TRANSPORTATION RESEARCH

RECORD

No. 1498

Planning and Administration

Transportation Finance, Training, Strategic Management, and Economic Analysis

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1995

Transportation Research Record 1498
ISSN 0361-1981
ISBN 0-309-06162-8
Price: $27.00

Subscriber Category
IA planning and administration

Printed in the United States of America

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Contents

Foreword

The papers in this volume deal with issues related to transportation finance, management, training, and economic development and analysis.

Three papers review international transportation finance. One paper focuses on toll revenues and a traffic study in Toronto, Canada; another examines cost allocation and equity of road user taxes in France; and the other presents an overview of the Russian road financing system. On the domestic front, one paper focuses on highway use tax alternatives applied to heavy trucks in Oregon, and two papers consider innovative financing techniques of congestion pricing, using a single toll plaza, and the socioeconomic consequences of applying highway impact fees.

The organizational structure of transportation agencies and managers' roles are undergoing substantial change. Four papers look at different aspects of this change and how to respond to it. Each paper discusses one of the following topics: (*a*) management performance indicators; (*b*) management succession planning; (*c*) the application of strategic planning, total quality management, and performance management to transportation organizations; and (*d*) transportation planning education.

Several papers in this volume address a diversity of economic issues. Presented are an appraisal of the economic implications on the transportation sector of a comprehensive peace in the Middle East, a model for evaluating pricing strategies, the economic consequences of stream degradation on highways and bridges, and the economic feasibility of rumble strips constructed along highway shoulders.

Highway Use Tax Alternatives for Heavy Trucks in Oregon

ROBERT E. RUSSELL

This paper presents a policy analysis of highway use tax alternatives for heavy trucks. It compares registration fees, fuel taxes and weight-distance taxes in terms of equity, compliance costs, administrative costs, and evasion potential. Three different tax scenarios are evaluated for the state of Oregon. The conclusion is that continued reliance on the weight-distance tax is the best option for Oregon.

Highway use tax systems are made up of three basic elements: vehicle registration fees, fuel use taxes, and "third structure" taxes. Vehicle registration fees are flat fees that must be paid on an annual or biennial basis and are generally associated with the vehicle license plate. Fuel use taxes are collected in cents per gallon of fuel purchased or used in a state. Third structure is the catchall classification that includes other taxes associated with the use of highways or operation of a vehicle.

Third structure taxes take a variety of forms, including ad valorem (property) taxes, fees, tolls, weight-distance taxes, and other miscellaneous charges extracted from the motoring public. However, the trucking industry normally associates the term with ton-mile or weight-distance taxes. This type of tax is collected in the form of a rate per mile of travel based on the weight of the truck.

Oregon's highway use tax system is relatively simple. All vehicle owners pay a registration fee. In addition, automobile owners pay highway use tax in the form of fuel taxes. Heavy-truck operators pay no fuel taxes in Oregon but they do pay the weight-distance tax. This is a unique arrangement. Currently, five other states use the weight-distance form of taxation, but they also collect fuel use taxes from the trucking industry. Oregon is the only state that does not collect a fuel use tax on heavy-truck fuels.

Oregon has a unique history in terms of highway use taxation. In 1919 Oregon became the first state in the nation to use fuel taxes to finance highway and road construction. In 1933 Oregon implemented the nation's first weight-distance tax, of the ton-mile type. Under a ton-mile system, a different tax rate is charged for each load transported by truck. In 1937 Oregon completed the first cost responsibility or cost allocation study. Such studies allocate the cost of highways proportionally to all highway users. In 1947 Oregon changed its ton-mile tax to the present weight-distance system, in which a single tax rate is charged for all miles of travel based on the highest operating weight of the truck. This tradition of leadership in the highway use tax area has continued. In 1990 Oregon implemented the first axle weight-distance tax that explicitly considers axle weights in the structure of the tax rates.

The trucking industry's opposition to Oregon's weight-distance tax began as early as the 1950s. In 1952 the industry sponsored a referendum that would have made weight-distance taxes unconstitutional. This measure failed by a 4-to-1 margin. However, opposition to the weight-distance tax continues today. The truckers' objections are that weight-distance taxes do not approximate highway costs, administrative and compliance costs are high, and evasion is widespread (*1*). A discussion of these issues follows.

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EQUITY

The contention that weight-distance taxes do not approximate highway costs is in reality a claim that this form of taxation is inequitable. In commercial trucking, tax equity is a significant issue. Trucking companies compete based on the efficiency with which they run their companies and the services they provide. An equitable tax, therefore, would be transparent in the marketplace. To achieve this objective, all users must pay their fair share for the use of the highway system. This is the underlying principle of cost responsibility that Oregon has long used to allocate highway costs among users of the system.

Two aspects of equity, horizontal and vertical, are considered in Oregon's cost responsibility studies. Horizontal equity means equal treatment of equals: owners of vehicles that have equal highway wear characteristics should pay the same amount of highway use taxes. Vertical equity means that unequals are treated unequally. For example, an owner of a truck that weighs 36 320 kg (80,000 lb) should pay more taxes than an owner of a truck that weighs 11 804 kg (26,000 lb). To achieve true equity, the tax system must achieve both horizontal and vertical equity.

The Oregon cost responsibility approach makes a basic distinction between the cost impacts of cars and trucks. Highway costs are allocated between the two groups based on traffic characteristics, level of highway expenditures, and engineering requirements. Using these three components, Oregon's 1992 Cost Responsibility Study determined that cars are responsible for 61.3 percent of the state's road costs and trucks are responsible for 38.7 percent (*2*). Once this basic allocation is made, trucks are further divided into 908-kg (2,000-lb) increments or classes to determine the appropriate cost responsibility for each group. The Oregon study recognizes 51 classes of trucks. This approach considers both horizontal and vertical equity.

Once cost responsibility characteristics are determined for each vehicle class, the tax system, to achieve true horizontal equity, must reflect the variability of actual usage. For example, a 21 792 kg (48,000 lb) truck being driven 161 km (100 mi) represents less cost than an identical vehicle being driven 1 610 km (1,000 mi) and should, therefore, pay proportionately less tax. Registration fees are flat taxes and do not reflect actual highway usage. However, Oregon's registration fees do vary according to the weight of the vehicle. There is an element of vertical equity. Because usage is not reflected, however, horizontal equity is not fully addressed.

Unlike registration fees, fuel taxes reflect usage. The more miles traveled, the more fuel burned and the more tax paid. Fuel taxes have an element of horizontal equity, but they do not reflect vertical equity because fuel consumption does not increase proportionately with increases in the weight of the vehicle. For example, a 1986 study found that the cost responsibility of an 36 320-kg (80,000-lb) truck is double that of a 22 700-kg (50,000-lb) truck, but the 36 320-kg (80,000-lb) truck uses only about 14 percent more fuel (*3*).

Weight-distance taxes, by their very nature, address both the horizontal and vertical equity because the tax is assessed for each mile of travel and is based on the weight of the vehicle. In the Oregon system, the tax rate is determined based on the actual costs the vehicle represents to the road system. This combination of the cost responsibility approach to highway use taxation and the reliance on the weight-distance form of taxation makes Oregon's system the most equitable in the nation. Critics of weight-distance taxes contend that they do not accurately reflect highway wear characteristics because they are based only on the overall weight of the truck and the distance traveled. They claim that the actual weight of each axle more accurately determines the road wear characteristics. This is true: cost responsibility rises steeply (roughly to the third power) as axle weights are increased. For example, the rear axle of a typical 11 804-kg (26,000-lb) truck causes over 1,000 times more road wear than that of a car (*4*). However, this aspect of cost responsibility is addressed by Oregon's axle weight–distance tax. With this form of tax, the rate varies not only by the weight of the vehicle, but also by the number of axles that distribute the load. Today, the axle weight–distance tax applies only to trucks weighing more than 80,000 lb. However, this approach could easily be extended to trucks operating at lower weights.

Administrative and Compliance Costs

The trucking industry contends that both administrative and compliance costs for weight-distance taxes are higher than for fuel taxes. The reality is that both types of taxes require taxpayer reporting and record keeping, and both also require compliance checks to minimize tax evasion.

Fuel taxes on automobile fuel do not require taxpayer reporting because they are collected at the pump. This approach does not work for heavy truck fuels, principally because most heavy trucks operate in more than one state and are equipped with large-capacity fuel tanks. It is common for a truck to fuel up in one state and then traverse one or more additional states without having to refuel. To ensure that trucking companies pay the appropriate tax based on the fuel used in each state, they must file tax reports. Currently, 47 of the continental states assess fuel taxes on trucks, and all require fuel use tax reporting.

Fuel use and weight-distance tax reports are based on mileage data. With a weight-distance tax, this mileage information is simply multiplied by the appropriate tax rate to calculate the tax due. Fuel use tax reporting requires not only mileage information, but also the number of gallons consumed. To reach this result, a miles-per-gallon figure must be calculated, then divided into the miles traveled in each state to determine the number of gallons used. The number of gallons of fuel must then be multiplied by the fuel tax rate in each state to determine the taxpayer's total liability. Fuel tax receipts must be maintained for presentation to compliance auditors. Thus, a fuel use tax reporting system actually requires more calculation and record keeping than a weight-distance tax.

Government administrative costs are also similar for both tax types. Each taxpayer must be registered, periodic tax reports must be processed and compliance audits must be conducted. The most significant difference between the two tax types is that fuel tax audits take longer because the auditor must not only verify mileage but also check fuel purchases.

Oregon Pubic Utility Commission figures show that administrative costs for collection of Oregon's weight-mile tax have averaged 4.5 percent of the tax collected over the past 10 years. Because Oregon does not have a heavy-truck fuel tax, diesel fuel is not tracked in the state. If Oregon were to implement a tax on diesel fuel, the amount of fuel consumed within the state would have to be monitored, and sellers of diesel fuel used for non-highway purposes would have to be licensed and audited. Non-highway uses include home heating oil, railroad fuel, steamship fuel, and fuel consumed in off-highway vehicles commonly used in the logging and agricultural industries. The additional bureaucracy this would require would significantly add to government costs and would impose new burdens on private businesses.

One factor supporting the trucking industry's contention that switching from the weight-distance tax to a fuel tax would save compliance costs is the relatively small number of states that have weight-distance taxes. Today, six states employ the weight-distance form of taxation. With the exception of Oregon, the other states also have fuel use taxes. Trucking companies operating in states with both weight-distance and fuel use taxes must comply with both types of taxes. If all states relied only on fuel taxes and registration fees, compliance costs would be reduced for firms operating in many states.

Further support for this argument results from the existence of base-state agreements. Base-state agreements are arrangements whereby trucking companies pay their tax liability to their home state for all states in which they operate. Each state then distributes the revenues among participating states. This approach reduces the number of registrations, tax reports, and compliance audits with which a trucking company must contend. There are four base-state agreements in existence: the International Registration Plan for the payment of registration fees, the International Fuel Tax Agreement and the Regional Fuel Tax Agreement for payment of fuel taxes, and the Weight-Distance Base-State Agreement for payment of weight-distance taxes.

The federal government requires that all states assessing registration fees and fuel use taxes join base-state agreements, but membership in the weight-distance agreement is not required.

There are advantages accruing to the states from base-state taxation. They have fewer tax accounts to administer, because they are only dealing with the companies located in their state. For example, at the end of 1993, Oregon had 27,460 weight-distance tax accounts, representing firms throughout North America. This compares to approximately 12,000 registration accounts, which is a rough estimate of the number of companies that are Oregon-based and would have to pay a fuel tax.

Although the number of accounts would be reduced, the complexity of the tax reports and compliance audits would be increased because they would reflect activity conducted in all states in which the companies operate. In reality, there would be some savings in the trucking industry's compliance costs, but little if any savings in government administrative costs, if Oregon were to switch to a diesel fuel tax.

Administration and compliance costs for truck-related highway use taxes will be reduced in the future, as new technologies are more widely implemented. Currently there are several projects under way that use intelligent vehicle highway system technologies to verify regulatory compliance and track transport equipment. Oregon has developed a camera system, which reads truck license plates, that is used for similar purposes. Additionally, many states are developing electronic communication systems that fall broadly under the heading of electronic data interchange. Reduction of the huge amounts of paperwork inherent in the transportation industries will drive costs down.

Tax Evasion

Two studies have been conducted to measure evasion of Oregon's weight-distance tax. In 1954, a study by the Stanford Research Institute concluded that the evasion rate was approximately 4.4 percent of the tax collected (*5*). In 1984, the Battelle Institute calculated an evasion rate of between 5.2 and 5.4 percent (*6*). It is interesting to note that in 1954, the Oregon Public Utility Commission (PUC) had 34 weight-distance tax auditors whereas it now has 29. The Stanford study concluded that evasion rates would not materially increase unless the Commission's compliance efforts were reduced. This observation appears to be supported by the results of the two studies.

Fuel tax evasion, on the other hand, is rampant in this country. According to the IRS and FHWA, diesel fuel tax evasion costs states and the federal government about $4 billion annually (*7*). Much of the problem stems from sales of diesel fuel in which the taxes are paid by the retail customers but never remitted to government tax collectors. In other words, it is not necessarily the trucking industry that is evading diesel fuel taxes, but rather those in the fuel sales and fuel distribution businesses. In many instances, organized crime is involved in these tax evasion schemes (*7*).

The principal reason for this high level of evasion is that the point of tax collection cannot effectively be moved up the distribution chain. Gasoline is taxed at the wholesale level and even at the refinery in some cases. However, most diesel fuel is not used as highway fuel. If it were to be taxed higher up in the distribution chain, the government would be faced with the need for a massive refund program. In 1990, 47 percent of the diesel fuel consumed in Oregon was used as a highway fuel (*8*). The balance was used for home heating oil, steamship fuel, railroad fuel, fuel for agricultural machinery, and other non-highway uses. Thus, 53 percent of the taxes collected would require refunds to non-highway users. This would not be a popular government program.

One recent effort to combat air pollution, which has implications for diesel fuel tax evasion, is the federal requirement for dyeing high-sulfur diesel fuel. This requirement went into effect January 1, 1994. The goal is to dye high-sulfur diesel and prohibit its use as a highway fuel, thereby reducing air pollution. Undyed, low-sulfur fuel is then taxed further up the distribution chain, reducing the opportunity for evasion. There are two problems with this effort. Much of the low-sulfur fuel is also used for non-highway purposes; exactly how much is not clear at this point because the program is so new. The other problem is that there is no effective enforcement mechanism to ensure that fuel burned in trucks is low-sulfur, taxed fuel.

OTHER POLICY CONSIDERATIONS

Fuel taxation, by its very nature, presents a public policy conflict. On one hand, a stable funding source must be ensured for highway construction and maintenance costs. On the other, non-renewable petroleum resources must be conserved. If government is successful with one of these policies, it is less successful with the other.

Another consideration, from the standpoint of highway users, is that highway use taxes should be spent on highways. The recent trend has been to raid highway trust funds to offset shortfalls in other areas; for example, there is a federal fuel tax that now applies to budget deficit reduction. Many states have also diverted highway funds to other uses. In Oregon, by constitutional provision, all road and vehicle use taxes are dedicated to highway purposes.

A 1991 study conducted by the American Trucking Associations indicates that the industry may reduce its support for fuel taxes and increase support for weight-distance taxes if fuel tax revenues are significantly diverted to non-highway uses (*9*). Because highways are the lifeline of the trucking industry, this position is perfectly understandable.

ALTERNATIVES TO OREGON'S WEIGHT-DISTANCE TAX

The following three tax scenarios are evaluated in terms of equity, compliance costs, administrative costs, and evasion potential. These scenarios are the most realistic alternatives to Oregon's present highway use tax system for heavy trucks.

Option 1

Oregon's weight-distance tax could be eliminated and replaced with a fuel use tax.

This option would be less equitable than the present system, cost nearly the same or more, and be susceptible to significant increases in evasion. The only way a fuel use tax could be as equitable as the existing weight-distance tax is if it were to have a variable-rate tax, with a different tax rate for each truck weight class. This approach would place a significant additional burden on fuel sellers. It would also complicate reporting requirements. This option has been considered in the past and dismissed as impractical.

Administrative costs would rise because of the additional requirement of tracking diesel fuel sold in the state. This could be partially offset by a slight reduction in PUC's administrative costs because of the benefits of the base-state fuel tax approach. The net change, however, is estimated to be minimal.

The trucking industry's compliance costs might be slightly reduced for those companies operating in numerous states because of the benefits of the base-state agreements. However, those Oregon-based companies which operate exclusively in the state would experience an increase in costs.

Under this option, the potential for evasion would increase substantially. The Oregon Department of Transportation estimates that a diesel fuel tax that would raise the same amount of revenue as the current weight-distance tax would require a tax rate of approximately 90 cents per gallon for a 36 320-kg (80,000-lb) truck. This would be far and away the highest fuel tax in the nation, and would provide great incentive for evasion. According to Bob Pitcher, Director of the Department of State Laws for the American Trucking Associations, the trucking industry would not support a state fuel tax rate in excess of 40 cents per gallon, because evasion would be so great that overall highway funding would be jeopardized.

Option 2

The weight-distance tax could be replaced with a 24-cents-per-gallon diesel fuel tax and registration fees increased.

This option suffers from the same concerns as Option 1 with respect to equity, compliance costs, and administrative costs. The evasion aspect is improved over that of Option 1 because the fuel tax rate is lower. However, evasion is still potentially higher than with the current weight-distance tax.

The real problem with this option is that it shifts the highway funding burden to those companies that operate mostly in Oregon. The registration fee component is estimated by the Oregon Department of Transportation to be $8,760 per year for a 36 320-kg (80,000-lb) truck. Interstate carriers would pay only a portion of this fee based on the proportion of miles operated in Oregon versus other states. For example, a company operating 80 500 km (50,000 mi) exclusively in Oregon would pay the full fee of $8,760 each year. However, a company operating 80 500 km (50,000 mi) in Oregon and 80 500 km (50,000 mi) in other states would only pay $4,380, or one-half the annual fee. This shift in tax liability could have a major negative impact on Oregon-based trucking companies.

Option 3

The existing weight-distance tax and registration fees could be retained. Future tax increases would be in the form of a fuel tax.

Equity could be maintained through adjustments in the weight-distance tax component. However, administrative costs would increase substantially because it would be a new program with no reductions in existing costs, and evasion could also increase.

CONCLUSION

The trucking industry has long objected to Oregon's weight-distance tax. An objective analysis of the alternatives shows that all are less desirable from a public policy perspective. In view of the facts, why do truckers continue to attack Oregon's highway use tax system?

A comparison of the truck operating taxes in the various states on a rate-per-mile basis indicates that Oregon is among the most costly states in the nation in which to operate a truck. Members of the trucking industry complain about the high level of taxation in Oregon and cite weight-distance taxes as the cause. But Oregon's heavy truck highway use taxes are high because they capture the trucking industry's full cost responsibility. Other states subsidize the trucking industry by collecting less than its fair share of highway costs.

The reaction from members of the trucking industry to a 90-cent-per-gallon fuel tax is virtually the same as it is to the existing weight-distance tax. The underlying issue is the level of taxation and not the type of tax.

This concern can be addressed by adjusting Oregon's weight-distance tax rates while at the same time maintaining the public policy benefits of weight-distance taxes. Oregon must only decide what level of highway funding is desirable and whether it wants to subsidize the trucking industry.

The weight-distance tax provides a stable source of highway funding that does not conflict with other public policy goals, the tax is by far the most equitable, and administrative and compliance costs are reasonable. Most importantly, tax evasion is very low. Oregon has an effective and efficient system. It would be unwise to discard it because of misguided arguments from an industry that really wants lower taxes.

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Publication of this paper sponsored by Committee on Taxation and Finance.

Toll Revenue and Traffic Study of Highway 407 in Toronto

ALI MEKKY

The Greater Toronto Area (GTA) is one of the fastest growing urban areas in North America, with a population of about 5 million, growing at the rate of 3 percent per year. Highway 407 (a six/four-lane freeway), in the GTA has been considered for many years as a relief for Highway 401, the busiest highway in North America, which is used by more than 1 million vehicles per day. Highway 407 is being planned and constructed as a toll highway. This paper includes results of a study to estimate Highway 407 future traffic and toll revenues. GTA mathematical model, within the EMME/2 environment, was used to estimate the travel conditions in the network and the revenue potential under various scenarios of horizon years/network combinations (5), time periods (3), toll levels (8), and toll collection technologies (3). The demand and the toll revenue estimation processes are described. The solutions adopted for the problems of overassignment, the estimation of the value of time, participation rates, and the ramp-up effect are explained. It is concluded that Highway 407 can generate substantial revenues, which might make it a self-financing facility. It will relieve Highway 401 and Highway 7 from part of their volumes and will decrease travel time for its users and some of the nonusers. It will also decrease travel time variability, improve accessibility to Pearson International Airport, and create jobs. On bad-weather days, some of the benefits are expected to increase.

The Greater Toronto Area (GTA) is one of the major urban areas in North America, with a population of about 5 million (1994), increasing at the rate of 3 percent per year (1986 to 1991). It is located in the southwestern part of Ontario, Canada (Figure 1). It extends over 8,200 sq km and consists of Metropolitan Toronto (population 2,400,000) and the Regional Municipalities of Peel (760,000), York (530,000), Durham (430,000), Halton (330,000), and Hamilton-Wentworth (460,000).

In the late 1950s, the Province of Ontario started the planning process for the development of Highway 407, a 130-km multilane freeway, to the immediate north of Metropolitan Toronto (Figure 1). Initially, the highway was envisaged as a new Toronto bypass that would provide relief to the congested Highway 401, which could not be widened in most of its sections in the GTA. At present, and after the high growth that occurred during the last three decades, Highway 407 is in the heart of the urban area of the GTA. The highway is considered to have urban, regional, interregional, interprovincial, and international functions for both person and freight traffic (*1*).

The entire Highway 407 extends from Highway 403 in the west near the Peel/Halton regional boundary to Highway 35/115 in the east, west of the Durham/Northumberland boundary. At present, the section under consideration extends over 67 km from Highway 403 in the west (at Halton/Peel boundary) to Highway 48 in the east, west of the York/Durham boundary (Figure 1). Over the last 6 years, a short section (8 km) of Highway 407 has been under construction. However, at that rate of construction, it could take more than 25 years to complete the highway.

Growing travel demand in the Highway 407 corridor, coupled with the unavailability of funds to speed up the construction of the highway has prompted the Ontario government to consider entering into a private/public joint venture to build the highway as a toll facility. In February 1993, the Premier of Ontario announced the provincial government's decision to accelerate the construction of Highway 407 using toll revenues.

In August 1993, two consortia completed a value engineering assessment of the project. This process identified savings of about $200 million on the Highway 407 project aside from $100 million in savings, which was identified through competitive bidding. The consortia then submitted proposals to finance, design, build, maintain, and operate the highway. After a comprehensive evaluation process, Canadian Highways International Corporation was selected and a contract worth $929.8 million was signed in May 1994. Financing the construction of the highway, however, will be done through a Crown agency (Ontario Transportation Capital Corporation).

Highway 407 will be constructed as a six/four-lane freeway. The first sections to be opened by the end of 1996 are from Highway 410 to Highway 404 (36 km). This will be followed by the sections to the east of Highway 404 to Highway 48 and to the west of Highway 410 to Highway 403, which will be opened by the end of 1998.

Several studies have been initiated by the Ontario government to determine the optimal geometrics of the highway as well as the traffic, toll levels, toll technology, etc. Also, various surveys were conducted to collect needed data and information—for example, focus group surveys (100 people surveyed), origin-destination surveys (21,000 questionnaires returned and coded), an incidence survey (1,000 people surveyed), and a stated preference survey (1,850 surveyed).

The objective of this paper is to describe the methodology and the results of one of those studies, namely, the traffic and revenue study. A similar study commissioned by the Ministry of Transportation, Ontario (MTO) was carried out simultaneously yet independently by a consultant (Wilbur Smith Associates). The results of that study are not reported in this paper.

Initially, three toll collection technologies were considered: (*a*) the closed cash-barrier system, (*b*) the fully electronic system, and (*c*) the "mixed" system. The latter is a combination of the fully electronic and the cash systems. At a later stage of the study, it became apparent that the electronic system has many advantages, and accordingly, the manual one was dropped from further consideration.

The traffic and revenue estimation study for Highway 407 in the GTA began in January 1993, and included the following objectives:

Transportation Demand & Forecasting Office, Transportation Systems Planning Branch, Ministry of Transportation, West Tower, 3rd Floor, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8, Canada.

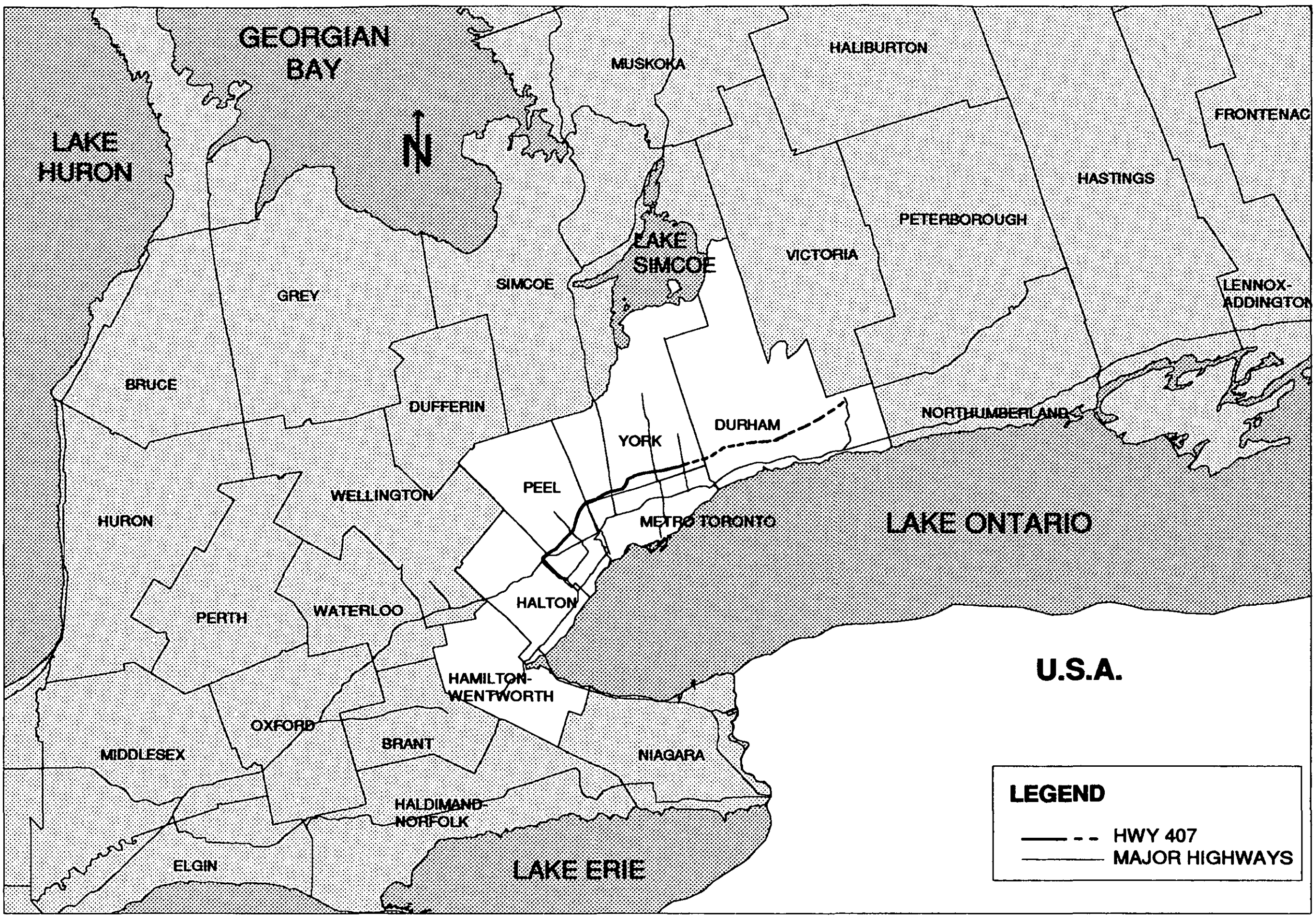


FIGURE 1 Highway 407 project.

- To evaluate the travel and traffic conditions on Highway 407;
- To estimate the highway toll revenues;
- To evaluate the effect of Highway 407 on the major provincial facilities in the area particularly on Highway 401 and Highway 7. Both highways are aligned in an east-west orientation; and
- To evaluate the effects of Highway 407 on municipal facilities.

Many scenarios were expected to be evaluated. They included combinations of networks, time periods, toll levels, and toll technologies.

This study has an emphasis on describing the activities and some of the results related to the first two objectives.

THE GREATER TORONTO AREA

Population, Employment, and Car Ownership Growth, 1986 to 1991

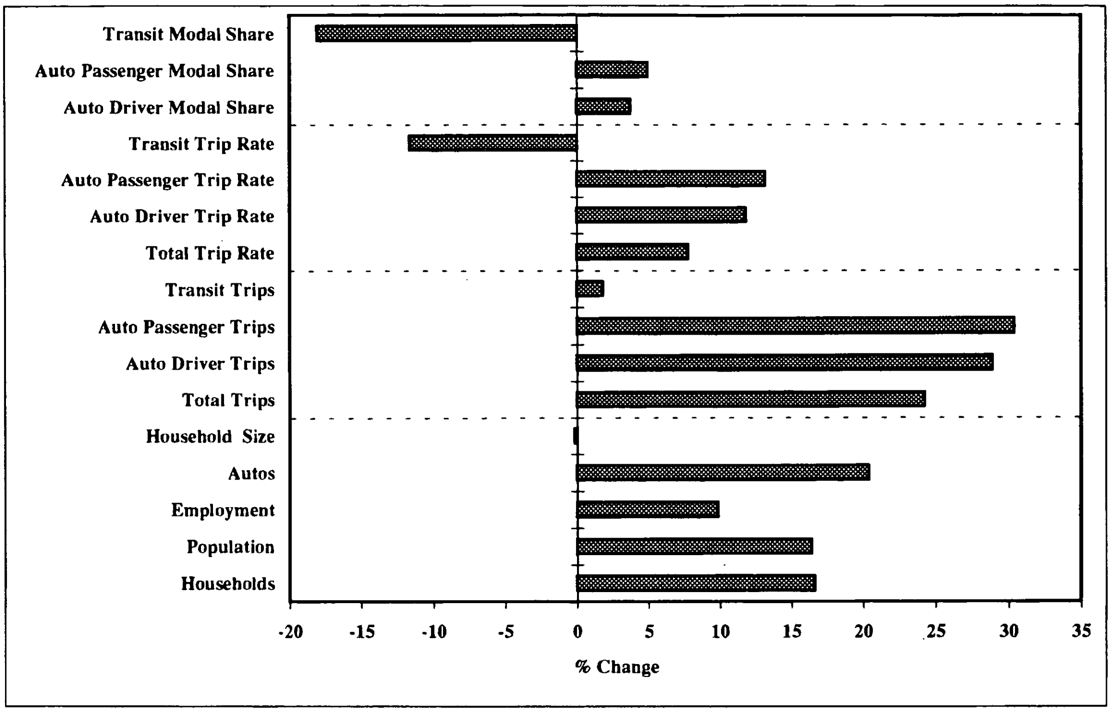
Over the last few years, the GTA has been experiencing significant growth in population, employment, and car ownership. Between 1986 and 1991, as shown in Figure 2, population and employment grew by 16 percent and 10 percent, respectively. The number of active automobiles increased by 20 percent. Accordingly, automobile driver trips grew by about 29 percent whereas transit trips grew by only 2 percent. As a result, the automobile driver and passenger modal shares grew by about 4 percent and 5 percent, respectively, whereas the transit modal share declined by 18 percent.

The population growth has not been uniformly distributed throughout the area. Between 1986 and 1991, Metropolitan Toronto population grew by about 4 percent while York experienced an explosive growth of about 43 percent. The regions of Peel and Durham increased by about 23 percent and 27 percent, respectively.

Currently, approximately 10 million person-trips are made daily in the GTA. One of the reasons for the large number of interregional trips in the GTA is the imbalance between jobs and the labor force. Metro Toronto had a significantly higher jobs/1,000 population ratio than any of the other regions in the area (601 in 1991). For the same year, that ratio was 521 for Peel, 500 for York, 390 for Durham, 452 for Halton, and 415 for Hamilton-Wentworth.

Travel Conditions in the Greater Toronto Area

As previously discussed, the rapid growth in the GTA has taken place in the regions west (Peel) and north (York) of Metro Toronto. This has resulted in a significant increase in the number of trips in the area, particularly the east-west ones. Those movements are



	1986	1991	Change	% Change
Households	1,466,000	1,710,000	244,000	17
Population	4,063,000	4,729,000	666,000	16
Employment	2,237,000	2,458,000	221,000	10
Autos	1,852,000	2,230,000	378,000	20
Household Size	2.77	2.77	0.00	0
Daily Person Trips for 11+:				
Total Trips	8,161,000	10,140,000	1,979,000	24
Auto Driver Trips	4,930,000	6,356,000	1,426,000	29
Auto Passenger Trips	1,160,000	1,513,000	353,000	30
Transit Trips	1,342,000	1,367,000	25,000	2
Daily Person Trip Rates for 11+:				
Total Trip Rate	2.34	2.52	0.18	8
Auto Driver Trip Rate	1.41	1.58	0.17	12
Auto Passenger Trip Rate	0.33	0.38	0.04	13
Transit Trip Rate	0.38	0.34	-0.04	-12
Modal Shares:				
Auto Driver Modal Share	0.60	0.63	0.02	4
Auto Passenger Modal Share	0.14	0.15	0.01	5
Transit Modal Share	0.16	0.13	-0.03	-18

Source: Transportation Tomorrow Surveys, 1986 and 1991

FIGURE 2 Changes in travel-related characteristics in the GTA between 1986 and 1991.

served by several facilities, the most notable ones are Highway 401, mainly a 12-lane freeway, and Highway 7, a 6-lane arterial. Highway 401 is the busiest highway in North America. It carries more than 1 million vehicle trips every day over its Peel/Metro portion. The annual average daily traffic (AADT), at its maximum point, was 351,000 vehicles in 1992, where the highway has 14 lanes. The summer annual weekday traffic at that location was 404,000 vehicles in the same year. The rate of growth over the past 15 years was 2.8 percent.

Highway 7, a six-lane, east-west arterial is also very busy. The AADT, at its maximum point, was about 61,000 vehicles in 1992. The summer annual weekday traffic at that location was 67,000 vehicles in the same year. The rate of growth over the past 15 years was 2.5 percent.

Currently, the volumes on some sections of the major highways in the GTA are at or near capacity. That is particularly true for Highway 401 and Highway 7 in the Metro/York and Peel regions. One of the recent studies in the GTA has estimated that congestion costs the GTA economy about $2 billion every year in wasted activities and lost productivity.

Therefore, in view of the current levels of congestion and the expected growth in population and employment, the need for improving both the highway and the transit systems has become increasingly necessary. Particularly, the need for a major east-west facility, Highway 407, has become urgent.

THE MATHEMATICAL MODEL

The MTO maintains a strategic mathematical model covering the entire GTA. The model has 1,366 zones, about 5,000 nodes, and 19,000 links. It is continuously updated and used in various planning and policy studies undertaken by the MTO, the regional municipalities, or both. One of the current studies using that model is the planning for Highway 407 and the evaluation of the effects of tolling it.

The GTA model is a traditional sequential four-stage model (Figure 3). It contains modules for the a.m. peak hour, the p.m. peak hour, and the off-peak hour. It uses regression analysis for trip generation, a Gravity model for trip distribution of work trips (and Fur-

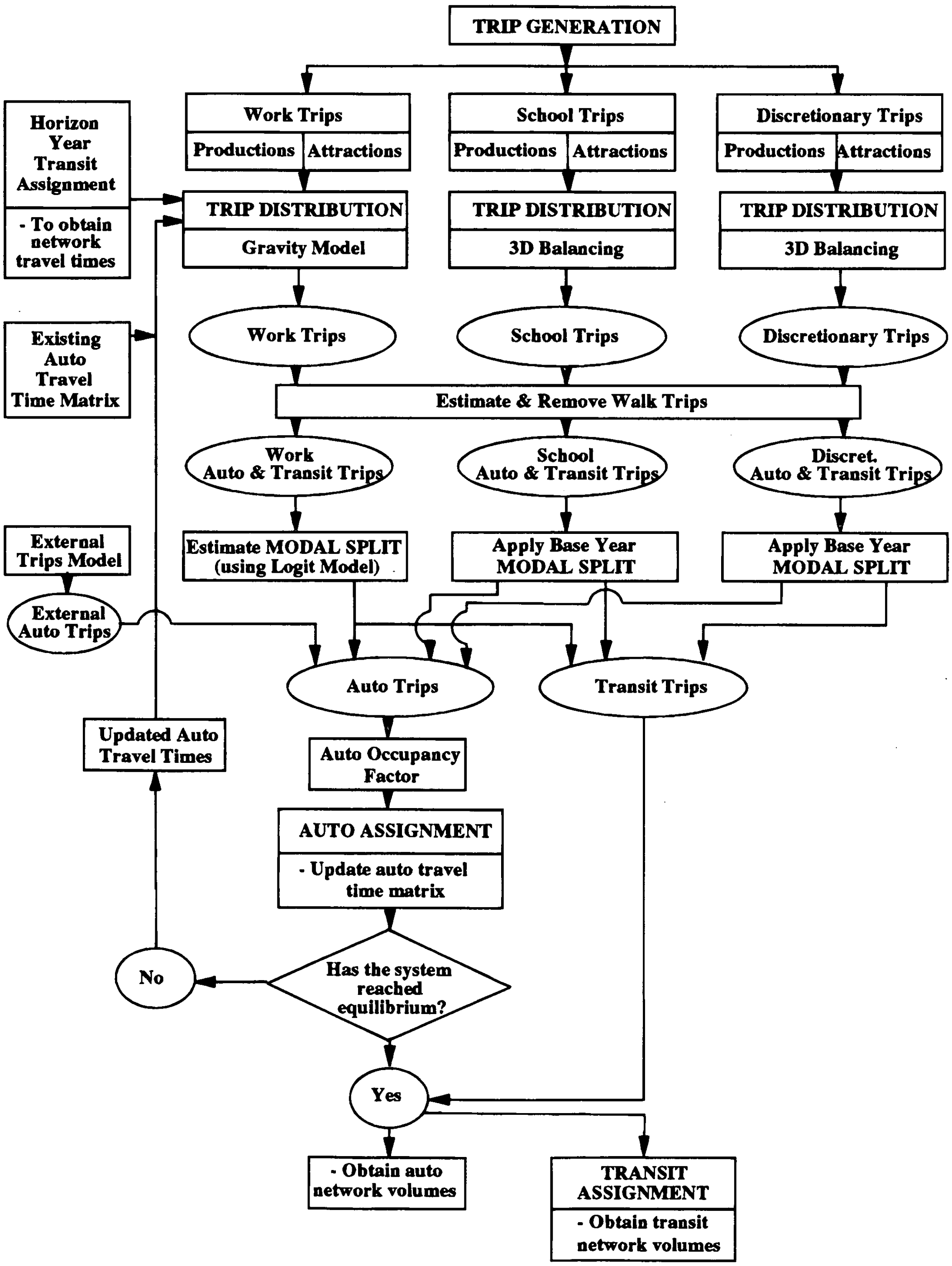


FIGURE 3 GTA travel forecasting model.

ness method for the other purposes), a Logit model for modal split of work trips, and an Equilibrium Assignment for trip assignment. The model operates within the transportation planning package EMME/2.

The main source of travel data available for transportation planning studies in the area is the Transportation Tomorrow Survey (TTS), a household telephone survey conducted in 1986. The coded data base includes the travel patterns for about 61,000 households. The technique included the tolling effect on Highway 407 by adjusting its volume-delay function (which accounts for the effects of distance and congestion only) to incorporate the effect of the tolls.

Effective Delay = Distance and Congestion Effects + Toll Effect

The Distance and Congestion effects were taken to be a Bureau of Public Roads (BPR) function of the form

$$\tau = \tau_0[1 + \alpha(v/c)^\beta]*L$$

where τ and τ_0 are the link actual travel time and free flow travel time, respectively: $\alpha = 1$, $\beta = 6$.

The toll effect was taken to be

$$T*L/V$$

where

T = toll in cents/km;
L = link length;
v = volume;
c = capacity; and
V = value of time.

VALUE OF TIME

Studies in travel behavior cited by Langdon (*2*) indicate that the value of time in travel is about one-quarter the wage rate (post tax). Other studies in San Francisco indicate half of the wage rate. Other studies confirm the use of factors from a half to a quarter. In the first phase of the Highway 407 study, the factor "half" was adopted. Sensitivity runs around that value were carried out. It became clear that the revenue results were very sensitive to the value of time assumed. Therefore, it was important to conduct a survey to measure that value.

Resource Systems Group (RSG) was retained to conduct the survey using an interactive video interview station (IVIS) system and stated preference technique. A self-administered computer-based questionnaire was developed (*3*). For each respondent, information was collected about a recent trip in the Highway 407 corridor, the time/cost trade-offs for that trip, and reactions to features of the proposed electronic system. The IVIS system has the capability of adapting to responses by branching around questions and providing detailed information about choice alternatives based on responses. The exercise was completed for car and commercial vehicle drivers separately. The results showed that the value of time varied by trip purpose, household income, and vehicle type. Travelers on non-work trips were found to have generally lower values of time than work commuters. For work commuting trips, the value of time was found to increase, but less than linearly with household income. For commercial truck trips, the value of time was similarly found to increase, but less than linearly with the number of vehicle axles (*3*).

The final (weighted) estimates of the values of time for the a.m., p.m., and off-peak periods were \$0.17, \$0.19, and \$0.15/min. For commercial vehicles, the calculated value was \$0.33/min. The weights used were the proportions of trips for the various trip purposes within the time periods under consideration.

SCENARIOS INVESTIGATED

The scenarios initially proposed were the combination of horizon years population and employment growth, network improvements, toll technologies, and toll levels.

Population and Employment Growth, 1991 to 2011

In the summer of 1993, the GTA land use planners finalized their work on the expected growth in the area for the horizon years 2001, 2011, and 2021. Five scenarios were produced. Scenario 1 was regarded as the most probable and was used accordingly in this study. Figure 4 shows the regions surrounding Metro Toronto growing at a higher pace than Metro. In fact a significant drop is expected in the Metro share of the population in the region from 54 percent in 1991 to 42 percent in 2011. Similar employment growth is expected in the area, with Metro's employment share dropping from 60 percent in 1991 to 50 percent in 2011.

It is interesting to note that the employment/1,000 population for Metro Toronto is expected to rise even more from 601 to 661, Peel from 521 to 539, York from 500 to 511, and Halton from 452 to 504. The ratio is expected to drop in Durham from 390 to 381 and in Hamilton-Wentworth from 415 to 398. Therefore, the growth patterns are conducive to more growth in the a.m. inbound trips to Metro Toronto.

Future Network Improvements

From the beginning of the study, it became apparent that there are at least two network scenarios that should be considered: (*a*) the base scenario, which included committed and almost committed improvements to the network for the near future (interpreted as the year 1998), with no more improvements until 2021; and (*b*) the sensitivity scenario, which included all the expected improvements at both the provincial and the municipal levels until the year 2021. Officials from the provincial and regional governments were consulted, and the networks were produced.

Time Periods

The a.m. and p.m. peak periods as well as the off-peak period were used.

Toll Technologies

Initially, three toll technologies were investigated; (*a*) manual/automatic coin machines, (*b*) the electronic, with automatic vehicle identification (AVI), and (*c*) mixed systems (AVI with manual/auto-

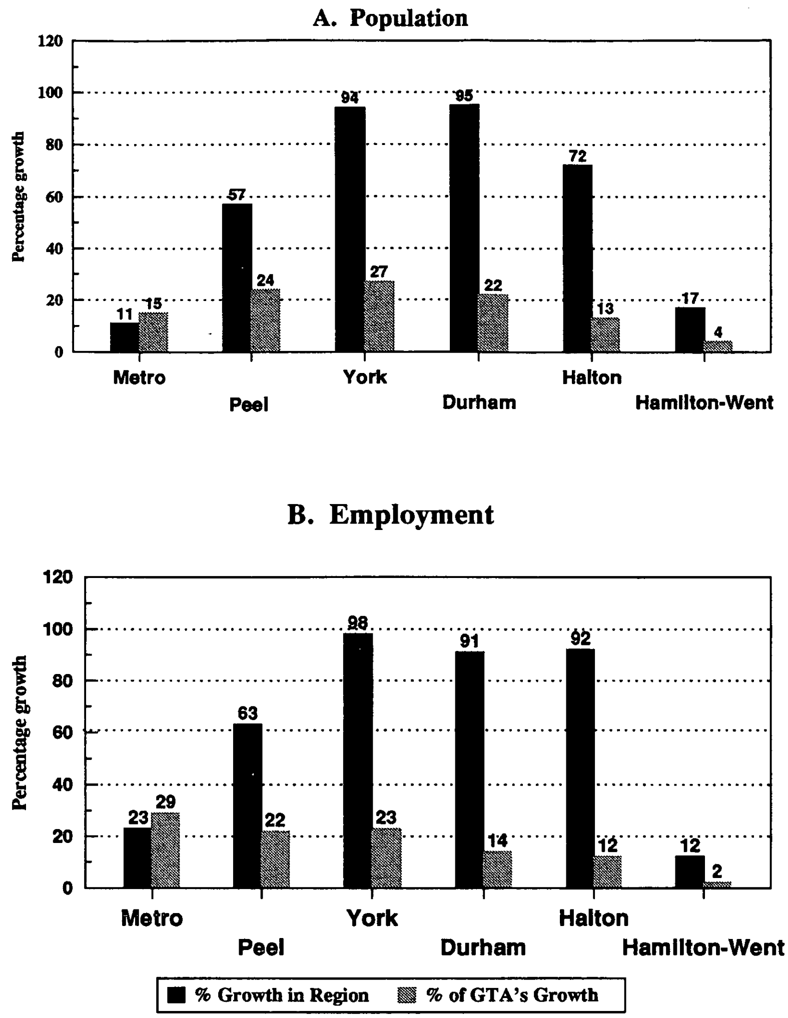


FIGURE 4 Percentage population and employment growth and share of growth in the GTA, 1991 to 2011.

matic coin machines). A later stage of the study concentrated only on the fully electronic technology, and only those results are given.

Toll Levels

Eight toll levels (0, 5, 5.5, 7.5, 10, 15, 20, and 25 cents/km) were considered. The reason for choosing 5 and 5.5 cents/km was to compare the results of the final runs with some previous results.

Summary of Scenarios

At the beginning of the study, the following scenarios were suggested:

- Five horizon years/network improvements combinations: 1998-Base, 2001-Base, 2011-Base, 2011-Sensitivity, and 2021-Base.
- Three time periods: a.m. peak period, p.m. peak period, and off-peak period.
- Three toll collection technologies: manual, electronic, and mixed.
- Eight toll levels: 0, 5, 5.5, 7.5, 10, 15, 20, and 25 cents/km.

These combinations total 360 scenarios. Not all of those scenarios were actually tested using model runs. For instance, the mixed technology scenario was evaluated by weighing the results of the fully electronic and the manual technologies in a worksheet. Based on a survey of a sample of the potential users, assumptions were made to estimate the market share of each technology.

DEALING WITH OVERASSIGNMENT

Overassignment occurs when flows on links exceed their capacities during the modeling process. It takes place, particularly when forecasting travel in congested high-growth areas (*4,5*). Overassignment might happen with almost any assignment technique. Attempting to dampen the overassignment effect by doing more assignment iterations might result in circuitous routes and unrealistically low speeds on the links. Such results are unreasonable in a "steady state" situation, which is the usual operating mode of the majority of the available packages (e.g., EMME/2). Accordingly, the results of such simulation runs are unreliable.

