highway noise and can act as an expert advisor to the novice engineer or as a colleague to more experienced engineers on complex abatement problems. TRALI is another example system, which provides assistance to traffic engineers designing traffic signal settings for isolated signalized intersections (20). This is a classic and common problem in transportation engineering. TRALI addresses a particular shortcoming of existing design aids that cannot deal with uncommon geometries. EXPERT-UFOS is an expert system that aids in designing optimal capacity additions and deletions from a transportation network (22). The system addresses network design problems that must be evaluated using multiple conflicting criteria. EXPERT-UFOS achieves this by incorporating a multicriteria evaluation method in the expert system.

Study Design

Data collection and sampling are needed to solve many transportation problems. A well-designed study and data collection program can provide a controlled environment and inference source for transportation planners and engineers. However, only a limited number of experienced engineers and planners can perform such activities well. An expert system that could make inferences about data sources and data types to suggest proper data collection methodologies and sampling techniques could substantially improve the quality and efficiency of local study designs.

Planning

Methodology

The choice of a methodological approach for urban transportation planning substantially affects the scope, duration, data intensiveness, policy sensitivity, and cost of the planning effort. The judgment and experience required to select appropriate analysis tools, such as system, sketch, or quick-response planning approaches, suggests a useful role for a planning methodology advisor. Also, the initial generation of transportation alternatives for subsequent analysis and evaluation is a critical but not well-defined step. An expert system could assist planners by relating appropriate transportation technologies and system management and control options to the intensity and distribution of trips, land uses, and socioeconomic characteristics in the study area.

Disaster Response Planning

Disaster response planning is a concern of all levels of government. To reduce the effects of disaster, it is often necessary to evacuate people from the disaster area and to send assistance teams and supplies into the area as soon as possible. Such a response depends on finding ways to use the transportation system effectively when it is damaged, badly congested, and not likely to be repaired quickly. An expert system that incorporates the knowledge of disaster response experts and local conditions and resources could be of substantial assistance in dealing with the dynamics of such situations.

Bus Transit Network Planning

Current urban transit bus networks are full of inefficiencies that are difficult to identify and even more difficult to remove without creating worse problems in other parts of the network. Yet some transit specialists can examine current route and schedule layouts and come up with diagnoses that lead to useful definitions of problems and corrective measures. If the capabilities of these persons could be incorporated in an expert system to aid local planners, productivity improvements in transit system performance could be expected.

Operations and Control

Traffic Congestion Diagnosis

The causes of traffic congestion are highly dependent on a variety of physical, environmental, operational, geometric, land use, human, and many other factors. Some experts can determine the major reasons for traffic congestion from their observations and knowledge. However, these experts are scarce and expensive. A traffic congestion diagnosis expert system that incorporates the knowledge and judgmental abilities of several experts could diagnose traffic congestion just like a human expert. The performance of the expert system would depend heavily on the expertise acquired from the specific experts and the manner in which it was integrated and organized.

The expert system HERCULES (21) addresses postdisaster traffic recovery and generates traffic control plans that would make good use of the links remaining in a damaged urban road network. HERCULES attempts to keep postdisaster congestion at tolerable levels by recommending control plans that limit allowable volumes on specific links.

Roadway Safety Diagnosis

The safety of a roadway is an important issue for transportation engineers. Many accidents are caused by poor design. There is a possibility that such engineering mistakes underlie many accidents. It is not possible, in practice, for every accident to be reviewed by a safety expert. An expert system that can detect any engineering design factors that may have contributed to an accident could provide a useful and inexpensive roadway safety diagnosis capability.

Hazardous Material Transportation

The problem of hazardous material transportation involves complex and multiple-objective decision making in a sociopolitical context that is difficult to represent in a simple numerical model. An expert system could provide assistance to such decision making and would be based on an extensive knowledge base of hazardous materials properties, population density and distribution, and roadway characteristics.

Air Traffic Control

The human air traffic controller currently plays a major role in the air traffic system. Handling increasing traffic volume safety places controllers under great pressures and much stress. Any mistake that the air controller makes could obviously cause many deaths. An air traffic expert system that incorporated appropriate heuristics, perhaps combined with algorithmic procedures, could provide much assistance to the human controllers. However, such an expert system must be tested completely before being placed in service. As long as the knowledge built into the expert system is comprehensive and organized correctly, the probability of a system failure or mistake can be reduced to a minimum. An air traffic control expert system can monitor human controller behavior and function as a warning or backup system to reduce the pressure on the human controller. Work on this topic is currently under way (17).