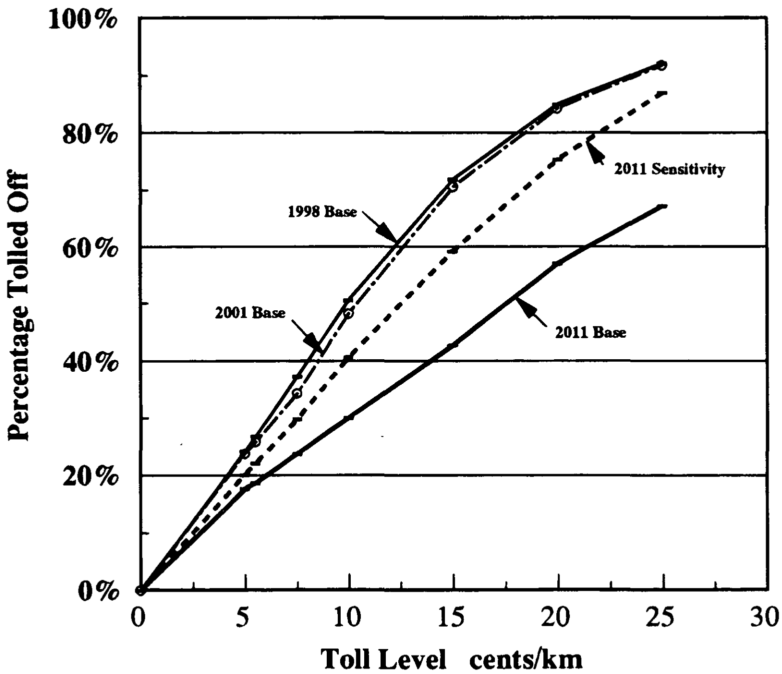
The Matrix Capping technique was used to alleviate the effect of overassignment and is discussed in the literature (*4,5*). Briefly, the steps are:

1. Assign the forecasting year matrix to the network.
2. Identify the links where the volumes (*V*) significantly exceed the capacities (*C*), defined as $V/C > 1.1$.
3. Adjust the forecasting year matrix using the capacities of the links where the volumes exceed capacities ($V/C > 1.1$), as the volumes that ought to be reproduced by the adjusted matrix.
4. Go to Step 1 and repeat the iterations until the volumes assigned to the links of the network do not significantly exceed the corresponding capacities.

TRAVEL DEMAND ANALYSIS

Although tolls, in the long run, might affect trip distribution and modal split, an assumption in this study was made that the effect is small because of the availability of reasonable alternatives to Highway 407 (e.g., Highway 7 and Highway 401). Therefore, the main effect of tolls was considered to be on the choice of routes (trip assignment).

Equilibrium assignment was carried out using EMME/2 for various scenarios. The "toll diversion effect" of some of those scenarios is shown in Figure 5. The effect of tolls is very dramatic, especially in the early years. A toll of 5 cents/km in 1998 could divert about 24 percent while a toll of 10 cents/km in 1998 could divert about half of the vehicle km away from Highway 407. The percentage of diversion increases with the increase of the toll level and with the decrease in congestion on the alternative roads. For the same toll level, the percentage diversion in the year 2011 (base network) is less than that in 1998 because in 2011 the congestion levels on alternative routes are worse than in 1998. Accordingly, a higher percentage of the travelers would find it more beneficial to use Highway 407 and pay tolls than to divert and experience long delays. The same idea applies for the year 2011 sensitivity network, which contains more improvements to the network than that of the 2011 base.



Toll	1998 Base	2001 Base	2011 Base	2011 Sen
0.00	00.00 %	00.00 %	00.00 %	00.00 %
5.00	24.17 %	23.72 %	17.61 %	20.04 %
5.50	26.78 %	25.84 %	18.61 %	21.99 %
7.50	37.24 %	34.31 %	23.68 %	29.78 %
10.00	50.55 %	48.24 %	30.01 %	40.67 %
15.00	71.86 %	70.55 %	42.78 %	59.17 %
20.00	84.98 %	84.28 %	57.07 %	75.33 %
25.00	92.17 %	91.80 %	67.17 %	86.98 %

FIGURE 5 Percentage of vehicle.km tolled off Highway 407 as a result of applying tolls, morning peak period.

TOLL REVENUE ANALYSIS

Revenues Under Limited Participation and No Ramp-Up

Preliminary estimates of revenues could be calculated using the simple equation:

Revenue = Vehicle·km * Toll Rate

In dealing with electronic revenue collection, a survey commissioned by MTO has shown that there is a certain percentage of the population that would not accept using transponders for privacy reasons. Therefore, the vehicle.km and the revenues should be adjusted at this stage to account for that limited participation.

In this study, the level of participation was assumed to be 75 percent in 1998. That figure was assumed to increase over time until it reaches 90 percent in the year 2021. These results were based on the stated preference survey discussed above.

Figure 6 shows the vehicle.km driven on Highway 407 during the a.m. peak period for various scenarios. As expected, the number of vehicle.km on Highway 407 decreases with the increase in the toll level. However, that decrease becomes smaller with more growth and less network improvements.

As shown in Figure 7, the revenue increases with the increase in the toll level up to a certain maximum. As the toll level increases further, the revenue decreases. The location of the maximum seems to depend on the degree of congestion in the network. The maximum revenue toll increases over time because of the increase in population and employment and it decreases with more improvement to the network. The latter is shown in Figure 7 with the maximum for the 2011 sensitivity network significantly lower than that for the 2011 base network.

The Effect of Ramp-Up

Like in many other projects, not all the potential users of a highway will start using it from the first day of its opening. This is particularly true for toll projects. To include that effect in the revenue estimation, the so-called "ramp-up" factors were used. Ramp-up factors decrease over time.

For the Highway 407 project the ramp-up factors were applied only to the first 4 years, starting in 1998 with a value of 13 percent (i.e., the revenues were reduced by that amount). That factor decreased over time and reached zero by the year 2003.

Revenue Stream Calculations

Figure 8 shows the growth in revenues from 1998 to 2021 for the toll levels 5.5, 7.5, and 10.0 cents/km for the base network scenario. Two groups of curves are shown, with no phototracking, no ramp-up (NT) and with phototracking and ramp-up (WT).

Simulation runs were carried out for the years 1998, 2001, 2011, and 2021 and for various toll levels. Revenues were calculated for the intervening years by interpolation.

As shown, between 1998 and 2021 for 7.5 and 10 cents/km, the (gross) revenues are expected to more than double. One can also see that there is a substantial increase in revenue if the toll is increased from 5.5 to 7.5 cents/km. However, increasing the toll from 7.5 to 10 cents/km does not cause a major change in revenues. This might have some policy implications. At a later stage of the project, the phototracking concept became an option. Under the phototracking system, passenger cars (trucks excluded) without transponders are allowed to use the road. Their license plates would be "phototracked" from the point of entry to the point of exit from the high-

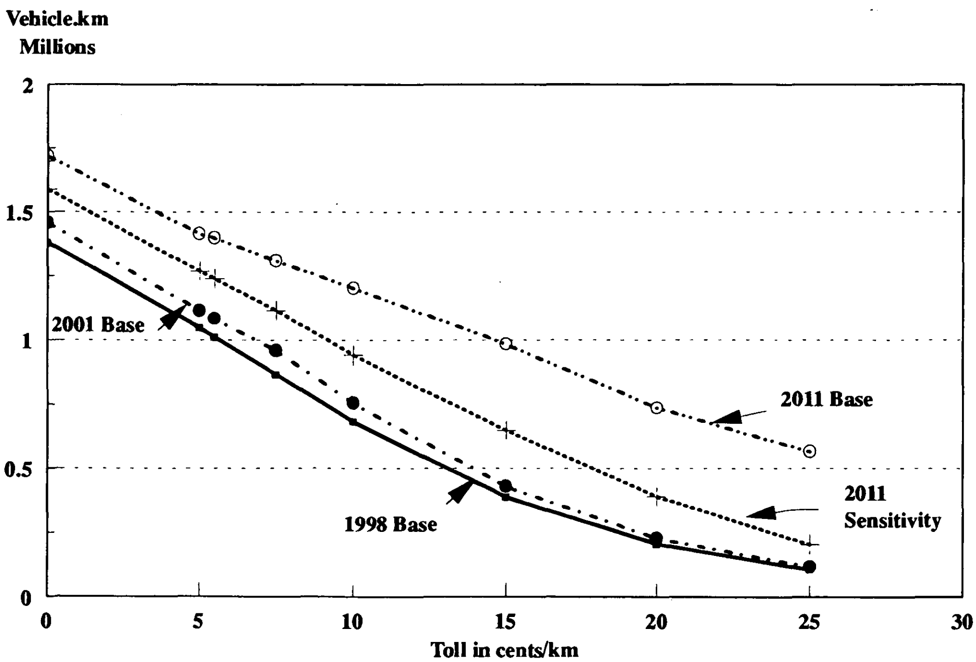


FIGURE 6 Highway 407 morning peak period usage; vehicle.km at various electronic toll levels.

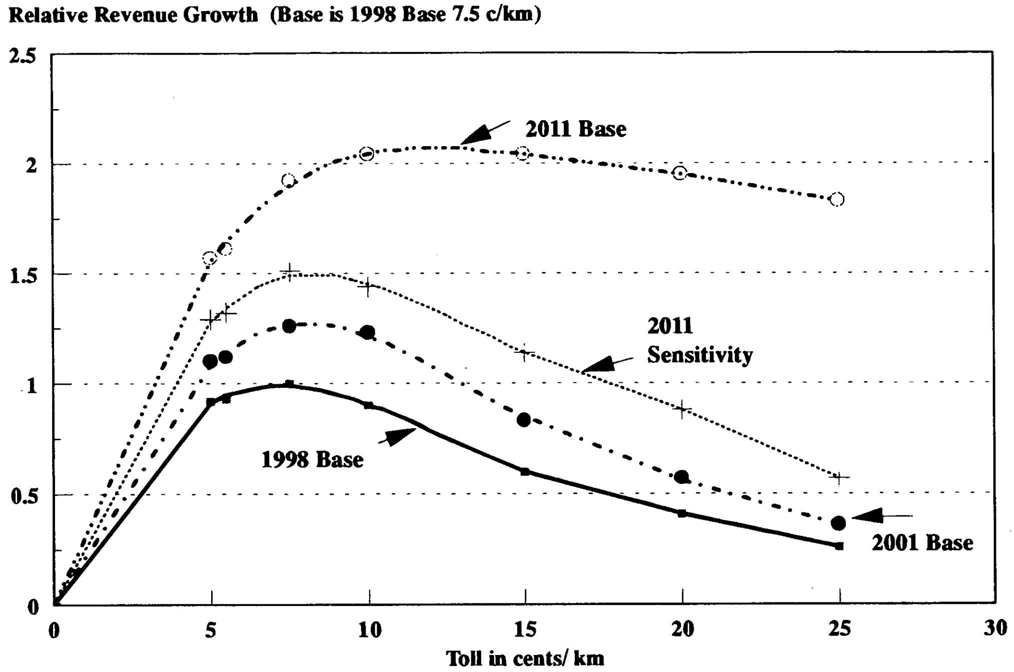


FIGURE 7 Highway 407 annual relative revenue; limited participation, no ramp-up.

way. The vehicle owner will be post-billed. To discourage too many cars from using this system and to cover the extra cost of photo-tracking, its toll rate is taken to be higher than the "transponder" tracking one.

Cost benefit analysis has shown that there is a reasonable chance that the revenues would cover all the costs of the project construction, which has been estimated to be slightly under 1 billion dollars. Runs with more optimistic land uses have shown that the toll revenues might cover even the operations and maintenance costs as well. However, this depends on the stability of interest rates, the inflation rate and the level of tolls in the various years.

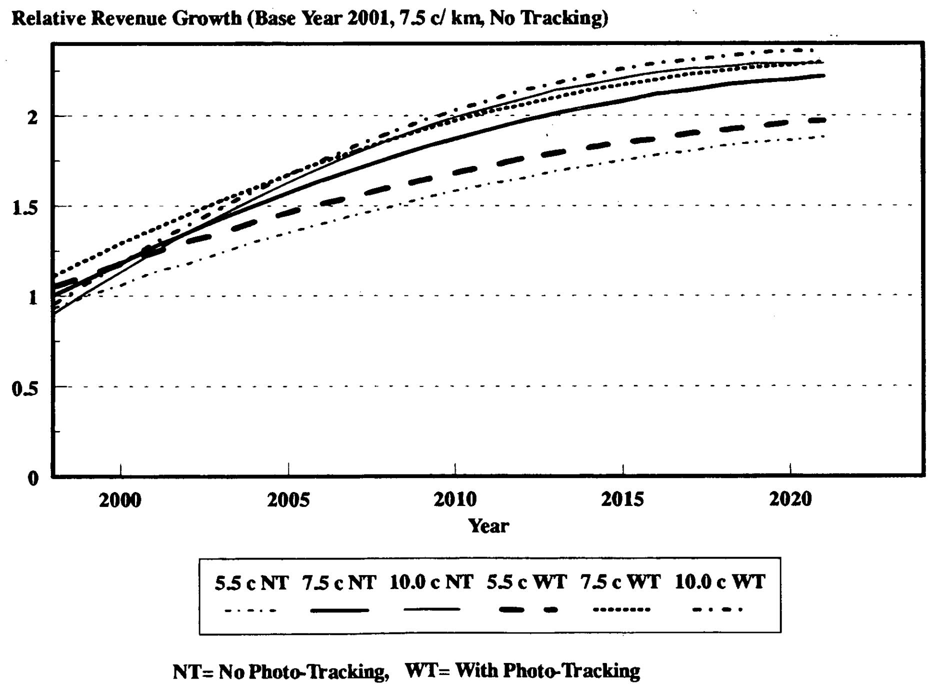


FIGURE 8 Highway 407 revenue growth forecast.

BENEFITS OF HIGHWAY 407

Decrease in Travel Time

One of the main benefits of Highway 407 is to save travel time. If all the highways are operating under ideal conditions (good weather, no accidents/incidents), travel time savings of Highway 407 users could be up to about 25 min. The average is about 5 min. Some nonusers of Highway 407 might also experience improvements in their travel times by shifting vehicles to the highway.

Highway 401 operates at full capacity during the peak periods, and any incident is likely to cause a prolonged delay on the highway. Accordingly, travelers would shift to the alternatives (e.g., Highway 407). Therefore, the actual travel time savings are expected to be much higher than what was calculated under ideal conditions.

During and shortly after rain- and snowstorms, the operating characteristics of highways differ significantly from the regular ones (during favorable weather conditions). Bad weather conditions were simulated by decreasing the free flow speeds by 10 percent and decreasing link capacity by 10 percent. Results showed that under those conditions, more travelers would shift to Highway 407. For instance, during the morning peak hour, the number of users would increase from 34,000 vehicles to about 41,000 vehicles, an increase of about 20 percent.

Decrease in Volumes on Highway 401 and Highway 7

As a result of building Highway 407, the most significant percentage decrease in other highway volumes is on Highway 7 (Figure 9). That decrease (in the morning peak hour) for Highway 7 eastbound reaches around 31 percent near Highway 404 and 33 percent at Highway 427. Generally, the decrease in volume on other facilities is larger in the inbound direction.

It is clear from Figure 9 that the most significant percentage decrease in Highway 7 volume takes place between Highway 427 and Highway 404. One of the reasons is that in that area Highway 407 runs very close to Highway 7 and offers a significantly better level of service. Volumes on Highway 401 also decrease with the construction of Highway 407. The decrease is the greatest in the eastbound movement in Peel. One of the reasons for that decrease is that the two highways (407 and 401) are near each other in that area.

Increase in Travel Time Reliability

It is expected that volumes on Highway 407 will be monitored and not allowed to exceed a certain maximum to maintain a good level

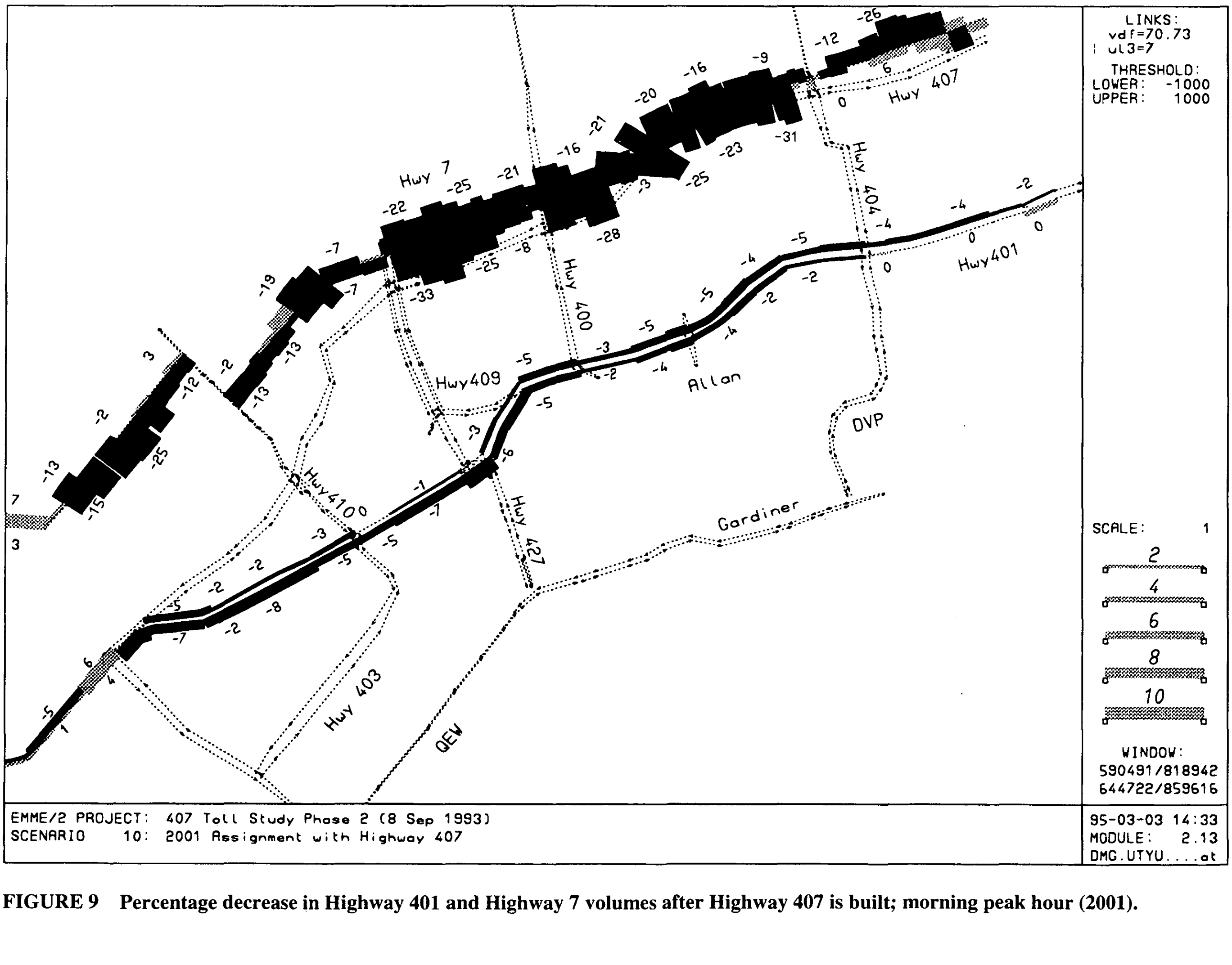


FIGURE 9 Percentage decrease in Highway 401 and Highway 7 volumes after Highway 407 is built; morning peak hour (2001).

of service that would attract travelers to use the highway. Previous studies (*6,7*) have shown that travelers highly value the facilities that offer reliable travel times. In fact, the benefit of offering more reliable travel time (with less variability) can be very substantial even if the (mean) travel time itself does not change. This happens as individuals usually allow extra time (safety margin) to avoid the possibility of arriving late at the destinations. Highways with less variability in their travel time allow individuals to reduce their "safety margins," which is a real time savings. This benefit was acknowledged in the Highway 407 study. However, no attempt was made to quantify it.

Other Benefits of Highway 407

The construction of the highway will enhance the economic growth of Metro Toronto as well as the regions of York and Peel. It will create about 20,000 jobs during the construction period. It will improve the accessibility to Toronto's Pearson International Airport.

SUMMARY AND CONCLUSIONS

The GTA is growing at a fast rate in terms of population, employment, and car ownership and availability. This led to some deterioration in the level of service on some sections of the highways. Highway 407 represents an opportunity to help improve travel conditions in the GTA. Highway 407 can generate substantial revenues, which might make it a self-financing facility. It will relieve Highway 401 and Highway 7 and will decrease travel time and improve its reliability. On bad weather days, some of the benefits are expected to increase.

ACKNOWLEDGMENTS

The author wishes to thank two anonymous referees for their helpful comments on an earlier draft of this paper.

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The views expressed and the figures included in this paper are not necessarily those of the Ministry of Transportation, Ontario. Currently, Wilbur Smith Associates are working on Phase Two of the project to produce final forecasts for MTO.

Publication of this paper sponsored by Committee on Taxation and Finance.

Road Transport in France: Its Balance Account for Public Finance

RICHARD DARBÉRA

Road transport is heavily taxed in most European countries. France is no exception. Just as in many other countries a debate is raging there about whether or not road users are paying a "fair share" for the costs they impose on the nation or at least on the Treasury. It is common wisdom in France that road use is subsidized, but this assertion is usually not based on fact, as if no data were available. However, cost allocation studies have been carried out, tax revenues have been reported, and officially published data give almost all the necessary elements to settle the debate. In my opinion, the confusion comes from the way taxes are accounted for. This study discusses the premises under which taxes paid by road users should or should not be considered as specific to the road sector and, thus, put in balance with public expenditure also specific to the road sector. It then proposes an account of this balance and concludes that: (i) as a whole, the road sector is amply a net contributor to the Treasury, (ii) the specific taxes and fees paid by trucks cover the public expenditure on road maintenance and operation and almost all investment expenditure that could be allocated to trucks, and (iii) cars and light commercial vehicles pay a disproportionate share of the total costs that, alone, outweighs all public expenditure on the road sector.

Road transport is heavily taxed in most European countries. France is no exception. Just as in many other countries a debate is raging there about whether or not road users are paying a fair share for the costs they impose on the nation or at least on the Treasury. It is common wisdom in France that road use is subsidized, but this assertion is usually not based on facts, as if no data was available. However, cost allocation studies have been carried out, tax revenues have been reported, and officially published data give almost all the necessary elements to settle the debate. In our opinion, the confusion comes from the way taxes are accounted for.

After a quick presentation of the relative weight of road transport within the transport sector in France, this report discusses the premises under which taxes paid by road users should or should not be considered as specific to the road sector and, thus, put in balance with the public expenditure also specific to the road sector. It then proposes an account of this balance, allocating both costs and revenues among the various road users (i.e., private cars, trucks, light commercial vehicles, and buses).

ROAD TRANSPORT IN FRANCE

What is the relative weight of road transport as compared to the rest of the transport sector in France? Such a question may have many answers. This weight could be measured in terms of traffic, in terms of value added or in terms of total sales. Comparisons in terms of traffic may make some sense for passenger transport, although one passenger-km in the Lyons subway is not economically equal to one passenger-km by plane between Paris and Montpellier. For freight, the difference is even wider; 1 ton-km of coal on the Lorraine canal is not at all equal to 1 ton-km of *foie gras* in Paris traffic jams. Similarly, comparing values added (as they are reported in national accounts) would totally ignore the fact that most of the road transport activity takes place outside the contract carrier firms. Neither would it take into account the wide differences in degree of integration between say, road and rail. As opposed to rail, the value added in road transport does not include infrastructure costs nor most of maintenance and repair services that can be subcontracted. For these reasons, together with data of Gérondeau (*1*), we prefer to make the comparison in terms of total sales. Of course, this will bring about some double counting, that is, the transport of the intermediate goods consumed by the transport sector. This flaw would be an obstacle if we were to measure the weight of the transport sector in the economy. However, for the purpose of comparison between modes, it is not, to the extent that we can assume the degree of double counting does not widely differ from one transport mode to the other.

Table 1 gives a precise enough idea of the relative economic weights of the various transport activities in France. With 91 percent for road transport and 6 percent for rail transport, the relative share of road transport is certainly underestimated, since the only taxes that could be deducted were the taxes paid by road transport and since rail total sales include a significant portion of coach and truck services provided by SNCF, the French National Railroad Undertaking.

To derive comparable figures for the United States from the *Transportation Statistics Annual Report 1994* (*2*) it was necessary to overcome two minor difficulties. First, for the household expenditure on public transit (only 0.4 percent of the total), the report does not distinguish between road (bus) and rail; we assumed that half of the household expenditure on public transit goes to urban rail systems. Second, to avoid double counting, we assumed that federal, state, and local transportation revenue by mode was already accounted for in the form of taxes in the total sales of each mode, and thus should be subtracted from government total expenditure on infrastructure, to keep only the net expenditure.

The results of these calculations are presented in Table 1. It was no surprise to note the relatively much more important role played by air in the United States where distances are much longer than in France. What was unexpected is that the difference would be totally taken up by road and not rail. As a result, road plays a relatively larger role in France than in the United States.

In France, the relative share of rail transport has been steadily declining over the recent decades, especially for freight transport. For passenger transport, the introduction of the very fast trains (TGV) has somewhat slowed down the decline of rail, but not reversed the trend. Table 2 illustrates this evolution when measured, in terms of passenger-km, over the past decade.

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TABLE 1 Transport Expenditure in 1991 (in Billions of Dollars)

	France bi.$	France %	USA %
Total road transport (taxes excluded)	142.5 (1)	91%	88%
—*Freight road transport*	*45.0* (2)	*29%*	
—*Households personal vehicle*	*58.0*	*37%*	
—*Buses and commercial cars*	*19.3*	*12%*	
—*Insurance and social security*	*3.5* (3)	*2%*	
—*Roads*	*16.7* (4)	*11%*	
Rail	10.1 (5)	6%	6%
Subways	1.7 (6)	1%	
Air	1.8 (7)	1%	5%
Inland waterways	0.4	0%	1%
Total	156.4	100%	100%
Taxes on road transport	39.2	25%	

Sources: France: adapted from (3), pp. 70-71, 116-127. USA: adapted from Bureau of Transportation Statistics (2), pp.105-106, 122-123].
Notes: US$ 1.00 = FF 6.00
(1) All taxes are excluded. They would increase this total by 27%, i.e., 38.5 bi.$.
(2) Includes both private (in firm) and public (commercial) freight transport.
(3) Net loss for social security due to road accidents.
(4) Central and local governments expenditure on road operation, maintenance and construction. Franchised highways are included in freight transport and household expenditure on toll roads.
(5) SNCF total sales include 25% subsidy and a small amount of taxes and significant road transport services (parcel delivery and coach services) operated by SNCF.
(6) RATP total sales include bus transport services. We assume these are equivalent to expenditure by the metro systems in the rest of France. Public transit sales include more than 60% subsidy.
(7) Air Inter total sales include taxes.

The total tax revenues generated by the road sector in France amount to $38.5 billion. It largely exceeds central and local governments' expenditure on road operation, maintenance and construction: $16.7 billion. This, however, is true for many sectors of the economy, since public expenditure on education, security, welfare, and so forth, has to be financed out of general tax revenue. A more interesting question is whether or not the public expenditure on roads balances the revenue of the taxes that are specific to the road sector and, within the road sector, what cross-subsidies take place between the various uses of road infrastructure. To answer these questions, we must identify and measure the specific tax contributions of each road user and allocate the road public expenditure among these users.

ROAD TAXATION IN FRANCE

Driving a car is one of the three most heavily taxed activities in France, together with smoking cigarettes and drinking spirits. Whereas almost all other consumer goods bear only an 18.6 percent value added tax (VAT), these three products bear specific taxes, on top of the VAT. On the other hand, some cultural and agricultural products benefit from reduced VAT rates. The specific taxation borne by road users on top of the VAT is not earmarked for any specific use. Earmarking taxes is not common practice in France. What is meant here by road taxes is thus the specific taxes that are paid only by road users, over and above the common taxation of economic activity. Table 3 ranks road user taxes by magnitude of revenue accruing to all levels of government.

The Fuel Tax

The major road user tax is the fuel tax (Taxe Intérieure sur les Produits Pétroliers, TIPP). It is also a major source of revenue for the central government, as can be seen in Table 4. It accounts for more than 10 percent of central government tax revenue, mainly in the form of road fuels taxes. It represents two-thirds of the personal income tax and roughly equals the corporate income tax. One should note that the major single tax in France is the VAT, which accounts for 44 percent of the total central government tax revenue.

The fuel tax, which is collected at the refinery, also applies to home heating oil and to industrial fuel oils, although at much lower rates (see Table 5). There is also a significant difference in tax rates between gasoline and diesel oil. The tax on gasoline is almost twice

TABLE 2 Modal Shares of Passenger Traffic, 1982–1991

Year	1982	1986	1991
Car	80.7%	81.6%	82.6%
Bus	6.8%	6.2%	5.9%
Rail	11.3%	10.9%	9.9%
Air	1.1%	1.3%	1.6%
Total (billions of passenger-km)	574	632	725
Index	100	110	126

TABLE 3 Government Revenues from Road Specific Taxation in 1990

	millions US$	%
Total	22 281	100.0%
Road fuels taxes	16 263	73.0%
Tax on vehicle insurance	2 793	12.5%
Annual vehicle tax	1 693	7.6%
Vehicle registration fee	772	3.5%
Tax on corporate cars	378	1.7%
Drivers licenses	144	0.6%
Tax on transportation contracts	85	0.4%
Axle load tax	82	0.4%
Traffic citations	71	0.3%
Tolls	2 723	

Source: (3), pp. 128, 146, 156.
Note: US$ 1.00 = FF 6.00

TABLE 4 Central and Local Governments' Tax Revenue in 1989

	Dollar/capita	%
Central government total tax revenue	3 824	100%
Value Added Tax (1)	1 686	44%
Personal Income Tax	729	19%
Fuel Tax (2)	404	11%
Corporate Income Tax	404	11%
Other Taxes	601	16%
Local governments total tax revenue	674	100%
Annual Vehicle Tax	35	5%
License Plate & Driver's License	4	1%
Other Taxes	635	94%

Source:
Notes: US$ 1.00 = FF 6.00
(1) Part of this revenue comes from the VAT on the fuel tax itself.
(2) More than 3/4 of the revenue from the fuel tax is generated on the road

as much as the tax on diesel oil, and the gap is widening. This difference, which was intended not to overpenalize truck operators and freight transportation, explains the relatively high percentage of diesel-powered private automobiles in France (38 percent of new car acquisitions in 1991, 49 percent in 1994).

The relatively heavy weight of road fuels taxes is further increased by the incidence of the VAT.

The Specific Effects of the VAT on Road Fuel Taxes

The VAT is a tax on final consumption levied at each step of the production and distribution process. Producers pay the full 18.6 percent VAT on the intermediate goods they purchase. In turn, they collect an 18.6 percent VAT on the goods they sell and return this sum to the Treasury *after deducting* the amount of VAT they have already paid on their own inputs. As a result only the value added is taxed at each step, whereas excise taxation, imposed upon the total price of the intermediate good, accumulates along the production chain. The difference comes from the fact that the VAT is "deductible" by businesses and professionals. As it is smoothly passed on to the final consumer, the VAT introduces very little distortion in the production process. For this reason, it has gradually replaced almost all the excise taxes in France and in Europe.

The effect of the VAT on the price of road fuel consumed by private car owners is straightforward: it increases by 18.6 percent the final price of the fuel, production costs, distribution costs, margins *and fuel tax* included. As a result, the tax content (measured in percent) of gasoline prices in France is generally the highest in Europe (see Table 6). Gasoline is more expensive in Italy and Denmark, only because refinery and distribution costs are higher.

The effect of the VAT on the price of road fuels consumed by carriers as intermediate goods should, at the end, be the same as the one on the fuels consumed by private car owners. Carriers would pay the VAT on both the fuel and the fuel tax, and pass it on to the final consumer of the transport service. Things are not that simple however. For some reason, the VAT paid by carriers on transport fuels is not fully deductible. Until recently it was not at all. As a result, a portion of the VAT on transport fuels is no longer a tax on the value added but rather an excise tax that accumulates along the chain. We will come back to the implications of this peculiar VAT treatment.

Tax on Vehicle Insurance and Other Central Government Road Taxes

In order to compensate for the loss incurred by the national social security system because of road accidents, a special earmarked tax was imposed on vehicle insurance fees and its revenue transferred to the social security. Over time, this tax was increased much beyond the costs it was supposed to cover. The other central government road taxes only bring minor contributions to the Treasury. Among them, the axle load tax is an example of an internalizing tax that misses its target because of much too low rates.

Local Government Road Taxes

There are three local and subnational government road taxes: (i) the annual vehicle tax (*vignette*), (ii) the vehicle registration fee, and (iii) the fee for the issuance of new driver's licenses. Together, these taxes represent above 6 percent of the local governments' tax revenues (Table 4). The annual vehicle tax rates are decided locally. They depend on horsepower, age, and use of the vehicle. Vehicles more than 25 years old are exempt. The vehicle registration fee is paid when a new license plate is issued, that is, when a vehicle is put on

TABLE 5 Fuel Tax Rates in France as of January 1994

	US¢/liter	US$/gallon
Premium gasoline	60.99	2.31
Diesel oil	35.37	1.34
Industrial high sulfur content fuel oil	2.03	0.08
Industrial low sulfur content fuel oil	1.51	0.06
Domestic fuel	8.12	0.31

Source: Institut Français du Pétrole

TABLE 6 Retail Price of Premium Gasoline (in Dollars/1000 L), May 15, 1990

	Before tax	Taxes	Total	% Taxes
France	211	710	921	77%
Italy	271	908	1 179	77%
Denmark	274	720	994	72%
Portugal	270	623	893	70%
Ireland	306	680	986	69%
Netherlands	290	620	910	68%
Belgium	272	577	849	68%
Greece	220	457	678	67%
Spain	261	505	766	66%
FRG	259	487	746	65%
UK	264	473	738	64%
Luxembourg	285	362	647	56%

Source: *Bulletin pétrolier de la CEE* quoted by *Le Monde* , Paris, Aug. 11, 1990
Note: in dollars, exchange rates May 15, 1990

the road for the first time, when it changes owner, or when the owner changes residence from one county to another. The driver's license tax is paid when a new license is issued. If they do not lose this document, automobile drivers pay this tax only once in their lifetime.

THE ALLOCATION OF ROAD PUBLIC EXPENDITURE

Every year in France, the Institut National de la Statistique et des Études Économiques (INSEE) and the Observatoire Économique et Statistique des Transports (OEST) jointly publish the *Comptes des Transports*, which is the report of the National Transport Accounts Committee. This report (*3*) addresses important economic issues on all the transport modes, and among them, gives special attention to the allocation of road costs and revenues. The section devoted to this issue distinguishes between four categories of road users: (i) the private and commercial cars, (ii) the light freight vehicles, (iii) the trucks, and (iv) the buses and coaches.

The private and commercial cars category (voitures particulières et commerciales) is mostly made up of households' private cars and motorcycles. It also includes taxis and company cars. The light freight vehicles (véhicules utilitaires légers) are the pickups and vans used either by households or for commercial purposes. The trucks (transport routiers de marchandises) are the heavy freight vehicles of the company fleets and the carriers. The buses and coaches (bus et cars) are the large passenger vehicles used for urban public transport, for intercity traffic coach services, tourism, and employees transportation.

The total expenditure to be allocated includes investment, maintenance, administrative expenditure, and police for all levels of government. It also includes the expenditure by the franchised highways companies that are responsible for more than 20 percent of road investment in France (see Table 7).

The allocation of public road expenditure among road users results from a thorough cost allocation study carried out in the early 1980s published in 1986 (*4*) and updated since then to take into account the evolution of the respective traffics. This method allocates separately the responsibilities for expenditure on investment on maintenance and on operation and administration. It does so by taking into account the number of kilometers run by the various types of vehicles and variables such as axle load, overall size, speed, and so forth specific to each type of vehicle. The social security expenditure considered is the share of accident costs not compensated by the vehicle insurance companies. It is allocated among the vehicle classes according to available statistics on accident responsibility (Table 8).

The method used by OEST for allocating road costs between road users has been criticized in recent years. It certainly needs to be updated at least to ensure some coherence between the various methods presently in use in Europe. Such a task is much beyond the scope of our study. Our main focus was on the identification of road public revenues.

THE IDENTIFICATION OF ROAD PUBLIC REVENUES

There are two options to calculate the balance between what road users contribute to the government's budget and what they cost. In the first option, one could put on the government's revenue side all the taxes paid by road users, including the common taxes such as the normal VAT and the corporate income tax paid by road construction firms. In this case, one has to put on the government's expenditure side all the costs such as the cost of the courts dealing with road related litigation, or the cost of the primary education that benefited the road workers and so forth. This would be both a cum-

TABLE 7 Distribution of Road Expenditure by Type and by Entity

	Operation	Investment	Total
Central Government	14%	4%	18%
Local Government	35%	32%	67%
Franchised Highways	5%	10%	15%
Total	54%	46%	100%

Source: adapted from (3), p.71
Note: Operation include maintenance, administrative expenditure and police

TABLE 8 Allocation of Road Public Expenditure for 1990 (in Millions of Dollars)

Vehicle Class	Car	Pickup-Van	Truck	Bus-Coach	Total
Road Expenditure by Governments	7 699	1 793	5 457	510	15 460
— (Allocation Key)	49.8%	11.6%	35.3%	3.3%	100%
Social Security	829	56	123	14	1 022
VAT on Road Exp.	1 153	269	818	76	2 316
Total Public Expenditure	9 682	2 118	6 398	600	18 798

Source: (3) pp.73, 156
Note: US$ 1.00 = FF 6.00

bersome and precarious task. In the second option, one would put on the government's revenue side only the taxes paid only by road users. And vice versa, on the government's expenditure side are only the direct costs of providing roads. In this case, the common taxes paid by road users, just like those paid by any other citizen, are not considered as government's revenue from roads but as constituent of the costs of using roads.

In order to implement the second option, it is necessary to clearly distinguish between common and specific taxation.

Common Versus Specific Taxation

The public administration performs various functions: some for the common interest of the nation or the community, others in the interest of a specific portion of it, for example, a given socioeconomic group, or a limited geographic area. Performing these functions entails expenditure: the wages of the civil servants, the purchase of goods and services. With the exception of some public services which beneficiaries can be directly charged for (e.g., public transport, water supply), to finance its expenditure, the public administration can only resort to taxes, or to inflation that is a disguised tax or to borrowing that is a postponed tax.

Taxation can take various forms. Depending on whether it bears in an undifferentiated manner upon all economic activities or upon a few limited ones, one can distinguish, at least theoretically, between common and specific taxation. On equity grounds, one may prefer that those functions the public administration performs for the common benefit be financed out of common taxation, and that those functions that are performed for only the benefit of a well defined social group or of a specific economic activity be financed by taxes borne specifically by these groups or activities. Unfortunately, efficiency dictates that functions for the common benefit be financed out of taxes on goods for which demand is the least elastic.

From an equity perspective, the incidence of common taxation upon a given good or service could represent the collective cost of the administrative actions (justice, police, education) that make possible the production of this good or service. To take an example, when I pay my barber $20 for a haircut, the $6 to $8 of taxes (income tax, property tax, sales tax, etc.) incorporated in this price represent my contribution to the costs incurred by the government to ensure that the barber will accept my $20 bill and not demand a payment in kind, or to make it possible to bring him to court in case he has cut my ear. These are the common functions of the public administration that are paid for through common taxation. These taxes are not a mere transfer; they represent a real cost. If there were no barbers, we would need less bank notes and less judges.

Conversely, when I pay $20 for a bottle of whiskey, on top of the $3 to $4 of common taxes that help guarantee that the product really corresponds to the label on the bottle and that the merchant will accept my $20, bill another $8 of specific "spirit tax" is collected for other purposes, maybe to discourage consumption or to compensate for the social costs of alcoholism.

Unfortunately, reality does not fit well into this simple dichotomy. It is often impossible to identify the direct and indirect beneficiaries of public action, practically or even conceptually. Moreover, public interest very often coincides with the interests of the individuals directly concerned. This is the case of the subsidized vaccine that protects the person who got the shot, at the same time preventing the disease from spreading. By the same token, the incidence of common taxation is never perfectly evenly spread. Taxes bear necessarily more on some activities than on others, or on some groups of the population than on other groups.

In France it is, however, reasonable to put in the "common taxes" category taxes such as the corporate income tax that is imposed upon all firms making profit, or such as the VAT that is indifferently paid by all final consumers of almost any good or service. For this reason, in the section above, we kept the VAT on road construction as a part of the total cost of providing the road. For the same reason, in the rest of the calculation, we will not consider the VAT at normal rates as a transfer that should be accounted for on the side of the government's road revenue.

As mentioned above, in France there are no taxes earmarked for road expenditure. Nevertheless, road transportation as an activity is subject to a very specific treatment on behalf of the Internal Revenue Services. Specific taxes apply that are not minor sequels of the pre-revolution tax system, and even the common tax, the VAT, does not operate in an ordinary way when it applies to the road transport sector.

Road Users' Contributions

The special insurance tax mentioned above is definitely a contribution specific to the road sector. It is imposed only on road vehicle insurance and can be put in balance with the public expenditure on road accidents. The VAT paid by road users on their insurance bill is calculated on the total cost of the insurance, including the special tax. For this reason we consider the part of the VAT bearing upon the special tax as a contribution specific to the road users. The special insurance tax and its VAT account for $2793 million + $520 million.

The investment and operation expenditures of the franchised highway companies (most of which are semipublic) were accounted for in the public expenditure on roads. We thus take toll revenues into account on the contribution side. Together with minor specific taxes, these account for $6349 million.

The fuel tax together with the VAT bearing on the fuel tax part of the fuel price are both specific contributions of the road sector.

At the end, they are paid by the final consumer of road services. They account for $16,263 million + $3,025 million.

The peculiar thing with the VAT on fuels paid by the carriers is that it is only partially deductible. Until 1982, the VAT on fuels was not deductible by carriers. Since then, the carriers have been progressively allowed to deduct a larger share of the VAT they pay on fuels, and it was planned that, by 1994, the VAT on fuels would be completely deductible. In 1990 it was not, and carriers paid it. Since they did not get it totally refunded, they added it to their costs where it was again taxed by the VAT as if it was a value added. This is why the nondeductible VAT should be accounted for as a specific road tax when it is paid by carriers together with the VAT that bears upon this fake VAT. According to available statistics this nondeductible VAT summed up to: $586 million + $1950 million for the pickups, vans, trucks, and buses and coaches. However, these statistics do not distinguish between what is paid by households and what is paid by carriers. What is paid by household should not be deducted since it is a common tax paid on final consumption, whereas what is paid on inputs by the carriers should be deducted to avoid double taxation. Based on household expenditure data we estimated the VAT paid by pickup and van owner households to be 120 + 332 millions of dollars to be subtracted from the nondeductible VAT estimate for pickups and vans. We also assumed that all trucks belonged to carriers and all cars to households.

This false VAT, that is in fact an excise tax specific to the transportation industry, when it is passed on to the consumer, is in its turn increased by the normal VAT that bears upon it. This adds another $386 million to the specific contributions of the road sector.

Another specific road tax was the differential of VAT tax rate discriminating against household cars. The rate on private cars used to be 25 percent. For harmonization reasons within the European community, this special rate has now been abandoned, but in the reference year of our study it still was 22.5 percent. The differential of VAT rate, which we consider as a specific road tax, provided the government an additional $568 million in revenue.

Table 9 sums up all the revenue as specific contributions from the road sector. It adds up to $31,978 million.

Finally, because it was not possible to get separately the total sales of the urban public transport services by bus, we could not estimate the subsidy embodied by the VAT at reduced rates (generally 5 percent) that benefit the bus riders. This subsidy could amount to $500 million. However, urban transit is a very special sector, with massive transfers and cross-subsidies. It would require specific research, beyond the scope of our study.

BALANCE ACCOUNT OF ROAD PUBLIC EXPENDITURE AND REVENUE

It is now possible to compare public expenditure and revenues. This is done in Table 10 where the balance is calculated together with the revenue/expenditure ratio. This table suggests three conclusions: (i) as a whole, the road sector is amply a net contributor to the Treasury; (ii) the specific taxes and fees paid by trucks cover the public expenditure on road maintenance and operation that could be allocated to trucks and almost all investment expenditure; and (iii) cars

TABLE 9 Road Public Revenue by Source for 1990 (in Millions of Dollars)

Vehicle Class	Car	Pickup-Van	Truck	Bus-Coach	Total
Special Insurance Tax	2 244	277	246	26	2 793
VAT on Insurance Tax	417	52	46	5	520
Tolls & Other specific taxes	3 830	385	1 844	290	6 349
Fuel Tax	11 526	2 153	2 343	242	16 263
VAT on Fuel Tax	2 144	400	436	45	3 025
Non Deductible VAT on Fuels*		411	156	19	586
— Of which households		-129			-129
Other Non Deductible VAT*		517	1 039	395	1 950
— Of which households		-332			-332
VAT on Non Deductible VAT		87	222	77	386
Additional VAT on cars**	568				568
Total	20 729	3 819	6 331	1 098	31 978

Source: Adapted from (3) pp.156.
Note: US$ 1.00 = FF 6.00
*Note: this figure includes VAT paid by households owning pickups and vans that should not be considered as a road specific tax. It is estimated in the line below.
**Note: Cars are subject to a higher rate of VAT (22,5%). The difference is considered as a specific road tax and reported in this line.

TABLE 10 A Balance Account of Road Public Expenditure and Revenue for 1990 (in Millions of Dollars)

Vehicle Class	Car	Pickup-Van	Truck	Bus-Coach	Total
Public Expenditure on Roads	-9 682	-2 118	-6 398	-600	-18 798
Road Specific Public Revenue	20 729	3 819	6 331	1 098	31 978
Net Balance for the Treasury	11 047	1 701	-67	498	13 179
Revenue/Expenditure ratio	2.1	1.8	1.0	1.8	1.7

Note: US$ 1.00 = FF 6.00

TABLE 11 A Balance Account of Road Accidents for the Public Sector in 1990 (in Millions of Dollars)

Vehicle Class	Car	Pickup-Van	Truck	Bus-Coach	Total
Special Insurance Tax	2 244	277	246	26	2 793
VAT on Insurance Tax	417	52	46	5	520
Social Security Expenditure on accidents	-829	-56	-123	-14	-1 022
Net Balance for the Treasury	1 832	273	168	18	2 291
Revenue/Expenditure ratio	3.2	5.9	2.4	2.3	3.2

Note: US$ 1.00 = FF 6.00

and light commercial vehicles pay a disproportionate share of the total costs that outweighs all public expenditure on the road sector and leaves the Treasury with a substantial benefit.

We have mentioned above that the special insurance tax was first introduced as a compensation for the accident costs borne by the general Social Security system. If this justification was to hold by itself, the tax rates should be much lower in general, and greatly reduced for light commercial vehicles, as can be seen in Table 11.

CONCLUSION

Despite its internationally praised railway network, France's transportation sector is even more dependent on roads than its American counterpart. Road transportation in France represents 91 percent of the total expenditure in the transport sector, whereas its share is only 88 percent in the United States.

Although, in France, no taxes are earmarked for road construction or maintenance, road transportation is heavily taxed over and above the common VAT borne by all goods and services sold in France. In addition to the taxes that are specific to the road sector, a special treatment is applied to its VAT that increases even further the transportation sector–specific contribution to the Treasury. As a result this contribution largely exceeds the total public expenditure on roads by a 1.7 ratio.

Another finding is that the various road users are treated very differently. Whereas, on the one hand, private cars and light commercial vehicles pay a disproportionate share, trucks, on the other hand, break almost even.

Some believe this excess fiscal contribution of automobile owners is small compared with the external costs they impose on society through pollution, noise, and accidents. This may be true, but it is another story.

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Publication of this paper sponsored by Committee on Taxation and Finance.

AM/PM Congestion Pricing with a Single Toll Plaza

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In an effort to reduce queuing delays at toll booths, many toll facilities now collect the toll only in one direction. In fact, many older facilities have removed existing toll plazas/barriers, and many newer facilities are constructing only a single plaza/barrier. Unfortunately, this makes it difficult to charge time-varying tolls in both directions even with electronic toll collection since it is unlikely that all vehicles will be equipped with this technology. This study explores how this difficulty might be overcome.

When toll facilities were first constructed and for many years thereafter it was common to collect tolls from vehicles traveling in both directions. Indeed, this approach is quite natural since in many cases it is not necessary to use the same facility in both directions. Unfortunately, as the amount of traffic on these facilities increased, so did the amount of time spent in queues waiting to pay the toll. In an effort to reduce the amount of time wasted in queues (and reduce the cost of collecting the tolls) many facilities began collecting tolls in one direction only, charging the round-trip toll in that direction. This policy has worked so well that many facilities removed the second (unnecessary) toll plaza/barrier (e.g., the tunnels and bridges connecting New York and New Jersey, the Sumner/Callahan Tunnels in Boston). In addition, many newer facilities are being constructed with a single toll plaza/barrier (i.e., in one direction only).

Unfortunately, while this practice does seem to have worked well in the past, it has been argued that it makes it very difficult to implement some kinds of pricing policies. Recall that toll policies can be used in different ways to influence the decision to travel, destination choice, mode choice, route choice, and departure time choice (*1*). When tolls can be collected only in one direction it becomes impossible to use time-varying tolls to influence the departure time choices of people traveling in both directions.

At first glance, it would seem that this problem could easily be overcome using electronic toll collection (ETC) (*2*). However, since it is virtually impossible (at this point in time anyway) to require that all vehicles make use of ETC, it is not immediately clear that this technological fix is workable.

In this report we will discuss how ETC may make it possible to implement a.m. and p.m. congestion pricing even when there is a toll plaza/barrier in only one direction and all vehicles are not required to make use of ETC. In addition, we will discuss how this approach may correct some of the adverse distributional impacts of congestion pricing, eliminate the need to redistribute the toll revenues, and allay the fears [see, for example, Higgins (*3*)] that congestion pricing is unfair, discriminatory, regressive, coercive and anti-business. The approach we suggest for achieving these goals makes use of both time-varying tolls and time-varying subsidies, as discussed by Bernstein (*4*).

To illustrate the potential benefits of this approach we extend the traditional one-directional model (*5–9*) so that it can be used to study a.m./p.m. commuting. As it turns out, this is not equivalent to simply "considering the a.m. peak twice" for several reasons. First, as discussed by Fargier (*10*), the commuting schedule in the evening is different from that in the morning (e.g., there is no desired arrival time for the p.m. trip). Second, work-to-home trips often involve secondary trips (e.g., shopping, dinner) making the origin/destination, route and departure time choices more irregular. Third, a.m. and p.m. decisions are not independent (i.e., the decision you make in the a.m. affects the one you make in the p.m.).

This study begins with a description of the model itself. It then considers a.m./p.m. tolling with one plaza when there is only one relevant route. Next, it considers the implications of a.m./p.m. tolling on multiple routes. Finally, it considers a variety of implementation details and concludes with a discussion of future research.

THE MODEL

In order to get some insight into commuters' route and departure time decisions, we will work with a model with N homogenous commuters traveling between home and work. The decisions for a commuter are to choose both their a.m. and p.m. departure times and routes in order to minimize their round-trip travel cost. The travel cost is composed of the total travel time and the schedule delay (plus tolls if any).

$$C = \alpha[T(t_a) + T(t_p)] + (\Phi_a + \Phi_p) + (\tau_a + \tau_p) \quad (1)$$

where C is the travel cost; $T(t_a)$ and $T(t_p)$ are the travel times for the a.m. and p.m. trips; Φ_a and Φ_p are the a.m. and p.m. schedule delays; τ_a and τ_p are the a.m. and p.m. tolls (or subsidies); and α is the dollar value of travel time. There is a desired work schedule starting from t_a^* and ending at t_p^*. Whenever a person does not arrive on time or leave on time, a positive schedule delay is incurred.

Of course, the a.m. and p.m. schedule delays may or may not be correlated. For example, suppose people must work exactly 8 hr every day. This implies that the departure time choices for the morning and evening are perfectly correlated (i.e., a person that arrived 20 min late in the morning must leave 20 min late in evening). However, this situation rarely occurs. In most cases, the 8-hr work day can be viewed only as a loose constraint. That is, the departure time decisions for the a.m. and p.m. are not always perfectly dependent. In fact, in some cases they are independent. For example, some people have fixed start and end times for their work day. Hence, even

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if they arrive after 9:00 a.m. they do not get compensated for working after 5:00 p.m. For simplicity, here we assume that the schedule delays are completely independent. The a.m. schedule delay depends only on when the commuter arrives at work in the morning, and the p.m. schedule delay depends only on when he/she leaves from work in the evening. Therefore the schedule delays are given by:

$$\Phi_a = \begin{cases} \beta[t_a^* - (t_a + T(t_a))] & \text{if } [t_a + T(t_a)] < t_a^* \\ \gamma[(t_a + T(t_a)) - t_a^*] & \text{if } [t_a + T(t_a)] \geq t_a^* \end{cases} \quad (2)$$

and

$$\Phi_p = \begin{cases} \delta(t_p^* - t_p) & \text{if } t_p < t_p^* \\ \theta(t_p - t_p^*) & \text{if } t_p \geq t_p^* \end{cases} \quad (3)$$

where β and γ denote the dollar penalties for early and late arrivals to work, and δ and θ are the dollar penalties for early and late leaves from work. In addition, following notations for some important time points are introduced: t_j^0 = beginning of peak ($j = a, p$), t_j^e = ending of peak ($j = a, p$) and $\tilde{t}_a$ = a.m. departure time to arrive at work on time [i.e., $\tilde{t}_a + T(\tilde{t}_a) = t_a^*$].

We also assume that the time needed to travel in each direction can be modeled as a deterministic queuing process in which:

$$T(t_j) = D(t_j)/s, \; j = a, p \quad (4)$$

where s is the service rate (road capacity) and $D(t_j)$ is the queue length at time t_j. This approach is believed to represent actual travel time functions fairly well. Finally, we assume that in equilibrium no individual has any incentive to change his/her departure time or route choice. The equilibrium departure rates that arise from such a model are given by:

$$r_a(t_a) = \begin{cases} s\left(1 + \dfrac{\beta}{\alpha - \beta}\right) & \text{for } t_a \in [t_a^0, \tilde{t}_a] \\ s\left(1 - \dfrac{\beta}{\alpha + \gamma}\right) & \text{for } t_a \in [\tilde{t}_a, t_a^e] \end{cases} \quad (5)$$

and

$$r_p(t_p) = \begin{cases} s\left(1 + \dfrac{\delta}{\alpha}\right) & \text{for } t_p \in [t_p^0, t_p^*] \\ s\left(1 - \dfrac{\theta}{\alpha}\right) & \text{for } t_p \in [t_p^*, t_p^e] \end{cases} \quad (6)$$

OPTIMAL PRICING ON A SINGLE ROUTE

We first assume that there is only one route between work and home, and that there is only one toll plaza (in the a.m. inbound direction). As shown by equations (5) and (6), both the a.m. and p.m. departure rates are greater than the service rate before the desired departure time and smaller than the service rate after that time. Thus, the queues in both directions reach their maximums at the desired departure times. With these results, we can now consider how to construct pricing schemes that eliminate congestion in both directions. As it turns out, there are at least three optimal pricing schemes, each of which is discussed in detail below. The analytical expressions for these pricing schemes are given in Table 1.

Scheme 1: a.m. Toll and p.m. Toll

The first scheme is a traditional one in which commuters are charged positive tolls for both their a.m. and p.m. trips. The optimal toll structure is shown in Figure 1. Here $\lambda = \beta\gamma/(\beta + \gamma)$ and $\mu = \delta\theta/(\delta + \theta)$. The a.m. peak starts at t_a^0 and ends at t_a^e and the p.m. peak starts at t_p^0 and ends at t_p^e.

Under this scheme, the tolls are zero at the beginnings and the ends of a.m. and p.m. rush hours, and they reach the peaks at the scheduled arrival time t_a^*, and the scheduled departure time t_p^*. The merit of this pricing scheme is that it only charges commuters (i.e., people who travel during the rush hours); noncommuters (i.e., people who travel outside of the rush hours) can continue to enjoy their trips free of charge in both directions.

Though in theory the above pricing scheme can eliminate traffic congestion and has some nice properties, in practice it is not the preferable approach for two reasons. First, this type of scheme is subject to the criticisms that it is unfair, discriminatory, regressive, coercive, and anti-business (3). The average individual's share for this "tax" in above scheme is clearly greater than zero and it increases as the peak duration becomes longer. It is not clear how this toll revenue is redistributed to the society. Second, this scheme requires two toll plazas, one in each direction, to collect the tolls. Note that this problem cannot be overcome by ETC unless all vehicles are equipped since there would be no way to charge unequipped vehicles without the toll plaza. Hence, there would be no way to influence their behavior. In addition, equipped vehicles would pay higher tolls than unequipped vehicles and hence would be encouraged to stop using ETC. It is clear that this pricing scheme cannot be implemented without two enforcement barriers no matter whether there exists an ETC or not.

Scheme 2: a.m. Toll/Subsidy and p.m. Subsidy

The second scheme is designed to consider the two practical requirements: that there is no barrier for the p.m. outbound and that the toll revenue must be zero. By imposing these two constraints, the drawbacks of the previous scheme can be eliminated. The method for incorporating these constraints is to impose negative tolls (subsidies) on the p.m. outbound direction in which there is no toll plaza. Such a pricing scheme with tolls and subsidies, which is still optimal, is drawn in Figure 2.

In Figure 2, it is interesting to note that the a.m. toll can be positive or negative depending on the parameters. If $\lambda > \mu$, then all commuters arrive before $t_a^* - [(\lambda + \mu)/\beta](N/2s)$ and after $t_a^* + [(\lambda + \mu)/\beta](N/2s)$ will receive a subsidy and all others have to pay a toll. However, if $\lambda \leq \mu$, then all commuters must pay positive tolls in the morning.

It is also interesting to note that the toll revenue collected in the morning is redistributed to the commuters in the evening. It can be seen from Figure 2 that the total toll revenue is zero. Therefore there is no reason for people to view this type of congestion pricing as a tax. More importantly, the p.m. subsidy can be distributed without a toll plaza. Vehicles equipped with ETC will be able to receive the subsidy and unequipped vehicles will not. Thus, this will encourage people to participate in the ETC systems.

TABLE 1 Pricing Schemes for One Route

Pricing Schemes	AM Peak			PM Peak		
	time	toll/subsidy	sign	time	toll/subsidy	sign
Scheme 1	$t_a^0 \sim t_a^*$	$\lambda \frac{N}{s} - \beta(t_a^* - t_a)$	+	$t_p^0 \sim t_p^*$	$\mu \frac{N}{s} - \delta(t_p^* - t_p)$	+
	$t_a^* \sim t_a^e$	$\lambda \frac{N}{s} - \gamma(t_a - t_a^*)$	+	$t_p^* \sim t_p^e$	$\mu \frac{N}{s} - \theta(t_p - t_p^*)$	+
Scheme 2	$t_a^0 \sim t_a^*$	$(\lambda + \mu)\frac{N}{2s} - \beta(t_a^* - t_a)$	+ if $\lambda<\mu$	$t_p^0 \sim t_p^*$	$-\delta(t_p^* - t_p)$	–
	$t_a^* \sim t_a^e$	$(\lambda + \mu)\frac{N}{2s} - \gamma(t_a - t_a^*)$	+ if $\lambda<\mu$	$t_p^* \sim t_p^e$	$-\theta(t_p - t_p^*)$	–
Scheme 3	$t_a^0 \sim t_a^*$	$\lambda \frac{N}{s} - \beta(t_a^* - t_a)$	+	$t_p^0 \sim t_p^*$	$(\mu - \lambda)\frac{N}{2s} - \delta(t_p^* - t_p)$	– if $\lambda>\mu$
	$t_a^* \sim t_a^e$	$\lambda \frac{N}{s} - \gamma(t_a - t_a^*)$	+	$t_p^* \sim t_p^e$	$(\mu - \lambda)\frac{N}{2s} - \theta(t_p - t_p^*)$	– if $\lambda>\mu$

Scheme 3: a.m. Toll and p.m. Subsidy/Toll

An alternative scheme that may also meet the requirements of zero toll revenue and one barrier is illustrated in Figure 3. In this scheme, a.m. toll is positive during the entire morning rush hours (a pure toll) and this would simplify the toll collection for the a.m. trips. However the p.m. toll can either be negative during the whole rush hour (a pure subsidy) or be negative in some periods and positive in the others (a mixed toll and subsidy), depending on the relationship among the parameters. If $\lambda \geq \mu$, then p.m. toll is a pure subsidy structure which is desirable. If, however, $\lambda < \mu$, then during any period between $t_p^* - (\lambda - \mu)/(N/2s)$ and $t_p^* + (\lambda - \mu)/(N/2s)$ a positive toll is charged. Nevertheless, as can be seen in Figure 3, the total toll revenue is always zero regardless of the parameters.

Comparing Different Schemes

Though in theory all three of the above pricing schemes are socially optimal, Scheme 1 is the most difficult one to implement. However, it is worth considering the pros and cons of Schemes 2 and 3 in somewhat more detail. Depending upon the parameters, either Scheme 2 or Scheme 3 must have a mixed toll/subsidy structure for the same direction trips. In Scheme 3, there might exist some periods during which the p.m. tolls are positive but clearly such positive tolls cannot be collected without a toll plaza. On the other hand, though Scheme 2 could be operated from a purely technological standpoint, it introduces a nontechnological problem. Observe that, under the condition of $\lambda > \mu$, there are some periods in the a.m. and all the periods in the p.m. during which commuters are actually

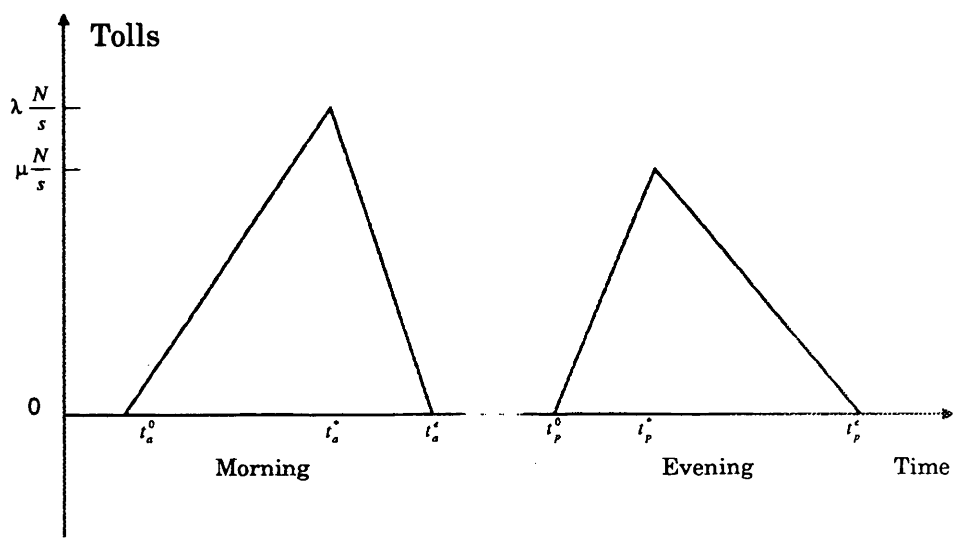

FIGURE 1 Scheme 1—a.m. and p.m. tolls.

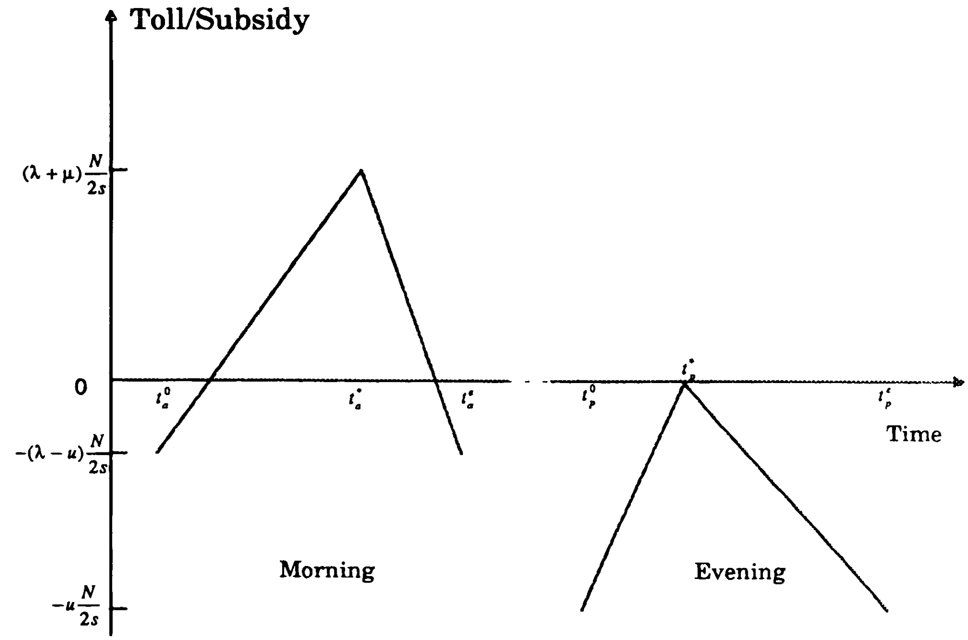

FIGURE 2 Scheme 2—a.m. toll/subsidy and p.m. subsidy.

being paid to use the road. Therefore it is possible that a person can make money simply by traveling back and forth during the subsidy periods. This means that Scheme 2 can encourage spurious trips (i.e., trips simply aimed at receiving subsidies). Though, as discussed later, there may be some ways to discourage such spurious trips using existing technologies, the incentive for such spurious trips should be kept as low as possible. Observe that a pricing program with a pure toll for the a.m. trips and a pure subsidy for the p.m. trips is implementable in our context. Such a pure toll/subsidy program may also discourage spurious trips because the a.m. toll may outweigh the p.m. subsidy.

It follows that if $\lambda < \mu$, then Scheme 2 should be chosen; if, however, $\lambda > \mu$, then Scheme 3 should be chosen. By this selection criterion, we can get a program with a pure toll for the a.m. and a

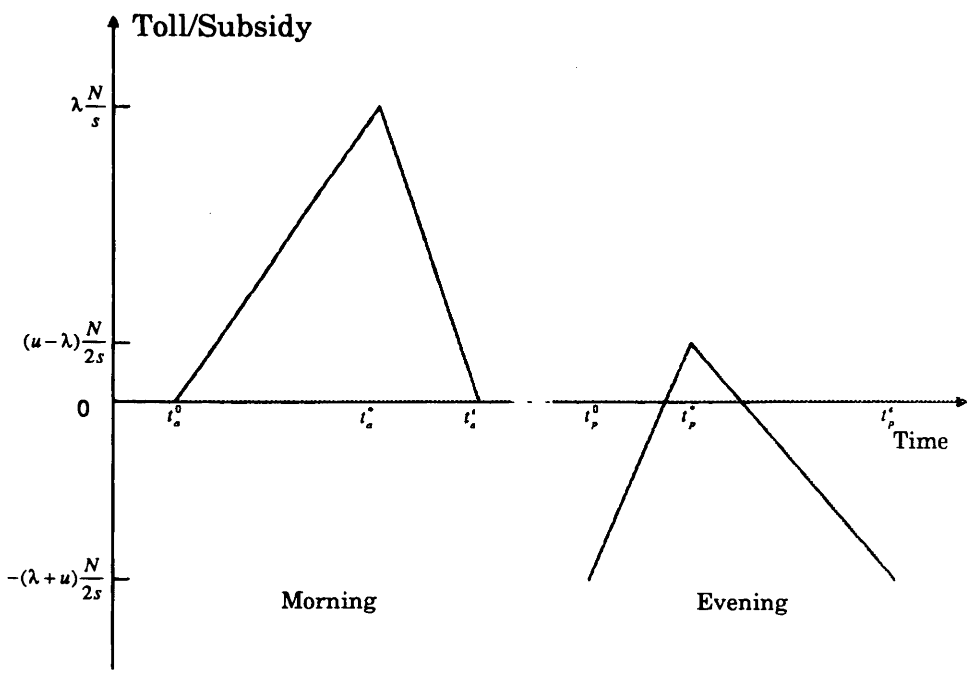

FIGURE 3 Scheme 3—a.m. toll and p.m. toll/subsidy.

pure subsidy for the p.m. When $\lambda = \mu$, there is no difference between Scheme 2 and 3. Observe that this selection criterion does not depend on the roadway condition (i.e., capacity). It is only determined by how people value the schedule delay and thus it is applicable anywhere.

A Numerical Example

In order to illustrate these ideas we consider a numerical example. We assume that $t_a^* = $ 9:00 a.m., $t_p^* = $ 5:00 p.m., $s = 6000$ vehicle-hr and $N = 10{,}000$ vehicles. For the shadow value parameters we use the oft-cited values for the a.m. trips (*11,12*) $\alpha = \$6.40$, $\beta = \$3.90$, $\gamma = \$15.21$. For the p.m. trips we arbitrarily use $\delta = \gamma = \$15.21$, and $\theta = \$3.00$. Here θ is assumed to be smaller than β because people can participate in secondary activities after work and before heading for home, such as shopping, dining and other social activities. This possibility decreases the shadow value of departing late (*13*).

In this case, the rush hour lasts from 7:40 a.m. to 9:20 a.m. in the morning and from 4:44 p.m. to 6:24 p.m. in the evening. Since $\lambda > \mu$ in this example, Scheme 3 is selected. As shown in Figure 4, the a.m. toll first increases smoothly from zero at 7:40 a.m., reaches the peak of \$5.17 at 9:00 a.m. and then falls to zero at 9:20 a.m. The p.m. subsidy begins with a maximum of \$4.17 at 4:44 p.m., falls to a minimum \$1.00 at the 5:00 p.m., and then increases and reaches the maximum again at 6:24 p.m.

We should compare our two-way work trip model with the one-way morning trip model. Table 2 shows the average costs per commuter under four scenarios: no toll, one-direction toll, two-directional tolls and two-directional toll/subsidy. From this table, it is clear that one-directional tolling is not efficient and can be improved (i.e., social savings increase from 27.7 to 50%).

OPTIMAL PRICING ON TWO ROUTES

We now consider a network in which there are two parallel routes. Let the capacity at Route 1 be s_1 and the capacity at Route 2 be s_2. When there is no congestion pricing, the equilibrium departure rates can be shown as follows:

$$r_{ia}(t_{ia}) = \begin{cases} s_i\left(1 + \dfrac{\beta}{\alpha - \beta}\right) & \text{for } t_{ia} \in [t_{ia}^0, \tilde{t}_{ia}] \\ s_i\left(1 - \dfrac{\beta}{\alpha + \gamma}\right) & \text{for } t_{ia} \in [\tilde{t}_{ia}, t_{ia}^e] \end{cases} \quad i = 1, 2 \tag{7}$$

and

$$r_{ip}(t_{ip}) = \begin{cases} s_i\left(1 + \dfrac{\delta}{\alpha}\right) & \text{for } t_{ip} \in [t_{ip}^0, t_{ip}^*] \\ s_i\left(1 - \dfrac{\theta}{\alpha}\right) & \text{for } t_{ip} \in [t_{ip}^*, t_{ip}^e] \end{cases} \quad i = 1, 2 \tag{8}$$

where $i = 1, 2$ is the route index. This result is similar to the single route case. It can also be shown that the beginning and ending times of peaks for two routes are the same:

$$t_{1j}^0 = t_{2j}^0, \text{ and } t_{1j}^e = t_{2j}^e \qquad j = a, p \tag{9}$$

The route split between two routes is proportional to the ratio of the capacities (s_1/s_2). This equilibrium split coincides with the system optimum. The intuition behind is clear: the larger the road, the more people are on that road.

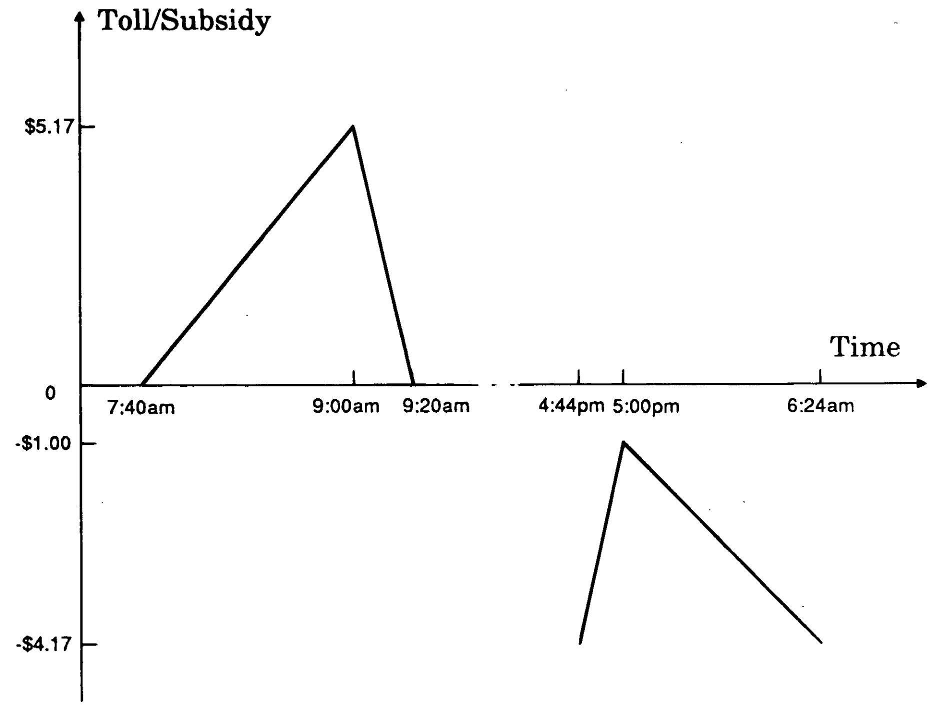

FIGURE 4 a.m. toll and p.m. subsidy.

TABLE 2 Average Costs Under Different Schemes

		Pricing Schemes			
		No Tolls	AM Toll only	AM & PM Toll	AM Toll & PM Subsidy
Schedule Delay	AM	\$2.59	\$2.59	\$2.59	\$2.59
	PM	\$2.09	\$2.09	\$2.09	\$2.09
Travel Time Cost	AM	\$2.59	0	0	0
	PM	\$2.09	\$2.09	0	0
Social Cost (exclude toll)		\$9.36	\$6.77	\$4.68	\$4.68
Commuter Cost (include toll)		\$9.36	\$9.36	\$9.36	\$4.68
Social Savings (%)		none	27.7%	50.0%	50.0%
Commuter Savings (%)		none	none	none	50.0%

This result seems to suggest that an optimal pricing scheme should not alter the users' route choices since they are already optimal. However, this observation may not be true in some cases when not all of the routes are priced. Once some routes cannot be priced, the best (i.e., system optimal) pricing scheme may be not achievable. Instead, the second-best should be used. We now consider a.m./p.m. pricing for two cases: when both roads can be tolled and when one must be left untolled.

Case I: Two Tolled Roads

In the first case we assume that both roads can be tolled. Specifically we assume that there are two toll plazas in the a.m. inbound direction, one in each road and there is no toll plaza in the p.m. outbound direction. Since there is no toll plaza in the p.m. outbound, subsidies are used to price the evening traffic.

Analogous to the one route case, there are two alternative optimal schemes combining tolls and subsidies, as given in Table 3. These two schemes are completely analogous to Scheme 2 and Scheme 3 in the single route case except that the service rate has been replaced by the summation of the two routes' service rates. Again, in order to get a pure toll/subsidy scheme, the selection between these two schemes depends on the parameters λ and μ. It is also interesting to see that the tolls or subsidies at two routes are always equal. Therefore the route split is unaffected since the equilibrium split is optimal.

In this case, we can extend above results to multiple routes in parallel. That is, they can be treated as one single route in which the capacity is the summation of all routes. The road usage is propor-

TABLE 3 Pricing Schemes for Two Tolled Routes

Pricing Schemes	AM Peak			PM Peak		
	time	toll/subsidy (route 1=route 2)	sign	time	toll/subsidy (route 1=route 2)	sign
Scheme 1	$t_a^0 \sim t_a^*$	$(\lambda+\mu)\frac{N}{2(s_1+s_2)}-\beta(t_a^*-t_a)$	+ if $\lambda<\mu$	$t_p^0 \sim t_p^*$	$-\delta(t_p^*-t_p)$	–
	$t_a^* \sim t_a^e$	$(\lambda+\mu)\frac{N}{2(s_1+s_2)}-\gamma(t_a-t_a^*)$	+ if $\lambda<\mu$	$t_p^* \sim t_p^e$	$-\theta(t_p-t_p^*)$	–
Scheme 2	$t_a^0 \sim t_a^*$	$\lambda\frac{N}{(s_1+s_2)}-\beta(t_a^*-t_a)$	+	$t_p^0 \sim t_p^*$	$(\mu-\lambda)\frac{N}{2(s_1+s_2)}-\delta(t_p^*-t_p)$	– if $\lambda>\mu$
	$t_a^* \sim t_a^e$	$\lambda\frac{N}{(s_1+s_2)}-\gamma(t_a-t_a^*)$	+	$t_p^* \sim t_p^e$	$(\mu-\lambda)\frac{N}{2(s_1+s_2)}-\theta(t_p-t_p^*)$	– if $\lambda>\mu$

tional to the capacity regardless of pricing or not. The starting times and the durations of the congestion are the same for all routes. Finally, the optimal time-varying tolls are also the same for all roads during any time of the day.

Case II: One Tolled Road and One Untolled Road

The more common situation in the real world is the existence of a mixture of tolled and untolled facilities. Therefore it is more important to study the case in which one route can be tolled and the other cannot be tolled. This may result because it is either physically impossible or publicly unacceptable to collect tolls on all facilities. More interestingly, this situation can also represent the single route case in which there are two types of toll booths: manual and ETC-only. The non-ETC lane and the ETC lane can be modeled as two routes and the decisions on equipping ETC tags or not can be seen as the choices between two different routes.

We assume, without loss of generality, that Route 1 can be tolled and Route 2 cannot. As shown in Figure 5, there is one toll station located on Route 1 a.m. inbound and one ETC reader on the Route 1 p.m. outbound. Since there is no enforcement mechanism at the ETC reader, the only practical pricing scheme must be an a.m. toll and p.m. subsidy scheme on Route 1.

There are four possible paths for a round trip as follows:

- Path 1: taking both Route 1 in the a.m. and p.m. ($1a \rightarrow 1p$);
- Path 2: taking both Route 2 in the a.m. and p.m. ($2a \rightarrow 2p$);
- Path 3: taking Route 2 in the a.m. and Route 1 in the p.m. ($2a \rightarrow 1p$);
- Path 4: taking Route 1 in the a.m. and Route 2 in the p.m. ($1a \rightarrow 2p$).

Once a toll/subsidy pricing program is implemented, the costs for these four paths are described as follows. On Path 1, a commuter must pay a toll in the a.m., receive a subsidy in the p.m. and incur no travel time cost on either trip. On Paths 2 and 3, there is no toll or subsidy but the travel time costs are nonzero. Though link $1p$ is used in the third path of ($2a$, $1p$), there is no subsidy received. As will be explained in the next section, only those persons who have paid the tolls in the a.m. can receive subsidies. On Path 4, a traveler must pay a toll in the a.m. and receive no subsidy and spend some waiting time in the p.m. Thus this path will never be used because its cost is always greater than the cost for Path 1.

We treat the above route choices as if they are made hierarchically. The first path's travelers are viewed as ETC users and the second and third paths' travelers as non-ETC users. The commuters first have to decide to use the ETC system or not. If they use ETC, then there is only one path. If not, they then have to choose between the second path and the third path. This structure is helpful because the congestion pricing scheme can only affect the first level decision—ETC or non-ETC. The route split between the second path and the third path for non-ETC users cannot be influenced since they are not controllable.

Let numbers of people using these three paths be N_1, N_2, and N_3. The equilibrium road usage can be derived as:

$$N_1 = (1 - \mathrm{A})\mathrm{N} \tag{10}$$

$$N_2 = \frac{s_2}{s_1 + s_2}\mathrm{AN} \tag{11}$$

$$N_3 = \frac{s_1}{s_1 + s_2}\mathrm{AN} \tag{12}$$

where $A = [(s_1 + s_2)\lambda + s_2\mu]/[(5s_1 + s_2)\lambda + (s_1 + s_2)\mu]$. The split between Paths 2 and 3 is based on the road capacities while the split between ETC and non ETC users depends on both the schedule delay parameters and the road capacities. This equilibrium route split for the non-ETC users is not optimal for most cases. This is because non-ETC users generate some unbalanced social costs on two paths while users only pay the private costs, which are equal on two paths. As a result, Path 2 is overused if the capacity of Route 1 is greater than the capacity of Route 2 and Path 3 is overused if the capacity of Route 1 is less than the capacity of Route 2. When the two routes have the same capacity, the equilibrium route split will be optimal.

The average toll for a commuter using Path 1 is

$$\bar{\tau} = \frac{\lambda AN}{s_2} - \frac{\lambda + \mu}{2}\,\frac{(1 - A)N}{s_1} \tag{13}$$

This toll revenue $\bar{\tau}$ can be positive, zero, or negative, depending on the relative capacities, (s_1/s_2), and the relative value of the schedule delay parameters, (μ/λ). For example, when the capacity of Route 1 is less than that of Route 2 (i.e., $s_1 < s_2$), the toll revenue is always negative regardless of the parameters of λ and μ. This also suggests that if we can only toll one road, we should toll the bigger road because tolling on the smaller road will result in a deficit. The optimal toll is given by:

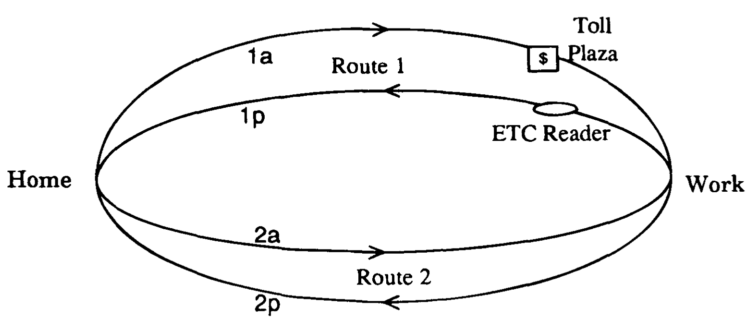

FIGURE 5 Two routes with one toll plaza.

$$\tau_a(t_a) = \begin{cases} \tau_a^0 - \beta(t_a^* - t_a) & \text{if } t_a \in [t_{1a}^0, t_a^*] \\ \tau_a^0 - \gamma(t_a - t_a^*) & \text{if } t_a \in [t_a^*, t_{1a}^e] \end{cases} \quad (14)$$

and

$$\tau_p(t_p) = \begin{cases} \tau_p^0 - \delta(t_p^* - t_p) & \text{if } t_p \in [t_{1p}^0, t_p^*] \\ \tau_p^0 - \theta(t_p - t_p^*) & \text{if } t_p \in [t_p^*, t_{1p}^e] \end{cases} \quad (15)$$

where $\tau_a^0 \geq \lambda(N_1/s_1)$ and $\tau_p^0 \leq 0$ are time-invariant uniform tolls and they must satisfy:

$$\tau_a^0 + \tau_p^0 = \left(\frac{\lambda}{s_2} + \frac{\mu}{s_1 + s_2}\right)AN \quad (16)$$

The pricing scheme for this case is suboptimal, in the sense that both the route split and the departure rate for the non-ETC users are not optimal. Because of the constraint of the optimal split between ETC and non-ETC, the toll revenue can no longer be set to zero.

IMPLEMENTING A.M./P.M. CONGESTION PRICING

There is one issue that needs to be addressed before a congestion pricing program with both tolls and subsidies is implemented. Observe that in the p.m. peak periods drivers are actually being paid to use the road. Hence, such a program, if implemented incorrectly, could generate spurious trips in which people drive simply to receive subsidies. Fortunately, there may exist some ways to prevent such trips [see Bernstein (*4*) for details] in general.

In the specific setting considered here, the most interesting method to discourage spurious trips is to give a subsidy only to those people who were tolled in the other direction. In such a system, if a driver would like to receive a subsidy in the evening peak, he/she would have to take an inbound trip in the morning and pay a toll first. Therefore it is important to have the information of the time and the route of the a.m. inbound trip for each vehicle traveled in the subsidized roads. Such a task is easy to implement using existing technologies. In fact, almost all ETC systems could be modified to record a.m. trip information and charge p.m. tolls (negative) based on the a.m. activities. However, it may be advantageous to use an ETC system with read-write capabilities rather than a read-only system. This is because with a read-write system the information can be recorded in the vehicles themselves rather than in a central computer. Thus there is no worry about "tracking" individual vehicles and invading anyone's privacy. In such a system, whenever a vehicle arrives at the subsidized outbound road in the p.m., the reader/writer on the roadside first checks the information stored in the in-vehicle unit. If it has been tolled in the inbound direction then a credit is refunded to the user's account. Any untagged or not qualified vehicle cannot receive a subsidy.

Of course, it is still possible to receive a pure subsidy even if a toll has been charged in the a.m. This occurs when the subsidy outweighs the toll. However, the time and money costs (e.g., the price of gasoline) would probably outweigh the net subsidy and, therefore, eliminate spurious trips. In addition, if there is a preexisting toll for the purpose of covering construction and maintenance costs, then the a.m. toll may be high enough during any periods to offset the p.m. subsidy.

CONCLUSION

This study explored two-directional congestion pricing for work trips. It extended a previous one-way home-to-work model to a two-way home⇔work model. It showed that by carefully designing a scheme combining tolls and subsidies, a two-directional pricing program could be implemented with one barrier only. Such programs might also assuage some of the opponents of congestion pricing. However, a great deal of further research on dynamic travel behavior is needed before any final conclusion can be drawn.

First, the model needs to incorporate the elastic demand. The travel cost will go down after implementing a toll/subsidy program and this cost reduction may attract more people. For example, noncommuting trips may switch from off-peak periods to peak periods and this can extend the duration of the peak substantially. In addition, it is also expected that some commuters switch from public transportation and this may offset the social savings in implementing such pricing programs.

Second, the schedule-delay function must be extended. Though separable schedule-delay functions greatly simplify the algebra and do yield some insights, it remains unclear how many of the results obtained here rely on this special piecewise linear function.

Third, we need to consider other toll structures besides our continuously time-varying toll/subsidy scheme. In particular, we must consider the step toll/subsidy in which the toll/subsidy is constant for some time intervals because such schemes are likely to be better understood by travelers.

Fourth, it has been assumed that commuters have the same characteristics, such as their work schedule time, their value of travel time, and their value of arriving late. This is clearly not the case in the real world. The extension to treat commuter heterogeneity is very important because it can help us understand how commuters respond to the pricing. The essential insight is that we need to model individuals' decisions instead of an average user's behavior so that the equilibrium can be sustained.

Finally, we need to extend this work to general networks. Simultaneous route and departure time choice equilibrium models (SRD equilibrium models) are now being developed (*14*). Further research needs to be done to apply these models to the study of congestion pricing.

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Publication of this paper sponsored by Committee on Taxation and Finance.

Socioeconomic Considerations of Road Impact Fees

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Unsophisticated applications of road development impact fees have adverse socioeconomic impacts. This occurs when road impact fees are not calibrated to account for variation in household commuting trip lengths by household income proxied by house size in square meters, or when such fees do not account for the variation in work trip generation rates by house location with respect to transit station distance. The purpose of this study is to indicate in what ways unsophisticated fees have adverse socioeconomic effects and pose reasonably straightforward ways in which to correct for those effects. Failure to make these adjustments could lead to inequitable and inefficient road impact fee programs that may result in more fiscal harm than good.

Development impact fees are one-time charges assessed against new development to generate new revenue to pay for new or expanded facilities to accommodate this new development. By some estimates, more than $1 billion annually is collected from transportation facility development impact fees (*1*).

To pass judicial muster, development impact fees should be consistent with several criteria (*2*). First, local governments must be able to reasonably associate new development with the need to expand facilities. Second, the cost of new or expanded facilities needed to accommodate new development must be reasonably estimated. Third, the share of such cost that may be financed from extrajurisdictional sources and locally dedicated or available funds must be accounted for. The result of these steps is the impact cost associated with new development. A final step estimates the present value of the stream of past and future tax payments that may be made by new development to help finance new or expanded facilities. These "credits" are subtracted from the impact cost to yield the impact fee level that should be assessed.

In the context of road impact fees, defensible impact fees are driven by the following general formula:

$$\text{Fee}_i = [(\text{Trips}_i)(\text{Trip Length}_i)(\text{Cost/Trip km})] - \text{Credits}_i$$

where

Trips_i = peak hour or average daily new trip generation by land use *i*,
Trip length_i = average new trip length by land use *i*,
Cost/Trip km = cost per trip kilometers of highway capacity, and
Credits_i = revenue credit per trip km by land use *i*.

A critical factor in this formula is the nature of the land use being assessed. Impact fees for nonresidential land uses are typically calibrated by the size of development, usually in units of floor area. For instance, as new trips and trip lengths vary by kind and size of shopping centers, so should the impact fees levied.

For residential impact fees, the situation is entirely different as fees are usually calculated on a purely per unit basis, although the type of residential use may be categorically differentiated as being single family or multifamily. When road impact fees are calculated in this manner, two important socioeconomic impacts are possible:

- House size regressivity
- Mode split inequity.

HOUSE SIZE REGRESSIVITY

Consider single family detached homes. The standard road impact fee formula is based on the trip generation and trip lengths for the average single family home within a community. Obviously, this means that certain types of single family homes that generate more trips or longer trip lengths than average are subsidized by single family homes that generate fewer trips or shorter trip lengths than average. This could mean that larger homes located farther away from work centers are subsidized by impact fees paid by smaller homes located closer to work centers. Moreover, homes located away from transit facilities—typically larger and more expensive homes—are likely to generate more and longer trips than homes located closer to transit facilities—typically smaller and less expensive homes. In effect, road impact fees based only on the average size of a single family unit are regressive because lower valued homes occupied by lower income households with smaller road impacts pay proportionately more than higher valued homes occupied by higher income households with greater road impacts.

We tested these general assertions using the 1985 *American Housing Survey* (AHS). The 1985 AHS national sample is the most complete source of information on household socioeconomic characteristics and commuting behavior. Although the 1990 *Nationwide Personal Transportation Study* and the 1990 *Detailed Census of Population and Housing* are more recent and larger samples, neither of these data sources can be used to correlate total household commuting distance to house size. The 1985 AHS is also decomposable into reasonably small geographic units. For this example, we selected those 1985 AHS records representing owner-occupied housing units located within the urbanized portions of metropolitan statistical areas but outside central cities. These households represent the urbanized suburbs.

Four variables are used: (1) total household commuting distance, which is the sum of each respondent's estimated commuting distance by household; (2) total household income; (3) house size in

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TABLE 1 Commuting Distance and Socioeconomic Relationships

Dependent Variable	Independent Variable: House Size, Square Meters	Household Income	House Value
Total Commuting Distance	1.2087 (t = 1.722) (n = 6,217)		4.3297 (t = 9.127) (n = 6,475)
House Size, Square meters		32.8868 (t = 28.808) (n = 8,458)	49.5017 (t = 40.845) (n = 8,616)
Household Income			16277.401 (t = 43.202) (n = 8,865)

Source: *American Housing Survey 1985*, national sample of owner-occupied households in urbanized areas of metropolitan statistical areas outside of central cities. Includes multiple wage earner-commuter households. Independent variables were transformed to natural logarithms.

square meters; and (4) self-assessed house value. Table 1 shows the following relationships.

We found that:

- Household income is positively associated with house value.
- Household income is positively associated with house size in square meters.
- House size in square meters is positively associated with house value.
- Total household commuting distance is positively associated with house value.
- Total household commuting distance is positively associated with house size in square meters.

Suppose a local government has a peak hour–based road impact fee of $60 per trip km, the average one-way commute trip is 27.4 km, and the peak hour trips generated per home is 1.0. This is just slightly less than the 1.02 reported by the Institute of Transit Engineers (*3*). Table 2 demonstrates the regressive effect of such a fee basis. It also shows what a fee should be if based on single family house size.

MODE SPLIT INEQUITY

It is almost axiomatic that the closer a home is to transit the more likely that it will use transit. It is equally axiomatic that such a home is less likely to generate automobile trips. Most road impact fee programs do not consider the rate of public transit use with respect to transit station distance. Thus, single family homes constructed near transit stations are not credited for their reduced impact on roads.

Table 3 illustrates this relationship for one urban county, DeKalb County, Georgia, which is served by the Metropolitan Atlanta Rapid Transit Authority's (MARTA) heavy rail system. Data are from 323 block groups as defined for the 1990 Census. The dependent variable is the percent of total work trips generated by households using nontransit modes. The independent variable is the distance of block group centroids from the nearest MARTA heavy rail transit station. This is easily measured using Atlas*GIS, a desktop geographic information system (GIS), with census TIGER files for DeKalb County and geocoded MARTA transit stations. Figure 1 shows block group proximity to transit stations as measured with the GIS. Table 4 applies these trip generation adjustment factors to transit station distance. There is an apparent relationship between transit station accessibility and automobile-related work trip

TABLE 2 Subsidy Gains and Losses by House Size

House Size in Square Meters	Trip Km	Standard Impact Fee	House Size-Based Impact Fee	Subsidy Gain (Loss)
50	7.3	$1,650	$438	($1,212)
100	14.7	$1,650	$882	($828)
150	22.0	$1,650	$1,320	(330)
200	29.3	$1,650	$1,758	$108
250	36.7	$1,650	$2,202	$552
300	44.0	$1,650	$2,640	$990
400	58.7	$1,650	$3,522	$1,872
500+	73.4	$1,650	$4,404	$2,754

TABLE 3 Automobile Work Trip Reduction Associated with Transit Distance

Regression Measure	Result (natural log)	Result (linear)
Constant	0.83537	0.85316
Standard error	0.09411	0.09814
R-Squared	0.2108	0.1417
Observations	323	323
Coefficient (km to station)	0.0555	0.0171
Standard error	0.0059	0.0015
T-ratio	9.261	7.280
Significance	< .0005	< .0005
Mean dependent variable	.906	.906
Mean independent variable	1.267	4.910
0 km from MARTA Station	83.5%	85.3%
1.5 km from MARTA Station	85.8%	86.9%
3.0 km from MARTA Station	89.6%	88.5%
4.5 km from MARTA Station	91.9%	90.1%
6.0 km from MARTA Station	93.5%	91.7%
7.5 km from MARTA Station	94.7%	93.4%
9.0 km from MARTA Station	95.7%	95.0%
10.5 km from MARTA Station	96.6%	96.6%
12.0 km from MARTA Station	97.3%	98.2%
13.5 km from MARTA Station	98.0%	99.8%
15.0 km from MARTA Station	99.0%	100.0%

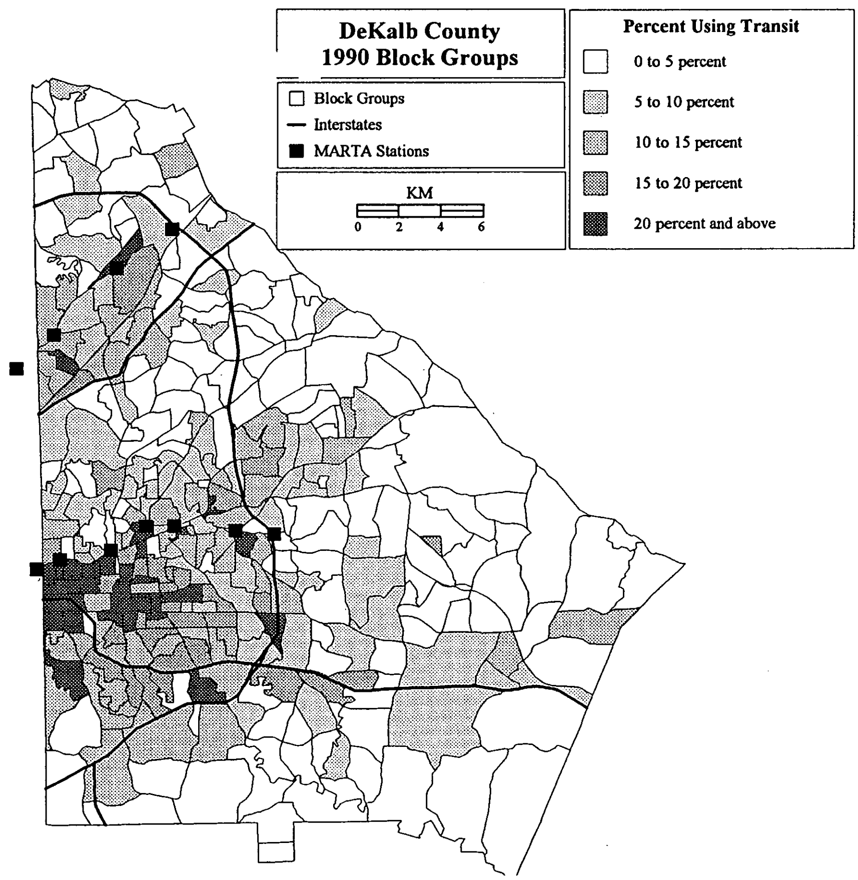

FIGURE 1 Block group proximity to MARTA transit stations.