Ground Traffic Signal Timing Control

As expert system that could provide expertise on the timing and coordinating of traffic signals would be helpful for many smaller cities. Such a system could provide a professional opinion to help local traffic engineers do their jobs more effectively. The characteristics of ground traffic control are in some ways more complex than those of air traffic control. Unlike air traffic control, which employs radar to monitor all elements of the system, the ground traffic control problem is poorly defined. Parts of the problem can be defined by the use of cameras, sensors, traffic controllers, and observers, but the data are often incomplete and may be faulty or conflicting. Such characteristics relate well to the capabilities of expert systems. An expert system that performs like a human expert at an isolated signal set can reduce manpower needs and provide continuous day and night service. Most of all, such an expert system would provide the best quality of service if the knowledge base were acquired from the best experts and modified to fit local conditions. Such an expert system has a different approach than do current algorithmic control systems, which usually cannot handle special events, emergency vehicle needs, unusual geometries, and risky situations. Another major difference is that algorithmic systems cannot handle incomplete and faulty data. It appears likely that a ground traffic control expert system that can control all of the traffic signals in a designated area would be most helpful in obtaining higher performance in the future.

Dispatching and Scheduling

It is clear that some dispatchers and schedulers can perform these tasks much better than most others. These people are experts at their jobs. It is normally difficult to transfer such expertise to other people or other locations. Usually, the knowledge that makes these experts better than their peers is difficult to represent in an explicit algorithm. An expert system that contains their knowledge could assist in solving the problem of knowledge transfer and improve local capabilities.

Maintenance and Rehabilitation

Transit Vehicle Maintenance

Many transportation systems use complex mechanical equipment. The sudden failure of such machines may cause critical problems. For example, the mechanical failure of an automated guideway transit system (people mover) may cause delays or system shutdown and, possibly, accidents. In most situations, faults must be repaired or a backup system invoked in the shortest possible time. Human experts may not be able to respond fast enough. An expert system that contains knowledge of all repair tasks and backup capabilities could be a valuable tool for transportation providers that cannot afford to have frequent failures on and off the system.

Pavement Rehabilitation

In recent years, continued deterioration of the highway infrastructure has led to increased emphasis on pavement rehabilitation, with national annual expenditures in the United States of billions of dollars. Given the pressure of limited budgets and the need to address extensive decay problems, decisions on pavement rehabilitation have become critical. There are only a few experts who, using field observations and their own knowledge and experience, can determine the causes of pavement decay and appropriate solution strategies with high confidence. Because the analysis and design of project-specific rehabilitation strategies rely so heavily on expert pavement engineers, and the tasks involved are both complex and ill-defined, conventional computer tools are of limited use.

SCEPTRE (18) is an expert system for flexible pavement rehabilitation decision making. Working from user inputs and a knowledge base constructed from several human experts, the system can deduce a set of feasible project-level rehabilitation strategies for subsequent detailed analysis and design. The system can also readily explain its reasoning and conclusions and is easily modified. It can therefore make its body of specialized knowledge accessible to a broad range of potential engineering users.

CONCLUDING COMMENTS

The objectives of this paper were to describe the characteristics of knowledge-based expert systems and to identify several high-potential applications in the field of transportation planning and engineering. As discussed earlier in the paper, not all problems are suitable candidates for the expert systems approach. A number of criteria were proposed for evaluating potential expert systems applications, and the steps involved in constructing an expert system were discussed. The most difficult phase of this process remains the acquisition and transformation of knowledge and expertise from one or more experts to the knowledge base. Although relatively little work on KBES in the transportation area has been reported to date, research is under way and can be expected to grow. In several other disciplines, operational expert systems have already been developed and their utility proven.

Because so many of the problems transportation professionals face require specialized knowledge, skill, experience, and judgment for determination of solution strategies, the authors believe that, in general, the potential appears high for KBES to become useful tools for practicing transportation planners and engineers. A number of potential applications were identified in the areas of design, planning, operations and control, and maintenance and rehabilitation. However, given the breadth of the transportation field, there may be many domains not included in this paper that also represent high-potential applications. To identify new applications and research needs, consultations with appropriate experts and a more careful and complete review of domain-dependent problems are required. Such work should be followed by development and evaluation of new prototype expert systems. This would improve the ability to assess the feasibility and true potential of such systems in transportation planning and engineering.

ACKNOWLEDGMENT

This research was partly supported by the National Science Foundation.

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Publication of this paper sponsored by Committee on Computer Graphics and Interactive Computing.