TABLE 4 Effect of Transit Station Distance on Road Impact Fee

Block Group Distance	% Above Ave. Auto Work Trips Generated by Home	Standard Impact Fee	Distance to Station-Based Impact Fee	Subsidy Gain (Loss)
0 km	-7.0	$1,650	$1,534	$116
1.5 km	-5.0	$1,650	$1,571	$79
3.0 km	0.0	$1,650	$1,634	$16
4.5 km	1.0	$1,650	$1,671	($21)
6.0 km	3.0	$1,650	$1,698	($48)
7.5 km	4.0	$1,650	$1,718	($68)
9.0 km	5.0	$1,650	$1,735	($85)
10.5 km	6.0	$1,650	$1,749	($99)
12.0 km	7.0	$1,650	$1,761	($111)
13.5 km	7.0	$1,650	$1,772	($122)
15.0 km	8.0	$1,650	$1,782	($132)

generation, which is then logically related to the road impact fee level that should be assessed.

COMBINING SOCIOECONOMIC FACTORS

The coefficients of a bivariate regression equation can be used to refine road impact fee calculations to account for the effects of house size and house distance from public rail transit stations on road impacts. The formula would be:

$$\text{Fee}_i = (\text{Square meters}_i * 0.1468 * \text{Cost/Trip km}) \\ *\{0.835 + [\ln(\text{Transit Station distance}_i) * 0.0555]\}$$

For example, the impact fee for a 100-m^2 house located 1.5 km from a transit station would be:

$$\text{Fee} = (100 * 0.1468 * \$60) * [0.835 + (.4055 * 0.0555)] = \$755$$

The impact fee for a 400-m^2 house located 12 km from a transit station would be:

$$\text{Fee} = (400 * 0.1468 * \$60) * [0.835 + (2.48 * 0.0555)] = \$3,427$$

POLICY IMPLICATIONS

Standard road impact fee methodologies do not account for the effect of house size variation or transit station access variation on road impacts. The result is that most road impact fees are regressive with respect to house size and inequitable with respect to access to public transit. This further results in smaller homes built for lower income households located near transit stations subsidizing larger homes built for higher income households located farther away from public transit stations.

Road impact fee methodologies should be adjusted to reflect at least these two socioeconomic considerations. In addition, impact fee credit calculations should also account for variations in tax contributions (sales, gasoline, and property) by household type and location. These adjustments are relatively easy to make, as demonstrated in this study. It is possible that in the absence of such adjustments, road impact fees in certain situations may contribute to urban fiscal disparities already witnessed by many metropolitan areas in the United States.

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Publication of this paper sponsored by Committee on Taxation and Finance.

An Overview of the Russian Road Financing System

FRANCK BOUSQUET, CESAR QUEIROZ, AND OLEG SKVORTSOV

The maintenance of highways in Russia has been seriously neglected in recent years with widespread adverse effects on the general economy. Both the federal road network and the regional roads have deteriorated because of inadequate maintenance. As a result, there is a large backlog of road maintenance that should be undertaken as soon as possible to bring the roads up to a good condition. Historically, funds for construction and maintenance of federal roads and about 15 percent of regional roads (formerly designated as republic roads) came from the federal budget and earmarked road user charges, including an enterprise tax. Funding for the remaining 353,000 km of roads came from regional budgets. In April 1992, road funds were established to fund both construction and maintenance of federal and regional roads and in 1993 amendments to the Law on Road Funds earmarked specific taxes to each type of road fund. This study provides information on the Russian road network, describes the road funds at the federal and regional levels, and outlines possible changes in the road financing system, along with the weaknesses of these funds. The cost of overcoming this backlog during the period 1994–2000 is estimated at $4.8 billion (U.S.)/year, whereas the resources available to the federal and regional road funds are roughly $2 billion annually, thus a deficit of about $2.8 billion/year. Possible measures to overcome this deficit would include increasing collection of road user charges and raising financing by multilateral and bilateral agencies.

The Russian Federation, with a land area of 17.1 million km^2, is by far the largest country in the world, stretching across 11 time zones. According to the new Constitution of the Russian Federation (December 12, 1993), Russia is divided into 89 regions, called "subiekti" of the Russian Federation, comprising 21 republics, 10 okrugs, 49 oblasts, 6 krais, 1 autonomous oblast, and 2 cities (Moscow and St. Petersburg).

Russia has 489,059 km of public roads, of which about 274,609 km (56.1 percent) are paved. Only outside-town roads are considered public roads and classified as being in (i) federal property or (ii) regional property. Federal roads comprise 40,622 km (8.3 percent) of the public road network and 89.4 percent of them are paved, whereas regional roads make up the remaining 4,448,437 km (91.7 percent), and 56 percent of them are paved. In addition, there are about 450,000 km of unclassified enterprise roads and 700,000 km of mainly access roads. There is some local pressure for many of the enterprise roads to be transferred to regional authorities since they are more public than private roads. However, the regional authorities are reluctant to accept the responsibilities for these roads as many of them do not meet public road design standards and also because of the additional funding required for their rehabilitation and subsequent maintenance.

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Due to reduced funding for road maintenance and rehabilitation over the last few years, and the poor quality of road construction and maintenance works, there is a growing backlog of road rehabilitation. According to Rosdornii, a Russian Scientific Research and Production Highway Institute, about 25 percent of federal roads are in fair condition and basically do not require rehabilitation, and 38 percent are in poor condition and require rehabilitation or reconstruction.

DESCRIPTION OF THE RUSSIAN ROAD FINANCING SYSTEM

The federal road network is under the responsibility of the Federal Highway Department (FHD) which is a department of the Ministry of Transport (MOT). Federal road construction and large rehabilitation works are carried out by mainly regional contractors. Of the federal road network, 39 percent is maintained by autonomous federal road maintenance agencies, called *uprdors*, and 61 percent of this same road network, plus almost all regional roads (42,000 km), are maintained by regional highway administrations, called *Avtodors*, Regional Road Committees or Regional Road Administrations, through contracts with FHD.

In the Former Soviet Union (FSU), funds for construction and maintenance of federal roads and roughly one-third of roads in the republics, came from both the federal budget and a collection of road user charges, including an enterprise tax. In 1991, 55 percent of road funding came from the federal budget and 45 percent from road user charges; funding for the remaining 353,000 km of regional public roads came from regional budgets. About 30–50 percent of funding for agricultural roads in that year came from federal ministry of agriculture budgets, and the remaining non-public roads were financed by individual state collective farms or enterprises.

In recent years, a number of federal Extrabudgetary Funds (EBFs), including the federal road fund were created (*1*). In 1992, 17 federal EBFs operated in the Russian Federation. In addition, several hundred regional and local EBFs were created throughout the year. No data are available on these EBFs and the federal government is unable to keep track of them. The gross revenues of the federal EBFs amounted to 3.3 trillion Rb or 18.2 percent of the gross domestic product (GDP).

In October 1991, the Russian government decided to eliminate all budgetary funding of roads and replace this system with an expanded road user taxation system. The Federal Road Fund (FRF) and 87 Regional Road Funds (RRF) were thus established by the Law No. 4226-I, dated December 25, 1992, to fund construction, maintenance and rehabilitation of public (federal and regional) roads (*2*). The combined budget is approved annually (by the

Supreme Soviet in 1992 and by Presidential Decrees in 1993 and 1994). The first full year of operations for both FRF and RRF was 1993.

FRF

The FRF consists of a nationwide fuel and lubricant tax; a vehicle production tax; and enterprise, vehicle sales, and vehicle registration taxes in the cities of Moscow and St. Petersburg. The detailed sources for FRF are:

1. Fuel and lubricant tax: This is a 25 percent tax on gasoline, diesel fuel, lubricant oil, and compressed and liquefied gas. The tax is levied on 32 Russian refinery firms which are located in 20 oblasts, and on all their resellers (including cooperatives and small plants). In case of resale of oil and lubricants, corporations, enterprises, organizations, and entrepreneurs pay the tax on the difference between their price of sale [less value-added tax (VAT) and their purchasing price (less VAT)].

However, a recent decree No. 1008 (*3*), dated May 23, 1994, establishes that "in assessing the tax on fuel and lubricant sales, the tax base shall exclude turnovers of producing enterprises as well as of other economic entities involved in selling products to non-CIS countries at prices close to world levels." Therefore, there should be no tax on exported fuels or lubricants for the FRF, a decision which is supposed to have reduced the amount of FRF resources by about 8 percent.

2. Vehicle production tax: The six Russian vehicle manufacturing firms, VAZ, AZLK, GAZ, YAZ, IXE, and OKA are taxed (the tax rate is 35 percent). This tax is paid three times a month (on the 10th, 20th, and 30th), and the mechanism used to collect this tax is similar to the one for the FRF.

However, a new decree No. 2268, dated December 22, 1993, regarding the Budget of the Russian Federation in 1994, changed the allocation of this tax. Starting from the beginning of the second quarter of 1994, this excise on sales of cars to private persons goes to the Federal Budget of the Russian Federation and no longer to the FRF.

3. Enterprise, vehicle sales, and vehicle registration taxes in the cities of Moscow and St. Petersburg: Generally, enterprise, vehicle registration, and vehicle sales taxes go to regional road funds. The cities of Moscow and St. Petersburg, however, collect these taxes for the FRF. These contributions are significant, representing 54.9 billion Rb in 1993 (January 1993 prices).

Total FRF collections in 1993 were 311 billion Rb (in January 1993 prices), about $642 million (U.S) equivalent. Of these taxes earmarked for the FRF, 204.1 billion Rb came from fuel and lubricants tax, 52.1 billion Rb from vehicle production tax, and 54.9 billion Rb from the enterprise, vehicle sales, and vehicle registration taxes in the cities of Moscow and St. Petersburg. The 1993 actual collection of 311.1 billion Rb compares favorably with the 1993 budget of 264.0 billion Rb (January 1993 prices). Table 1 shows the FRF collections in 1993, by month and by tax, taking into account the inflation.

FHD has a three-level collection system, corresponding to the three different administrative-territorial divisions. Tax collection is enforced by Rosnalogsloujba, an organization located in Moscow and in each oblast and rayon in Russia, with roughly 200,000 employees on the whole and 570 in Moscow.

Federal Tax Service (FTS) and the corresponding regional tax agencies and inspections are responsible for collecting all kinds of taxes and controlling this process in accordance with the existing laws and regulations. Each quarter, FTS submits to FHD a report on

TABLE 1 Federal Road Fund Collections in 1993 (in Billions of Rubles)

Month	Fuel and lubricant tax	Vehicle production tax	Moscow and St Petersburg Collections	Total	Inflation index*	Total January 1993 Prices
January	10	1.7	4.6	16.3	126	16.3
February	15.1	4.8	4.4	24.3	162	19
March	28.9	9.7	9.5	48.1	190	32
April	39.8	14.4	19.9	74.1	221	42
May	32.8	9.9	7.7	50.4	264	24
June	38.9	10.2	9.6	58.7	310	24
July	37.8	10	8.6	56.4	370	19
August	76.6	17.8	16.3	111	478	29
September	70.8	17	13.4	101	578	22
October	128.8	30.4	27.7	187	693	34
November	137.8	28.7	28.7	195	832	30
December	128.7	12	17	158	998	20
Total (current prices)	746	166.6	167.4	1,080		**311**
Total (January 1993 Prices)	**204.10**	**52.14**	**54.92**	**311**		

* December 1992 = 100
In January 1993, 1 US$ = 484.2 Rb
Source: Road Fund Division

tax collections into RRFs and FRF by region. FRF's money is entered in accounts No. 750xxx in regional state banks and transferred to the account No. 750001 in the Central Bank of the Russian Federation. FHD receives data from this Bank on the entry of FRF's money to the account and compares these data with those given by FTS. The explanation of the differences is that almost all regions transfer FRF's money with delays.

RRFs

Taxes for the RRFs come from the following:

1. Enterprise tax: Most enterprises are taxed a minimum of 0.4 percent on sales, except commercial firms, for which the tax rate is 0.03 percent or higher. In most regions, this rate is now between 1.5 percent and 3.5 percent. This is a tax paid by all enterprises, organizations and entrepreneurs having the status of a "legal entity" in the Russian Federation. This status includes all enterprises with foreign investments, international corporations, and organizations involved in activity in Russia through their permanent representations. The following enterprises are exempt from the enterprise tax: collective farms, farms, corporations, joint-stock companies, and enterprises producing agricultural products provided that their receipts gained from farm produce sales constitute more than 70 percent of their gross receipts.
2. Vehicle sales tax: This tax is paid by enterprises, organizations which acquire vehicles through purchase, exchange, and leasing. The rate of this tax is set as a percentage of the sales price (less VAT) at: (i) 20 percent for trucks, vans, minivans, buses, and cars and (ii) 10 percent for trailers and semitrailers.
3. Vehicle registration tax: Levied on both firms and citizens, this tax ranges from 30 kopeks per horsepower to 7.15 Rb per horsepower per year. Because of inflation, these rates have been increased by the regions. This tax applies to all vehicles, including cars, motorcycles, scooters, and buses and other self-propelled machines using pneumatic tires. Tax enforcement comes mainly from the road police, called Gai. The Regions have the right to increase the rate of this tax. The date of the tax collection is fixed by Republican parliaments and corresponding authorities of the autonomous okrugs, krais, regions, and cities of Moscow and St. Petersburg.

RRFs also receive subventions and grants from the FRF (Figure 1). Moscow oblast, for example, receives 20 percent of all the collections from FRF (47,160 million Rb out of 223,637 million Rb). RRF grants, called "dotatsii," are based on the importance of the local economy of the region road network and the length of its network. RRF subventions, called "subventsii," are based on the number of kilometers of former republican roads which became regional roads, and the particular projects for which the region is requesting federal funding. With the breakup of the FSU, some former republic roads were reclassified as regional and are now under the oblasts' responsibility.

The State Duma annually votes the global amount of subventions and grants for each oblast. In 1993, the corresponding total amount was 537.8 billion Rb (current prices) and should be approximately 1540 billion Rb (January 1994 prices) in 1994. However, in some regions where the Uprdors are not only in charge of federal roads but also of regional roads, the Oblast Road Administrations have to redistribute to the Uprdor a part of the subventions received from

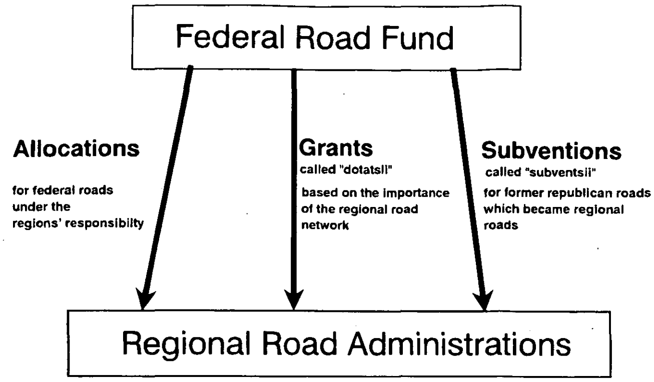

FIGURE 1 Financial transfers from Federal Road Fund to the regional road administrations.

FRF. This is for instance the case of Mosavtodor, the Moscow Oblast Road Administration.

The federal roads under the Uprdors' responsibility are financed by the FRF whereas the federal roads under the Regional Road Administration's responsibility are financed by the RRF through allocations from the FRF.

The regional roads under the region's responsibility and which were republican roads before the breakup of the FSU are financed by the subventions to the Regions from the FRF; lastly, the regional roads under the Uprdor's responsibility are financed by the Uprdors, which receive allocations from the regions for specific works.

The 1993 total RRFs actual collection was 417.9 billion Rb (in January 1993 prices), whereas the budget estimate was 182.5 billion Rb. Of the 417.9 billion Rb collected, 304.1 billion Rb came from enterprises tax, 90.3 billion Rb from vehicle sales tax, and 23.5 billion Rb from vehicle registration tax. Table 2 shows RRF Collections in 1993 by month, taking inflation into account.

CURRENT PROBLEMS IN ROAD FINANCING

Problems at the Resources Level

Tax Collections

There were substantial problems with tax collections when the new Road Fund system was introduced in 1992 because most of the taxes, including the fuel tax, were collected at the regional and local level. Many of these taxes were never collected, in part because: (a) the system of tax collection was inadequate, (b) some regions were reluctant to remit taxes to Moscow, and (c) many enterprises were in poor financial condition, and inter-enterprise indebtedness mounted rapidly. To meet the shortfall in funds for federal roads during the construction season, FHD borrowed from the Central Bank. Most of these loans have been repaid. Fuel taxes presently are mainly collected at the refinery level. Fuel and vehicle excise taxes are allocated to the FRF and taxes described as "road user" (enterprise) taxes, vehicle sales taxes and registration taxes are allocated to RRFs. Therefore, FHD does not need to rely on local authorities to remit taxes owed, whereas regional governments can put more pressure on enterprises located within their regions to pay their taxes. As of 1993, the regions were also given authority to raise the level of road user tax, vehicle sales tax and registration tax. These

TABLE 2 Regional Road Fund Collections in 1993 (in Millions of Rubles)

Month	Enterprise tax	Vehicle sales tax	Vehicle registration tax	Total	Inflation index*	Total January 1993 Prices
January	20203	4546	505	25254	126	25254
February	18689	7208	801	26698	162	20765
March	27076	16062	2753	45891	190	30433
April	64096	21060	6410	91566	221	52205
May	54926	19385	6462	80773	264	38551
June	65386	17914	6270	89570	310	36406
July	100054	25366	15502	140922	370	47990
August	86842	24123	9649	120614	478	31794
September	116525	28573	4512	149610	578	32614
October	162790	44870	5342	213002	693	38728
November	184571	39640	5829	230040	832	34838
December	175481	44071	4898	224450	998	28337
Total (current prices)	1076639	292818	68933	1438390		417914
Total (January 1993 prices)	304099	90295	23519	417914		

* December 1992 = 100
In January 1993, 1 US$ = 484.2 Rb
Source Road Fund Division

various measures improved the 1993 collection of taxes for the federal and RRFs.

Nature of Taxes Collected

Current taxes collected for the road fund are not based on the real economic costs of road use attributable to different kinds of vehicles. Under normal conditions, heavy vehicles, together with environmental factors, are the principal cause of road deterioration. Therefore, it is not fair to charge all road users a uniform rate.

Road User Charges

Some taxes, such as the enterprise tax, are not user charges and therefore there is no rationale for their inclusion in the Road Fund. The regions receive subventions and grants from the FRF which amounted to 537.9 billion Rb (current prices) in 1993. Subventions to the regions from the FRF are essentially based on the number of kilometers of regional roads that were formerly Republican roads. Grants are based on "the importance" of the local economy served by the regional road network. However, the State Duma annually votes *only the global amount* of the subventions and grants. Therefore, the exact criteria for allocating these funds to the regions are not explicit enough.

Complex Flow of Funds

The system of revenue collection is rather complex, involving major intermediaries in the flow of funds. The revenues through FRF to road expenditure agencies are largely determined by the various categories of roads and the level of government (federal and regional) under which they are. The introduction of a new road classification constitutes an aspect of the decentralization reform process (*4*). The decentralization (if accompanied by accountability) can provide substantial benefits in terms of public sector efficiency; however, and conversely, it can result in financial instability, waste of resources, and social inequities. Therefore, in the highway subsector, the flow of funds has to be clarified and simplified as much as possible to improve transparency and accountability.

Delays and Tax Avoidance

The remaining obstacles affecting the FRF include the withholding of fuel taxes from refineries located in one or two autonomous republics which assert a relatively large degree of independence from central government. Another problem is the delay, averaging 1 month, for transfer of funds from banks in the regions to the FHD bank accounts in Moscow. There are also problems with tax avoidance (for example, by falsifying figures on exports of fuel). Opposition to the energy tax originates mainly with the energy lobby and other interests which want to see fuel taxes reduced or eliminated altogether.

Problems at the Expenditures Level

Availability of funds is only one side of the road financing equation; funds need to be allocated and used efficiently which implies an efficient road agency and adoption of appropriate strategies.

Transparency, Monitoring, and Accountability

Transparency is a necessary condition for an optimal allocation of funds in any economy. Currently, there is a need to detail and break down road and bridge expenditures at both the federal and regional levels. The assignment of detailed expenditure responsibilities between the federal and regional level has not been formalized. The road fund is not audited or monitored by any independent agencies.

Quality of Works

Quality of works and materials is uneven. Uprdors and Avtodors spend much of the funds available on poor quality road rehabilitation and construction works which ultimately leads to increased road expenditure requirements. Most complaints focused on the quality of materials and the outdated technology of material production facilities. Moreover, continuous and permanent site supervision has not been customary, oversight activities being carried out on an erratic basis. Contract management and supervision of road construction and maintenance have also been very weak in the past and both were generally undertaken by the contractor himself. Supervision was mostly visual and involved few measurements and tests.

Competition

Execution of road works under competitive bidding has not been used in the past. The various obstacles to the introduction of a competitive bidding system for road contracts have been the following:

- Lack of experience with preparation of bids since contracts for all road works are based on standard designs and bills of quantities, with unit prices which are adjusted for inflation and the inclusion of a generous profit margin (up to 30 percent in some cases);
- Poor monitoring of actual bills of quantities since there is no compensation for any changes in contract quantities of work unless there are additional activities clearly outside the scope of the original contract;
- An accounting methodology which only partially takes account of inflation and does not depreciate based on replacement value; and
- Inefficient organization of road works, difficulty keeping to work schedules, and no penalties for late completion of contracts.

PROJECTED ROAD FINANCING NEEDS AND AVAILABLE RESOURCES

Federal Roads

The expenditures on rehabilitation and maintenance of the federal highway network in 1993 were $138.2 million (U.S. equivalent), or 46 percent of total expenditures in that year. Total collection of funds in the FRF in 1993 was $704.1 million (U.S. equivalent). Not all of the $704.1 million was allocated to federal highways; about half of these funds or $352.9 million was allocated as subventions to oblasts for the purpose of maintaining certain regional roads that were formerly part of the federal network. The remaining $351.2 million was allocated to (1) federal roads for both highway rehabilitation/maintenance and construction/reconstruction ($298.6 million) or (2) reserves ($52.6 million).

The estimated cost of bringing the federal road network up to a reasonable standard during the next 6 years, that is to the year 2000, is roughly $5,200 million (U.S.) to $7,600 million (say $6,000 million), or about $1,000 million/year over the 6-year period. The basis for this estimate is summarized here. The present condition of the 41,000 km of federal roads is as follows: 15,200 km are good, 10,100 km are fair, and 15,715 km are poor. The cost per km of returning the fair roads to good condition is estimated at $100,000–180,000 and the cost per kilometer of returning roads from poor to good condition is $250,000–350,000. Routine maintenance of all federal roads for 6 years is about $246 million, based on an average $1,000/km/year.

The size of the FRF in 1993 was $704.1 million (U.S.). If this fund were to increase at the rate of 6 percent/year, the fund would rise gradually to a level of $1,058.7 million in the year 2000. Assuming that a continuing 50 percent of the FRF is allocated for subventions to oblasts, the available resources from the FRF for federal road works would average about $500 million/year over the period. Thus the funds would fall substantially short of the $1,000 million annual requirement for overcoming the backlog of maintenance of federal roads. It appears that the annual average shortfall would be about $500 million, assuming that all road fund resources would be applied to maintenance and rehabilitation (that is, no new construction would start before the year 2000).

Regional Roads

The expenditures for rehabilitation and maintenance on one category of the regional roads in 1993 was $548.6 million (U.S.). In addition, $352.9 million was expended on "former federal roads," and we estimate that half of that amount, or $176.8 million, was used for rehabilitation and maintenance of these roads. Thus the total expenditure on this activity was $725.4 million. The overall expenditures on regional roads was $1,409.4 million. The total collection of revenues in the regional road funds from various taxes in 1993 was $945.5 million.

In addition to these funds, the regions have access to subventions from the FRF which in 1993 amounted to $352.9 million (U.S.), as indicated above. Thus in that year the regions had available for regional roads a total of $1298.4 million. Of this latter total, $725.5 million, or 56 percent, were used for road rehabilitation and maintenance. Since the regional funds had $1298.4 million and the expenditures were $1409.4 million, it appears that the funds had a small deficit of $111 million or about 9 percent of the total amount collected including subventions.

The estimated cost of bringing the regional road network up to a reasonable standard during the next 6 years is roughly $20,700 million, or about $3,500 million/year. The basis for this estimate can be summarized. The present condition of the 414,000 km of regional roads is presumably similar to that of the federal road network. The cost per kilometer of returning the fair roads to good condition is approximately $40,000 and the cost per km of returning roads from poor to good condition is about $100,000. Routine maintenance of all regional roads for 6 years is about $207 million, assuming an average cost of $500/km/year.

The amount of regional road funds in 1993, as indicated above, was $1298.4 million including subventions. If these funds were to increase at the rate of 6 percent per year, the level of the funds would rise gradually to $1959 million in the year 2000. Since the estimated average annual cost of regional road maintenance in the next 6 years is about $3500 million/year and the projected average regional road funds available are only $1500 million per year, it appears that there will be a shortfall of about $2000 million a year during the 6-year period to overcome the backlog of regional road rehabilitation and maintenance. These estimates assume, as in the case of federal roads, that no new construction would start before the year 2000.

Bridges

Bridge rehabilitation and replacement works also need large financial funding. A total of 4,468 bridges are located on federal roads, and 32,430 bridges are on regional roads. Of a total of 36,898 bridges on the public road network, 11,504 are wooden bridges which may require more frequent maintenance.

Surveys that started in 1991 indicate how the bridges on federal roads as classified into four categories:

1. Emergency condition: A total of 3.4 percent of the federal bridges belonged to this category in 1993. These bridges have serious structural damage and pose a serious danger to road users.
2. Poor condition: In 1993, 27.7 percent of the federal bridges were classified as being in poor condition. The type of damages involved is mainly concrete deterioration and cracking. Rehabilitation work would involve redecking.
3. Fair condition: 59.6 percent of the federal bridges were found to belong to this category in 1993.
4. Good condition: 9.3 percent of federal bridges.

The estimated cost of bringing the federal bridges up to a reasonable standard during the next 6 years is about $1100 million. This estimate assumes half of the bridges are replaced and half are widened while rehabilitating the existing portion. An average bridge size of 50 m by 20 m was assumed. Routine maintenance of federal bridges will also be necessary at an estimated level of $15 million to $40 million/year. The FHD bridge data indicates there are 32,400 regional bridges. Based on a field review of a sample of local bridges carried out in mid-1994, their condition is similar to the federal bridges. The same standard designs are used and the bridges are roughly of the same age. The estimated number of regional bridges requiring replacement is 6,800. Another 6800 require widening and major rehabilitation. The cost of bringing these regional bridges up to a reasonable standard during the next six years is roughly $6.1 billion. This estimate assumes half the bridges needing work within 6 years are replaced and half are widened with major rehabilitation of the existing portion. An average bridge size of 31 m by 11 m was assumed. An average cost for replacement of $650/m^2 of bridge was used. The estimate does not include costs to upgrade timber bridges. Routine maintenance of regional bridges will also be necessary at an estimated level of $10 million to $40 million/year.

Roads and Bridges

Taking into account both roads and bridges at the federal and regional levels, the total needs up to the year 2000 amount to about $28.8 billion (U.S.), estimated as follows:

1. Federal: $6.0 billion (roads) + $1.1 billion (bridges), or a total of $7.1 billion
2. Regional: $20.7 billion (roads) + $1.0 billion (bridges), or a total of $21.7 billion
3. Total needs at the federal and regional levels: $7.1 billion + $21.7 billion = $28.8 billion.

Therefore, the estimated cost of bringing the Russian road and bridge network up to a reasonable standard during the next 6 years is roughly $4.8 billion/year. Given the available resources per year being estimated at about $2 billion/year, approximately an additional $2.8 billion/year is required to eliminate the backlog by the year 2000.

CROSS-SECTION ANALYSIS

Road transport is an important sector of economic activity. The lack of accessibility or poor road conditions are real barriers to agriculture, industry and trade, and may hinder the entire development effort. Following this idea, an investigation of the association between road expenditures (RE) and gross national product (GNP) was carried out. Cross-section analysis of data from 36 countries indicated a consistent and significant association between these two variables. The data used in this analysis were gathered from different sources: population from the World Tables 1994 (*5*); road expenditures compiled from different World Bank reports; and GNP from the International Monetary Fund. Figure 2 shows the results of the regression analysis carried out for the year 1992, using GNP as the dependent variable.

The resulting correlation equation is: RE = 0.013 × GNP − 1309 where RE = annual road expenditures in million dollars, and GNP is expressed in million dollars (both in 1992 prices). The R^2 value, which can be interpreted as the proportion of the variance in road expenditures attributable to the variance in GNP, is equal to 0.95; the number of degrees of freedom is 35, and the t statistic of the coefficient is 25.5. The Durbin Watson test indicates that the residuals are independent, which makes the regression result more reliable. If we force the equation through the origin, the resulting regression equation is still significant: RE = 0.012 × GNP, with an R^2 of 0.94. This indicates an average ratio RE/GNP of 1.2 percent, which gives a basis to assess the situation of each country in terms

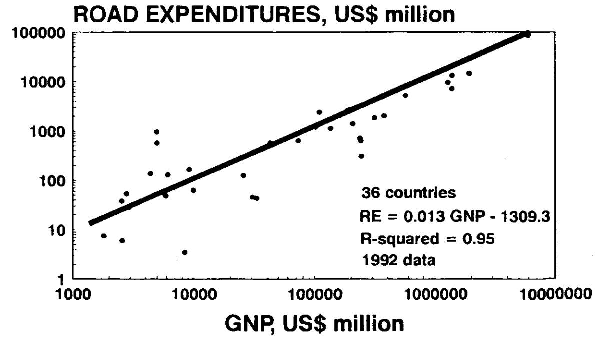

FIGURE 2 Relationship between road expenditures and GNP in 1992.

of annual road expenditures. For Russia, this ratio was 0.54 percent in 1992, substantially lower than the average.

The coefficient in the above equation (1.2 percent) can be used as a rough indicator of the relative adequacy of road expenditures in a country. Although correlation does not imply causality, it is significant that economic development and road expenditures are closely associated. As stated in the 1994 World Development Report, many studies have concluded that the role of infrastructure in growth is substantial, significant, and frequently greater than that of investment in other forms of capital.

POSSIBLE EVOLUTIONS OF THE ROAD FUND

Incorporation of the Road Fund into the Budget

A recent government decree indicates that the FRF may soon be incorporated into the Federal Budget of the Russian Federation. Decree No. 1008 of the President of the Russian Federation, dated May 23, 1994, "on the Federal Road Fund of the Russian Federation," states that the Government of the Russian Federation shall incorporate as a separate line in drafts of the federal budget, starting from 1994, revenues and expenditures of the FRF of the Russian Federation and recommends that the regional authorities consolidate regional road funds within budgets, retaining their target-oriented nature.

The principal objections to earmarking are that it: (a) hampers effective budgetary control, (b) leads to a misallocation of resources by concentrating too many funds on the earmarked activities regardless of other needs, and (c) tends to make the budget inflexible. The large proliferation of extrabudgetary funds in Russia since mid-1991 presents some problems for effective budgetary management at the macroeconomic level (*6,7*). Extrabudgetary funds are said to function as parallel budgets, implying a loss of control and information.

In the case of an integration of the Road Fund into the Budget, the Ministry of Finance (MOF) would have to negotiate with the MOT an action plan which should serve as a basis for future understandings between the MOF and the MOT. If the road fund is kept as a separate line in the budget, the MOT and MOF have before to agree on a fiscal plan to cover the cost of road rehabilitation, maintenance, and reconstruction. This agreement between the two ministries would consist in avoiding the underfunding of maintenance and in improving the allocation of resources in the short run. The integration of the road fund into the budget must not lead to an irregular highways funding. Many countries' experience indicates that the failure to assign appropriate priority to road maintenance often explains the deterioration of national road system. Needed road maintenance has to be reliably funded.

Road Fund Envisaged as an Extrabudgetary Fund

Adherents to the road fund concept, that is, an off-budget fund, argue that earmarking: (a) gives more assurance of minimum levels of financing for public services that governments consider worthy, (b) provides more stability and continuity of funding since more irregularity is introduced when the activity is part of the normal budgetary process, and (c) establishes a strong link between taxation and spending and therefore can give authorities "appropriate signals" for the efficient allocation of resources. Also an extrabudgetary fund helps to reduce uncertainties during the budgetary process (*8*). Consequently, at both the federal and regional levels, the authorities use these funds to shelter revenue from sharing arrangements. Earmarking can help preserve critical expenditures on high priority needs and bridge the gap between economic benefits and political indifference; a reduction in road rehabilitation and maintenance expenditures has, for example, not the same political costs as a reduction in the allocation for the public sector wage bill. Therefore earmarking of funds should be used for the expenditure items which are generally associated with high rates of return but which are also politically less visible. In any case, keeping a road fund is a short-term solution to a long-term problem and needs to be reviewed periodically.

RECOMMENDATIONS

Recommendations at the Resources Level

The collection system would be improved by giving greater effect to economic efficiency in road user charges. Although the Russian road fund collections have increased in recent years, the 1993 resources represent only about $2,450/km of public roads, well below the requirements of some $15,000/km. A road user charge system should be based on the economic efficiency principle that prices should equal the short run variable cost of road use, including the damage to road pavement caused by different types of vehicles, the cost of road congestion and road accidents, and environmental costs that vehicles impose on society.

The present system of road user charges needs to be reexamined and a new system established which more effectively promotes the efficient use of the road network, does not adversely affect vehicle efficiency, and does not distort other sectors of the economy.

Recommendations at the Expenditures Level

Maintenance and Rehabilitation versus Construction

As stated in the World Development Report 1994 (*9*), inadequate maintenance is an almost universal (and costly) failure of infrastructure providers. For example, a well maintained paved road surface should last for 10–15 years before needing resurfacing, but lack of maintenance can lead to severe deterioration in half that time. Failing in maintenance is often compounded by ill advised spending cuts. Curbing capital spending is justified during periods of budgetary austerity; but reducing maintenance spending is a false economy. Such cuts have to be compensated for later by much larger expenditures on rehabilitation or replacement.

Transparency in Road Expenditures

Transparency has also to prevail at the expenditures level. The road fund, if kept in its current form, needs to be audited or monitored by an independent agency. The establishment of a road fund also involves more than just earmarking revenues to road maintenance and rehabilitation. It should also include reforms to improve the efficiency of road agencies and the establishment of road boards.

Quality of Works, Supervision, and Competition in the Highway Subsector

Both quality and prices of road works could be improved by increasing competition in the highway subsector. An adequate contract management and supervisory system needs to be established for the federal road network. This will require training of FHD staff and local consultants, and improved laboratory facilities. In order to guarantee good road construction work it is also important that each party (client, designer, engineer, contractor) has clear functions, roles, and responsibilities. The development of guidelines, procedures and regulations is a first priority. It should be followed by a transfer of information and training of personnel. It is clear that a major emphasis should be put on training of supervisors, including not only construction supervision, but material testing and certification, both at the source of manufacture and on site.

New Ways of Financing

The MOT of the Russian Federation began in 1992 taking the necessary organizational and legal actions to provide for the construction of toll highways. By Decree No. 1557 of December 8, 1992, "On the Construction and Operation of Automobile Roads on a Commercial Basis" (*10*), the President of the Russian Federation authorized FHD to contract for road construction and operation and monitor their implementation. Legislation, still under preparation, would allow foreign investment on such programs, with the proviso that there must be some local financial participation and there must be a non-toll public road running parallel to the toll road. FHD's proposals "On the possible involvement of foreign investments for the road construction in Russia" were submitted to MOF on July 7, 1994.

The government has indicated interest in considering, for toll road financing, at least two major highways: Moscow-Minsk (the section near to Moscow) and Moscow-St. Petersburg (the two sections on the approaches to Moscow and St. Petersburg). A section of Moscow-Nishnii.-Novgorod highway, on the bypass around the city of Balashikha could also be tolled. Currently, there is one toll bridge in operation in Russia, located in Voronesh Oblast, across the Don river.

Traditional government financing of infrastructure is proving vastly inadequate to meet the huge demand. Today's resurgence in toll road construction reflects practical reality: roads are needed for economic development, but the financial and managerial capacity of the public sector is limited. The new approaches to organization and management of transport infrastructure which are beginning to emerge include (*11*): breakup of vertically integrated monopolies, mixed public/private ownership, separation of the ownership from the operation of facilities, private concessions or operations of the infrastructure facility under contract, and in some cases even private ownership. The extent of involvement of the private sector in the partnership can be placed anywhere along the continuum from purely public to purely private. Approaches in common use include: contracting out, leasing, joint ventures, concessions, BOT, BOO, and full private ownership. Given the enormous financing needs projected for the future in Russia, it may prove a feasible option to complement public sources with private risk capital.

CONCLUSION AND RECOMMENDATION

This report presented an overview of the existing system to finance roads in Russia, including a description of perceived deficiencies and recommendations for improvement. Recommendations have to be given at both the resources and expenditures levels since the availability of funds is only one side of the road financing equation; funds need to be allocated and used efficiently, which implies an efficient road agency and adoption of appropriate strategies. A major step will consist in clarifying and detailing both the road tax collections and road expenditures. Transparency is a necessary condition for an optimal allocation of funds in any economy. Currently, there is a strong need of detailing and breaking down road and bridge expenditures at both the federal and regional levels. The assignment of detailed expenditure responsibilities between the federal and regional level has to be formalized.

It might be interesting to explore new ways of financing since traditional government financing of infrastructure is proving vastly inadequate to meet the huge demand. However, public/private partnerships, especially those involving private finance, are more complex than traditional project finance mechanisms, and require significant support from independent legal and financial advisory services.

ACKNOWLEDGMENTS

The authors benefited from comments from Kenneth Clare, Gennadii Alekseyev, and Sergey Zaichkin.

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The findings, interpretations, and conclusions expressed in this paper are entirely those of the authors and should not be attributed in any manner to the World Bank or the Federal Highway Department.

Publication of this paper sponsored by Committee on Taxation and Finance.

Facilitating Transportation Agency Management Through Performance Measurement: The NYSDOT Experience with the "Management Performance Indicators" Report

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Performance measurement is a powerful management tool to help an organization accomplish its mission and build a more productive work environment. This paper describes steps undertaken by the New York State Department of Transportation (NYSDOT) to develop an executive-level performance measurement system—the "Management Performance Indicators" report (MPI). It was developed to meet executive management information needs, but over time has evolved into a tool for monitoring and assessing departmental performance. Its development and evolution are explored, as well as benefits derived from its use. Components of the MPI are surveyed, as well as lessons learned in its use and its future within the agency. The MPI is a management resource for NYSDOT, providing early warning of potential problems and allowing modification of processes to improve performance. Longevity and continued success of the MPI are based on its flexibility, ability to hold the interest of top management, and the atmosphere of cooperation it encourages among program areas. Executive focus on program areas identified by the MPI has improved the department's productivity in numerous program areas. Its introduction has also fostered development of more reliable data and a team spirit among managers to address potential areas of concern. A performance measurement system benefits all levels and all functions of an organization. Usefulness of an executive-level MPI can be expanded through extension of performance measurement into all NYSDOT areas.

Measurement and evaluation are important management tools for monitoring performance of programs. They take place on all levels and across all functions on a continuous basis. Performance measurement can help accomplish an organization's goals, and at the same time build a productive work environment. Private industries have used performance measurement systems to facilitate improvements of existing corporate or divisional reporting systems; enhance communication links, enabling managers to stay in tune with critical activities in the organization; and improve program management capabilities. The need to improve performance and enhance communication exists in the public sector just as it does in private sector corporations.

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OVERVIEW

What Is the MPI?

The New York State Department of Transportation (NYSDOT) staff created the "Management Performance Indicators" report (the MPI) to provide upper-level managers with current information and specific data on the performance of major processes. It has met three primary objectives identified by NYSDOT's executive managers:

1. It should provide a continuous view of how NYSDOT is performing as an organization,
2. It should help managers identify potential problem areas earlier, and
3. It should strengthen communication among department managers.

Advantages and Benefits of the MPI

A periodic report such as the MPI has many important advantages:

1. Executive management regularly receives reports and analysis on the progress of important programs so they can direct corrective action and/or provide positive feedback,
2. Program managers have more incentive to try to improve their performance because they are being reviewed,
3. The data used to monitor program performance becomes more reliable because it is being monitored by executive management,
4. Where information is not available, reporting "pushes" development of data systems to assist management in monitoring critical processes, and
5. A baseline is established for historical performance of key performance measures.

Why Was It Created?

In 1985, NYSDOT began moving its management culture toward greater use of operational planning and goal-oriented management to improve performance and manage resources more effectively.

These initiatives, however, required performance indicators and data to measure achievement of goals and plans. When a new commissioner of Transportation began his tenure at NYSDOT in 1986, he discovered that executive management could not review current NYSDOT performance in a single document. Individual reports and staff briefings were available, but it was difficult to synthesize the flood of information from NYSDOT's many programs to understand how NYSDOT was doing in areas of greatest concern. To solve this problem, the Management Systems Bureau (MSB) was asked to develop a prototype—the "MPI," or Management Performance Indicators report.

How Was It Created?

MSB had been established within the department as "internal" management consultants, and was ideally positioned to develop the MPI. MSB's work includes policy analysis, organizational assessments, systems analysis, and quantitative analysis. These activities put them in close contact with department management as well as provided them with an opportunity to become familiar with departmental operations.

The first step was to develop a list of potential measures representing key indicators (in the joint opinion of each organization and MSB) for NYSDOT's major activities. To assist in this effort, MSB staff reviewed department reports and statistics and searched the literature. MSB's familiarity with program area activities as well as the often excellent rapport its staff had established (through previous assignments) went a long way in breaking down any barriers between the commissioner's staff and program staffs that might have created reluctance on the part of program managers.

Unfortunately, most of the measures initially identified indicated results (e.g., how many bridges were designed or traffic signals installed) but did not indicate efficiency or effectiveness. Although helpful, such indicators do not tell how well an organization delivers its key products and services.

The literature search found that only a few other transportation organizations were producing performance reports. Most were project-related, reporting on the status of individual projects, then "rolling them up" into summary reports. These are certainly useful, but measure only parts of an agency's performance.

The result of this joint effort with various program managers was a list of nearly 100 possible measures covering virtually every departmental service and product. Obviously, these were far too many for an executive report. After several meetings, the commissioner and staff selected 15 measures to be developed and reviewed—5 to be reported quarterly and 10 monthly. Indicators may be reported either monthly or quarterly, depending on rate of change or cyclical nature of the data.

The decision to limit the number of measures was based on management preference, reasonableness of the number to be analyzed, and amount of MSB staff time available to develop the report. This required two staff members to work half-time for 9 months to identify potential indicators, and to work with executive managers to select specific measures to be included in the report. It then required one person full-time and another person quarter-time over a 3-month period to work with program area staff translating the indicator ideas into actual performance measures. Currently, the MPI requires one person half-time to maintain and enhance the report, plus another person quarter-time to produce it.

Issues in Its Development

Circulation was restricted, at least initially, to key department executives. It was uncertain what such a report would reveal or how it might be used outside the department.

The first reports were internal working documents, distributed to key department managers. They provided the basis for discussion among executive staff to identify and focus management efforts on areas of greatest concern. The key indicators were viewed as preliminary, based on available data. It was anticipated that data accuracy and reliability would improve over time. As will be described, this proved to be a critical success factor for the report's longevity and acceptance.

THE MPI TODAY

How It Is Prepared

The Monthly Report

An MSB team of analysts prepares the MPI each month, receiving data from various staff members responsible for the activities measured in the report. Typically, the MPI team prepares the graphs and tables that are the basis of the analysis. The format for presentation of performance indicators has been standardized for consistency and easy comprehension. This format includes: 1) a detailed description of each measure, 2) an explanation of impact of the performance of the indicator, 3) the data source, 4) the goal (target), if any, 5) a trend analysis, and 6) data presentation in both tabular and graphic formats. A typical MPI report is represented in Figure 1.

The team's analysis for each indicator usually consists of one to two pages and includes historical trends, comparisons among regions, and comparisons of performance to an administratively set goal or standard. (NYSDOT has 11 administrative-geographical "regions.")

New Indicators

The consensus-building process previously described in the MPI's development continues today as new indicators are identified and developed. The MPI team, in conjunction with program personnel, produces a package for each indicator containing graphs, tables, and narrative that highlight trends and developments. This package is then discussed and reviewed with program area managers.

If agreement is reached, the package is forwarded to the program's assistant commissioner and/or the regional director(s) for final approval. Once final approval is obtained, the indicator becomes part of the MPI report. When data is unavailable for developing an indicator, the MPI team sometimes works with the program area to develop a supporting data system.

How It Has Changed

In 1993, another new commissioner of Transportation was appointed. After being briefed on the report and hearing comments

TITLE: Orders-On-Contract **FREQUENCY: Monthly**

DESCRIPTION:

The following graph and table report on the level of orders-on-contracts received for construction contracts that have been completed over the last twelve months. The graph presents the final amount paid for a contract as a percentage over or under the original bid price, for all contracts in a Region.

Since the February 1993 MPI, this indicator has included only construction contracts which have been completed. Comparisons to prior MPI's, which include canceled construction contracts and emergency/contingency contracts (where bid amount and final amount may bear little relation to each other), are invalid.

IMPACT: **Positive percentages indicate that, on average, projects cost more than the awarded amount. Negative percentages indicate that, on average, final costs were lower than the awarded amount. Ideally, there should be no difference between the awarded amount and the final project cost. However, in the construction industry, orders-on-contract in the range of two to four percent are considered acceptable depending on the nature and type of work.**

SOURCE: **Construction Division**

TREND: **Contracts Closed:**

In a typical MPI, the current month's performance is compared to the prior month and the prior year performance. Both statewide and regional performance is analyzed. Occasionally, the MPI will include a long-term analysis.

FIGURE 1 Typical MPI report; table and bar graph show hypothetical data. *(continued)*

from program staff, he readily agreed to continue the MPI. He did, however, make one significant change: the report is now widely distributed throughout the department (to both the main office and regions). This decision has brought immediate benefits. Mid-level managers are now actively involved in analysis of these measures and many use them in their day-to-day work. The indicators are regularly discussed, as well as causes for particular trends. There is also spirited but friendly competition among regional groups as to their "standings."

With expanded distribution of the MPI, opportunities occurred to ask users directly what changes they would like to see. In January 1994, MSB distributed a survey to improve usefulness of the MPI. This was the first time since the report began in 1989 that recipients were asked directly for their input. Comments were requested on each component (analysis, tables, graphs) for the current indicators (both monthly and quarterly). Recipients were encouraged to offer comments, suggestions, and alternative measures of assessing NYSDOT performance. Using survey results as a base, discussions were held with executive managers. The result was a work program to "fine-tune" current indicators, develop additional ones, and discontinue others to better reflect the changing needs of NYSDOT managers. The MPI reader survey produced the following top-rated new indicators.

1. Summary of the current letting program with respect to miles of roads and number of bridges to be constructed or rehabilitated (planned versus actual).
2. Report on the department's ability to accurately assess construction costs.
3. Report on the department's ongoing highway and bridge maintenance program (planned versus actual).
4. Report on recruitment and promotion of women and minorities within the department.
5. Report analyzing the cost of producing the Capital Program.

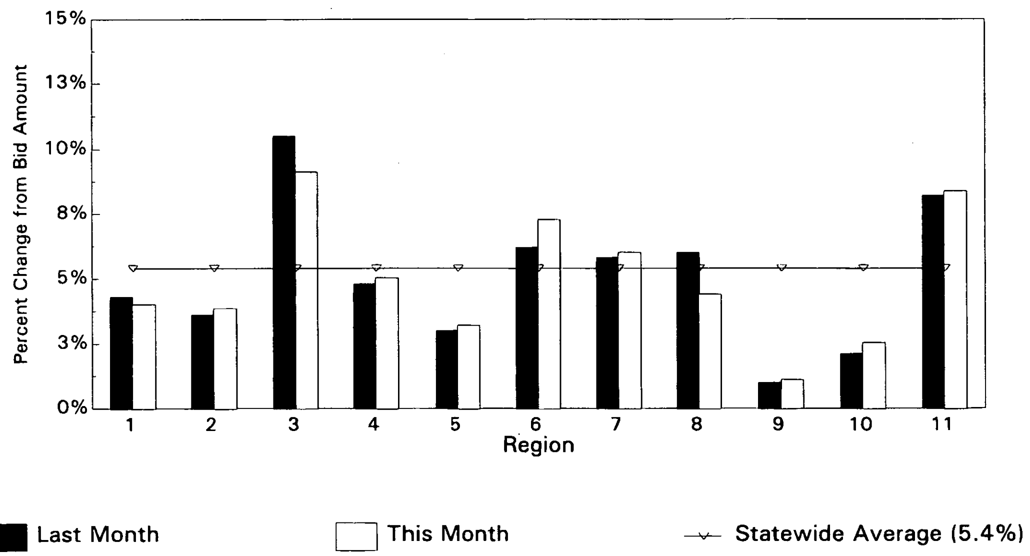
The MPI team plans to ask readers periodically for their feedback to ensure that the report will maintain its relevancy and usefulness.

The MPI Today: What It Contains

The MPI format corresponds to NYSDOT's major functions. It presents data and analysis of key activities in the NYSDOT capital program: project scoping, design, and construction; project cost estimating; obligation and disbursement of funds; administrative support; and specific areas of executive interest.

When warranted, MSB develops and includes special indicators on a time-limited basis to track performance of activities having

Orders-On-Contract
Contracts Closed from 4/93 to 3/94



ORDERS-ON-CONTRACT
CONTRACTS CLOSED
(4/01/93 to 3/31/94)

Region	Award Amount (Millions)	Final Amount (Millions)	Final/ Award
1	$37.4	$38.9	4.0%
2	$59.7	$62.0	3.9%
3	$51.6	$56.3	9.1%
4	$43.7	$45.9	5.0%
5	$74.8	$77.2	3.2%
6	$35.8	$38.4	7.3%
7	$25.0	$26.5	6.0%
8	$120.5	$125.8	4.4%
9	$36.5	$36.9	1.1%
10	$161.8	$165.9	2.5%
11	$263.8	$285.9	8.4%
Total	$910.6	$959.7	5.4%

Source: Construction Division

FIGURE 1 (*continued*)

high levels of executive or program interest. For example, in April 1988, the department accelerated efforts to recruit and hire entry-level engineers and to expand affirmative action efforts for these titles. The goal was to recruit the most qualified entry-level engineers while accelerating the process of diversifying NYSDOT's engineering forces. This indicator summarized the results of NYSDOT's efforts in accomplishing the established goal, and was dropped from the report when the goal had been achieved.

The following discussion describes each current indicator in the MPI. As previously noted, indicators are reported either monthly or quarterly, depending on the rate of change or cyclical nature of the data.

Capital Program Management: Letting Program Indicators

The *Letting Program* measures NYSDOT's progress in obligating federal aid and state aid funds during the current fiscal year. Monthly and cumulative performance is measured against quarterly and fiscal year targets. This information is aggregated on a statewide basis and also presented by region.

Letting-to-Award Processing measures NYSDOT's efficiency in awarding construction contracts. It reports the percent of contracts that progressed from acceptance of bid to contract award within a department standard period of 46 days. It also presents information on the median number of days required to process a contract, and the longest and shortest processing times.

Capital Program Management: Project Development Indicators

Status of Project Development: 5-Year Program measures the department's progress in predesign (planning) and preconstruction project development for all projects scheduled to be let in the current 5-year capital construction program. It compares actual project development elapsed time against the most recent target schedules. Projects are represented in one of six phases of development: not yet begun, scoping, preliminary design, final design, submission of plans specifications and estimates, and let.

Status of Project Development: Current Fiscal Year measures the department's overall progress in project development for the current state fiscal year. Information on the number and current estimated value of projects in the scheduled phase of development is compared to the actual phase of project development. The indicator tracks the percentage of the program on schedule, which ultimately allows NYSDOT to meet its annual letting target.

Project Cost History measures NYSDOT's ability in accurately estimating construction costs of capital projects as they progress through the development process. Initial cost estimates established at the beginning of project scoping are compared to final cost estimates contained in engineers' estimates at the end of the detailed design process. Accuracy of the estimates is an important factor in the department's ability to manage its 5-year Capital Program. This indicator is analyzed by project type and region. Currently, the Project Cost History Indicator is being modified to reflect feedback from the MPI reader survey. Managers responded that a more accurate measure would compare project cost estimates at several points in the design process.

Capital Program Management: Construction Program Indicators

Construction Schedule measures NYSDOT and contractor effectiveness in meeting construction completion targets. A contract is defined as "on-time" if it is completed (i.e., the contractor's last day of work occurred) on or before the completion date specified in the original (awarded) contract. This indicator presents the number and value of construction projects scheduled for completion in the most recent 12-month period, and the percent and dollar value that were completed on schedule.

Orders-on-Contract reports the level of change orders received for construction contracts completed over the last 12 months, and information on change orders approved or being processed for all construction contracts under way at this time. Performance is compared within regions and by the department over time and against customary construction industry standards.

Real Estate Acquisition presents data on NYSDOT's performance in making payments to property owners affected by right-of-way activity on federal aid projects. Federal law requires that the state either pay the property owner the full amount of appraisal, or deposit the amount of the state's offer in an interest-bearing account before the project's award date. This indicator compares NYSDOT's performance against a goal of 100 percent payment.

Administrative and Financial Indicators

Consultant Contracts Processing measures NYSDOT's efficiency in the processing of consultant contracts for bridge and highway design or construction inspection. This process consists of five steps: designation (selection), price and scope negotiation, draft of contract agreement, funding, and contract approval. This indicator reports the median number of days required for each step and compares these medians to NYSDOT's standard for each step. The department is moving to "just-in-time" processing, which delivers the contract on a date requested instead of within a standard time frame. When this shift is completed, this indicator will be revised to report the percentage of contracts delivered by the requested date.

Internal Affirmative Action Goal Attainment measures the department's performance in attaining its affirmative action hiring goals. Overall targets are set for each region and the main office, and their performance results are reported. At the commissioner's request, MSB has expanded this indicator to report on progress in improving the status of women and minorities in the department (i.e., hires and promotions).

Disadvantaged Business Enterprise (DBE) indicators measure NYSDOT's ability to meet federal and state goals for use of DBE and MBE (Minority Business Enterprise) construction contractors, subcontractors, and consultants. They report the percent of construction contract funds awarded to firms owned by one or more socially and/or economically disadvantaged persons (minorities, women, and/or other disadvantaged persons.) Both the federally assisted and state-funded programs are monitored. Participation goals have been established for contractors and subcontractors, and the department's performance is measured against these goals. The department is currently establishing goals for consultant participation.

General Fund Disbursements: State Operations and Local Assistance Accounts measure NYSDOT's ability to manage accounts for State Operations and Aid to Localities. The department's projected and actual cumulative disbursements are compared. If actual disbursements are much greater than projected, NYSDOT may risk exceeding its limit and may require additional disbursement approval from the State Division of the Budget to fund operations. If actual disbursements are much lower than those projected, NYSDOT may risk reduced appropriations in future fiscal years.

Current Areas of Executive Interest

Public Claims and Tort Liability measures NYSDOT's ability to manage its liability for actions (and nonactions) relative to its highway programs. This indicator presents data on claims filed against the department by the public for alleged departmental torts (e.g., negligence in design, maintenance, etc.). The indicator also reports the number and value of torts closed and identifies whether they have been dismissed, discontinued, awarded funds, or settled.

Departmental Safety measures managers' and employees' ability to adhere to safety rules as measured by the number of personal injuries, vehicle accidents, and lost-time days reported during the current calendar year. These figures are reported on a regional basis for departmental employees. Both preventable and total number of personal injuries and vehicle accidents are reported. This indicator was recently revised and enhanced based on the feedback obtained through the MPI reader survey. Lost-time days were added to the measure.

MPI SUCCESS AND LONGEVITY

Success

Reports alone do not improve performance, but the MPI report has had an impact on how the department monitors programs and measures performance. Before the MPI's existence, program managers did not universally and consistently share, discuss, and examine their data; executive managers did not have regular performance information in an easy-to-understand format; and performance was not generally compared to targets or historical data. Because of the MPI, the following events now occur.

- Executive managers hold regular monthly meetings focusing on program areas of interest, and program managers consequently are actively involved in improving and clarifying their data.
- Program data is regularly examined by a team of analysts who are not directly involved in program area work, providing a valuable "outsider's" view and a quality assurance function. As a result, data systems and reporting have improved. For example, the MPI recently added a new indicator for "Letting Program Accomplishments," which reports the number of bridges and lane miles that will be reconstructed or rehabilitated as a result of capital projects let in the current state fiscal year, and compares these figures to goals set earlier in the year. When this indicator first appeared, some regions had yet to report information for their lettings. When they realized that executive management was reviewing this information, this important data quickly began appearing.
- Executive managers now have a single source for much important information readily available (and in an easy-to-understand format) to provide the public and outside control agencies with information on exceptional and/or improved performance, achievement of goals, and areas where action is being taken for improvement. For example, in 1987, 405 days was the median required for processing of a consultant contract. After review and modification, the median processing time fell to 217 days in 1993. Similarly, during calendar year 1990, NYSDOT staff had 585 preventable personal injuries. With implementation of a state-wide training initiative and management emphasis on prevention, these declined to 436 by 1993.
- Perhaps the greatest success of the report is in opening a two-way dialogue between executive management and program areas. Attitudes of the program managers have changed from hesitation and reluctance to readiness to suggest their own indicators for inclusion in the report. The Real Estate Acquisition indicator discussed earlier is an example of an indicator suggested for inclusion from the program area.

As knowledge and acceptance of the report expand, and the base of historical information grows, optimism increases about the future of the report and continued successes such as those described above.

Longevity

The longevity and continued success of the report are due to the following four significant factors.

Ensuring Flexibility and Relevance

Virtually every measure has evolved since it was originally developed to better reflect the true circumstances yielding the indicated results. NYSDOT's experience has indicated that even the most straightforward indicators must be carefully developed and revised to present a truer picture of the activity measured. For example, the Construction Schedule indicator originally did not take into account the seasonal nature of construction. Data presentation was revised to consider this factor.

Indicators that are no longer relevant are discontinued. For example, the MPI included an interstate pavement striping indicator to monitor regional performance in meeting goals to convert 4-in. striping to 6-in. pavement striping. The indicator was discontinued at completion of a 3-year conversion program.

✓*Continued Interest from Top Management*

As mentioned earlier, each month the executive assistant to the commissioner selects a measure to discuss at the executive staff meeting. Although this measure is often selected because of an unusual trend (in either a positive or negative direction), great care is taken to ensure that every measure is periodically discussed at the executive staff meeting. In this way, every measure receives attention, and continued program interest is encouraged.

Close Coordination between MSB and the Organization Responsible for the Activity Being Measured

This includes joint development or revision of the measure, prior program manger review of the analysis to be included in the report, and joint development of all presentations to executive management. In instances of disagreement over interpretation of results, every effort is made to reconcile the differing views. In the rare instances when that is not possible, the program manager's dissenting analysis is also included in the presentation. This combination of close and regular contact creates a bond of trust tending to alleviate apprehension that can often exist in such a reporting system. As a result, people can more quickly address the message, instead of arguing with or criticizing the messenger.

MPI Discussions at Executive Staff Meetings Focus on Problems, Not People

Because program managers have "bought into" the measures and because they know the measurements, open discussion of issues raised by the MPI lose any accusatory, inquisitorial edge. Executives can more quickly identify reasons for trends, what managers are doing to address them, future prospects, and what NYSDOT responses are needed.

LESSONS LEARNED AND FUTURE ACTIONS

Observations and Opportunities

Over the years, performance measurement has gradually expanded into the lower levels of NYSDOT's organization. Some managers embraced performance measurement wholeheartedly, even before introduction of the MPI. Unfortunately, use of performance measurement as a management tool is not universal. In part, this may be because of the difficulty of measuring some activities. In other instances, it may simply be a case of a manager being uncomfortable with the tool. Another factor may be unintentional messages presented by an executive report. If performance for a particular program area is not measured, it is sometimes wrongly perceived that this program is not important. To address this misconception, the department may ask all organizations to develop and maintain their own key indicators and highlight appropriate indicators in the executive report on a rotating basis.

The department also struggles with the issue of how to measure more difficult areas such as planning. Delivery of required plans and systems on time and within estimated resources has been the focus to date, but has produced only limited success. A new indicator under development measures the Preliminary Engineering (PE) costs for construction projects. One component of this PE cost is planning. NYSDOT has begun reporting on the level of planning effort expended by project type and by region. This is a first step in establishing a benchmark concerning planning levels for construction projects.

As ability to understand the usefulness and importance of performance measurement expands, the focus of the measures sometimes changes. NYSDOT's performance measures generally concentrate on output (volumes and costs), but an effort to measure quality has begun in several activities. An example of this effort is the Real Estate Acquisitions indicator, reporting on NYSDOT's performance in making payments to property owners affected by right-of-way activities. This measure addresses the quality of NYSDOT's performance, because the "customer" is clearly more satisfied if paid before the start of a construction project.

What Has NYSDOT Learned?

Through development and refinement of the MPI, NYSDOT has learned several points about performance measurements:

- Close involvement of program staff is essential in developing, modifying, and interpreting data. Data are only useful if they help staff identify their own opportunities to improve. Those closest to the data must be actively involved.
- Performance should be measured as a means to identify opportunities to improve it, instead of a means to assign blame for apparently poor performance. The experience, knowledge, and data gained from this effort should be shared throughout the organization.
- Managers should resist the temptation to enlarge the report; 15 to 20 measures is an optimal number. As new indicators are needed, managers should expect to drop those that are less revealing. If an agency believes it needs more measures, it could report on some other measures less frequently.
- Because of management principles in general and the MPI success in particular, organizations within a transportation agency (e.g., offices, divisions, districts, and regions) should have their own MPI reports.
- The process is dynamic. Virtually every MSB indicator has been modified to reflect MSB's improved understanding of issues and associated problems. This continuous improvement is consistent with the department's management culture.
- Some measures simply do not fulfill their expectations and should be dropped. Staff should use the technical and analytical experience gained from each measure for continuous improvement of other existing measures or develop better future measures.
- One last comment: managers get what they measure. Staff tend to focus on particular areas to the detriment of others. Select performance measures carefully and be sure that all critical program areas get attention.

It is important to remember that performance measurement is not an end in itself, but rather a management tool that helps an organization accomplish its mission and build a more productive work environment. As such, measures should meet needs of the organization's managers, and provide the information needed to improve and monitor their programs. MSB continues to refine and enhance the MPI to reflect executive interests.

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

As mentioned in the paper, the MPI is an evolving document and NYSDOT continuously seeks to improve the usefulness of this management tool. The authors would also be interested in speaking or corresponding with individuals or organizations that have had experience with management performance measurement systems.

Readers who would like more information on NYSDOT's MPI Reader Survey should contact the authors at:

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Succession Planning at the State DOT Level

LESTER A. HOEL AND MICHAEL A. PERFATER

In this paper the development of a program of succession planning for the Virginia Department of Transportation (VDOT) is addressed. Transportation industry findings, confirmed by VDOT demographics, indicate a greater-than-average turnover among senior transportation professionals during the 1990s. This problem is accentuated by experience gaps, economic disincentives within the agency, and decreasing numbers of university graduates with training in transportation. The paper contains reviews of prior transportation professional needs studies, with an examination of the demographic makeup of VDOT's existing work force, including those who resigned or retired. A profile of resignees, developed from historical data, is used to develop a model to help predict future attrition patterns. VDOT's mission and goals in the future and how it will respond to staffing needs were addressed by a series of focus group meetings held with division and district administrators. Study results suggest that the replacement work force will be recruited from a pool of applicants significantly different from that which VDOT has traditionally used. VDOT will require new recruitment programs to attract professionals with a new set of skills if it is to be successful in replacing its work force in the decades ahead. Recommendations that can assist VDOT and other state DOTs in addressing changes in the makeup of its future work force are grouped under four basic objectives: (a) increase the quantity and quality of new transportation professionals, (b) improve the retention rate, (c) improve career opportunities, and (d) determine the extent of near-term employee shortages.

During the 1990s, many state DOTs, including the Virginia Department of Transportation (VDOT), will lose many senior engineers and managers to retirement. For example, between 1990 and the year 2000, one third of VDOT's professional work force is expected to become eligible to retire, partly because of an early retirement incentive program implemented in 1991.

Many factors can affect a state DOT's ability to replenish its professional staff. Among these factors are: (a) a slower-growing work force, (b) the changing composition of the working population, and (c) shortages of technically trained replacements. Demographers forecast that during this decade, the number of people in the work force will grow more slowly than in the recent past, and the composition of the work force will change as the proportion of women, immigrants, and minorities increases. Finally, statistics also indicate that the number of graduating civil engineers has been declining. Since this area of specialization comprises such a large percentage of transportation professionals in the nation's federal and state transportation agencies, this shortage will also affect the makeup of the future DOT workforce.

A number of recent studies have addressed these issues from a national perspective. Although these efforts have provided useful information for decision-makers in their efforts to respond to severe problems of professional shortages, the studies do not address the specific conditions and changes within each state transportation agency. In this paper is a report on a research study identifying work force trends within VDOT and suggesting how the agency can position itself to develop a professional work force that will be responsive to the challenges of the 21st century.

First, published studies of needs for transportation professionals are reviewed. Next, the demographic profiles of current and former VDOT professionals are examined, coupled with an investigation of historical trends with respect to attrition, especially retirement. Using a sample of individuals who occupied VDOT positions in professional grades between 1984 and 1991, demographic and attrition data are presented regarding the characteristics of individuals who left VDOT and why they did so. A trend model to forecast future attrition is described that can be used to project retirement dates for current professional employees, and a series of focus group sessions held with key VDOT managers and administrators is used to solicit their views about the agency's future and the skills that will be required of the professional staff. Finally, a set of recommendations is offered for succession planning, involving recruitment and retention of state DOT professional staff.

PRIOR TRANSPORTATION PROFESSIONAL NEEDS STUDIES

In 1985, the first comprehensive assessment of the nation's needs for transportation professionals was published by the Transportation Research Board (TRB) (*1*). The TRB report predicted a greater-than-average turnover among senior transportation professionals in the late 1980s and early 1990s, and forecasted that during that period approximately one-third of the professional engineers in state and county governments would retire.

The TRB study addressed the problem of a waning transportation work force from a national perspective and provided an overall strategy for its resolution. At the state level, however, DOTs were also faced with the reality of a work force that would radically change from past patterns. A study completed in 1987 by the Hudson Institute for the U. S. Department of Labor (*2*) identified five demographic trends that will affect the workplace of the future:

1. The population and work force will grow more slowly than at any time since the 1930s.
2. The average age of the population will rise, and the pool of younger workers entering the labor market will shrink.
3. More women will enter the work force.
4. Minorities will occupy a larger share of new entrants into the work force.

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5. Immigrants will represent the largest share of the increase in the population and work force since World War I.

In 1990, the American Association of State Highway and Transportation Officials (AASHTO) published a guide that sought to define and develop a recruitment and retention program as well as a national "marketing" program to expand interest in civil engineering as a career (*3*). The purpose of the guide was to create a joint effort among AASHTO member departments to support recruitment and retention and foster interest in civil engineering. This guide contains practical ideas and suggestions for recruiting qualified applicants, and is directed at recruiters in state DOTs. That same year, TRB published a study to synthesize recruitment, training, and management-development practices found to result in long-term success (*4*). Personnel directors of the state DOTs and Canadian Provinces who were surveyed reported that in their agencies, training and development is focused primarily on improving current job skills rather than on meeting future needs. The study found that agencies rely heavily on training assistance provided by professional associations, universities, community colleges, and private contractors.

Two reports address methods for attracting students to careers in transportation engineering. The first, published in January 1990 by the Institute of Transportation Engineers (ITE) (*5*), directs the transportation industry to:

1. Develop written and audiovisual materials for students in elementary school, high school, and college that present a positive image of transportation engineering as a career.
2. Secure a commitment from ITE members and others to assist in the distribution of these materials to students at all levels and to recruit them to the profession.
3. Develop activities within the profession and with employers that promote recognition of the value of high quality professional transportation engineering.
4. Encourage and promote adoption of policies that provide effective competition for the best professionals, especially salaries and the work environment.

In May 1992, a report on civil engineering careers was published by the National Cooperative Highway Research Program (NCHRP) (*6*). This document confirmed demographic trends noted in other reports that point to an increasingly diverse population in the future. The report notes that both ethnic minorities and women are underrepresented in civil engineering and have poor retention rates in engineering programs. The study also found that the market is demanding three strategies targeted at the different developmental stages of future civil engineers. The strategies are to:

1. Heighten awareness of technology, engineering, and civil engineering.
2. Increase retention of the existing pool of future undergraduates.
3. Modify the existing curriculum from kindergarten through college.

WHO WORKS FOR VDOT AND WHY DO THEY LEAVE?

To understand the nature of the problem of recruitment and retention of transportation professionals, the demographic makeup of VDOT's existing work force was examined based on information obtained from historical monthly records of the agency's Personnel Management Information System (PMIS). This profile serves as a basis for identifying the recruitment and retention challenges that will likely be faced by many state DOTs and furnishes insight as to how they might be addressed.

Profile of the VDOT Professional Work Force

Table 1 presents a statistical summary of VDOT's professional work force (grade 12 and above) as of 1990. The data in this table indicate that the typical VDOT professional is white, male, and has an engineering title. He is a U.S. citizen in his mid-40s and has 20 years of service. The typical VDOT nonengineering professional is

TABLE 1 Profile of Existing VDOT Professional Work Force (1990)

	Professional Staff			Engineers			Nonengineers		
	Total	M	F	Total	M	F	Total	M	F
Employees (%)	100	88.8	11.2	69.5	63.9	5.6	30.5	24.9	5.6
Race (%)									
White	93.2	93.9	87.4	93.9			91.6		
Nonwhite	6.8	6.1	12.6	6.1			8.4		
Citizenship									
U.S.	99.0								
Other	1.0								
Age (yr)	45.7			46.1			44.7		
Length of Service (yr)	20.0			21.6			16.4		

TABLE 2 Profile of Professional Work Force that Resigned or Retired Between 1984 and 1990 (Grade 12 and Above)

	All	M	F	Engrs.	Nonengrs.	White	Nonwhite
Retirements (N=82)							
Age (yr)	60.4			60.8	59.1		
Service (yr)	34.9			36.7	27.7		
Resignations (N=75)							
Age (yr)	32.8	33.7	30.4	31.9	34.9	33.1	30.8
Service (yr)	5.2	5.4	4.9	4.6	6.8	5.7	2.4

also a white male U.S. citizen, in his mid-40s, with 16 years of service. There is a higher proportional representation of females in this group than in the engineering group. Because engineering professionals have worked longer for VDOT than nonengineers and are slightly older, it is reasonable to expect that a higher percentage of them will be eligible to retire earlier than was the tendency in the past, say at age 55 or less.

Profile of the Professional Work Force Recently Resigned or Retired

The data in Tables 2 and 3 indicate that the typical retiree who left VDOT between 1984 and 1991 was a white male U.S. citizen about 60 years old with 35 years of service. Engineers tend to be slightly older than nonengineers at retirement and also tend to have worked for VDOT longer. The number of professional VDOT employees who retire each year has been fairly constant. The number of retiring engineers tends to be much greater than the number of retiring nonengineers. Historically, engineers have made up a much greater proportion of the professional work force and tend to have longer VDOT careers than nonengineers. The average number of engineers who resigned each year was lower than the average number who retired. The percentage of all resignations from the engineers' group reflects the fact that engineering positions comprise 70 percent of the work force. The number of resignations among professional nonengineering VDOT employees each year has been fairly constant and is almost the same as the average number who retired. The reasons employees gave for resigning varied but could, to some extent, be categorized. Of the 75 professional employees who left the agency between 1984 and 1990, 68 percent did so to accept a better job, 13 percent moved from the area, 4 percent cited home responsibilities, 3 percent said they were dissatisfied, and the remaining 12 percent listed a variety of reasons. Eighty-four percent of the resigning employees were white and 16 percent were minorities. These percentages are slightly less than the ones for the white employee population as a whole, and slightly more than those of the minority VDOT professional work force, respectively. Females comprised 11.2 percent of the VDOT work force during the study period, but they represented 29 percent of those who resigned. Unfortunately, employees who left VDOT during this period could not be interviewed individually during this study, so more extensive data about the reasons for their resignations are unavailable.

Employees who leave VDOT are likely to do so within about 5 to 7 years after they enter the agency. Those who remain beyond 5 to 7 years tend to remain until retirement. Those who resign tend to

TABLE 3 Number of Engineers and Nonengineers Who Retired or Resigned, by Year (Grade 12 and Above)

	Retired			Resigned		
Year	Engineers	Nonengineers	Total	Engineers	Nonengineers	Total
1984	9	2	11	6	1	7
1985	8	5	13	9	4	13
1986	13	1	14	11	2	13
1987	14	2	15	6	2	8
1989	14	4	18	11	5	16
1990	9	2	11	10	8	18
Total	66	16	82	53	22	75
Percentage	80.5	19.5	100	70.7	29.3	100
Average	11.0	2.7	13.7	8.8	3.7	13.6

be in their early 30s, which may be a critical age for those in transportation careers. Beyond that, other factors, such as family considerations, spousal employment, etc., definitely tend to affect employment stability. Furthermore, as employees stay longer with an organization they become vested, with benefits such as accrued vacation, sick leave, and health benefits, thereby increasing their commitment to remain with the agency. Engineers do tend to resign from VDOT at a younger age than do nonengineers. One could surmise that this happens because upward mobility for engineers seeking better jobs is easier than it is for nonengineers, thus resulting in the latter group staying at VDOT longer. Again, the details given for resigning are not specific but "obtaining a better position" is often entered on the separation form.

Both the average age and average length of service of minorities who resign are less than those of whites who resign. The data do not divulge why nonwhites who resign do so much sooner during their term of employment with VDOT than do whites. Again, better job opportunities elsewhere or the small percentage of minorities in the work force may be factors in accelerating the decision to leave the agency. Whatever the reason, these data seem to indicate that efforts by VDOT to retain minorities should begin fairly soon after they are hired.

A METHOD FOR PREDICTING RETIREMENTS

The profile of retirees developed from historical data was used to develop a trend model for making predictions about future retirement patterns at VDOT. In developing this model, which can be applied to forecast general trends in the VDOT work force, probabilities were used to represent the timing of retirements.

Figure 1 shows the cumulative distribution of the combined age at retirement and length of service of employees in grade 12 and above who retired between 1984 and 1990. For example, the graph shows that 50 percent of VDOT employees retired when their age and years of service totaled 98 years or less, and 100 percent of all employees retired by the time their age and years of service equaled 109. The median (or 50th percentile) value in the graph is 98.2 years. If these data were used for predictions, we could state that 50 percent of retirements occur when combined age and years of service are less than 98 years. Another 50 percent of retirements occur later. The information presented in Figure 1 can be used to develop a mathematical model for predicting future attrition. The retirement data in Figure 1 can be mathematically represented by dividing the overall probability range into 10 equally likely categories, each interval representing a 0.10 probability range. The categories would be from 0 to 0.10, 0.10 to 0.20, etc. For each category, there is a 0.10 probability that the retirement outcome will occur in that category based on the historical data. A combined age and length-of-service value is selected at the midpoint of the category. The total of all of these midpoint values is 957.2. Because each value of age and years of service occurs with a probability of 0.10, the overall expected value for all professional VDOT employees is 0.10 times 957.2 years or a combined 95.72 years of age and length of service. The date that employees will reach an average combined age and service level of 95.72 years can be used to predict retirement. For example, if Mr. Jones, a grade 14 VDOT employee, is 46 years old in 1993 and has 10 years of service, at what age and year will he likely retire? Using the probability model, we can say that Mr. Jones' age (46) plus his length of service (10 years) now totals 56. If 56 is subtracted from 95.72, the result is 39.72. For each additional year he works for VDOT, he will accumulate 2 years of age and service, so 39.72 divided by 2 comes to 19.86 years of added work with VDOT. Since Mr. Jones was 46 years old in 1993, he will be 65.86 (46 plus 19.86) when he retires. The year of retirement is then predicted to be 2013 (1993 plus 19.86). The reader should bear in mind that this proposed formula is not intended to furnish estimates of individual retirement dates but to develop a likelihood of the event taking place when summed over all the employees in the organization.

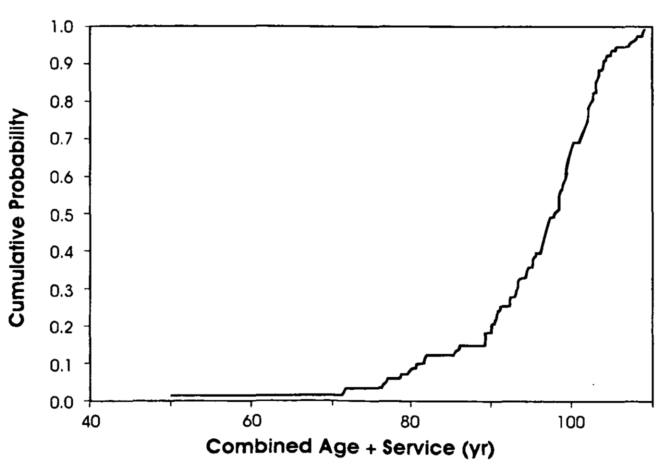

FIGURE 1 Cumulative distribution of retiring VDOT professionals 1984 to 1990.

VDOT MANAGEMENT VIEWS REGARDING FUTURE STAFFING

The current managers at VDOT constitute a vital source of information and perspectives regarding the future of the agency, including its organizational staffing. A series of focus group meetings were held with 31 of the 36 division and district administrators who manage the agency's daily central office and field operations. Each individual was asked for his or her views about what VDOT will be doing in 10 years and how the agency will staff those activities. These sessions produced a variety of observations and opinions about the VDOT of the future.

The key prognostication was that although VDOT will continue its traditional activities (designing, building, maintaining, redesigning, and rebuilding roads), local governments will be more involved in decision-making, perhaps to the point of actually building infrastructure (VDOT is one of only 5 state DOTs that build and maintain county roads).

Significant changes in the composition of the work force are also foreseen. Managers foresee an increase in the percentage of women, minorities, and foreign nationals in VDOT's work force. The managers need the appropriate training and skills to deal with such a diverse work force.

The managers feel that VDOT will continue to be an engineering-oriented organization, and its employees will continue to require certain basic technical and engineering skills. There is also the feeling, however, that a higher level of communications, financial, and "people" skills will be required of managers (and the general work force). All agreed that computer skills will ultimately be a requirement for nearly all employees.

Many managers feel that there will be less of a tendency for employees to remain with VDOT for their entire career. This will result, in part, from the changing demography of working professionals (dual-earner families and different attitudes and expectations among young workers) as well as certain disincentives in VDOT's career ladders. They cite a lack of economic incentives for promotion, the absence of relocation incentives provided by VDOT, and the Commonwealth's very conservative approach to providing reimbursement for relocation costs as major career-ladder impediments. The result of these disincentives, they say, is a tendency for fewer and fewer moves from the field divisions to the central office, which will lead to the underuse of valuable experience. For instance, if a resident engineer in the field accepts a central office position at the assistant division head level, he or she will (a) receive only a one-pay-grade increase, (b) move from being chief administrator of a unit to a position of less authority and thus experience a loss of autonomy, and (c) likely have to relocate. Thus, the managers say, the only incentive is monetary, which in this instance is probably not enough to offset the cost of the move.

Regarding recruitment procedures and practices, VDOT's managers feel that VDOT attracts a diverse applicant pool but is experiencing strong competition from the private sector, especially with respect to attracting female and minority engineers to VDOT careers. Most felt that training should play a stronger role in the organization than it does now and that training programs should be developed to address nontraditional as well as traditional areas of expertise. There was the feeling that training should seek to expand employees' skills rather than merely teach them how to do their current jobs better and that the existence of established training opportunities for employees may be very important to the agency's recruitment efforts in the future.

A RECOMMENDED PROGRAM FOR RECRUITMENT AND RETENTION OF TRANSPORTATION PROFESSIONALS

Based on the findings, conclusions, and general observations of this study, a set of recommendations is offered, grouped under four basic objectives:

1. To increase the quantity and improve the quality of new transportation professionals within its ranks.

    –VDOT should continue to provide fellowships for college and university students for postgraduate training that link support with guaranteed employment. Special emphasis should be placed on recruiting minorities and women into these programs;

    –Someone within VDOT should be charged with keeping abreast of national developments in recruitment practices in the transportation profession, particularly within AASHTO, and with informing agency management of new or promising developments in this field.

2. To improve the retention rate among transportation professionals, especially women and minorities within the agency.

    –There is a need for in-house training programs on managing diversity in the work force. The programs should be designed to: (a) identify the benefits of a diverse work force, (b) define and set forth the managers' responsibilities for maintaining an environment that provides equal opportunities for all employees, and (c) provide the improved communication and "people" skills that will enable employees, especially managers, to work effectively in a dynamic work environment.

    –VDOT should consider developing a mentor program that links newer employees with individuals who have been with the organization for 5 or more years. Mentors could have a positive effect on the adjustment of new arrivals, enhance their early career development, and ensure that their expectations during this critical period in their employment are understood and met.

    –Incentives are needed that will increase the likelihood that employees will remain with VDOT beyond the critical period (2 to 6 years) when most resignations tend to occur. Such incentives might include more tuition refunds, co-op training, full-time graduate study, and other training opportunities.

    –VDOT's human resources staff should periodically conduct a series of focus groups with a sample of transportation professionals hired within the past 5 years. The purpose of these focus groups would be to: (a) determine employees' expectations upon arrival in their new job, (b) monitor how well these expectations are being met, and (c) encourage the sharing of common concerns.

    –Human resources staff should consider conducting either interviews or focus groups with recent resignees to learn more about why employees leave VDOT.

3. To improve career opportunities for employees who have remained with the agency beyond the so-called critical period (2 to 6 years).

    –An aggressive program should be instituted that encourages career advancement for technicians and other employees through job rotation, attendance at short courses, and professional society memberships and designations.

    –A committee should be established to examine both VDOT's and the Commonwealth's policies and practices regarding employee relocation. The committee's efforts should include: (a) an assessment of existing incentives and the extent to which they foster employee development and upward mobility and, (b) a determination of how current relocation policies and practices could be altered to provide greater assistance to employees and incentives that encourage career mobility within the agency.

4. To determine the nature and extent of near-term employee shortages.

    –The Human Resources Division of VDOT should test the predictive model presented in this paper to determine its reliability for predicting retirements.

    –The model should be tested in a variety of central office and field units, over a cross-section of classes and employee demographic categories. If the model provides a reasonably accurate prediction of when employees retire in terms of their age and years of employment with the agency, it could fairly accurately predict when large cohorts of the agency's staff will likely retire.

SUMMARY

Managing a changing work force of transportation professionals has been addressed at the national level in studies conducted over the past decade. The potential for newly reconfigured and revitalized state DOTs is, indeed, great as highly trained, computer-literate young professionals enter the work force. In this paper, it was described how one state has examined demographic changes and the implications of these changes for a succession of new talent into the 21st century. The composition of the work force recruited in the near future will differ significantly from the current profile. Since professional resignations from the state DOT disproportionately include many minorities, women, and recent hires, special programs will be needed to mitigate this exodus. Further, the career expectations of newly hired employees will differ from the career-minded professional of the past. These trends call for a more aggressive program of career development and retention than has been required in the past.

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

Transportation Planning Education in Urban and Regional Planning Graduate Programs

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Recent federal legislation has resulted in significant changes in the transportation planning and decision-making process. The Clean Air Act Amendments, the Intermodal Surface Transportation Efficiency Act, the Americans with Disabilities Act, and other regulations establish new federal priorities for the surface transportation system and contain guidelines for planning, financing, and administering the different modes. Transportation planners with a wide variety of skills will be needed by public agencies and private businesses to adequately respond to these new responsibilities. Educational programs, especially those at the graduate level, must be attuned to these changes to help ensure that the current and future demands for transportation professionals are met. In this research the skills and areas of expertise needed in the transportation planning marketplace were examined and the responsiveness of current urban and regional graduate planning programs to meeting those demands was analyzed. This was accomplished through an analysis of recent federal legislation, national research problem statements, interviews with 46 transportation professionals, and a survey of 78 graduate planning programs in the United States. The research results indicate that while the current transportation planning curriculum addresses many of the existing and anticipated demands of the transportation marketplace, improvements are needed to adequately prepare graduate students for future jobs. The research identified 12 knowledge and 9 skill areas as important for future transportation professionals. The evaluation of the current curriculum indicates that many, but not all, of these areas are being addressed. Based on this analysis, knowledge and skill areas are identified for more extensive coverage in graduate courses.

Maintaining a viable surface transportation system that provides for the efficient and effective movement of goods and people is critical in ensuring the economic and social health and vitality of cities, states, and nations. Increasing traffic congestion, declining mobility, air quality and environmental concerns, deterioration of the transportation infrastructure, and limited resources are all major issues facing transportation professionals and decision-makers today. Further, additional demands are being placed on these groups in response to recent legislation at the federal, state, and local levels; rapid changes in technologies; and increasing complexities in the workplace.

Historically, transportation planners, along with transportation engineers and others, have played important roles in addressing these issues. To respond to these new challenges, however, transportation planners today must possess a wide range of technical skills, multiple areas of expertise, an understanding of the institutional settings within which transportation decisions are made, and the policy implications of alternative recommendations. Urban and regional planning education, especially at the graduate level, represents a major source for developing this knowledge. To ensure that graduate students in transportation planning are adequately prepared to meet the challenges and opportunities facing this country, the programs offered by urban and regional planning graduate schools must focus on providing an understanding of a wide range of subject areas, knowledge of the policy and political processes, and training in basic technical skills.

The research documented in this paper was undertaken to provide an enhanced understanding of the current and projected needs of the transportation planning marketplace and to analyze the extent to which graduate programs in urban and regional planning are presently addressing these needs. This was accomplished through an analysis of recent federal legislation, national research problem statements, interviews with 46 transportation professionals from throughout the country, and a survey of 78 urban and regional planning graduate programs.

This paper is a summary of the process used in this research and presents the results of this analysis. To accomplish this, the paper is divided into five major sections. Following this introduction, the second section briefly describes the methodology used in the research. This is followed by an examination of the knowledge and skill areas identified as important for transportation planners based on a review of previous studies, recent federal legislation, national research problem statements, and interviews with transportation professionals from a variety of backgrounds. These sources provide a perspective on the current and future needs of the transportation planning marketplace. The third section summarizes the results from the survey of urban and regional planning graduate programs. The number and nature of transportation-related courses are examined, along with special degree programs. The paper concludes with a comparison of the needs of the transportation planning marketplace and existing urban and regional planning courses and programs. Knowledge and skill areas not currently being addressed are identified and potential changes and additions in graduate transportation planning curriculum are suggested.

The research results presented in this paper should be of interest to transportation professionals; educators; national planning and transportation organizations; transportation agencies at the federal, state, and local levels; and ultimately, the general public. Ensuring that transportation planners emerging from urban and regional planning graduate schools possess the necessary training and skills is of great importance to public-sector agencies and private firms responsible for all aspects of transportation planning, operation, and management; to educators and university administrators; and to national planning and transportation organizations.

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RESEARCH METHODOLOGY

The research conducted in this study focused on two major activities. First, the current and projected skills and areas of expertise for transportation planners were identified through a review of previous research, an examination of recent federal legislation and policy requirements, research problem statements issued by federal agencies and national organizations, and interviews with key transportation professionals. The approach used in the research was consistent with techniques used in previous studies examining other subjects offered by urban and regional planning programs (*1–7*).

The review of recent literature included an examination of the recommendations from recent conferences sponsored by the Transportation Research Board (TRB) (*8–10*) and other articles on transportation education (*5,11–17*). These articles and conference proceedings identify the historical areas of expertise for transportation planners. Recent legislation and regulations were reviewed to better understand the current and future knowledge and skill areas. These included the Americans with Disabilities Act (ADA) of 1990, Clean Air Act Amendments of 1991, and Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Recent problem statements issued by the TRB, the FHWA, and the FTA were also examined.

Interviews were conducted with selected transportation professionals from throughout the country for additional insight into current and future demands on the transportation planning profession. A total of 46 interviews were conducted with transportation professionals from federal agencies, national organizations, state departments of transportation, transit agencies, metropolitan planning organizations, local municipalities, consulting firms, transportation research institutes, and universities. A semistructured questionnaire was used with the interviews. Thirty of the 46 interviews were conducted in person, and 16 were completed over the telephone. A list of the individuals interviewed is provided in Table 1.

Second, a survey was conducted to obtain information from the 78 urban and regional planning graduate programs accredited by the American Planning Association (*18,19*). A questionnaire was sent to the director at each university requesting information on the number and nature of transportation courses, the existence and requirements of a specialization in transportation planning or a joint degree program, and specific topics addressed in the transportation courses. Information was obtained from all 78 schools, accounting for a 100-percent response rate. Realizing that other disciplines—primarily civil engineering, business, and economics—also play a significant role in training future transportation planners, information on courses offered in other departments was also obtained. This included information from schools participating in the Council of University Transportation Centers (*20*).

TRANSPORTATION PLANNING KNOWLEDGE AND SKILL AREAS

The information obtained through the reviews and interviews identified the key knowledge and skill areas for transportation planners. The results of this analysis are summarized in this section. The

TABLE 1 Transportation Professionals Interviewed

Federal Agencies	**Transit Agencies**
Ronald Fisher, FTA	Robert Babbit, MTA—Nashville
Dennis Judycki, FHWA	John Bartosiewiez, "T"—Fort Worth
Thomas Larson, FHWA	Michael Bolton, AATA—Ann Arbor
Lawrence Schulman, FTA	Larry Heil, McDonald Transit—Fort Worth
National Organizations	Judith Hollander, RTB—St. Paul
Thomas Brahms, ITE	Robert MacLennan, METRO—Houston
James Costantino, ITS America	Patricia McLaughlin, LACMTA—Los Angeles
Grace Crunican, STPP	**Consulting Firms**
George Marcou, APA	Donald Capelle, PBQD
Richard Weaver, APTA	Peter Fausch, SRF, Inc.
State Department of Transportation	Richard Pratt, RHPC
Leslie Jacobson, WSDOT	Tad Widby, PBQD
William Jeffrey, VDOT	Richard Worral, JHK
John Kilian, CDOT	**University Research Institutes**
Alvin Luedecke, TxDOT	Richard Braun, Minnesota
Eugene Ofstead, MnDOT	Thomas Humphrey, MIT
Metropolitan Planning Organizations	James Miller, Penn State
Patti Bass, Waco MPO/TTI	Robert Paasuell, City University of New York
Alan Clark, HGAC—Houston	C. V. Wootan, TTI
Natalio Diaz, Metropolitan Council	**Educational Institutions**
Janet Kennison, San Antonio MPO	C. T. Fielding, California, Irvine
Ronald Kirby, WASHCOG	Michael Meyer, Georgia Tech
Joel Markowitz, MTC—San Francisco	G. Scott Rutherford, Washington
Cities	Robert Stokes, Kansas State
Oliver Byrum, Minneapolis	Martin Wachs, UCLA
Rebecca Kohlstrand, San Francisco	
Ann Perry, Minnetonka	
William Stockton, Austin	

reviews indicated that the ADA, the Clean Air Act Amendments, the Intermodal Surface Transportation Efficiency Act, and other factors are combining to place additional responsibilities and requirements on federal, state, metropolitan, and local transportation agencies.

Although the direction and nature of many of these requirements are not new, the scope, magnitude, and implication of the Acts are. In many cases, the legislation provides a statutory basis for what were previously only guidelines. Further, the three Acts combine to establish a new vision and direction for the future transportation system in this country. This new vision is based on an intermodal approach focusing on better managing all elements of the existing transportation system, addressing air quality and environmental concerns, and providing equal access to transportation services by all segments of society. These changes place additional demands on transportation professionals. To respond to the changing transportation planning marketplace, transportation professionals in the future will need a wide range of skills and areas of expertise. While many of these build on the historic strengths of transportation planning and transportation engineering, many represent new and emerging skill areas.

A typology is presented in Table 2 summarizing the current and anticipated future demands of the transportation marketplace by knowledge areas and technical skill areas. This typology was used to differentiate the general subject areas that transportation professionals should have an understanding and awareness of, and the more specific areas of technical expertise. It is recognized that there is overlap between the two general categories, and that it is not possible for students or professionals to possess expertise in all of the skill areas noted. The classification system is useful, however, for identifying the topics that should be covered in graduate transportation planning courses and classes in other fields to better meet the anticipated future demands of the transportation planning marketplace. Each of the major knowledge and skill areas is briefly summarized in this section, along with the key areas of expertise identified through the interviews.

TABLE 2 Summary of Knowledge and Skill Areas for Future Transportation Planners

Knowledge Areas
- Intermodal/Multimodal Focus
- Individual Mode Characteristics
  - -Highways
  - -Transit (bus, rail, paratransit, rideshare)
  - -Bicycles
  - -Pedestrians
  - -Goods Movement
- Transportation/Land Use Interrelationships
- Traffic Engineering
- Air Quality and Environmental Impacts of Modes
- TSM, TDM, and TCM
- Travel Demand Forecasting Process
- ITS and Advanced Technologies
- Federal and State Requirements
- Transportation Planning and Decision-Making Process
- Public Participation Process
- Management

Skill Areas
- Travel Demand Modeling
- Air Quality and Environmental Analysis Techniques
- Financial Analysis Techniques
- GIS
- Database Management
- Mode Specific
- Evaluation Techniques
- Problem Solving Techniques
- Communication Skills

Although the 46 individuals interviewed represented a variety of backgrounds, technical areas of expertise, and current job responsibilities, a number of similar ideas were voiced on the current status of the transportation profession and the future demands of the transportation planning marketplace. In addition, a number of unique perspectives were also presented by individuals from the different agencies and organizations.

All of the individuals interviewed were in agreement that significant changes were occurring in the surface transportation system and the transportation profession. Although a number of people indicated that many of the these trends were not new, all stressed that the 1990 Clean Air Act Amendments and the 1991 Intermodal Surface Transportation Efficiency Act formally established a new direction for the nation's transportation system. Most of the representatives noted that these two Acts have significantly changed the planning, development, implementation, and operation of the surface transportation system. Rather than continuing to build new capacity and expand facilities, the Acts refocus future efforts on better management of the existing transportation system and addressing current air quality concerns. Further, many individuals noted that numerous factors are combining to make all aspects of the transportation system and the responsibilities of transportation professionals much more complex today.

To respond to these new demands, most of the individuals suggested that the roles and skills of transportation professionals will also change somewhat in the future. Although stressing that many of the traditional areas of expertise will still be in demand, most indicated that professionals with a variety of backgrounds and skills will be needed in the future. A number of individuals, especially those with federal agencies, national organizations, and universities, stressed that the transportation profession should embrace people from diverse disciplines and backgrounds. In addition to the traditional fields of civil engineering and planning, other disciplines noted were law, political science, public administration, computer science, business, finance, management, geography, sociology, and human factors. Thus, the need for a multidisciplinary approach to transportation planning and operation was promoted by many of the individuals interviewed. Multidisciplinary programs were noted as particularly important in the areas of intelligent transportation systems (ITS), travel demand management (TDM), intermodalism, and air quality and environmental analyses.

Further, in addition to specialized expertise in some of these areas, many individuals stressed that transportation professionals should have an understanding and familiarity with all of these subjects. Although they may not be experts in all areas, many of the representatives indicated that transportation planners should have a working knowledge of the different technical tools and techniques. This understanding was identified as important to support the role transportation planners play in linking the technical and policy levels.

The direction provided by the ISTEA clearly reflects a future vision of an integrated multimodal and intermodal transportation system. This system would maximize the advantages of each mode and would provide a variety of choices for operators and users. It appears appropriate that transportation planning education begin to reflect this vision by adopting a multimodal and intermodal approach. Such a focus would provide students with an understanding of the multimodal and intermodal concepts and the methods, techniques, and facilities needed to encourage greater integration of all modes.

Although there is a need to reflect an intermodal focus, there is also a need to provide students with an understanding of the characteristics of the individual modes. Given the broad scope of the ISTEA and the factors that need to be considered in the different plans, students should be exposed to not only highways and transit modes, but also bicycles, pedestrians, and goods movement. Further, the transit component should cover bus, rail, paratransit, and ridesharing systems. Topics to be addressed should include the capital and operating costs associated with each mode, the basic planning techniques used to estimate the demand for different modes, and issues unique to each mode.

To address many of the factors included in the state and metropolitan long-range plans and to take a more proactive role in addressing the issues facing urban areas, future transportation professions will need to understand the relationships among the different elements of the transportation system, land use, economic development, and social factors. This need was stressed by the representatives from MPOs, state DOTs, transit systems, federal agencies, and local communities. Graduate transportation programs should provide students with a perspective on the interaction of all these elements and the influence transportation decisions may have on other components. Further, planning students should understand the tools and techniques available to influence and control development and land use patterns. These may include such topics as zoning and other land use controls, economic development strategies, joint development techniques, and other approaches. In addition, transportation planners should be trained in the basic planning process, including the articulation of goals and objects, the development and evaluation of alternative plans, the selection of the recommended concepts, and the ongoing monitoring and updating of plans.

Transportation planners should also have an understanding of the basic concepts of traffic engineering. This should include such elements as the functional classification system, level of service characteristics, volume and capacity features, traffic flow concepts, basic design elements, and traffic management techniques. This is not to suggest that planners will perform traffic or transportation engineering. Rather, it recognizes the importance of many of the basic engineering concepts for facility design, operations and management, and travel demand modeling. Transportation planners who do not have an engineering background should have an understanding of these basic concepts to enhance their ability to conduct different studies, better coordinate activities and communicate with engineers, and provide a link between the technical and policy levels.

The requirements of the ISTEA and the Clean Air Act Amendments provide a clear indication that air quality and environmental concerns will be significant factors in future decisions regarding the overall transportation system and specific projects. Many of the individuals interviewed indicated that students with expertise in environmental areas were currently in demand. As a result, transportation professionals will need to have a much better understanding of the environmental impacts and consequences of different transportation improvements and the ability to conduct environmental analyses. Further, the Clean Air Act Amendments and the ISTEA require the examination and implementation of techniques to encourage greater use of high-occupancy commute modes and to increase vehicle occupancy levels. Various Transportation System Management (TSM), Travel Demand Management (TDM), and Transportation Control Measures (TCM) strategies will be necessary to meet the requirements of these Acts and other state legislation. Graduate transportation planning curriculum should cover not only the general concepts associated with the different strategies, but also the techniques to estimate demand, and implement, monitor, and evaluate selected programs.

Many of the individuals interviewed stressed that the travel demand forecasting process represents a basic component of the transportation planning process. Although not all transportation planners will be experts in use of travel demand models and forecasting techniques, an understanding of the basic concepts is important. This should include a comprehension of the factors considered in travel models, the strengths and limitations of different types of models, and typical applications. The importance of skills in these areas can be noted by the inclusion of additional training in the use of travel demand models as a technical area of expertise.

There continues to be a great deal of interest in the development, testing, and deployment of ITS and other advanced technologies to improve the overall efficiency of the transportation system. Numerous activities at the federal, state, and local levels are focusing on the application of a wide range of evolving technologies. Many of the individuals interviewed noted that professionals from many disciplines will be needed to successfully develop, implement, and operate ITS. Graduate planning students should be provided with at least a general introduction to ITS to help prepare them for future work in this area.

It is important that transportation professionals and graduate students have an understanding of the requirements of the ISTEA, the Clean Air Act Amendments, and the ADA. Planners with a knowledge of not only the regulations, but also the methods, techniques, and plans necessary to address the requirements will be in demand in the future. Graduate transportation planning curriculum should cover the important elements of all three Acts and the basic components of the different plans. For example, graduate students should know the factors that must be addressed in the metropolitan and statewide long-range plans and how to conduct the necessary analyses. In addition to the requirements of recent federal legislation, relevant state and local laws should also be included.

Many of the representatives interviewed, especially those associated with state and local agencies, stressed that transportation planners should have an understanding of the transportation planning process, the local decision-making process, and the political process. To respond to this identified need, these topics should be covered in graduate transportation planning curriculum. Topics to be addressed include the roles and responsibilities of the different agencies, the nontransportation factors that may influence the decision-making process, and possible methods to coordinate transportation and land use decisions.

Related to the transportation planning process is the need for transportation professions to have an understanding of the public participation requirements associated with the development of the different plans, programs, and project selection activities. The mandates contained in the ISTEA, the Clean Air Act Amendments, and the ADA for early and ongoing public involvements are requiring major improvements in the citizen involvement programs of many agencies. Thus, it appears that planners with an understanding of the requirements and the skills to conduct public participation strategies will be in demand. Graduate planning programs should help prepare students to meet these needs by providing not only an overview of the requirements and the different approaches that can be used, but also experience in the use of different strategies.

The last knowledge area suggested as important for transportation planners, and thus graduate students, is management. A number of the representatives interviewed indicated planners need both project and people management skills. Capabilities in these areas were noted as especially important as people move up within organizations. Most of the individuals interviewed noted that not all students might have an interest in management courses. Providing the opportunity to take management classes was suggested as important for those students that do, however.

In addition to understanding the basic concepts in these areas, transportation professionals will also need a variety of technical skills to be competitive in the future transportation planning marketplace. The individuals interviewed provided suggestions on these technical areas of expertise. As identified in Table 2, these include a variety of computer, analytical, and communication skills. Given the widespread use of computers today, it is critical that future planners have an understanding of the different programs and are comfortable working in a computer-assisted environment. Further, to perform the analyses required in many of the knowledge areas, transportation planners will be needed with technical skills in the areas of travel demand modeling, air quality and environmental analyses, financial analyses and cost-benefit techniques, geographic information systems (GIS), and database management. Providing students with exposure to these areas and allowing them to develop practical skills in the use of different computer programs and techniques will enhance their marketability.

A number of other basic skills were highlighted by the transportation professionals interviewed. For example, all of the individuals interviewed agreed that transportation planners need good communication skills. The ability to write and speak clearly, make presentations, and work with diverse groups of people and individuals was stressed as critical attributes for transportation professionals. There was strong sentiment among all the representatives that communications skills are critical; without the ability to communicate clearly a planner cannot be effective.

In addition, a number of people suggested that successful planners will need more than just the basic communication skills. To respond to these demands, graduate programs should also be teaching advanced communication techniques. For example, one individual noted that their Planning Commission and City Council meetings are broadcast on local cable television. As a result, it was suggested that students should be exposed to the use of television and other innovative communication techniques. The need for good interpersonal skills was further stressed to allow planners to successfully interact in the diverse workplace environment, with a variety of groups and individuals, and with elected representatives. To help promote the development of interpersonal skills, a number of people encouraged the use of group projects, especially those involving students from different disciplines.

Representatives from all nine categories supported the use of internships as a way of providing graduate students with valuable practical experience. Internships and other training allows students to test and practice the skills and techniques they have learned. Further, students have the opportunity to develop skills in areas of specialization that may not be available through their normal course work. Almost all of the individuals interviewed indicated that the agencies or businesses they work for use interns or student workers. In addition to providing practical experience for students, a number of benefits to the agencies were identified. For example, many people noted that internships not only provide students with contacts that will assist them in their careers, but also that agencies use internships as one method for identifying future employees.

Finally, it is interesting to note that the university professors and the representatives from the transportation research institutes identified many of the same needs and priorities as representatives from private and public-sector agencies and organizations. Thus, the results from the interviews seem to indicate that many university faculty and staff are aware of the changing demands of the transportation marketplace. Further, most identified the need for university programs and courses to change to meet these new demands. The faculty and staff members provided a realistic assessment of the ability of universities to respond to these new demands, however. Funding limitations for new equipment and the long and cumbersome process to add or change courses were two of the limiting factors identified by the university representatives. Even with these limitations, however, the professors and staff members were unanimous in their enthusiasm toward the future opportunities in the transportation profession.

CURRENT TRANSPORTATION PLANNING EDUCATION

A total of 134 transportation-related courses were identified in the survey as being offered at the 78 urban and regional graduate planning programs. The number of transportation courses reported by each program is shown in Table 3. A total of 22 programs, or 28 percent of all the schools surveyed, do not offer any transportation courses. Correspondingly, a total of 56, or 72 percent of the urban and regional planning programs, offer one or more transportation courses. A total of 24 schools reported offering only one course, 11 offer two courses, and 19 programs list between three and five transportation classes. Finally, two schools reported eight transportation-related courses.

The nature of the 134 transportation courses offered at the different programs reflects a wide variety of subject areas. Table 4 presents a summary of the courses using a topology covering 13 general areas. As illustrated, introductory classes in transportation planning and urban transportation planning are the most commonly offered courses, accounting for 27 percent and 23 percent of the total, respectively. Courses in transportation policy, transportation and land use, public transportation, and infrastructure/comparative urban systems form a second grouping. Between 7 and 14 courses focus on each of these topics. Finally, only a few programs offer specialized courses in advanced transportation planning, trans-

TABLE 3 Urban and Regional Planning Programs—Number of Transportation Courses Offered

Number of Courses	Number	Percentage
None	22	28%
1	24	31%
2	11	14%
3	9	12%
4	5	6%
5	5	6%
5+	2	3%
Total	78	100%

TABLE 4 Urban and Regional Planning Programs—Transportation Courses by General Type

General Topic	Number	Percentage
Introduction to Transportation Planning	36	27%
Urban Transportation Planning	30	23%
Transportation Policy	14	10%
Transportation/Land Use	12	9%
Public Transportation	8	6%
Infrastructure/Comparative Urban Systems	7	5%
Advanced Transportation Planning	6	4%
Transportation Systems	6	4%
Transportation Economics	5	4%
Transportation Modeling and Techniques	5	4%
Environmental	3	2%
Transportation Regulation	1	1%
Transportation Engineering	1	1%
Total	134	100%

portation systems, transportation economics, travel demand modeling, environmental issues, transportation regulation, and transportation engineering.

The survey also contained a matrix listing 13 topic areas. Respondents were asked to check the topics covered in the different courses and in other classes within the program. The most frequently noted topics were land use and transportation, public transit, transportation modeling, introduction to transportation, TDM/TSM, and air quality and environmental issues. Thus, it appears that the 68 courses listed under the general titles of introduction to transportation and urban transportation planning cover a variety of transportation modes and subjects. Topics that are currently receiving less emphasis include goods movement, GIS, ITS, and statistics. Respondents from 16 programs indicated that consideration was being given to adding new transportation courses. The most frequently mentioned subject areas being considered were public transportation, transportation modeling, transportation policy, land use and transportation, and multimodal planning.

According to the survey responses, a total of 31 urban and regional planning programs offer a transportation emphasis area. These schools are listed in Table 5. Thus, the survey results indicate that 40 percent of the graduate urban and regional planning pro-

TABLE 5 Graduate Programs in Urban and Regional Planning with Transportation Emphasis Areas

Alabama A&M University—Community Planning and Urban Studies
University of California, Berkeley—City and Regional Planning
University of California, Irvine—Urban and Regional Planning
University of California, Los Angeles—Urban Planning
Columbia University—Urban Planning
Eastern Washington University—Urban and Regional Planning
Florida State University—Urban and Regional Planning
Georgia Institute of Technology—City Planning
Harvard University—City and Regional Planning
Hunter College of the City University of New York—Urban Planning
University of Illinois at Chicago—Urban Planning and Policy
University of Illinois at Urbana-Champaign—Urban and Regional Planning
Iowa State University—Community and Regional Planning
University of Iowa—Urban and Regional Planning
University of Kansas—Urban Planning
Massachusetts Institute of Technology—Urban Studies and Planning
Memphis State University—City and Regional Planning
Michigan State University—Urban Planning
University of Michigan—Urban and Regional Planning
New York University—Urban Planning
University of North Carolina at Chapel Hill—Regional Planing
University of Oklahoma—Regional and City Planning
University of Pennsylvania—City and Regional Planning
Portland State University—Urban Studies and Planning
Rutgers University—Urban Planning and Policy Development
San Jose State University—Urban and Regional Planning
State University of New York at Albany—Geography and Planning
Texas A&M University—Landscape Architecture and Urban Planning
University of Texas at Arlington—City and Regional Planning
University of Washington—Urban Design and Planning
University of Wisconsin, Milwaukee—Urban Planning

grams offer emphasis areas in transportation planning. A total of 12 programs, accounting for 15 percent of the total planning programs, offer a joint degree or concurrent degree option. As shown in Table 6, 10 of these joint degree programs are offered with engineering departments, one interdepartmental program is provided in transportation planning, and one certificate in ITS is offered in cooperation with a civil engineering department. In addition to these programs, one university reported a separate department in transportation studies.

Survey respondents were asked to identify transportation-related courses in other departments that were available to graduate students in the urban and regional planning program. A total of 115 courses were listed in the surveys. The most frequently noted courses were in traffic and transportation engineering and urban transportation planning. All but five of these were offered by civil engineering departments. Geography, economics, and business comprised the other departments with courses listed. A number of respondents indicated that students interested in transportation planning are encouraged to take courses in civil engineering and other departments.

CONCLUSION

It appears that the current transportation course offerings in urban and regional planning programs address some, but not all of the knowledge and skill areas identified previously in Table 2. Approximately half of the transportation classes currently offered in planning programs are introductory in nature. From the course topics identified in the survey and copies of the course outlines provided by some respondents, it appears that many of these classes provide a good overview of the basic elements involved in transportation planning. For example, most seem to address the different modes, TDM and TSM, land use and transportation, and the travel demand modeling process. Fewer courses appear to cover multimodal and intermodal planning, goods movement, air quality and environmental issues, ITS, GIS, and other emerging knowledge areas, however.

Although the current courses seem to offer an adequate general overview of many of the key knowledge areas, little depth is available in many programs after the first introductory course. For example, 31 percent of the urban and regional planning graduate programs offer only one transportation course. The remaining 41 percent provide two or more courses. Thus, few specialty courses are available within many programs. Of the transportation knowledge areas, only 14 programs offer a course in transportation policy, only eight offer a course in public transportation, only five offer a modeling course, and only three offer a course in transportation and the environment.

Educational opportunities in the more specialized skill areas identified previously are also lacking in many programs. Although a number of topics are covered in the general introductory courses, few programs offer specialized classes in travel demand modeling, environmental analysis techniques, public transportation, and GIS. Although courses in these topics are offered in civil engineering departments at some universities, it appears that additional courses within both disciplines would be beneficial.

Thus, if urban and regional graduate planning programs wish to assist in meeting the current and future demands of the transportation marketplace, additional courses and enhanced curriculum will be needed. These enhancements should focus on both the knowledge and technical skill areas identified previously. Graduate programs should focus on providing students with a comprehensive understanding of a number of subject areas and more specific technical skills.

Based on the assessment of the needs of the transportation planning marketplace, the examination of current course offerings, and the examples noted above, a number of suggestions can be made for future enhancements to the transportation curriculum offered in urban and regional planning programs. First, it is suggested that introductory courses provide students with a multimodal and intermodal perspective to transportation planning, implementation, and operation. This approach is in keeping with the vision of the ISTEA and other recent legislation. Further, although the focus of future transportation education should be on a more integrated approach, students should still learn the basic characteristics of the different modes. This should include a discussion of highways, transit, goods movement, bicycles, pedestrians, and techniques to integrate these different modes. In addition, an introductory course should also provide students with a basic understanding of the requirements of recent legislation, the transportation planning process, and the use of emerging technologies and techniques.

Other courses should be provided focusing on more specific knowledge areas and technical skills. Examples of courses appropriate to meet the demands in the identified knowledge areas include transportation and land use; the transportation planning process, policies, and legislation; the environmental impacts of alternative modes and analysis techniques; the travel demand forecasting process; transit and TDM; and ITS and advanced technologies. Further, students interested in transportation should be provided with the opportunity to take courses in management and business administration.

TABLE 6 Joint or Concurrent Degree Programs in Transportation

University of Arizona—Interdisciplinary Planning and Civil Engineering
Auburn University—Planning and Civil Engineering
California Polytechnic, San Luis Obispo—Planning and Engineering
University of California Berkeley—Planning and Engineering
Georgia Institute of Technology—Planning and Engineering
Iowa State University—Interdepartmental program in Transportation Planning
University of Iowa—Urban and Regional Planning and Engineering
Massachusetts Institute of Technology—Planning and Civil Engineering
University of Michigan—Certificate in Transportation Studies: IVHS
Ohio State University—City and Regional Planning and Civil Engineering
Virginia Polytechnic Institute & State University—Planning and Engineering
University of Wisconsin, Milwaukee—Urban Planning and Engineering

The technical areas of expertise that should be covered in transportation or other planning courses include a variety of computer, analytical, and communication skills. In general, all planners should be comfortable working with computers and should have an understanding of the different programs that can enhance their jobs. Transportation planners should be provided with further opportunities to learn technical skills in the areas of travel demand modeling, financial analysis techniques, air quality and environmental analyses, statistics, GIS, and database management. In addition, a course should be provided addressing the communication skills planners will need to be effective problem solvers. This should include writing and presentation skills and the use of video and other technologies.

Developing enhanced transportation emphasis areas based on these suggestions will position urban and regional graduate planning programs to better respond to the anticipated future demands of the transportation planning marketplace. Further, it will provide graduate students with an understanding of the knowledge areas and the technical skills necessary to compete in the job market and to respond to the complex issues facing all areas of the country. Thus, enhancing transportation emphasis areas in urban and regional graduate planning programs will benefit students, the institutions, and society, in general.

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Publication of this paper sponsored by Committee on Transportation Education and Training.

Strategic Planning, Total Quality and Performance Measurement: A Quality Director's View

JAMES S. ETMANCZYK

In this paper the Wisconsin Department of Transportation Division of Highways' journey from strategic planning to total quality and performance measurement is described. The journey and reflections are presented from a quality director's point of view. The lessons learned in the journey are summarized. The focus is on improving the organization's performance—lowering costs, improving service, and increasing customer satisfaction. The private sector bottom-line focus is emphasized while transforming a governmental organization to total quality.

As the 1990s approached, the Wisconsin Department of Transportation's Division of Highways was in the midst of a series of challenges. The division chose to make some drastic changes to chart its future course.

Various challenges confronted the division. The Interstate highway building era was over. No longer would the division be building highways on new locations to any great extent. It was entering an era of preservation and system management, and the difficulties of building new highways were increasing. In the 1970s it took 5 years to develop and build a major highway project, while in the 1990s it was taking as long as 8 years. The average age of the work force was declining due to an early retirement opportunity in the 1980s. In some areas the average period of experience was less than 10 years. This less experienced work force required additional training. Lastly, competition developed for the division's core work. In the mid-1980s, $1 out of every $7 of program delivery costs was going to engineering consultants. In the 1990's, $1 out of every $2 was going to consultants.

As the division's quality director through this journey over the past few years, I have included in the Reflections sections some lessons we learned along the way.

Figure 1 illustrates the course we are following to become a successful, quality organization. The paper is organized according to the major activities on the chart.

VISIONING—DETERMINING OUR DIRECTION

The senior management team began discussing the need for formal strategic planning in 1991 to determine the division's direction over the next decade. It became apparent that transportation demands in the future would be different than they were in past years, and that the organization must be prepared to meet the challenges.

A cross section of the staff from throughout the division, in an intense 2-day session, developed a vision, mission, and set of underlying principles to guide the organization. A group of 100 volunteers from the central office and the district offices fine-tuned the draft versions, producing ultimately a succinct statement of lasting importance for the division as follows.

Our VISION: What we want to be.

People who care, creating quality transportation . . . today and tomorrow.

Our MISSION: What business we're in and why.

We are a team entrusted with the development and safe operation of Wisconsin's transportation systems. We strive to satisfy the diverse mobility needs of all citizens while retaining a responsible concern for the environment.

Our UNDERLYING PRINCIPLES: The organizational values we hold.

- The quality of what we do is measured by the satisfaction of those we serve;
- We will continually improve the way we do business and be responsive to the need to change;
- We build organizational strength through teamwork and organizational trust through respect for each other;
- The excellence of our team is derived from the excellence of its members;
- We will maintain the highest level of integrity;
- The opportunity for personal and professional growth is essential;
- Each member of the team has the responsibility to add value to our products;
- Diverse opinions and discussions contribute to the central goals of the team;
- Partnerships enhance the effectiveness of our team.

REFLECTIONS—Our vision started with emphasizing people who care, which pointed to our multitalented team working with a sense of concern for our customers. This differed from our traditional view of engineers building highways. We included "creating" to identify the responsibility of looking for new ways to do our business and empowering the staff to use ingenuity and innovation. The use of "transportation" instead of highways was a paradigm shift for the division. We felt our strength as an organization was in our ability to implement projects, no matter what the mode of transportation was. The last words, "today and tomorrow," stressed that we didn't want to rest on yesterday's successes, but to continue to grow and improve.

A few things became clear. Quality was a main focus in the vision and underlying principles. The volunteer group included many front-

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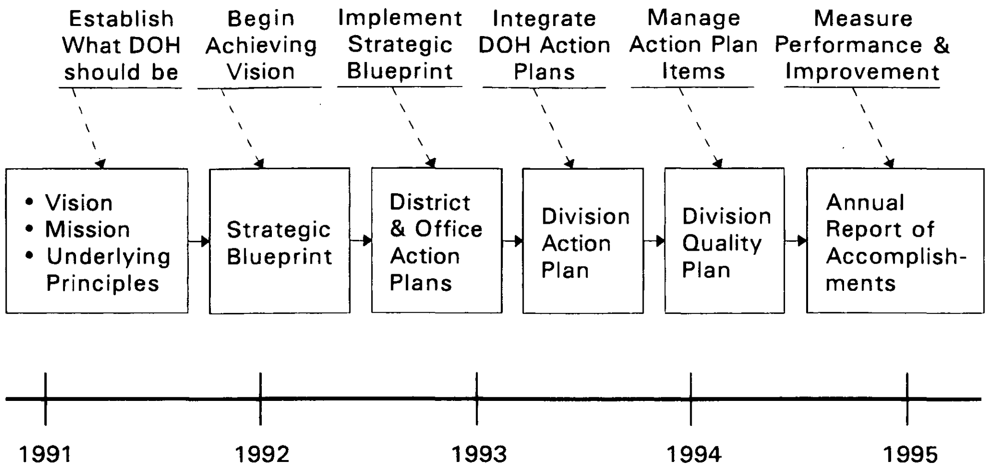

FIGURE 1 The strategic journey.

line employees in the organization who had been disenfranchised (out of the normal hierarchy) and were now being given a voice. Our challenge was to tap into this resource and still maintain the trust and confidence of the managers and supervisors.

STRATEGIC PLANNING

With the vision, mission, and underlying values in place, we took the next step in 1992 to determine what key organizational issues needed attention. This became our strategic planning effort. Six emphasis areas were identified and defined, with current and future descriptions of the division activities and their related measures. It was our first step in measuring progress.

Our volunteer group of 100 met again at a 2-day meeting to review and finalize the strategic plan that we entitled the Strategic Blueprint.

We identified six emphasis areas necessary for attaining the vision.

- Focusing on customers: Conscientiously seeking to identify and satisfy those people who have a claim on our services.
- Making good decisions: Determining the appropriate action in a particular situation and when and how to do it, and communicating the results.
- Operating by teams: Accomplishing tasks by drawing on the collective talents of diverse individuals on the basis of shared goals.
- Managing production and performance: Measuring division accomplishments in terms of generally accepted goals.
- Increasing job satisfaction: Creating an environment in which all division employees can do meaningful work and maximize their personal accomplishments in contributing to the division's goals.
- Managing our resources: Acquiring and utilizing efficiently the materials, facilities, manpower, and equipment needed to carry out the division's mission.

As part of the strategic planning process, all employees were surveyed, and some were given the opportunity to participate in focus groups or in-depth interviews as part of the division's organizational assessment in 1992. Employee perceptions of the division helped to pinpoint strengths and areas needing improvement. This was the first time the division had ever surveyed its internal customers. The management team agreed that the results of the assessment would be shared with every employee even though some of the results did not reflect positively on management.

Each of the districts, bureaus, and offices considered the findings from the assessment while developing specific Action Plans unique to their areas. These Action Plans were to relate the Strategic Blueprint emphasis areas directly to their operations. Each office developed a plan to address their most critical issues and started teams to solve these issues.

REFLECTIONS—Certainly, if our organizational change process was linear, we would have started with an organizational assessment. The assessment was a key to uncovering problems and establishing a baseline for improvement actions. One statement from the assessment summarized the awakening for all of us in stating that "... fundamentally, the organization is run as an 'old boys' club' where power resides with tradition and the status quo."

Through the meeting with our 100 volunteers, meetings with other employees, and the organizational assessment, it became clear much of the organization had become "entitled." Judith Bardwick describes this entitlement in her book Danger in the Comfort Zone as "the result of too much generosity. We give people what they expect and we don't hold them accountable for meeting criteria of excellence." (1).

The offices created teams to work on the issues identified in their Action Plans. As teams addressed the various subjects, it became clear that they focused mainly on "warm fuzzy" solutions, including things like employee picture directories, better ways to assign fleet cars, new bulletin boards, and so forth. These sorts of things made the office a more comfortable place to work, but they didn't necessarily improve products and services for the end user or reduce the cost of delivering these products and services.

It was clear that we needed to break out of our entitlement, improve our competitive performance and address the concerns in the organizational assessment.

DIVISION ACTION PLANNING

Work began in early 1993 to create a Division Action Plan, which pulled the Strategic Blueprint activities in a clearer direction. The challenges to the division needed to be met with a clear statement of goals. The Division Action Plan contained nine goals that charted a course to improve our performance and address some of the issues raised in the organizational assessment. The nine goals were as follows.

1. Engineering costs: In-house design and construction engineering costs must be equal to or less than the costs of the same services provided by the private sector.

2. Unprogrammed costs: Unprogrammed costs must be decreased to 10 percent of the let program over time, and incremental reductions of 2 percent per year should be realized until the broad goal is achieved.

3. Performance measures: Measures and data-collection methods will be established for each major functional area for use as a monitoring tool for both organizational and individual performance.

4. Transforming to quality-based leadership: All employees will be trained in quality principles and commit to improving the quality of our products and processes.

5. Improving the way we do business: Process activities will be integrated to reduce redundancies and complexities and improve flexibility, product excellence, and customer satisfaction.

6. District–central office relationships: Foster networks, teams, and partnerships within and between all areas and functions within the division; identify and remove barriers to teamwork and cooperation.

7. Performance appraisals and action plans: Action Plans will be developed throughout the division, and leadership will take an active role in their implementation.

8. Affirmative Action and equal employment opportunities: Our work force will be diverse in terms of ethnicity, gender, and professional training.

9. Personnel reclassification backlog: Reclassification actions will be processed within a predetermined time frame and under performance standards negotiated between the Division of Highways and the Bureau of Human Resource Services.

REFLECTIONS—At this point, organizational expectations were identified, but many in the division asked how they were related to the strategic plan, action plans, quality, and improving performance. We had developed our goals but had not established tools for implementation. Nor had we related the goals to our vision for the future. We needed to merge strategic planning and the transformation to quality. It was becoming clear that our quality efforts had to form the umbrella for all of the organizational change activities.

QUALITY-BASED LEADERSHIP

To blend our past strategic planning activities and the quality process, we looked to the outside for assistance. We retained 3M Quality Management Services to assist the division in successfully implementing quality. 3M was chosen because they are a recognized leader in quality innovation, products, and customer service. We called our Total Quality Management process Quality-Based Leadership because we thought the use of the term "management" was not sufficiently comprehensive. There are many leaders outside of the management ranks.

We embarked on the process of transforming the division's culture, organization, and attitude to Quality-Based Leadership. We formed a quality steering team, composed of a small group of senior managers, to guide the overall transformation. To lead the quality awareness training, 10 individuals were chosen through a self-nomination process to be Quality Leaders. These leaders instructed our 400 managers and supervisors in the basics of Quality-Based Leadership.

The impact and importance of quality in achieving our vision was a key. The quality process called for identifying our customers, knowing their expectations, and finding ways to meet and exceed their expectations. We then needed to measure customer satisfaction and develop strategies to continuously improve our products and services.

The quality process would enhance the business side of our organization. Improving the business side would be accomplished by creating our Critical Success Factors and Evidence of Success Statements.

The Critical Success Factors are a number of accomplishments that must be present for an organization to attain its vision. The Evidence of Success Statements are measurements that enable the division to determine if the Critical Success Factors have been achieved.

We identified four critical success factors. Within each of these factors, there are several Evidence of Success statements. The target date to achieve the business goals critical to our success is 1997.

1. We must provide the quality transportation services expected by the public.
   a. Customers have been surveyed for their perception of what constitutes quality transportation services.
   b. Management systems have been developed that link infrastructure measurements with customer perceptions.
   c. Our management systems indicate continuous improvement in measurements of customer satisfaction.
   d. The quality of highway services is consistent across district and jurisdictional boundaries.
   e. Public satisfaction with the quality of service provided is expressed through the public's willingness to provide sufficient funds for that service.
2. We must provide these quality services at an acceptable cost.
   a. The production index, as measured by the product per dollar of delivery, has steadily increased from 3.3 in 1993 to 3.9 in 1997.
   b. In-house design and construction engineering costs have been reduced to less than the costs of similar services provided by the private sector.
   c. Unprogrammed costs have been reduced from 18 percent to 10 percent of project lettings within 4 years.
   d. All projects are delivered on-time and within budget.
   e. Performance measures are routinely used in all functional areas.
3. We must attract, develop and retain qualified people to provide these services.
   a. All employees receive Quality-Based Leadership training.
   b. All personnel reclassifications delegated to the department are completed within 90 days from the date the employee signs the new position description.
   c. Our nontraditional employees are valued and respected by their fellow employees and are comfortable working here.
   d. Employees are routinely involved in the selection and evaluation of managers.
   e. Standard training or certification programs are in place for all employees.
   f. Employees have been surveyed in 1995 to determine their attitudes and perceptions about working in the division and whether the above statements have been achieved.
4. We must build cooperative relationships with others to provide these services.
   a. We have initiated innovative, cost-effective working relationships with all our partners.

b. We aggressively pursue issues that strengthen our partnerships.
c. Contracts are awarded on the basis of quality as well as price.

REFLECTIONS—Our effort really started to pay off at this point. Hiring 3M for assistance served notice to our organization that we were serious about this effort. We also needed an outside look at our results and how we were managing the division. 3M asked for a commitment of top management time and the appointment of a quality director to lead the quality process. We agreed to these requests.

In our overall journey, this was a pivotal point. We needed to make the transition from "warm fuzzy" activities to business improvement projects. 3M brought not only the expertise but also the push we needed to overcome some organizational inertia. They also gave us insight to our management style. We had become an organization that needed consensus on almost all issues. At virtually any time one of our managers could raise an objection and have an entire issue reviewed. Consequently, most of our time at management meetings was spent rehashing old issues and problems.

The Critical Success Factors and Evidence of Success statements were a new concept to the organization. Many were very interested to see if top management was committed to carrying them out. Recently, a district office director was selected with participation by an employee group from that district office. The group solicited questions for the candidates from other employees and interviewed the top three candidates. Their recommendation was part of the final decision-making process. This was noticed not only in this district office but throughout the organization. It showed top management's commitment to "walking the walk" as well as "talking the talk."

QUALITY IMPLEMENTATION

While the quality awareness training continued, the Quality Steering Team solicited possible quality projects of division-level significance. These projects had a clear mission, focused on problem-solving or process improvement, related to the Critical Success Factors or Evidence of Success statements, and used the concepts of quality improvement. The teams that would work on these projects would be facilitated, and both the team leader and facilitator would be trained in problem solving. We selected the following five projects to be completed by the end of 1994.

- **Improving maintenance uniformity across county lines:** Highway maintenance practices are not always uniform, and our policies appear to differ across county and district lines. This project will look for causes behind the lack of uniformity and seek solutions to ensure uniform maintenance practices. Its goal is to reduce to zero the number of comments and complaints about uniformity of maintenance service by calendar year 1996.
- **Streamlining environmental processes:** The environmental aspects of highway improvement projects have grown sporadically over the years as new federal and state laws have been enacted. This project reviews the entire environmental analysis in an effort to eliminate redundant activities and automate when practical. Its goal is to complete 100 percent of Environmental Impact Statements started after January 1, 1995, in 18 months or less.
- **Increasing improvement program stability:** The size of our highway improvement program changes throughout the life of a project. As a result, some projects are moved ahead more quickly while others are delayed. These unplanned changes can then trigger other problems. The project will review the factors that cause improvement projects to change from the original schedule. Its goal is to let all projects in the year they are originally programmed.
- **Improving the reclassification process:** Processing of employee reclassification actions is handled by both our division and the department's personnel office. The time needed to process employee reclassifications is excessive and backlogs are frequent. This project's goal is to complete reclassification processing within 90 days from the date the employee signs the new position description.
- **Reviewing construction materials process:** The division spends a great deal of time and effort in testing and accepting materials that are used in highway construction projects. This project will evaluate the current specifications and procedures, identify essential materials tests that are linked to performance, and investigate alternative methods to ensure that quality materials are used in construction. The goal of the project is to develop a more cost-effective method of accepting materials and a simplified way of documenting the quality of construction materials.

Figure 2 shows the link between the vision, critical success factors, evidence statement, and our quality projects.

REFLECTIONS—Using the 10 internal quality leaders as trainers has been universally well received. Even our harshest critics appreciated being trained by individuals who know the business. All managers have been trained and front-line employees are currently receiving similar training. These employees are testing us. They are watching to see if their supervisor and manager make a change; when they do, front-line employees notice.

We realized that our team leaders and facilitators needed special training in problem solving before starting the division's projects. It was amazing that we were very good at project implementation but didn't have good problem-solving skills. Training for this has been started and continues. Again, we are using internal trainers.

MEASURING PERFORMANCE

The organization now has a strategic direction, a set of goals, and some legitimate, bottom-line quality projects; however, management must be enticed to use the quality tools. This is when performance measurements become critical.

Performance measurements serve to focus the organization on the right direction. Measurement allows the whole organization to know it is doing good versus feeling it is doing good. In short, if performance is not measured, it is hard to tell success from failure.

What is our definition of a performance measure? It is defined as an index of the results or outcomes of a process. Performance measures are used to develop a baseline of performance and to set goals for improvement.

We chose to focus on each functional area with four general criteria: on-time, on-budget, at a reasonable cost, and of high quality. We have developed performance measures for our design and construction functions and are currently working on other areas.

Our on-time, on-budget, and quality measures have a long-term goal of 100 percent. We have set interim targets to be achieved in the next 2 years in the 80 to 85 percent range. The reasonable cost goal, which measures our engineering cost, has a 2-year goal set in the 13 to 16 percent range. For reasonable cost the long-term goal is to gradually reduce target goals. Since this is our first attempt to set reasonable targets, we tried to develop goals that would stretch the organization but could be accomplished. The performance of our competitors, the engineering consultants, will be monitored in conjunction with ours.

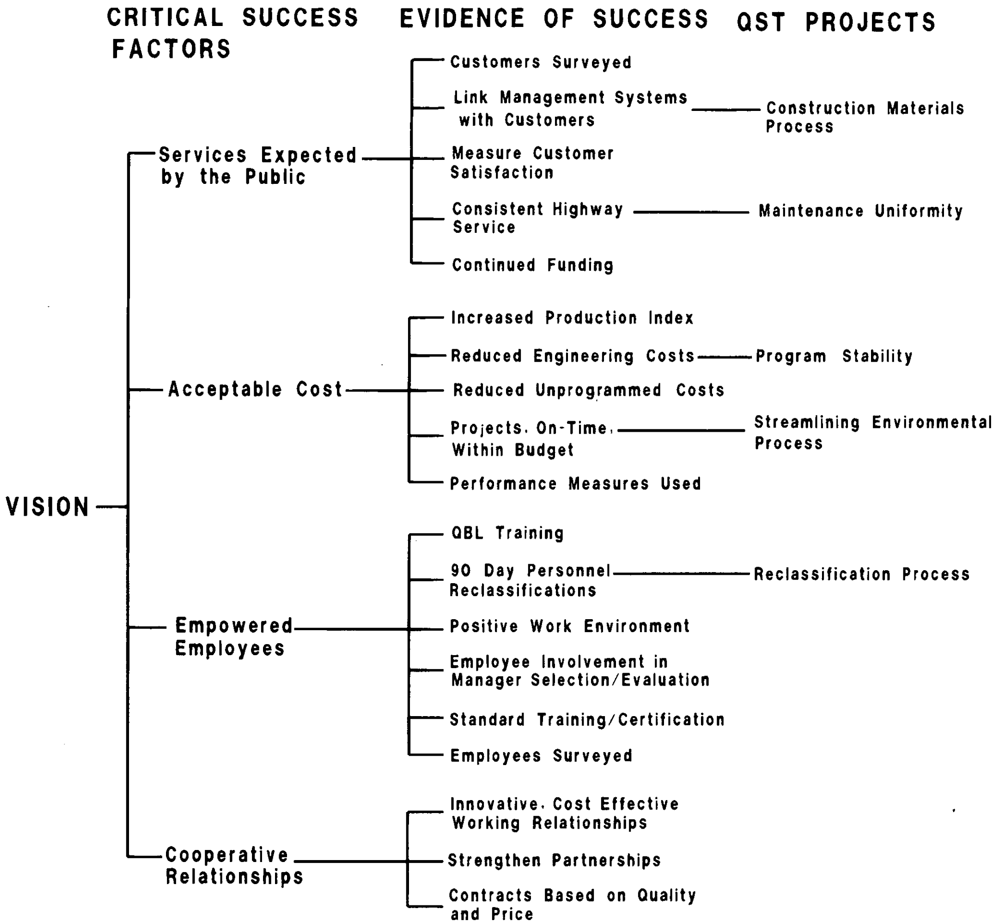

FIGURE 2 Relationship between the vision, critical success factors, evidence statement, and quality products.

These performance measures must continue to be refined as to what is measured and how it is measured. The proposed performance measures may not be perfect, but they start the measurement process. In the next few years, these measures will be improved as data are collected and tracked. In time, we will arrive at a set of measures that all will agree measures performance accurately.

REFLECTIONS—Although performance measures are common in the private sector, they are relatively unfamiliar in government. In our organization, performance measures were a foreign language. One of our folks noted that if Latin is a dead language, performance measurement is a language that hasn't been invented yet for our organization. Surprisingly, however, many in the organization actually wanted measures to document their performance and to document improvements they were making.

LESSONS LEARNED

Looking back at the overall effort, it is easy to pick out some of the keys to our success thus far. But one word of caution: every organization is different and no one recipe will fit all organizations. What worked for us may not work for another transportation agency.

1. A commitment from the top person is crucial. The division administrator is convinced we are on the right track and is willing to discuss quality with groups of employees at any time. He estimates that activities involved in extending the Quality-Based Leadership culture require at least 40 percent of his work time. Don't embark on this journey without commitment from the top or you'll only be fooling yourself. You'll be able to make some modest changes but you won't be able to transform the organization to quality.

2. You need someone to guide you on this journey. A consultant is necessary. You must have someone who can bring an unbiased view to your organization and its problems. Make sure you spend adequate time making this selection. We were unsuccessful with our first consultant. When we hired 3M, we wanted to find a firm that not only taught quality but practiced it in its business activities.

3. Someone must be dedicated to making the change happen. We appointed a quality director from our existing staff. This person must have the energy, interest, and strength to work with senior management and front-line employees. Also, the quality director should report to the top person in the organization.

4. Set 3- to 5-year goals. It takes time to accomplish a change of this magnitude. Our critical success factors have a 4-year completion time frame. You should measure your progress quarterly; progress does not happen in one day or one week.

5. Performance measures are a must. If you don't know how much your product or service costs, how long it takes to deliver, how much is being produced, and whether the end result matches the customers' expectations, what are you managing? Our philosophy is to hold tight to the performance targets but loosely to the methods our organization uses. To support this, we are providing tools that every individual performance center can use to improve its effectiveness.

6. Find champions and emphasize the positive. There are some folks who naturally deliver the quality services and products, and some who have a strong desire to make quality happen. Search out these people and make use of them wherever you can. We used self-nominated Quality Leaders as internal trainers, which was received positively throughout the organization.

7. Management must lead. As important as the top person is, you will need a top management team that is willing to stand up and be counted. Each member of our Quality Steering Team has made presentations to at least 10 groups of employees. Quality must be communicated by more than the top person and the quality director.

8. Don't waste time on the tough nuts. Developing a quality organization takes time, precious time, and you can't be sidetracked catering to those who do not want to buy in. There is just too much to accomplish when you are starting out. You can work with these people as time goes on, but get the critical mass of support moving first.

9. Balance process and people. Some in the quality business want to concentrate only on process. These people think that after employees see the changes made in the processes, they will become convinced of quality's benefits. Yet many times the process-driven people forget to communicate with those they need the most—the front-line employees. Remember, you can't satisfy customer expectations with dissatisfied employees.

10. This is hard work. Many of our employees have taken the quality awareness training and wonder why all of the organization doesn't buy into this concept. It takes more from all concerned. Often, those who have experienced initiatives before that produced little change are skeptical. You have to work hard to conquer these skeptics. Try to recharge the key leaders in your organizational change process with seminars or quality networks to keep their enthusiasm up.

The goal of all of our efforts is to improve performance of the organization—lower costs, improve service, and increase customer satisfaction. Some have said that the process of strategic planning is as important as the products. I don't buy it! If the process does not improve your performance, ask yourself why you're doing it. It is just using resources, raising your costs, and not serving your customers better. Don't let strategic planning, quality, and visioning become ends unto themselves. Stick to the goal of improving your performance.

It's important to remember that quality is a journey. We have accomplished a great deal; however, much work remains to be done as we continue down the path of continuous improvement. W. Edwards Deming noted that we should "create constancy of purpose toward improvement of product and service, with the aim to become competitive and to stay in business, and to provide jobs" (*2*).

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Publication of this paper sponsored by Committee on Strategic Management.

Implications of Comprehensive Peace on the Middle East's Transportation Sector

MOHAMMAD M. HAMED AND BASHIR KH. AL-ZU'BI

The spread of peace in the Middle East is expected to bring major reductions in military spending, freeing up funds that could be used in the transportation sector which is, at present, underdeveloped. A case study of 10 Middle Eastern countries shows that if these countries were to cut their defense budgets, as a percentage of the gross national product, to the world average, total annual savings would amount to more than $24 billion (U.S.), $2 billion of which could be spent in the transportation sector. As a result, countries such as Israel, Syria, and United Arab Emirates could expect to increase transportation spending by more than 80 percent.

The economic development of any nation depends largely on the development of its transportation infrastructure. An efficient intracountry transportation network provides accessibility and mobility for the movement of people and tradable goods. Furthermore, well-developed inter-country transportation networks are vital for trade between neighboring countries.

Most countries in the Middle East have inefficient transportation infrastructures. Government spending has been inadequate and below the world average. Nearly all urban areas in the region suffer from recurring traffic-related congestion. The main reasons for this are budget constraints, dense urban populations, and other priorities, such as defense spending.

The general perception in the Middle East, and probably the world, is that the Arab-Israeli conflict is the major source of instability in the region. This perception is wrong: Iraq-Iran, Arab-Turkish, and Arab-Arab rivalries represent long-standing conflicts. The recent crisis in Kuwait demonstrates this clearly. However, there is no doubt that a comprehensive peace between Israel and its Arab neighbors would be a major step toward stability in the region.

The strengthening of economic and political relations and genuine arms reductions are happy consequences of peace. Funds derived from reduced military spending can be allocated to needy areas. In this paper our discussion is limited to transportation, a sector in desperate need of financial aid. We examine the effect of a "peace dividend" on 10 countries: Egypt, Iran, Israel, Jordan, Kuwait, Oman, Saudi Arabia, Syria, United Arab Emirates, and Yemen. All these countries have been affected, directly or indirectly, by the Arab-Israeli conflict. It is hoped that this discussion will help motivate other Arab and Israeli intellectuals to continue cooperative research to benefit the cause of peace and the quality of life in the Middle East.

REGIONAL MILITARY EXPENDITURE

Middle Eastern countries make up about 4 percent of the world's gross national product (GNP) and about 3.5 percent of its population (*1*). Their average defense spending between 1980 and 1988 was about 9.1 percent of the world's total (*2*). Although military expenditure in the Middle East constitutes a small percentage of the world's total, it is significantly higher than world averages in a number of ways:

- Military expenditure as a percentage of GNP (from 1980 to 1988 the total average military expenditure for the 10 countries was more than $42 billion, 6.1 percent higher than the world average);
- Military imports as a percentage of total imports (from 1980 to 1988 the total military imports for the 10 countries were 8 percent of the total merchandise imports, compared with the world average of 2.1 percent); and
- Central government spending (from 1980 to 1988, 29 percent of the total government expenditure for the 10 countries was allocated to the military, compared with the world average of 16.5 percent over the same time period).

Between 1980 and 1988, the total average military expenditures by the 10 countries were more than $42 billion, or about 14.9 percent of the GNP (Table 1) (*3*). However, both Iran and Kuwait were excluded because their military spending ratio is below the world average. The world average during this period was 4.9 percent of the GNP. Of the $42 billion, Saudi Arabia, Israel, and Iran accounted for more than 70 percent, while Jordan and Yemen made up only 2.3 percent. In fact, the military spending-to-GNP ratio of most countries in the region is higher than the world average (*3*).

Available data indicate that average annual military imports in the Middle East between 1980 and 1988 amounted to more than $5 billion, or about 8 percent of total merchandise imports. The world average ratio during this period is estimated to be 2.1 percent. Clearly, reductions in military expenditure to average world levels would release much funding, which could improve the balance of trade, reduce debt, and improve life in the area.

MILITARY EXPENDITURE CUTS

The transportation infrastructure in the Middle East is inadequate and underfunded. To increase spending and improve the situation, governments might (a) borrow or otherwise obtain financial aid from abroad; (b) increase local taxes; or (c) cut military spending. Increasing foreign debt is undesirable, and foreign aid in a global recession is becoming harder to get. Obtaining the funding by increasing local taxes is an unwelcome option. With the growing prospects of regional stability, providing money through defense cuts appears to be the best option.

In this case study we examine the effect of reducing the amount of GNP spent on the military to the world average of 4.9 percent.

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TABLE 1 Military Expenditures and Their Proportion to GNP Averaged During the Period 1980 to 1988 (in Millions of U.S. Dollars)

Country	GNP	Military expenditures	Military expenditures as percent of GNP
Egypt	37,679	3,139	8.3
Iran	192,016	5,300	2.8
Israel	26,191	5,710	21.8
Jordan	5,522	502.7	9.1
Kuwait	28,014	1,257	4.5
Oman	6,944	1,686	24.3
Saudi Arabia	102,694	19,859	19.3
Syria	14,177	2,801	19.8
United Arab Emirates	27,694	1,803	6.5
Yemen	4,656	454	9.8
Total	445587	42511.7	14.9*

* Iran and Kuwait were excluded since their military spending ratio is less than 4.9%.
Source: IMF Government financial statistics (different issues).

Table 2 shows the average annual funds released in our scenario (countries whose spending ratio is less than 4.9 percent are not considered). Total average annual savings are about $25 billion for the remaining eight countries.

More savings would come as transportation spending on military activities is reduced. Unfortunately, these savings cannot be quantified because the information required is classified. Additional benefits can be expected from the conversion of military transport facilities, including airports, naval bases, and military roads, to civilian use. For instance, with only two passenger-oriented airports in Jordan (in Amman and Aqaba), intercity air transportation is limited (rail links are also not available). With military airports located in different areas across the countries in question, the conversion of some of these airports for civilian use would ease the movement of both people and goods. In addition, such conversion would enhance the economic development of remote areas.

Because military bases may contain materials used in the production of chemical, nuclear, or biological weapons, additional funding should be allocated for the conversion of these facilities in an environmentally safe way. Advanced recycling techniques are needed to dismantle and destroy such weapons and store or convert their components safely.

WHERE THE FUNDS WILL GO

Table 3 presents government expenditures on transportation and the relative sizes of the transportation sectors as a percentage of gross domestic product (GDP) for the 10 countries in this study. On average, the transportation sectors contribute 9 percent of the GDP in these countries (*4,5*). Table 4 shows the percentage increase in government spending on transportation that might be expected. The numbers were computed based on the relative share of this sector as a percentage of GDP (Table 3). Israel, Syria, and United Arab Emirates can expect to increase government spending by more than 80 percent. In the next section are details of areas in the transportation sector that would benefit from increased government spending. Because of a lack of detailed data, it is difficult to specify exactly how much funding will be allocated to each subsector.

TABLE 2 Scenario in Which Military Expenditures Are Cut as a Percent of GNP to Match World Average of 4.9 Percent of GDP

Country	Military expenditure savings in millions of U.S. dollars
Egypt	1292.7
Iran	---
Israel	4426.6
Jordan	232.1
Kuwait	---
Oman	1346.1
Saudi Arabia	14826.8
Syria	2105.8
United Arab Emirates	446.0
Yemen	226.2
Total	24,902.2

TABLE 3 Total Government Expenditures Versus Government Transportation Expenditures Averaged During the Period 1981 to 1990 (in Millions of U.S. Dollars)

Country	Relative share of Transportation sector as percent of GDP	Total expenditure	Transportation expenditure
Egypt	9.9	18627	571
Iran	9.1	52007	2818
Israel	9.3	20361	497
Jordan	9.2	1902	126
Kuwait	7.8	9375	448
Oman	8.7	4035	340
Saudi Arabia	7.4	71291	6014
Syria	9.3	6325	226
United Arab Emirates	7.2	4350	38
Yemen	8.1	1673	68

TABLE 4 Percent Increase in Government Transportation Spending Under the Defense Cutback Scenario in Table 2

Country	Transportation expenditure before funds allocation	Transportation expenditure after funds allocation*	Percent increase
Egypt	571	699	22.4
Iran	2818	---	---
Israel	497	909	82.9
Jordan	126	147	16.7
Kuwait	448	---	---
Oman	340	457	34.4
Saudi Arabia	6014	7108	18.2
Syria	226	423	87.2
United Arab Emirates	38	70	84.2
Yemen	68	87	27.9

* on the basis of the relative share of the transportation sector as percent of Gross Domestic Product (GDP).

Flow of Crude Oil

Much of the world is dependent on crude oil from Persian Gulf countries. Peace and stability in the region would bring many advantages and could lead to:

- The reopening of the Trans-Arabian Pipeline (Tapline) from the Saudi oil fields via Jordan to the port of Haifa in Israel. It was closed in 1948. Until recently, only Jordan has used it as a major source of oil. It is expected that Israel, Jordan, and Saudi Arabia would benefit from this reopening. Israel's reliance on foreign crude oil has increased in the wake of the 1979 Camp David agreement and the return in 1982 of the Sinai to Egypt. With the pipeline in operation, Israel could satisfy some or all of its crude oil demands in return for port privileges and exported merchandise. Some consumers of Saudi oil would find the Israeli ports more convenient than the Arabian Gulf-Red Sea routes. Kuwait, too, could benefit from access to the Mediterranean. Syria is expected to allow Iraq to resume pumping crude oil through the Iraq-Syria-Lebanon pipeline, presently closed.
- The diversion of funds for the exploration and development of oil and natural gas resources in Jordan and Syria. Israel would also benefit from a natural-gas pipeline in the gulf. Gas-driven turbines can generate electricity, which is an exportable commodity.

Land Transportation

The construction of efficient international roads and railways between Middle Eastern countries would facilitate the flow of merchandise and labor. In fact, the Camp David agreement called for the building and maintenance of highways between Egypt, Israel, and Jordan near Eilat with guaranteed free and peaceful passage of persons, vehicles, and goods between Egypt and Jordan.

Besides improving the flow of goods, an efficient international transportation network would ease cultural tensions and promote tourism in the region. All countries in the area are considered favorable for tourism. However, increasing intra- and inter-country tourism requires developing, investing, and expanding the transportation network.

More investments can be made in the field of intraregional container transportation by using container transshipment technology. Investments are also warranted in projects designed to increase the capacity of urban arterials and highways and improve safety conditions on those facilities.

Public Transportation

Public transportation, especially in the Arab countries, has not developed enough to satisfy the needs of commuters, and the demand for better services is growing rapidly. Governments heavily subsidize mass transit services, but these subsidies are not enough to improve and expand services. Recent events such as the Persian Gulf War and massive relocations of people (especially in Jordan) have only aggravated the problem.

An influx of funds to this sector could improve the present system's quality and accommodate future demand, increasing access to cheap mobility for more people across a wider area.

Village and Agricultural Roads

Most transportation networks in the region, excluding Israel, do not extend over all rural areas. In many cases nearby villages are not connected to each other and are connected to the nearest major town only by a narrow road. Because many of these outlying areas are agriculturally productive but inaccessible, no significant economic growth is registered.

Table 5 shows how village and secondary road lengths have evolved in Jordan. The figures reflect a lack of continuous or significant growth, mainly due to a lack of funds. By contrast, Saudi Arabia's wealth and emphasis on agriculture have resulted in the construction of agricultural roads. Table 6 shows clearly how the network has grown between 1970 and 1990.

It is hoped that after a peace treaty, a country's underemployed army could play a major role in the construction of agricultural and village roads.

TABLE 5 Road Length Classification Development in Jordan (in km)

Year	Village Roads	Secondary Roads	Primary Roads
1985	2088	869	1928
1986	2134	879	2005
1987	1428	1533	2354
1988	1525	1606	2396
1989	1691	1626	2548
1990	1822	1664	2521

Source: Transportation Bulletin of ESCWA, United Nations, No. 1 December, 1985.

TABLE 6 Road Length Classification Development in Saudi Arabia (in km)

Year	Paved Roads	Agricultural Roads
1970	8440	3487
1975	12167	8510
1980	21581	24186
1985	29655	50655
1990	38000	78000

Source: Transportation Bulletin of ESCWA, United Nations, No. 1 December, 1985.

Road Maintenance and Rehabilitation

Road length over the whole region has increased since 1972, with a concomitant increase in maintenance. Heavy trucks (higher axle loads) and lack of routine maintenance, however, have contributed to pavement and structure deterioration. Most countries in the region have done little to maintain road networks, and as a result, road quality has deteriorated. Only recently have authorities in the region considered ways to maintain the road system. Figure 1 compares road maintenance and construction expenditures in Jordan between 1983 and 1990. On average, the expenditure-construction ratio was about 8.6 percent (*6*). However, from 1988 to 1990, this ratio fell.

Increased road rehabilitation and maintenance efforts are expected to reduce road-user costs and result in greater economic savings (as well as an increase in safety). A technical report by the Economic and Social Commission for Western Asia recommended that funding for road rehabilitation and maintenance be increased to levels ranging from 30 to 40 percent of construction funding. Furthermore, this funding should be increased annually in a systematic fashion. Current levels of road maintenance expenditure range between 5 and 20 percent (*6*).

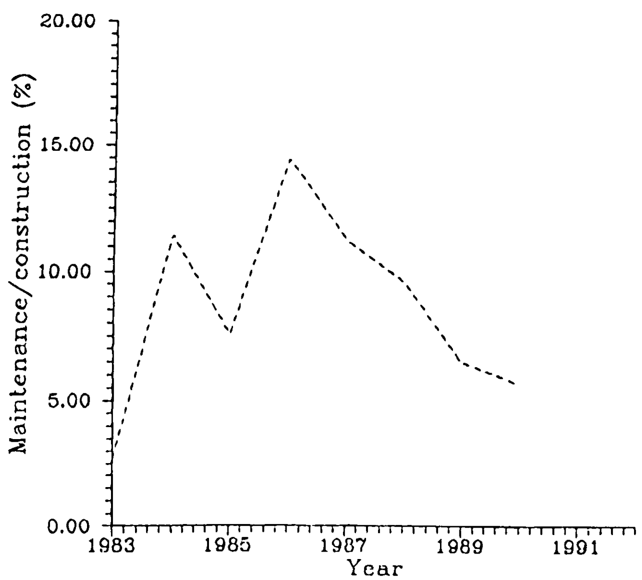

FIGURE 1 Road maintenance expenditures as a percent of construction expenditures in Jordan.

Joint Free Zone Development

The Camp David agreement called on Egypt and Israel to grant normal access to each other's ports for vessels and cargoes. Ideally, free zones should be established between Israel and Jordan, Israel and Syria, and Israel and Lebanon. A joint free zone (JFZ) could be established between Israel and Jordan in the Gulf of Aqaba area between Aqaba and Eilat, where warehouses, shipyards, and port and container facilities already exist. A wide range of economic activities could take place in the JFZ areas.

Regional Environmental Transport Policy

An increase in spending on transportation, while generally favorable, would produce a number of undesirable side effects. Traffic congestion, air and noise pollution, traffic accidents, and shipping accidents (including oil spills) could all increase as the countries of the Middle East upgrade their transportation systems. A comprehensive transportation policy to protect the environment and enhance the quality of life, particularly in urban and suburban areas, is proposed. Governments would have to work together to produce such a policy, and funds would be needed to establish and operate it.

CONCLUSION

Comprehensive peace and genuine arms reductions in the Middle East will generate a great demand for more efficient movement of people and goods. Air, land, sea, and pipe transportation can be used efficiently to satisfy this demand and can be financed by cuts in defense spending.

Because funds may soon be available for transportation investment, there should be a strategy for the development of the transportation sector during the coming decade. The strategy should be formulated with economic and political realities in mind and should be based on regional and international needs.

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Publication of this paper sponsored by Committee on Transportation and Economic Development.

Model Improvements for Evaluating Pricing Strategies

WILLIAM G. ALLEN, JR.

Travel models are commonly used to forecast vehicle-kilometers traveled (vehicle-miles traveled) and speed, from which mobile source emissions are calculated. Most existing models were developed for planning transportation facility improvements and are not well suited for analyzing pricing strategies. Since these models still represent the best available travel database in most urban areas, there is a desire to adapt them to meet a wider range of needs. The Environmental Protection Agency recently commissioned a study on the effects of transport pricing on emissions. This required a planning tool that could analyze many different pricing actions. This project borrowed parts of existing good models to create a pricing-sensitive model set. The resulting model was applied using actual data from one area, for more realistic results. This approach represents an incremental advancement in modeling practice by successfully combining features of the more advanced four-step models. Trip distribution uses a composite definition of impedance that reflects time and cost of all modes. Mode choice is a logit model with some degree of nesting in the carpool mode; it is sensitive to peak and off-peak automobile operating cost, tolls, transit fare, and parking cost. A logit path choice procedure models the effect of tolls on drivers' selection of free and priced paths. All highway paths are based on a combined time and cost impedance. Emissions are sensitive to changes in vehicle age mix, as adjusted based on age- or emissions-based registration fees.

In most larger urbanized areas, a travel forecasting model is used to estimate trip-making activity for future years. This activity is usually expressed in terms of daily or peak hour traffic volumes on each link of the highway network and daily transit passengers. Various other impacts can be derived from these traffic estimates, such as average speed and vehicle-kilometers traveled (VKT) (vehicle-miles traveled [VMT]). Mobile source emissions are then calculated using these statistics.

The detailed nature of most travel models requires that huge amounts of data be provided as inputs. These commonly include estimates of households and jobs by small area (traffic zone), a complete description of the current and future highway and transit systems, and other pertinent information, such as parking cost. Because of the quantities of data needed, computers are required to apply the models and calculate the impacts. Special programs known as travel forecasting software have been written to facilitate the application of complex travel models in urbanized areas.

Almost all existing travel models were developed for planning major transportation facility improvements. They are sensitive mainly to changes in transportation supply and are not specially designed for policy analysis. In particular, most models are not well suited for analyzing the full range of impact of different transport pricing strategies on travel. Although these models are generally not adequate for assessing the impacts of public policy actions, they still represent the best available data base of travel within most urban areas. Thus, there is a strong desire either to modify existing models or to develop new models that can meet a wider range of needs. Some areas are doing both: upgrading their existing models while pursuing the development of entirely new model sets.

The Environmental Protection Agency (EPA) recently commissioned a study on the effects of transport pricing on emissions (*1*). This required a planning tool that could forecast the travel and emissions impacts of many different pricing actions. As resources were not available for calibrating new models, the project borrowed parts from existing good models from around the United States and assembled them into one model set that could be expected to exhibit reasonable sensitivities toward pricing measures.

A side benefit of this approach is that the resulting model would not be biased toward any one urban area, but would represent a composite picture of several areas, which was desirable from a research perspective. The model would, however, be applied using actual data from one metropolitan area, in order to produce more realistic results. (An earlier plan to apply the model using data from several cities was unfortunately dropped due to time and data constraints.) The resulting model set is referred to as the case study model, because it was used to analyze the different market-based case studies for this project. This model is described further in the next section. The focus of this study is on changes in forecasting methodologies; therefore, results of this analysis are not presented. Readers who are interested in the results should consult the EPA report (*1*).

CASE STUDY MODEL SET

Issues in Forecasting

The estimation of pricing impacts on travel is somewhat controversial. It is instructive to review some of the issues of contention as a way of introducing the model specification.

Almost all current travel models are based on cross-sectional survey data, which is a "snapshot" of travel conditions at one particular point in time. This obviously provides no information on how individual travelers actually respond to travel cost changes, because each trip is observed under only one set of pricing conditions. The theory is that if you observe enough travelers under a sufficiently wide variety of travel conditions, then you will be able to derive information about those travelers' sensitivity to cost. Unfortunately, transportation analysts are seldom able to put this theory to a rigorous test.

In response to this problem, some researchers advocate panel surveys, in which a group of travelers is surveyed several times during a multiyear period (these are sometimes called time series surveys). If the sample size is large enough and is exposed to a variety of cost

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changes, it would seem that this approach would produce reliable estimates of the true sensitivity of travelers to cost changes. Only a few areas in the U.S. (Portland and Seattle, for example) have conducted such surveys, and the resulting models are still being evaluated by the planning community. In a few more years it should be possible to conclude whether this approach produces forecasting tools of higher quality.

Another issue concerns the very nature of the four-step process: are the travel decisions of individuals made sequentially or simultaneously? It is becoming clearer to travel forecasters that an individual's choices of whether to make a trip, where and when to go, and how to get there are not made independently of each other, but are usually connected in some way. Few four-step models recognize this, so some researchers (particularly in California) have developed other approaches that model these decisions in a somewhat more connected fashion. Clearly, if the four-step process is to continue to be of use, it must be modified to improve the linkages between its steps.

When using travel models for evaluating pricing changes, it must be kept in mind that the models try to forecast an equilibrium situation. However, changes in pricing may have nonlinear short- and long-term effects. Moreover, the short- and long-term cost elasticities and responses are likely to be different for different people. For example, analyses of panel data have shown that sometimes people react to changes in transport conditions not right after the change but when they need to reconsider their behavior for other reasons (e.g., change in job). At the risk of oversimplifying the problem, the current discussion ignores this potentially important consideration.

Some travel models do a good job of modeling complex travel relationships, but achieve this accuracy by requiring input data values for future years that are beyond the capabilities of most transportation planners to forecast. The approach taken in this work is that it is preferable for models to use the simplest input variables possible, which must not exceed the model user's ability to estimate them. If complex variables are warranted, then submodels should be developed to forecast their values.

According to the theory of discrete travel modeling, mode choice models that are calibrated using the behavior of individuals should be transferable among urban areas. If the model is properly specified, its input variables will account for most of the differences in behavior among different kinds of people in different urban areas. In fact, various reviews of the coefficients for the logit mode choice models of several U.S. cities reveal some commonality of travelers' sensitivity to cost changes. There are always some exceptions, but for the most part forecasters have been successful in adapting one city's coefficients for use in another city with some measure of confidence. Although we have not yet reached the stage of having a truly generic model set, the central tendencies of certain parameters are high enough such that we can adopt generalized values with a reasonable level of confidence.

Model Specification

As noted above, the case study model set is adapted from travel forecasting models from various urban areas in the United States. This approach was taken in order to save time and to make the best use of available data. Further, despite some of the issues concerning the four-step process, it is still the most widely used and readily understood modeling approach. It was an explicit premise of this project that most of the problems with the four-step process are related to the way in which the steps are applied and other deficiencies in the input data, rather than flaws inherent in the process itself. The project's researchers believed that a model set could be developed that would satisfy the need for specific sensitivity to pricing measures within the context of the four-step process.

Figure 1 is a flowchart depicting the overall structure of the case study model set. The following sections describe how each component of the model was crafted, with emphasis on the nature of the sensitivity to pricing.

Trip Generation

This component is the most traditional part of the model set. Daily person trips produced by households are estimated as a tabular function of the joint number of households by size and vehicles ownership (i.e., standard cross-classification tables). Daily person trips attracted to a zone are estimated as a linear function of the number of households and employment by type. Four trip purposes are used: home-based work, home-based nonwork, non–home-based, and truck. Internal-external trips are estimated as a percentage of total trip ends. Work trip ends are balanced to the attraction total and trip ends for the other purposes are balanced to production totals. The trip rates and attraction equations were derived from the models of Washington, D.C., Dallas, and Minneapolis-St. Paul (*2–4*).

Few trip generation models are sensitive to pricing. There is little convincing documentation that the cost of travel exerts a measurable influence on the total daily person trips made by a household. This is further complicated by the lack of a consistent definition of "cost" in this context, since cost is more clearly understood in terms of a trip between a specific origin and destination. Still, it seems intuitive to suppose that in some way, the cost of travel should have an effect on the number of trips made. Thus, an attempt was made to model this effect indirectly. A California model was found that related the number of vehicles owned by a household to the annual cost of owning a vehicle (*5*). It was hypothesized that changes in vehicle ownership cost (e.g., from an annual emission fee) would change the number of vehicles owned, thus affecting the number of trips made. Unfortunately, not enough documentation on this California model was available, which prohibited further development of this concept.

Considerable research effort has recently been devoted to the phenomenon of trip chaining (defined as a trip with intermediate stops to pursue additional activities) and it is believed that certain types of chaining activity might be sensitive to travel cost. As that research matures, it should be easier to make trip rates sensitive to pricing.

In summary, the case study model's trip generation process is not sensitive to pricing but is representative of typical good practice throughout the United States.

Trip Distribution

In most areas, the distribution of trips from an origin zone to potential destination zones is performed using a gravity model. This model distributes trips as a function of the number of trip attractions and a measure of the separation of the zones. Almost all areas use travel time by automobile as this measure of separation. However, researchers have long known that factors other than highway time play a role in the allocation of trips to destination zones. For exam-

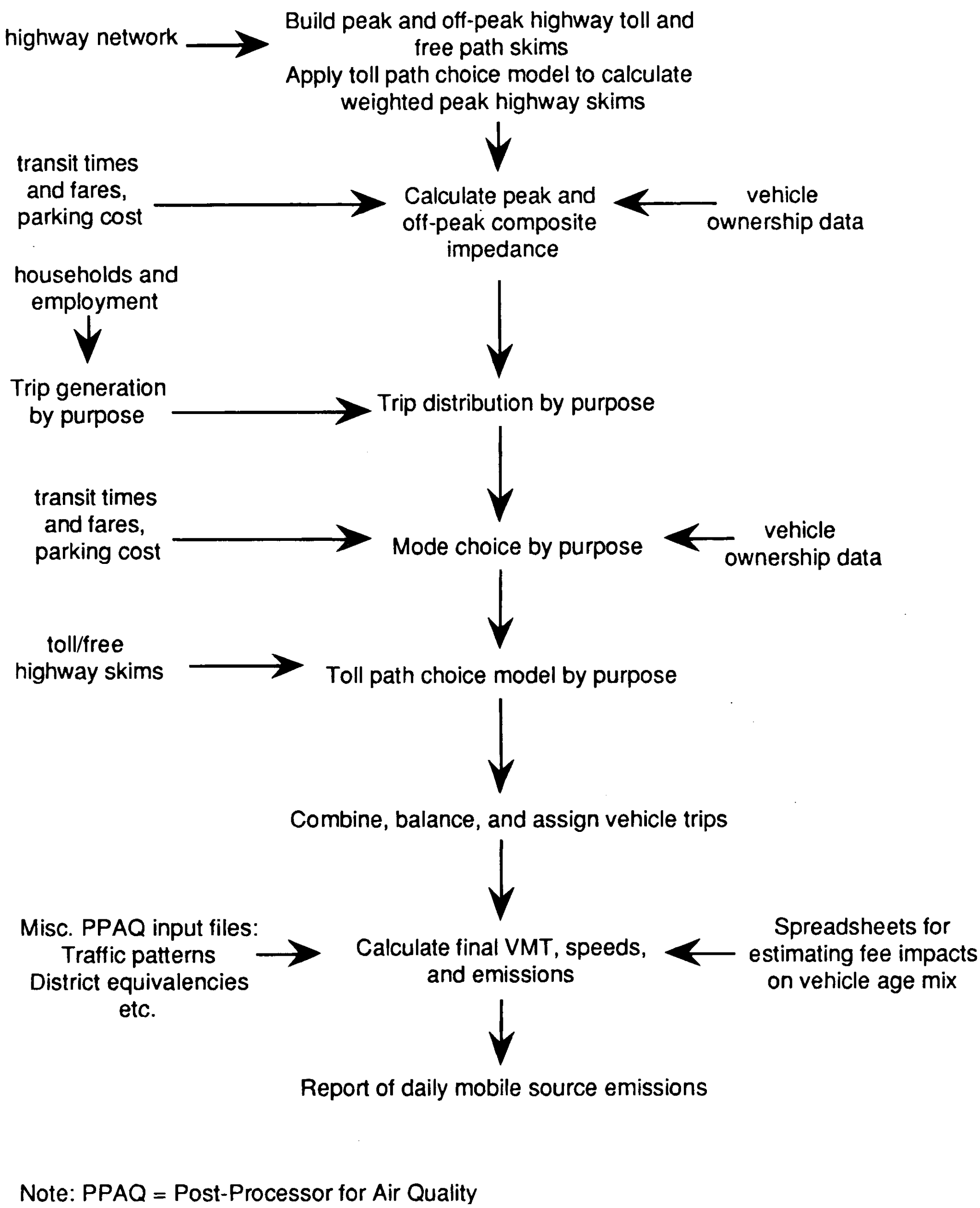

FIGURE 1 Case study travel forecasting model flowchart.

ple, there is considerable evidence that the presence of good transit service between two zones will result in an increase in the number of person trips between those zones. A logical extension of this concept is that other components of this separation, such as cost, should also influence destination choice and thus be accounted for. This effect appears to have an intuitive and empirical basis that cannot be ignored.

So far, very few urban areas have developed distribution models that are sensitive to the cost and service levels of all travel modes (also referred to as composite impedance). Some examples include San Francisco, Boston, New Orleans, Atlanta, and Denver. Most areas that use this formulation use it only for work trips, but in theory it should be applicable to all trip purposes. This is a well-documented process and was adopted for the case study model.

The case study model distributes trips for all purposes with a standard gravity model that uses composite impedance as its measure of zonal separation. This impedance is defined as the log sum from the mode choice model, that is, the natural logarithm of the sum of the exponentiated disutilities of all available travel modes (the denominator of the mode choice equation). This method was adopted from the New Orleans regional model. This version of composite impedance includes all incremental travel costs: automobile operation, tolls, transit fares, and parking. The use of this function makes the allocation of trips to destination zones sensitive to differences in those costs. For example, if transit fares were to decrease in a certain corridor, not only would the transit share increase for those trips (from the mode choice model), but the number of person trips in that corridor would increase, because the decrease in fare causes a decrease in the separation between zones in that corridor. Further, using information from the mode choice model addresses the need for model connectivity, even though the models are still applied sequentially.

In the New Orleans model, composite impedance is used to distribute work trips but not nonwork trips. In the calibration of that model, it was found that travel costs and transit service were uncertain influences on nonwork destination choice. However, it seems reasonable that travel cost should affect nonwork trip patterns in some way, so the case study model uses composite impedance to distribute home-based other, non–home-based, truck, and external trips as well. The case study distribution models were calibrated so as to match overall average trip lengths by purpose, as had been previously reported for the Washington area. *K* factors were used to reduce the tendency of trips to cross the Potomac River.

Mode Choice

Within the four-step process, current mode choice models stand out as being the most rigorously developed and properly cost-sensitive component. Many larger urban areas have developed sophisticated logit models that estimate the share of person trips by mode, based on the socioeconomic level of the traveler and the time and cost attributes of the various modes. The case study mode choice model is based on the approach used in the Washington, D.C. area, which is considered typical of advanced practice (*3,4*).

The mode choice model splits person trips into transit, drive-alone, and carpool modes. Carpool trips are subsequently split among two-person carpools, three-person carpools, and four-or-more-person carpools. Those percentages are used to estimate the average attributes of the carpool mode, which are used in the main mode split. Separate walk-access and drive-access markets are used to calculate the transit split. These calculations are sensitive to various automobile attributes, including terminal time, driving time, automobile operating cost, tolls, and parking cost, as well as transit attributes such as walk time, initial wait time, transfer time, in-vehicle time, and transit fare. A special high-occupancy vehicle (HOV) feature allows the user to define HOVs as having two, three, or four or more persons per vehicle and uses special travel times and costs for such trips. The Washington model's coefficient values were replaced with those representing an average of experience from around the country (which, interestingly, were not substantially different from the Washington coefficient values).

Path Choice and Traffic Assignment

Studies of toll roads focus on drivers' trade-off between paying a toll and saving time. Traditionally, relatively less attention has been paid to drivers' path choices, as planners have relied mainly on traffic assignment software to handle that task. However, recent toll road studies have discovered that such software is inadequate for modeling complex toll versus time trade-offs and have developed more sophisticated models of path choice. These models determine the best free path for each zone-zone pair (i.e, the best path that does not use the toll facility). They then determine the best path that includes the toll facility. Those paths are analyzed to determine their time and toll difference, which is then used in a logit model to estimate the split of trips between the two paths. This is done for every zone-zone pair in the network. Separate toll and time sensitivities are used for work and nonwork trips. Recent advances in assignment software permit the two resulting trip tables to be assigned simultaneously, each to its own set of paths. Within the multiple iterations of assignment, trips are allowed to migrate between paths to a limited degree in response to congestion. The result is a more realistic assignment of trips to toll facilities, in a manner that is sensitive to the level of toll as well as to the capacity of the alternative nontoll routes.

This kind of process has been recently used in toll road studies in Denver and New Jersey, and was adapted for use in the case study model (*6*). It is assumed that this process is suitable for analyzing roadway pricing measures. The resulting toll values affect not only the path choice, but also the mode choice, which uses toll as an input. (The toll value for any zone-zone pair is a weighted average of the tolls on the toll path and the free path: by definition, zero.) Because toll is part of the composite impedance calculation, toll values affect the distribution of trips as well.

The traffic assignment procedure, also adapted from the Washington model, uses four iterations of incremental, capacity-restrained assignment, with 25 percent of the trips assigned on each iteration. Thus, the assignment of trips is sensitive to roadway capacity in an incremental fashion: some trips see an open roadway, while others see a congested one. The input daily vehicle trips are split by four categories: low-occupancy vehicle (LOV) free path, LOV toll path, HOV free path, and HOV toll path. Each category of trips is assigned to its own set of paths on each iteration, respecting the presence of priced roadways and HOV roadways. Finally, the definition of the minimum path for all trips is sensitive to cost, because the path-building criterion is not just time, but a weighted average of time and cost. This weighted average is calculated using $6.00/hour as the average value of time and $0.068/km ($0.11/mile) as the average cost of driving (expressed in 1980 dollars). The output of this process is a loaded network with daily traffic volumes on each link.

Emissions Calculation

The estimation of mobile source emissions requires two basic data items from the traffic assignment: VKT (VMT) and speed. EPA's MOBILE5a emission factor program was applied in this project to calculate emission rates in grams per mile for the criteria pollutants (the EMFAC7F program is used in California). These rates are a function of the mix of vehicles by eight types: the average distance they travel per year, average travel speeds, ambient temperatures, inspection and maintenance programs, and fuel policies, among other factors. The Post-Processor for Air Quality (PPAQ) program (*7*) is used to read the loaded network, recalculate the link speeds by facility type and time period, summarize VKT (VMT) by facility type and time period, and apply the MOBILE5a emission factors. PPAQ requires a series of input tables that reflect the mix of vehicle types by roadway type, the percentage of traffic by hour, and other parameters that describe traffic patterns in more detail. These parameters have been adopted from work recently performed in the Philadelphia region. The result of a PPAQ run is an estimate of total daily kilograms (tons) of HC, CO. and NO_x from mobile sources.

Changes in most of the pricing measures under study, such as roadway pricing, transit fares, and parking costs, are reflected in the assigned link volumes. The exceptions are the measures involving registration fees that are based on age or emission level, and an old-vehicle scrappage program. It was assumed that such strategies have no measurable impact on the number of VKT (VMT), but they will affect the mix of vehicles by age. Strategies that make it more expensive to own an older vehicle should result in fewer older vehicles on the road. Since older vehicles were generally built to less stringent emission standards and are usually less well maintained, a reduction in such vehicles can be expected to reduce the emission rates calculated by MOBILE5a.

Spreadsheets were developed for age-based fees, emission-based fees, and scrappage programs, which estimate the impact of different fee structures and scrappage rates on the default MOBILE5a vehicle mix by year for each of the eight vehicle types. For each vehicle type and year of age, an average vehicle value is estimated. The added cost of registering the vehicle, due to its age or estimated emission level, is compared to that value and an elasticity factor derived from the literature (*8*) is applied to estimate the proportion of that year's vehicles assumed to be taken out of use. Older vehicles removed from the fleet are assumed to be replaced by newer vehicles, in the same proportion as they exist today, so that there is no net change in the number of vehicles, only the average age of the fleet. The output of these spreadsheets is a revised set of vehicle age mixes that can be input directly into MOBILE5a.

Model Application

The case study model set is applied in a series of 15 program steps, most of which use the MINUTP planning software system. Custom FORTRAN programs were written to prepare the land use data and to apply the mode choice model. PPAQ and MOBILE5a are standalone programs and the age mix spreadsheets are in Microsoft Excel. The full model set requires about 9 hours to apply using an 80/486-based computer running at 66 MHz.

The case study model set was applied using basic land use and network data from the Washington, D.C., area (1,478 zones), representing approximate 1996 forecast conditions. However, since the model incorporates components from various cities, the results do not reflect actual or forecasted conditions in Washington and cannot be compared to the results from the Washington area's own model set. The Washington area is projected to comprise about 1.3 million households, 4 million persons, and 3 million jobs. The area has an extensive Interstate system, including the Beltway, which runs around the city and its close-in Maryland and Virginia suburbs. In addition to an extensive bus network, the area is served by the nearly completed 167-km (103-mi) Metrorail system and four commuter rail lines. Major HOV facilities exist in Virginia on Shirley Highway (I-395 and I-95) to the south and I-66 to the west. There is one existing toll road, connecting the Beltway to Dulles International Airport to the west.

As Figure 1 shows, the model set is applied backward, in the sense that the path choice model is applied to derive weighted average highway time, distance, and toll values. Peak period values are used for work trips and off-peak values are used for all other purposes. The mode choice program is then applied to calculate the composite impedance value by zone-zone pair. Next, trip generation and distribution are applied, followed by the mode choice model again, this time to split person trips by mode. Then the path choice model is applied again to split vehicle trips by toll versus free path and the vehicle trips are assigned. Finally, the age mix spreadsheets are applied to determine changes in the age mix, and PPAQ and MOBILE5a are applied to compute emissions from the loaded network.

The case study model has not been calibrated in the true sense, since it was developed from data representing several urban areas. However, the results of the various components were checked for internal consistency and to ensure some approximate level of correspondence with the Washington, D.C. area highway network.

EVALUATION OF THE CASE STUDY MODEL

This section summarizes some of the advanced features of the case study model and identifies some areas of improvement that should be addressed in future research.

Advanced Features

A noted above, the case study model is not based on new research and does not represent any breakthrough in the state of the practice in travel demand modeling. Its advancement is that it was created from the best features from several other well-documented model sets that have been extensively tested through the years. It is very likely the first time that these various components have been assembled in quite this way. This demonstrates one way in which the four-step process can be enhanced to be sensitive to policy issues, such as pricing.

The most noteworthy features of this model set include the following:

- Use of composite impedance for trip distribution for all trip purposes;
- Integration of a toll path–free path choice model within a four-step process;
- Fairly rigorous mode choice model, including a nested carpool occupancy model;
- Parking cost submodel within the mode choice model that estimates separate parking costs for LOVs and HOVs;
- Synthesis of off-peak time and cost values based on peak values;
- Assignment procedures that simultaneously handle LOV versus HOV and toll path–free path trips;
- Ability to easily calculate effects of changes in the vehicle age mix; and
- Integration of mobile source emission calculations within a four-step process.

Areas for Future Improvement

In developing this model set, several shortcomings became apparent. Time and data resources did not permit their resolution, but they are listed here as guidance for enhancing this model set. Additional research should be devoted to these issues in designing future models.

Income Stratification

It would be preferable to stratify the entire model set by income level. This would permit the identification of differential cost sensitivities by income level and would facilitate the examination of the differential effect of pricing policies by income level. As detailed

1990 data on income by trip maker becomes available from the Census Bureau for many urban areas, it will be possible to devote more attention to this issue.

Speed Feedback

The case study model begins with peak and off-peak speed values, the peak speeds having been derived from previous model runs. It would be preferable to run the entire model set at least one more time, using the speeds from the first run (modified as necessary to match observed data more closely) as peak speeds in the second run. However, that would require a total of 18 hours per application, instead of 9. Additional research might identify parts of the model set that would not be affected by speed feedback, thus providing some savings in the running time. As noted above, more effort must be devoted to ensuring that some kind of short-term equilibrium is achieved.

Automobile Access to Transit Trips

Very few models account for automobile access to transit by including such trips in their vehicle trip table. To do so requires data regarding access to transit network (such as Park and Ride lot locations), which was unavailable for this study as well as additional processing steps and time. Still, this phenomenon should not be overlooked, because some improvements to transit service can increase emissions by enticing some who carpool or who walk to transit to switch to driving to transit. Although most drive-access trips are short, they almost always involve a cold engine, and increasing the number of such trips might not be compensated for by the fact that the rest of the trip is made in a transit vehicle.

Parking Cost Sensitivity

Parking cost is probably the most important variable in determining mode choice. Thus, it would be preferable to measure it more carefully, specifically modeling the proportion of travelers who have free parking (instead of accounting for that effect in the average value, as the case study model does). This would require some additional programming effort and detailed data that are difficult to obtain.

Effect of Cost on Trip Generation

In this model set, the trip rate per household or employee is completely insensitive to the incremental cost of travel by any or all modes. This might be remedied by including some kind of zonal composite accessibility measure as part of the trip generation functions. More specific consideration of trip chaining might also address this issue. Some researchers believe that a logical and likely response to increases in the cost of travel is for people to make trips more efficiently. It would be helpful if the model set could reflect this phenomenon. Travel surveys that may have been taken during the time of the 1979–1980 oil crisis could be examined to see if a cost-related effect on the rate of person trips or the type of trips (chained versus non-chained) can be discerned.

Long-Term Land Use Effects

It would be very desirable for the model to adjust the long-term allocation of households and jobs in response to permanent, systemic pricing changes. Care must be taken to separate long-term land use effects from short-term travel decisions. For example, if there were a sharp increase in employee parking cost in an area, some employers would probably decide to move away, resulting in a change in the intensity or character of the area's remaining development. Although this effect would be extremely difficult to calibrate, it might be amenable to some kind of organized sensitivity analysis.

Time of Day

This model set estimates total daily travel only. Although separate peak and off-peak impedances are used to represent those periods, the model does not account for the possible migration of trips from one period to the other. Such migration might occur due to congestion, pricing, or employer policy. Without this feature, the model cannot analyze peak-only pricing measures, which is particularly unfortunate since a probable major response to such measures is to shift the time of travel, more so than the amount or destination or mode of travel.

Nested Logit Model

Although the multinomial logit model is the most widely used formula for mode choice modeling, it is starting to be replaced by the nested logit model. This is because the true nested model is more adept at handling sub-mode splits (e.g., bus versus rail, the transit mode). There is also some evidence that the nested logit structure more closely represents travelers' trade-offs of attributes when selecting a travel mode.

Alternative Composite Impedance Definitions

This model set distributes all trips using a composite measure of time and cost for all modes. The use of such a measure for truck and external trips is questionable. Perhaps a separate combination of highway time and cost, or a different measure altogether, would be more suitable for such trips. In addition, this research disclosed that some hypothesized increases in parking cost for nonwork trips had the effect of slightly increasing average trip lengths, resulting in a net increase in emissions. This effect should be investigated more thoroughly.

CONCLUSIONS

A number of conclusions can be reached concerning improvements to travel forecasting procedures in order to make them more useful for modeling transportation pricing strategies and policies.

- The four-step process can be modified and enhanced to be usable for policy analyses involving pricing measures. This approach has the advantage that such a model can be assembled fairly quickly and uses components that have a proven track record in other areas.

• This analysis makes it clear that time of day models are necessary in order to handle peak-period–only pricing measures. Such models should be sensitive to congestion, peak versus off-peak pricing, and employer policies (perhaps related to employment type). The pricing relationships will need to be developed either from overseas experience or perhaps from transit ridership data under conditions of differential peak and off-peak fares.

• More research is needed into the effects of pricing on trip generation, including how pricing should be represented in trip rate modeling and how trip chaining is affected. Information from the 1979–1980 oil crisis should be further examined to discover any such effects.

• This study's use of composite impedance to distribute nonwork trips should be reexamined. Few, if any, other cities use composite impedance for nonwork trips; it is used only for work trips. More research is needed to determine whether the combined time and cost of all available modes affect the selection of nonwork destinations in the same manner as they appear to affect work destinations.

• More desktop computing power is needed in order to gainfully apply complex model sets like this one, in which pricing is integrated throughout the model chain. Because of this integration, almost any change in pricing requires the entire model to be applied, which can be very time-consuming.

• Today, almost all applications of travel forecasting models are accompanied by the need to determine the impact on mobile source emissions. Thus, an integrated step to adjust network speeds, account for other assignment irregularities, accumulate VKT (VMT), and apply emission factors becomes a necessity. This study's use of the PPAQ program greatly facilitated the analysis of emissions impacts.

ACKNOWLEDGMENTS

The work described herein was conducted by the author under subcontract to COMSIS Corporation, which was under contract to the EPA. The author wishes to recognize the valued contributions of the COMSIS principal staff, Dr. Robert M. Winick, Ernie Mosbaek, and Mark Roskin, as well as the comments and observations of the EPA contract monitor, Will Schroeer. The opinions expressed in this paper are solely those of the author, who is responsible for the quality of this work.

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Publication of this paper sponsored by Committee on Transportation Economics.

Impact of Stream Degradation on Bridges and Rural Travel Patterns

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Stream degradation has resulted in significant damage to rural roads and bridges in several areas of the United States. Western Iowa is one region that has been severely affected. In the beginning of the 20th century, many streams throughout Iowa were channelized to reduce flooding and to open more land to farming. Channel straightening accomplished its goal, but led to greater stream flow velocities, causing degradation on stream channels. This widening and deepening of streams resulted in damage to rural roads and bridges. This study evaluates the effects of stream degradation on county bridges and rural travel patterns in western Iowa. A conceptual model for measuring the benefits and costs of reconstructing, maintaining, or closing county bridges is presented, and a budget constraint model is constructed to show how limited funds might be distributed among various bridge projects. This model will be compared with the benefit-cost analysis based on net benefits and the benefit-cost ratio method of allocating funds.

Natural streams are seldom in a true state of equilibrium. If the stream bed continues to lower because more sediment leaves than enters it (throughout a reach or over a considerable length of channel), this nonequilibrium condition is called "degradation" (*1*). Channel degradation also can lead to mass landslides, which result in increased channel widths (*2*).

Stream straightening has been cited as a primary cause of channel degradation in western Iowa. Until the early part of this century, western Iowa streams were meandering natural rivers that overflowed frequently, preventing the conversion of prairies or pastures to cropland and damaging agricultural crops planted in flood plain areas (*1*). From the turn of the century until about 1960, many creeks and rivers throughout Iowa were channelized to achieve better drainage on flood plains and to open bottom lands to farming. Channelization usually accomplished its goal. Most Iowa creek and river flood plains today are productive cropland (Adkins, unpublished data).

Channelization straightened previously meandering streams (*3*), reduced stream lengths, and increased channel grades. However, it also resulted in greater stream flow velocities. Increased run-off into streams had already begun with the conversion of native prairies and forests to cropland. The smooth, straight sides of the new ditches, combined with an increase of gradient, velocity of flow, and the tractive force exerted on the bed and banks of stream channels, contributed to their degradation (*4*). The streams of western Iowa have degraded 1.5 to 5 times their original depth since channelization. This vertical degradation is often accompanied by increases in channel widths of 2 to 4 times original widths (*2*).

Stream degradation is causing significant damage to rural roads and bridges. The deepening and widening of the streams has jeopardized the structural safety of many bridges. The condition of Iowa's rural roads and bridges is deteriorating rapidly, and the funds are not available to maintain and reconstruct them (*5*). Economical stabilization structures to control stream channel degradation and protect roads and bridges are desperately needed. Closing or posting bridges that pose severe safety hazards is a temporary solution, but a procedure for their repair and reconstruction is required in order to ensure the efficient allocation of scarce resources (*6*).

THE HISTORY OF RURAL ROADS AND BRIDGES

Numerous writers have discussed the deteriorating conditions of the local rural road and bridge system. However, only a few studies (*7–9*) have attempted to identify alternative solutions. Fewer yet have attempted to research the effects of deteriorating roads on travel costs or the benefits of alternative solutions for travelers and for local governments faced with tight budgets.

Nyamaah and Hitzhusen used a circuitry model to estimate the rerouting costs to road users when 15 rural bridges in Ohio were posted or closed (*6*).

Baumel and Schornhorst illustrated the characteristics of local rural roads and bridges in the United States. They proposed several alternative policies to deal with the problem of inadequate funds to rebuild and maintain all the existing county roads and bridges to handle the levels and types of traffic moving on the system (*8*).

Chicoine and Walzer surveyed farmers, township officials, and agricultural and rural business officials in four Midwestern states on a variety of rural road and bridge issues (*9*).

Several studies have suggested a potential cost savings from the abandonment of local rural roads. Baumel et al. were the first to evaluate the impact of local road abandonment on all traffic types using the rural road and bridge system (*10*). In the update and extension of the Baumel study, a benefit-cost analysis was used to examine the effects of alternative investment strategies on local rural roads and bridges (*11*).

No studies have been found that estimate the costs of keeping individual bridges that cross degrading streams. To the authors' knowledge, the current research is the first to address the problem of stream degradation's effects on county road bridges.

METHOD OF ANALYSIS

Benefit-Cost Analysis

The study area for this research includes four streams and road networks in eight counties in western Iowa. The streams studied were McElhaney Creek in Woodbury County, Indian Creek in Pottawattamie, Montgomery, and Mills counties, Keg Creek in Shelby, Pottawattamie, Harrison, and Mills counties, and Willow Creek in

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Crawford, Monona, and Harrison counties. These streams were judged to be representative of the many degrading streams in western Iowa. Several have been the subject of previous engineering analyses (*12*).

When the structural integrity of a bridge is compromised because of stream degradation, decisions must be made regarding costs associated with repair, reconstruction, or abandonment. If a bridge is closed, some motorists may have to travel farther to reach their destinations, increasing travel costs. A benefit-cost analysis was used to evaluate the benefits of keeping a bridge versus the costs of maintaining and reconstructing it. Bridges that do not generate positive net benefit to society would become candidates for abandonment. Three categories of costs that were estimated in the benefit-cost analysis were: (a) reconstruction, (b) maintenance, and (c) traffic rerouting.

The net benefit of keeping a bridge in the road system is calculated as

$$NB = TC - (AC_{RC} + AC_{MC}) \tag{1}$$

where

NB = net benefit of keeping a bridge in the road network,
TC = the annual traffic rerouting cost,
AC_{RC} = the annualized reconstruction cost, and
AC_{MC} = the annualized maintenance cost.

A positive number of net cost savings indicates a bridge should be reconstructed and kept open. A negative number shows a bridge should not be rebuilt.

Reconstruction Costs

The reconstruction cost is defined as the cost of reconstructing a new bridge or the cost of adding approach spans, or both. The estimated reconstruction costs are based on the length of a bridge needed when reconstruction is carried out or approach spans are added.

Scant published data exists on original straightened stream depths. Most of the original stream straightening records have been discarded by drainage districts and county recorders (*12*). This study relied on the few original stream straightening records that remain in county recorder and engineering offices where the study streams are located. Some original depth data were taken from previous studies (*1,13*). The original channel depths were grouped by size of drainage area. A generalized channel depth was assumed for all drainage areas of similar size on the study streams.

Data on stream depths after channelization were obtained from an Iowa Department of Transportation (Iowa DOT) bridge inventory report. These data were used in a regression to estimate the degradation rate for each stream. Stream depths were estimated at each drainage area interval on each study stream after channelization. The lengths of bridges needed for reconstruction or approach spans were calculated, and reconstruction costs were estimated.

Estimation of Stream Depths The depth of a stream is calculated as

$$D_t = 30.50 - E_t - 1.22 \tag{2}$$

where D_t is the depth of the channel from stream bed to flood plain in meters at time t. The design standard for the distance from the flood plain to the bridge deck is always 1.22 m. The elevation of the bridge deck is 30.50 m at any time for any bridge, and E_t is the stream bed elevation at time t.

The stream bed elevation at time t is estimated by Equation 3.

$$E_t = E_0\, e^{-kt} \tag{3}$$

where

E_0 = stream bed elevation at time of channelization,
t = years since channelization, and
k = rate of degradation.

Estimation of Bridge Length The length of a county bridge was calculated by Equation 4. The bottom width of the stream was assumed to remain constant over time.

$$L_t = 2[m\,(D_t = 1.22)] + BW_t \tag{4}$$

where

L_t = the length of a county bridge at time t,
m = the retained design slope of 2 for county bridges, and
BW_t = the bottom width of the stream at time t.

Costs of Reconstruction and Approach Spans The selected bridges were divided into four groups, A(P), B(P), A(G), and B(G), based on the type of road the bridge serves (paved or gravel) and the year the bridge was built. A and B represent the relative times in which a bridge was built; P represents "paved road"; G represents "gravel road"; and Y_0 denotes the year the bridge was built. The definitions are as follows:

- Group A(P) are bridges on paved roads that were built on or before 1949 ($Y_0 \leq 1949$);
- Group B(P) are bridges on paved roads that were built after 1949 ($Y_0 > 1949$);
- Group A(G) are bridges on gravel roads that were built on or before 1934 ($Y_0 \leq 1934$); and
- Group B(G) are bridges on gravel roads that were built after 1934 ($Y_0 > 1934$).

The reconstruction date is calculated as

$$Y = Y_0 + N \tag{5}$$

where Y is the reconstruction date and N is the life cycle of a county bridge. N is 45 years for paved road bridges and 60 years for gravel road bridges (*11*). Based on Equation 5, bridges in group A(P) and A(G) should be rebuilt on or before 1994. The assumption was made that they will be reconstructed in 1995. Bridges in group B(P) and B(G) should be rebuilt after 1994.

For bridges in group A(P) and A(G), decisions were based on whether they should be rebuilt in 1995. The present value of reconstruction costs includes the present value of the cost of rebuilding a bridge in 1995, plus the present value of the cost of adding approach spans after 1995 until the next reconstruction date. There is no standard length of approach spans. The cost of adding approach spans is estimated by the additional length of a bridge according to the increasing stream depths every year. The present value of reconstruction costs is estimated by Equation 6.

$$PV_{RC} = \frac{L_{1995}WC}{(1 + i)} + \sum_{t=0}^{N-1} \frac{(L_{1996+t} - L_{1995+t})WC}{(1 + i)^{1995+t-1994}} \quad (6)$$

where

L_{1995+t} = the length of a bridge in meters, t years after 1995,
W = the width of a bridge,
C = the cost of construction per square meter at the bridge deck in dollars, and
i = the long run real interest rate of 4 percent.

Paved road and gravel road bridges are 9.15 and 7.32 m wide, respectively. The reconstruction cost is \$430/m^2.

For bridges in group B(P) and B(G), investment decisions were based on whether these bridges should have approach spans added between 1994 and the reconstruction date. A paved road bridge built in 1960 should be reconstructed in 2005; therefore, the cost of adding approach spans from 1994 until 2005 is considered. The cost of adding approach spans is estimated by calculating the difference between the length of a bridge at $t+1$ years after 1994 and the length at t years after 1994. The present value of reconstruction costs is calculated as

$$PV_{RC} = \frac{\sum_{t=0}^{N-1} (L_{1995+t} - L_{1994+t})WC}{(1 + i)^{1995+t-1994}} \quad (7)$$

where N is the number of years in the future in which the reconstruction is required (defined as: the year built + life cycle of a bridge − 1994).

The present value of reconstruction costs is annualized as follows (for all the bridges):

$$AC_{RC} = PV_{RC} \frac{i\,(1 + i)^N}{(1 + i)^{N-1}} \quad (8)$$

where AC_{RC} is the annualized reconstruction cost over the life cycle of the bridge, and N is the life cycle of a bridge.

When an approach span is added, it becomes part of the original structure, so its life cycle depends on the life cycle of the original structure. Therefore, the life cycle of an approach span is the same as that of a bridge.

Maintenance Costs

For bridges in group A(P) and A(G), the maintenance cost after the bridge is rebuilt in 1995 until the next reconstruction date was estimated as

$$PV_{MC} = \sum_{t=0}^{N} \frac{L_{1995+t}\,WC}{(1 + i)^{1995+t-1994}} \quad (9)$$

where

PV_{MC} = the present value of maintenance cost of a bridge,
C = the cost of maintenance per square meter (3.66 dollars per square meter), and
N = the life cycle of a bridge.

For bridges in group B(P) and B(G), the maintenance cost from 1994 until the next reconstruction date is calculated as

$$PV_{MC} = \frac{\sum_{t=0}^{N} L_{1995+t}\,WC}{(1 + i)^t} \quad (10)$$

where N is the number of years in the future when the reconstruction will be required.

For all bridges in the study area, the present value of maintenance costs was annualized using the following equation:

$$AC_{MC} = PV_{MC} \frac{i\,(1 + i)^N}{(1 + i)^{N-1}} \quad (11)$$

where AC_{MC} is the annualized maintenance cost and N is the life cycle of a bridge.

Traffic Rerouting Costs

The data base of the streams and roads involved in the study area was input into TransCAD, a Geographic Information System software program that performs transportation analysis. A network model was used to determine the minimum-cost routing from each origin to each destination for each vehicle type. The minimum-cost routings were estimated for household and farm travel. No other commercial traffic occurs on these low-volume rural roads. Because of data limitations, assumptions were made to select origins and destinations. Generally, a node close to the bridge was chosen as the origin. For household travel, the county seat was selected as the destination; for farm traffic and post office traffic, the nearest town was selected as the destination; and for school buses, the nearest town with a school was chosen as the destination.

First, a base solution was run to determine the minimum-cost route with a specific bridge open. Then, a second minimum-cost solution was obtained after a specific bridge was closed. The difference between total travel costs in these two solutions was the estimated cost of traffic rerouting. Equation 12 was used to calculate travel costs.

$$TC = \sum_{d}^{2} \sum_{v}^{5} \sum_{r}^{3} (VC_{rvd} \times M_{rd} \times TP_{vd}) \quad (12)$$

where

TC = total travel cost for 1 year,
VC_{rvd} = the variable cost per kilometer by vehicle type v to destination d on road type r,
M_{rd} = the number of kilometers for each road type r to destination d, and
TP_{vd} = total trips for each type of travel to destination d.

The Data

Rate of Stream Degradation Over Time

Equation 13 was used to estimate the rate of stream degradation over time for each study stream (2). This is simply another form of Equation 3.

$$ln(E/E_0) = -kt \qquad (13)$$

Assume the year of stream straightening is 1954 for McElhaney Creek, and it is 1920 for all the other study streams (3). To estimate the rate of degradation, Equation 13 was regressed on stream bed elevation data obtained from the Iowa DOT bridge inventory report. In the Lohnes model (2), k varied by drainage areas. Because of data limitations, k was assumed to be constant over entire streams.

Estimation of Bridge Length

There are 126 county bridges on the four study streams. Among them, 29 bridges were selected for rerouting analysis. Table 1 shows the lengths of the selected bridges at the most recent inspection date, and the estimated lengths at 1994.

Rerouted Bridge Traffic

State highway, county highway, and gravel road variable vehicle operating costs were based on cost estimates drawn from a study by Baumel et al. (14). Table 2 shows the variable costs per vehicle kilometer for each type of vehicle in the analysis.

Benefit-Cost Ratio Method

Because the benefit-cost ratio (B/C) method is still widely used by county engineers, it is illustrated in this study and is expressed in Equation 14. Using this method of analysis, any investment alternative that has a $B/C > 1$ is economically feasible. The alternative that has the highest B/C is indicated as the preferred investment (15).

$$B/C = \frac{TC}{AC_{RC} + AC_{MC}} \qquad (14)$$

Results

The following assumptions were made in this analysis:

- The traveling public attempts to minimize the travel costs from an origin to a destination;

TABLE 1 Estimation of Bridge Length for Each Selected Bridge (in m) 1994

Stream	Bridge	Year built	Length at the latest inspection date	The latest inspection date	Length (1994)
McElhaney	C 213	1984	33.55	1992	33.96
McElhaney	C 274	1950	11.29	1992	11.59
Indian	IC-157	1931	46.06	1991	46.37
Indian	IC-122	1964	32.03	1991	32.35
Indian	IC-160	1965	39.04	1991	39.37
Indian	IC-153	1973	30.50	1991	30.83
Indian	GARF 501	1971	15.25	1989	15.86
Indian	LINC 3201	1941	31.11	1989	31.66
Indian	GR 20	1920	12.20	1992	12.51
Indian	WV 15	1987	30.50	1992	30.73
Indian	WV 13	1900	9.46	1992	9.76
Keg	OAK 0-90	1970	50.33	1991	50.67
Keg	KC-2	1955	43.62	1989	44.17
Keg	HA-1	1958	45.75	1991	46.08
Keg	YO-19	1960	45.75	1991	46.08
Keg	YO-4	1983	24.71	1990	25.01
Keg	WASH 21	1955	21.05	1990	21.66
Keg	S 80 07 210	1940	7.02	1992	7.32
Keg	L 99 07 210	1945	14.03	1992	14.34
Keg	L 99 05 110	1990	10.07	1992	10.37
Keg	L 99 18 110	1954	15.56	1992	15.86
Willow	MAGN 17	1940	45.14	1990	46.06
Willow	LINC 9	1930	50.63	1992	50.94
Willow	LINC 8	1977	58.26	1992	58.56
Willow	LINC 7	1972	21.35	1992	21.66
Willow	S22-1	1979	20.74	1992	21.05
Willow	S12-1	1952	45.75	1992	46.36
Willow	WILLOW 2	1949	15.86	1992	16.47
Willow	WILLOW 4	1961	21.35	1992	21.96

TABLE 2 Estimated Variable Cost per Vehicle Kilometer and Road Type in Dollars per Kilometer (*14*)

	Type of road		
Type of vehicle	State highway	Paved county	Gravel road
Auto/pickup	0.1254	0.1342	0.1742
SA	0.2658	0.2791	0.3881
TA	0.3644	0.3826	0.5321
Semi	0.4156	0.4364	0.6068
TW	0.7019	0.7370	1.0248

- The number of trips from an origin to a destination does not change as because of changes in the road system;
- The routes used to travel from an origin to a destination can change if the road system changes;
- The variable vehicle travel costs are a linear function of distance;
- The U.S. Postal Service serves all residences that have a passable road access;
- School buses provide school transportation to all residences with school-age children; and
- The road maintenance costs and reconstruction costs are functions of bridge length and width, and are independent of traffic levels.

The savings to the traveling public incurred by keeping a bridge in the road system are defined as traffic rerouting savings. The costs to the counties of keeping a bridge in the road system include bridge maintenance and reconstruction costs. Table 3 summarizes the results of the benefit-cost analysis. The bridges in Table 3 are ranked by average daily traffic (ADT) and listed in ascending order. Table 4 shows the results of traffic rerouting.

Low Traffic Volume Bridges

A low-volume bridge is defined as a bridge with an ADT < 20. The first seven bridges in Table 3 are low-volume bridges. They are all gravel road bridges, classified either in group A(G) or B(G). The net benefit of keeping such a bridge in the road network ranged from −$7,582 to $2,255. Benefit-cost ratios ranged from 0.11 to 2.55. Three of these bridges (LINC-9, WV-13, and LINC-8) had benefit-cost ratios less than 1, and thus should not be reconstructed.

Bridges LINC-9 and WV-13 belong to group A(G), because they are gravel road bridges built before 1934. LINC-9 was built on Willow Creek in 1930, and WV-13 was built on Indian Creek in 1900; neither has been reconstructed since. Both have an ADT of 10. It was assumed that these 10 ADT bridges serve only as field access roads.

Bridge LINC-9 LINC-9 has a very small annual traffic rerouting cost, not only because of low ADT, but also because the change in total kilometers of the second solution is only 16.79 percent of the total kilometers in the base solution. If this bridge is rebuilt in 1995, the costs of reconstruction and approach spans will be high. Its length was 50.63 m in 1992, making maintenance very costly. Based on the data used in this analysis, LINC-9 should not be reconstructed.

Bridge WV-13 WV-13 has a traffic rerouting cost of more than $1,000. The annualized reconstruction cost for this bridge is slightly higher than the annual traffic rerouting cost. The maintenance cost is less than one-fourth of that of LINC-9 because WV-13 is a much shorter bridge (9.46 m in 1992).

Bridge LINC-8 All low-volume bridges in group A(G) have annualized reconstruction costs higher than $1,000 because decisions were based on whether these bridges should be rebuilt in 1995. The low-volume bridges in group B(G) have much lower annualized reconstruction costs because only the cost of adding approach spans is considered. LINC-8 in group B(G) has a negative net benefit because it had a length of 58.26 m in 1992, and therefore had a high maintenance cost.

Low traffic volume bridges tend to have smaller traffic rerouting savings. Some have negative net benefit-cost savings. Bridges with greater benefit-cost ratios should be rebuilt; bridges with ratios less than 1 should not be rebuilt.

Middle Traffic Volume Bridges

Middle-volume bridges are defined as those whose ADT is between 20 and 100. All are gravel road bridges. They are listed in the middle of Table 3, from YO-4 to MAGN-17. Annual traffic rerouting costs ranged from $1,000 to $7,000. Annualized reconstruction costs ranged from $87 to $743. Annualized maintenance costs are usually several hundred dollars. The benefit-cost ratios varied from 0.33 to 43.85, and the net benefit varied from −$422 to $21,364. All selected middle-volume bridges have benefit-cost ratios greater than 1 except WASH-21.

Bridge WASH-21 It was assumed all farm traffic and post office vehicles travel to the nearest town of Persia. In the base solution, the minimum cost route from farms to Persia was over the bridge. The base run route to Persia included 6.02 km of gravel road and 4.60 km of state highway. After the bridge was closed, a vehicle needed only to drive an additional 0.016 km on a gravel road to reach Persia without crossing the bridge. Distance traveled and travel costs increased only slightly in the second solution. For school bus and household traffic, the results were similar. This example shows that change in kilometers is an important factor in measuring traffic rerouting costs.

TABLE 3 Estimated Benefit-Cost Analysis

Stream	County	County bridge code	Average daily traffic	Year built	Group	Annualized reconstruction cost	Annual traffic rerouting cost	Annualized maintenance cost	Net benefit	Benefit cost ratio
Willow	Harrison	LINC 9	10	1930	A(G)	$7,124	$963	$1,420	-$7,582	0.11
Indian	Pottawattamie	WV 13	10	1900	A(G)	1,654	1,550	321	-425	0.78
McElhaney	Woodbury	C 213	10	1984	B(G)	589	2,776	993	1,194	1.75
Willow	Harrison	LINC 8	15	1977	B(G)	595	1,257	1,566	-904	0.58
Indian	Pottawattamie	GR 20	15	1920	A(G)	2017	3,663	394	1,252	1.52
Indian	Montgomery	GARF 501	15	1971	B(G)	635	1,124	431	58	1.05
Indian	Mills	IC-160	15	1965	B(G)	562	3,714	897	2,255	2.55
Keg	Pottawattamie	YO-4	20	1983	B(G)	325	1,655	713	616	1.59
Keg	Shelby	L 99 18 110	20	1954	B(G)	232	1,105	291	582	2.11
Keg	Shelby	L 99 07 210	20	1945	B(G)	149	1,619	172	1,298	5.04
Indian	Pottawattamie	WV 15	20	1987	B(G)	743	3,623	935	1,944	2.16
McElhaney	Woodbury	C 274	20	1950	B(G)	326	2,203	196	1,681	4.22
Willow	Crawford	WILLOW 2	20	1949	B(G)	364	3,195	257	2,574	5.14
Keg	Pottawattamie	KC-2	25	1955	B(G)	213	1,598	802	582	1.57
Indian	Mills	IC-153	25	1973	B(G)	640	5,599	811	4,147	3.86
Willow	Crawford	WILLOW 4	30	1961	B(G)	523	7,054	500	6,032	6.90
Keg	Shelby	S 80 07 210	30	1940	B(G)	87	5,234	56	5,090	36.53
Keg	Pottawattamie	HA-1	35	1958	B(G)	232	4,397	906	3,259	3.86
Indian	Mills	IC-122	40	1964	B(G)	254	3,323	727	2,343	3.39
Willow	Monona	S12-1	45	1952	B(G)	400	4,537	775	3,362	3.86
Keg	Shelby	L 99 05 110	50	1990	B(G)	375	1,649	344	930	2.29
Indian	Montgomery	LINC 3201	55	1941	B(G)	92	3,487	265	3,130	9.77
Keg	Harrison	WASH 21	70	1955	B(G)	229	208	401	-422	0.33
Willow	Harrison	MAGN 17	70	1940	B(G)	155	21,862	344	21,364	43.85
Willow	Harrison	LINC 7	120	1972	B(G)	575	22,315	599	21,141	19.01
Willow	Monona	S22-1	190	1979	B(G)	626	7,556	634	6,295	5.99
Keg	Pottawattamie	YO-19	300	1960	B(P)	268	71,543	1,037	70,238	54.82
Keg	Mills	OAK 0-90	400	1970	B(P)	293	56,729	1,228	55,208	37.30
Indian	Mills	IC-157	580	1931	A(P)	8131	277,028	1,643	267,254	28.34

TABLE 4 Results of Traffic Rerouting

Bridge	Percentage of Change in Kilometers Traveled over Base Solution: Household	Farm	Total	in Travel Costs over Base Solution: Household	Farm	Total
LINC 9	--[a]	16.79	16.79	--	13.14	13.14
WV 13	--	6.47	6.47	--	12.26	12.26
C 213	--	78.09	78.09	--	67.06	67.06
LINC 8	--	8.32	8.32	--	9.76	9.77
GR 20	6.61	41.77	9.89	6.31	43.20	12.32
GARF 501	0.44	45.29	9.02	1.19	32.35	10.04
IC-160	8.25	296.97	14.84	12.13	235.95	22.31
YO-4	6.64	18.20	7.88	4.19	18.32	6.89
L 99 18	-11.41	-1.13	-9.63	3.68	29.25	9.97
L 99 07	9.63	9.56	9.61	11.62	17.93	14.18
WV 15	5.97	17.81	7.53	6.69	19.42	9.14
C 274	3.21	10.98	4.12	5.54	20.22	8.03
WILLOW 2	23.14	0.84	18.65	7.96	12.41	9.11
KC-2	10.44	9.89	10.32	11.58	0.70	8.41
IC-153	11.52	277.64	16.95	12.70	233.88	21.54
WILLOW 4	27.70	14.35	25.20	22.11	12.17	19.78
S 80 07	12.76	46.09	16.50	12.61	37.46	17.10
HA-1	1.65	63.74	8.21	3.30	57.95	13.15
IC-122	-0.39	8.62	0.33	4.47	40.34	8.81
S12-1	0.99	3.26	1.23	4.47	14.94	6.39
L 99 05	-6.90	-17.54	-9.59	6.17	5.48	5.95
LINC 3201	-0.49	35.84	6.95	1.96	19.83	7.46
WASH 21	0.05	0.15	0.10	0.06	0.17	0.19
MAGN 17	25.34	85.02	37.25	49.35	97.73	63.40
LINC 7	9.99	24.28	12.20	12.89	28.66	16.56
S 22-1	2.87	12.10	4.14	1.06	6.38	2.17
YO-19	4.08	55.90	11.52	20.56	30.89	23.33
OAK 0-90	10.47	57.14	12.57	25.30	84.89	29.24
IC-157	25.07	2204.00	43.69	32.67	2580.47	67.44

[a]not applicable.

Bridge L 99 05 110 Table 4 shows that distance driven in the second solution usually increased, but in some cases, it decreased. In the base solution for this bridge, vehicles traveled 1.16 km on gravel roads and 6.83 km on paved county roads per trip. After the bridge was closed, vehicles traveled only 6.58 km on gravel roads, or a reduction of 1.41 km per trip. Because the second solution contains more gravel roads, and the base solution has more paved county roads, the travel cost is lower in the base solution than in the solution without the bridge.

Most of the middle-volume bridges have large benefit-cost savings and should be kept in the road system. Some, however, have low traffic rerouting savings and thus low positive or negative net benefit-cost savings. In addition to ADT, change in kilometers is an important factor in deciding traffic rerouting costs. The type of road is also a factor to be considered.

High Traffic Volume Bridges

High volume traffic bridges are defined as having an ADT $\geq$ 100. The last five bridges in Table 3 are high-volume bridges. The benefit-cost ratios of these bridges ranged from 5.99 to 54.82. YO-19 has the highest benefit-cost ratio among all the selected bridges, and thus should be repaired and rebuilt with priority. Bridges with high traffic volume tend to have significant traffic rerouting savings and large benefit-cost ratios. There also are significant potential cost savings in keeping these bridges in the road network.

BUDGET CONSTRAINT MODEL IN A LINEAR PROGRAMMING FRAMEWORK

The benefit-cost analysis used in this study implies that every bridge with a positive net benefit should be reconstructed. Budgets available to local governments, however, are limited. Thus, budget constraints play an important role in decision making. In this section, a budget constraint model in a linear programming framework will be introduced to solve the problem.

There are two important classes of mathematical programming problems: linear programming (LP) and integer linear programming (IP). LP can be used when a problem under consideration can be described by a linear objective function to be maximized or minimized, subject to linear constraints, which may be expressed as equalities or inequalities or a combination of the two (*16*). IP problems are essentially the same kind of problem, with one important difference: some or all of the variables are restricted to integral values. IP is called mixed integer programming (MIP) if some decision variables are continuous and some are integer.

Model of Study

A MIP model was developed to maximize the total social benefit subject to the budget constraint of a local government (*17*). This model is presented in Equation 15.

$$\text{Maximize } U = \sum_{j=1}^{n} b_j x_j + f(y)$$

$$\text{Subject to } \sum_{j=1}^{n} c_j x_j + y \leq I, \quad (15)$$

$$y \geq a,$$
$$x_j = 0 \text{ or } 1.$$

where

U = the total social benefit from all the services provided by the local government,
b_j = the present value of benefit from keeping the jth bridge,
c_j = the cost on the jth bridge,
x_j = the status of a bridge (x_j = 1 if a bridge is open, or x_j = 0 if a bridge is closed),
y = all the other services provided by the local government,
$f(y)$ = the net benefit of all the other services (assume $f(y) = y$),
a = the minimum money on all the other services, and
I = the total budget available.

The Data

There are 378 county bridges in Pottawattamie, Iowa (unpublished data). Among them, 31 have been closed, and approximately one-third have been posted. A posted bridge has a weight limit of less than 36,320 kg. Seven of these bridges were selected for this traffic rerouting study. They are WV-13, GR-20, WV-15 on Indian Creek, and YO-4, KC-2, HA-1, and YO-19 on Keg Creek. Only WV-15, HA-1, and YO-19 have legal weight limits, and the other four are posted. The coefficient b_j is defined as the present value of traffic rerouting cost savings for the jth bridge, and c_j is defined as the amount of money invested in the jth bridge in 1994. Assume that c_j is equal to the sum of the present value of reconstruction and maintenance costs of bridge j, and it will be expended on the jth bridge in 1994. Table 5 shows the present value of benefits and 1994 investment costs of these seven bridges.

For bridges in group A(P) and A(G), the present value of traffic rerouting cost after the bridge is rebuilt in 1995 until the next reconstruction date was estimated by Equation 16:

$$b_j = \sum_{t=0}^{N} \frac{TR_j}{(1 + i)^{1995+t-1994}} \quad (16)$$

where TR_j is the annual traffic rerouting cost of the jth bridge.

For bridges in group B(P) and B(G), the present value of traffic rerouting costs from 1994 until the reconstruction date is calculated by Equation 17:

$$b_j = \frac{\sum_{t=0}^{N} TR_j}{(1 + i)^t} \quad (17)$$

The total county budget I is assumed to be $26 million. The total budget includes $6.9 million of road funds, and $19.1 million for services other than roads, mostly mandated mental health funding. There are three categories of fixed road funds ($5,158,000): engineering and administration, equipment and building maintenance, and road maintenance.

TABLE 5 Present Value of Benefit and 1994 Investment Cost for Selected Bridges in Pottawattamie County

Stream	Bridge	Average daily traffic	Year built	Group	1994 bridge investment cost	Present value of traffic rerouting savings	Present value of net benefit	Ratio of benefit to cost
Indian	WV 13	10	1900	A(G)	$44,682	$35,268	-$9,414	0.79
Indian	GR 20	15	1920	A(G)	54,549	83,346	28,797	1.53
Indian	WV 15	20	1987	B(G)	37,968	82,868	44,900	2.18
Keg	YO-4	20	1983	B(G)	23,502	36,975	13,473	1.57
Keg	KC-2	25	1955	B(G)	22,981	24,017	1,035	1.05
Keg	HA-1	35	1958	B(G)	25,746	71,438	45,692	2.77
Keg	YO-19	300	1960	B(P)	27,031	1,214,998	1,187,967	44.95

The problem was formulated as follows: suppose that money spent on all the other services must be equal to or greater than \$24,258,000, which is the sum of the three items of fixed costs and the non-road use funds. How much of the remaining funds should be expended on these seven bridges?

Results

The model was solved using a computer program in General Algebraic Modeling System (GAMS) (*18*), and the optimal solution was found to be:

$(x_1, x_2, x_3, x_4, x_5, x_6, x_7) = (0, 1, 1, 1, 1, 1, 1)$, with y = \$25,808,000, and U = \$27,322,000

where $j = 1, 2, \ldots, 7$ represents bridges WV-13, GR-20, WV-15, YO-4, KC-2, HA-1, and YO-19, respectively. The x_j's show that bridge WV-13 should not be reconstructed and repaired, but the other six bridges should be reconstructed and remain open. This is exactly what the benefit-cost ratio indicates. Only WV-13 has a benefit-cost ratio smaller than 1. Thus, if there is sufficient funding to reconstruct and maintain all the bridges, the results from the budget constraint model will be the same as those from the benefit-cost ratio method.

Suppose the federal government requires the local government to spend more money on health and education projects. The money for all the other services will be at least \$25,838,223. Only \$161,777 would be designated for these seven selected bridges. The problem was solved again, and the second optimal solution was found:

$(x_1, x_2, x_3, x_4, x_5, x_6, x_7) = (0, 1, 1, 0, 0, 1, 1)$, with y = \$25,855,000, and U = \$27,307,000

The results show that bridges WV-13, YO-4, and KC-2 should not be reconstructed. Because the present value of net benefit for WV-13 is negative, the decision variable x_1 in the optimal solution will always be zero. It is not reasonable to invest in something that costs more than it returns. In Table 5, YO-4 has a higher benefit-cost ratio than GR-20. Based on the benefit-cost ratio analysis, YO-4 should be reconstructed before GR-20; however, the second optimal solution shows an opposite decision. The reason is as follows: There is at most \$161,777 available on these seven selected bridges. YO-19, HA-1, and WV-15 are bridges with significantly high benefit-cost ratios, and therefore should be invested in first. After reconstructing and repairing these three bridges, \$71,032 remains. The remaining money is insufficient to invest in the remaining bridges. Only four alternatives remain:

1. The money could be spent on both YO-4 and KC-2,
2. on GR-20 only,
3. on YO-4 only, or
4. on KC-2 only.

Alternative 1 is better than 3 or 4 because the social benefit from 1 is a sum of that from 3 and 4. The social benefit of alternative 2 is \$22,354 more than that of 1. Therefore, 2 is the best choice. After reconstructing GR-20, only \$16,483 is left, which is not enough for either YO-4 or KC-2. This remaining money will be invested in all the other services, or held over for bridges in the next year.

The preceding example shows that the benefit-cost ratio method will not necessarily give the optimal solution. A bridge with a higher benefit-cost ratio will not necessarily have priority over another bridge with a lower benefit-cost ratio. The budget constraint model maximizes the total social benefit of all the services provided by the local government, rather than the benefit of a single bridge.

The benefit-cost analysis implies that projects can be ranked according to net benefits from the highest to the lowest until the money is exhausted. In the case of limited funds, however, this analysis is insufficient to make the best decision. For example, suppose b_j = \$40,000, \$12,000, \$10,000, \$8,000, \$6,000, \$3,000, \$1,500; c_j = \$20,000, \$6,000, \$5,000, \$4,000, \$3,000, \$1,000, \$1,000 for $j = 1, 2, \ldots, 7$; and net benefits are \$20,000, \$6,000, \$4,000, \$5,000, \$3,000, \$2,000, and \$500, respectively. Suppose that the total budget is still \$26,000,000, and $y \geq$ \$25,980,000. If selecting by net benefits, the first bridge should be reconstructed because it has the highest net benefit; this is the only bridge that could be invested in with the available money. However, the optimal solution solved by the MIP model is as follows:

$(x_1, x_2, x_3, x_4, x_5, x_6, x_7) = (0, 1, 1, 1, 1, 1, 1)$, with y = \$25,980,000, and U = \$26,020,500

If bridge x_1 is selected, the MIP analysis indicates that the total social benefit will be \$500 less than if bridges x_2, x_3, x_4, x_5, x_6 and x_7 are reconstructed. Thus, the total social benefit is maximized under the MIP model. This example shows that a combination of small projects may yield greater benefit than a single large project. The examples shown here are very simple. When there are numerous alternative projects with numerous constraints, this budget constraint model with mixed integer programming will be very efficient in providing optimal solutions. Only seven bridges are tested in this model, but there are 347 open bridges in Pottawattamie County. The MIP model would be very useful in allocating funds among all bridges and roads in the county.

The present values of benefits and 1994 investment costs were obtained from only seven bridges in Pottawattamie County. Furthermore, the 1994 investment costs were assumed to be the sum of present value of reconstruction and maintenance costs, which is not true in reality. Therefore, the optimal solutions presented are not actual best solutions, but only a demonstration of how to select a combination of projects that yield the greatest social benefit subject to a budget constraint.

CONCLUSIONS

This study evaluated the impacts of degrading streams on county bridges and rural travel patterns in western Iowa, and developed a method to allocate limited funds to various bridge projects. Benefit-cost analysis was used to evaluate the alternative strategies on affected bridges in the study area. Costs for traffic rerouting, bridge maintenance, and reconstruction were considered. Decisions were made after evaluating the net benefits of a bridge remaining open and the costs of providing the bridge. Only bridges with positive net benefits were recommended for reconstruction. Because the benefit-cost ratio (*B/C*) method is widely used by county engineers, it was illustrated in the study.

The following results were obtained from the benefit-cost analysis:

1. All high volume bridges (ADT $\geq$ 100) had a positive net benefit;
2. Some low-volume bridges (ADT < 20) should not be reconstructed because of low ADT over the bridges and the maintenance and reconstruction costs to the county exceeded traffic savings to the public;
3. Most middle-volume bridges (20 $\leq$ ADT < 100) should be rebuilt, but some should not because of the small change in kilometers and high maintenance and reconstruction costs.

The analysis supports the option of abandoning bridges, with a net gain to society.

The benefit-cost analysis indicates that every bridge with a positive net benefit should be reconstructed; however, budgets available to most local governments are limited. A MIP model was developed to maximize the total social benefit of all the county bridges subject to the budget constraint of a local government. The model evaluated all combinations of projects to select the set that yielded the optimal total social benefit under a budget constraint.

If funds are sufficient to rebuild all the bridges, the results from the budget constraint model will be the same as those from the benefit-cost analysis and the benefit-cost ratio method. If funds are insufficient, the net benefits and benefit-cost ratio methods will not necessarily give an optimal solution. A combination of small projects may yield greater benefits than a single large project; a bridge with higher benefit-cost ratio will not necessarily have priority over another bridge with a lower ratio. The budget constraint model will always find the optimal solution that maximizes the total social benefit.

The method presented can be used to estimate the costs of reconstructing bridges on degrading steams. It is useful for any state that borders the Missouri or Mississippi rivers in the United States (i.e., Iowa, Nebraska, Illinois, Tennessee, Arkansas, etc.). It also could be applied to other countries, or areas where degradation affects streams, such as the Yellow River in China. In the absence of degradation, the conventional procedure illustrated in the Baumel study (*11*) should be used to evaluate bridge replacement.

This research is based on limited data. The study demonstrates how to estimate the benefits and costs of reconstructing bridges crossing degrading streams, and how to select a combination of projects whose total social benefit is maximized subject to a budget constraint. The study should be viewed as a demonstration and not as a source of precise estimates for the study bridges. The limitations mentioned should be properly noted in any future study.

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Publication of this paper sponsored by Committee on Transportation Economics.

Economic Feasibility and Related Issues of Highway Shoulder Rumble Strips

A. M. KHAN AND A. BACCHUS

Highway shoulder rumble strips are intended to alert drivers of errant vehicles by providing audible and tactile warning. Although recent literature has advanced the state of knowledge in this subject, a number of information gaps remain. This paper reports research in the economic feasibility of shoulder rumble strips and related issues of technology, design, and maintenance. Specifically, facets of this subject covered include rationale for the use of rumble strips, existing practice, technology of installation, design, noise characteristics, maintenance issues, effect of indented rumble bars on the service life of paved shoulders, effectiveness in reducing run-off road accidents, and cost-benefit of rumble strips. The installation of rumble bars requires partially or fully paved shoulders as a prerequisite, so the cost-benefit of paving shoulders with rumble strips is reported for two-lane highways, multilane highways, and freeways. Results are highly favorable in terms of economic feasibility of installing rumble bars on existing paved shoulders. The installation of rumble bars enhances the economic feasibility of paving shoulders. Design innovations are noted that can address a number of highway operation and maintenance problems.

A variety of shoulder delineators for enhancing safety has been in use over the years. These include edgeline marking, contrasting pavement color, textured pavement (rumble areas), and rumble bars. Rumble strips installed on paved shoulders of highways are intended to alert errant drivers to reduce "run-off-road" (ROR) accidents. These have been used mostly on access controlled highways (i.e., freeways). For highways with at-grade intersections or for highways with narrow bridge approaches, rumble strips could alert drivers who encroach on shoulders to become more attentive upstream of potentially hazardous sites.

A recently published synthesis of highway practice by the NCHRP covered the use of rumble strips to enhance safety (*1*). A number of future research needs were identified, including safety effectiveness on the left and right sides of the traveled way and cyclist issues. There are other information gaps in the use of rumble strips that were not noted in the NCHRP study. These include the use of rumble bars on partially paved shoulders, noise characteristics of rumble bar designs, the effect of indentations on the service life of shoulder pavement, maintenance issues, and recent cost-effectiveness information. This paper reports research results that supplement the findings of the NCHRP study and addresses information gaps.

RATIONALE FOR THE USE OF RUMBLE STRIPS

Over the years, studies sponsored by transportation agencies (e.g., the FHWA, the NCHRP, and others) recommended that textured shoulders should be considered for delineating pavement edges to alert errant drivers at high ROR accident locations. Commercial vehicle safety studies focusing on trucks colliding with parked or stopped vehicles on highway shoulders recommended the use of a contrast in texture for alerting dozing drivers (*2*).

Rumble areas, whether bars or textured pavement, provide a vibration as well as varying noise tones. The purpose is to alert the driver into taking the appropriate actions.

Shoulder rumble strips are primarily intended to be installed on long, straight stretches of rural highways that are known to cause drivers to become inattentive or fall asleep while driving. For freeways shoulder rumble strips have been installed on the long, straight stretches and at approaches to bridges. For highways with at-grade intersections, these have been used to alert drivers who encroach on the shoulder to be more attentive to major intersections downstream.

The pattern of ROR accidents suggest that drivers of errant vehicles could take appropriate action to avoid a crash if alerted to the fact that they are heading away from their travel lane. Such drivers frequently do not notice edgeline stripes or color contrasts between main-lane and shoulder pavements, if present. For night driving conditions or when the pavement is covered with snow or slush, such methods of shoulder delineation may not be effective at all. When visibility is good, in relative terms, edgeline stripping is believed to be just as effective and cheaper than color contrasts between main-line and shoulder pavements. A high percentage of highway accidents are the ROR type, so there is a logical role for shoulder rumble strips.

On highways with medians, errant vehicles could exit a travel lane toward the outside shoulder or median shoulder. Figure 1 shows that a high percentage of median cross-over accidents at selected locations could be prevented through the use of rumble areas on shoulders (e.g., about 20 percent of accidents were classified as "apparently asleep" and "inattentive").

EXISTING PRACTICE

In the early 1980s, the state of California installed shoulder rumble strips on selected Interstate highways. This practice has continued over the years. A questionnaire survey carried out indicated that in Canada and in the United States, there is a growing trend toward the use of shoulder rumble strips, although a blanket policy and formal warrants for the use of shoulder rumble strips are not available. Even in the state of California, which pioneered the development and successful application of shoulder rumble strips, a blanket policy of grooving shoulders is not followed. In the United States, district/regional transportation engineers specify sites and projects for the installation of rumble areas based on their judgment.

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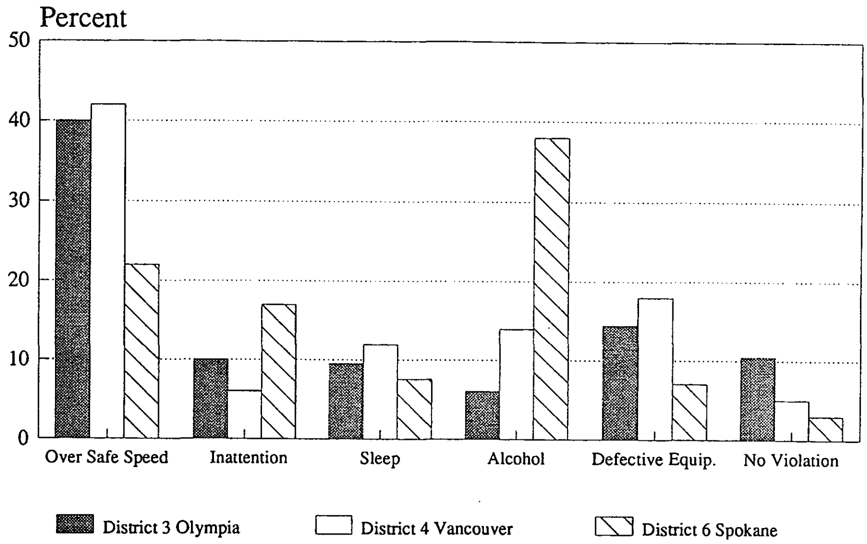


FIGURE 1 Median crossover accidents at selected locations in Washington state, January 1985 to December 1989.

A number of U.S. State Departments of Transportation have tested and now use shoulder rumble strips. According to one study, more than 60 percent of U.S. states use rumble bars as low cost countermeasures for ameliorating ROR crashes (*3*). In Canada, the province of Ontario has installed a short test section on Highway 401, west of Toronto. The province of Alberta has recently adopted the practice of including the placement of rumble strips on paved shoulders of freeways and multilane highways as part of paving contracts. In all cases, the rumble strips are placed on the outside as well as on the median side of paved shoulders.

The U.S. FHWA Technical Advisory T5040.29 recommends that consideration should be given to the installation of rumble strips on the shoulder portion of widened lanes (*4*). According to this advisory, in cases in which a full width paved shoulder cannot be cost-effective, a standard widening of 0.61 m (or 0.5 m) to 0.91 m outside of the travelled way should be considered. Considering the safety requirements, the placement of rumble strips could be considered for partially paved shoulders of 0.5 m to 0.9 m paved width.

TECHNOLOGY AND DESIGN

Many types and designs of shoulder rumble strips have been developed. These can be characterized according to technology and design features. The technology factors are (*a*) indented versus raised surface features, and (*b*) rolling indentations in new or reconstructed shoulder pavement versus grinding grooves by tungsten or diamond tip machine. The design factors are (*a*) continuous versus clusters of rumbles, (*b*) spacing of bars, (*c*) spacing between clusters, and (*d*) shape, dimensions, and angle of indentations (bars).

Technology Factors

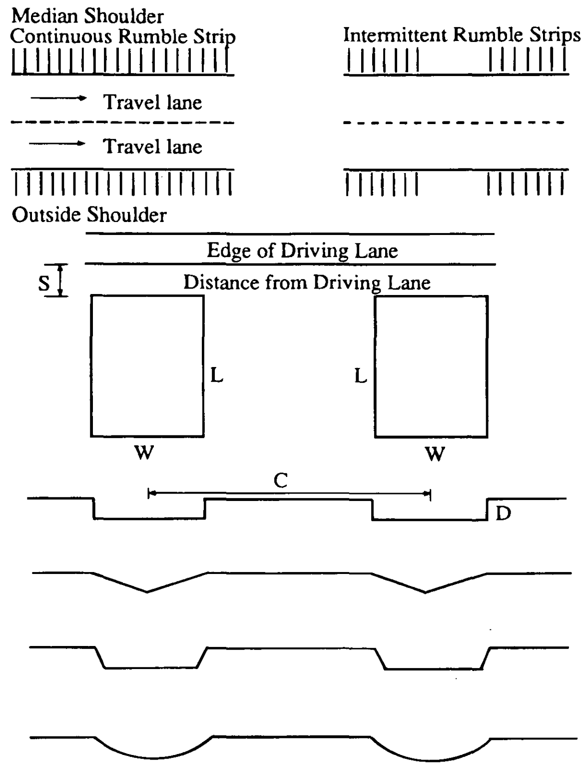
The rumble strips of prime interest in this study are those that are indented on the shoulder part of the highway cross section just outside the edge line (Figure 2). For regions in the snow belt, raised surfaces interfere with snow plough operation. In such areas, it is logical to find that the application of indented rumble bars is the common practice. For asphalt pavements, indented rumble strips can be formed by rolling asphalt concrete with a modified roller, or they can be milled-in. In the case of portland cement concrete, rumble areas are generally formed by combing the new surface. Although asphalt shoulder grooves can be applied at the time of new construction or while resurfacing highways, in the case of concrete, shoulder textured treatments can be added to new construction.

The State of California initiated the trend of rolling rumble bars (of 0.91 m length) on Interstate routes just outside the edgeline to form a continuous strip. The indentations were achieved by compacting the pavement with raised bars on vibratory rollers. Other states, namely Utah, Arizona, and Nevada, have also used this technique. More recently, among other jurisdictions, the province of Alberta has also used this approach. A prerequisite for the rolling-in technique is that new asphalt shoulders must be under construction or shoulder pavements must be being overlaid.

According to recent practice, existing or new shoulder pavements can be equipped with grooves by the milling-in process. For example, the Ontario test section was milled-in. A number of districts in the state of Washington prefer to grind rumble bars as opposed to rolling them. The reasons stated were that the resulting indentations keep their intended shape during construction and produce a better sound effect than those that are rolled-in. However, no comparative decibel data have been reported in support of this observation. It was also suggested that the rolling-in technique of obtaining grooves according to specifications requires good quality control during construction. A limitation of this technique is that it does not deliver satisfactory shoulder compaction because of the presence of the rumble bars.

According to the experience of the Pennsylvania Turnpike Commission, milling-in rumble bars was preferred by contractors than the roll-in method. Even in the case of repaving of the highway, which provided the opportunity to roll-in indentations, the milling-in process was chosen and was carried out after repaving and line painting (*5*).

The shapes used by various agencies have varied, although the semi-circular shape has been widely used for rumble bars formed



Range of Values of Design Variables

W	C	L	S
1.27 - 17.8cms	19.1 -91.4 cms	50-152.4cms	0-76.2cms

FIGURE 2 Shoulder rumble strip design factors.

by the rolling process. This shape results in very little tearing of the mat during placement and provides a good finished appearance. Although the temperature of the mat required for construction of semicircular grooves is a critical factor, it has been found to be workable. For rolling operation, this shape is the easiest to weld to the drum of the roller, and it is relatively easy to keep wet during placement.

The triangular (V) shape is easier than other shapes to roll-in because the temperature of asphalt concrete could be cooler than required for other shapes. On the other hand, during placement, this shape tends to tear the mat. It produces a good depression, and its sound effect was rated good (*6*).

The rectangular shape is suitable for milling-in operations, but it tends to tear the mat during construction by the rolling method. The shape with side slopes combines the attributes of the triangular and rectangular cross section. It lends itself to both the rolling and milling-in methods of construction without adverse effects.

Design Factors

A number of design factors of rumble bars are shown in Figure 2. Also, the range of values of design variables is noted. In the case of asphalt concrete, rumble bars are installed at a right angle to the travel direction, although angles other than 90 degrees have been used. These could be continuous or intermittent type. There is no basis for installing spaced rumble bars through the use of a roller. For the sake of economy, rumble bars can be clustered but would require appropriate milling-in equipment.

As for safety, studies of accidents did not show significant differences between intermittent versus continuous shoulder textured treatments (*7*). This result is not surprising. For the speed and entry angle of vehicles, the distance between clusters of rumble bars can be traversed in less than a second. Consequently, spaced rumble bars can potentially perform the same function as the continuous variety.

The choice of distance from driving lane is influenced by functional, operational, and maintenance factors. Although safety considerations may call for the placement of the strip close to the edge, in order not to interfere with the smooth snow ploughing operations, a buffer distance is allowed. In the case of forming rumble bars by the rolling method, because of the difficulty of maintaining the precise line of the roller and the need to avoid placing the rumble bars on the traveled way, a certain amount of separation is allowed.

A variety of shapes and dimensions of rumble bars has been used (Figure 2). The design of the rumble areas is intended to provide the required audible and vibrational effect regardless of where a vehicle exits. For drainage reasons, in all cases, the rumble bar is beveled.

The decision to form various shapes is guided by the method of indenting bars, known noise characteristics, and maintenance considerations. There is no consensus on the best shape or dimensions. As discussed in the following section, from a noise perspective, for a given center-to-center distance (C), the higher the width (W) and depth (D), the better the noise performance. These observations of course apply within the range of values of variables tested. According to studies, accident reduction experience does not show any significant difference between wide versus narrow shoulder textured treatment (*7*).

In all cases, the groove depth is less than the depth of the asphalt concrete lift. The depth is also affected by the temperature of the asphalt concrete (*6*).

As for the length of the rumble bar, recent experience suggests the desirability of short bars for economy and highway operation and maintenance reasons. A design with sloped sides and continuous pattern adopted for installation throughout the Pennsylvania Turnpike calls for short rumble bars close to the edgeline in order not to encroach on the wheel paths of maintenance vehicles that use shoulders for debris collection (*5*). Other reasons for using short bars and placing these close to the edgeline are (a) highway shoulders can accommodate a bicycle lane on the outside shoulder, and (b) shoulders could be used for traffic on a temporary basis.

NOISE CHARACTERISTICS

Tire-rumble bar contact shown in Figure 3 explains how a tire deforms and produces noise when it touches the side of the rumble bar. Because of higher degree of tire surface contact with bars in the case of wide bars, a higher noise level is emitted. In order not to create uncomfortable vibrations and not to damage the suspension system of the vehicle, the width of rumble bars should not be increased beyond the limit noted in Figure 2.

The sound performance of all shapes is generally recognized to be satisfactory. According to research reported by the state of California, the sound effects of groove spacing tended to favor

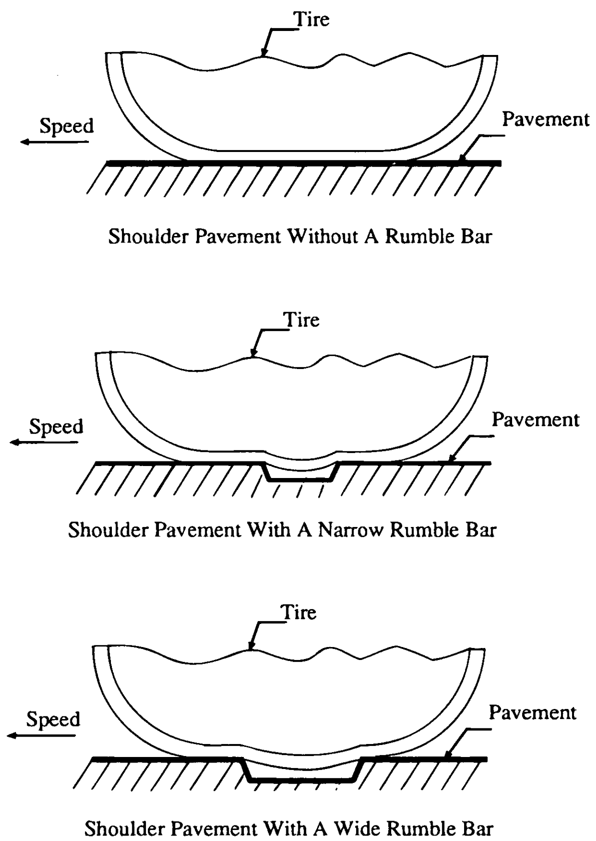


FIGURE 3 Tire–rumble bar contact.

20 cm (*6*). Other studies show that rumble bars within a cluster could be placed closer for a higher noise effect than is the case with the continuous design.

According to noise tests carried out for the Pennsylvania Turnpike Commission, rumble strips of 10.2 cm width, 1.3 cm depth, and 0.305 m center-to-center distance produced satisfactory noise level for alerting drivers of errant vehicles. For example, at 96.5 km/h, a sedan produced 80 decibels. This design resulted in 82 decibels in a truck cab at 96.5 km/h. The sound level in a truck cab was 79 decibels without a rumble bar, so a rumble strip had to produce a higher noise level to be effective for truck traffic (*5*). Another design tested had a 17.8 cm width, 1.3 cm depth, and 0.305 m center-to-center distance. This design yielded, on the average, 3 decibels higher than the design described above (*5*).

Past research indicates that a 4-db(A) increase above the ambient noise level produced by rumble areas tested was judged to be sufficient to be noticed as a warning device (*8,9*). It is believed that shoulder rumble strips produce a noise level higher than this magnitude inside automobiles. In the case of trucks, a noise level of 79 decibels in truck cab would require 83 decibels to be effective. According to the Pennsylvania Turnpike study, a rumble bar design with W = 10.2 cm and D = 1.27cm produces 82 decibels at 96.5 km/h and 86 decibels at 104.6 km/h. A design based on W = 17.8 cm and D = 1.27 cm produced 3 decibels more than that of W = 10.2 cm.

On the basis of noise data produced for the Pennsylvania Turnpike Commission, regression equations (Figure 4) were developed for the estimation of noise inside a sedan. The designs tested kept the center-to-center distance between bars (C) constant at 25.4 cm and varied W, D, and speed (V). Although both linear and nonlinear forms of the equation are satisfactory, in relative terms, the nonlinear equation shows better calibration results. The equations suggest that decibels of noise increase with increasing W, D, and V. The limits of values for the variables are noted in Figure 4.

MAINTENANCE ISSUES

Literature citations and survey returns have not uncovered significant maintenance problems with indented rumble strips. No maintenance issues have been reported for the Ontario rumble strips. In the case of Alberta, there is a lack of information on structural and maintenance problems with shoulder rumble strips because of only 1 year of experience.

According to literature, a partial accumulation of foreign matter in the rumble recess was observed only in isolated instances in the United States (*7*). Studies carried out by the Pennsylvania Turnpike Commission over an 18-month period revealed no problems with debris, water, ice, or snow accumulation in the rumble bars (*5*).

In general, grooved rumble strips do not appear to retain debris and winter abrasives (e.g., sand). In most situations, the sand debris is blown out by traffic. Even in wet conditions, because of the drainage design of rumble bars, the potential for accumulation of sand is rather limited. Because of salt application, there is no freezing of water. However, in extreme conditions encountered in areas such as Yukon, where less salt or no salt is applied, the water may freeze in rumble bars and over time may result in loss of aggregates.

Normally, shoulder textured treatments do not require maintenance. According to Caltrans Highway Maintenance Department, the rumble strips installed in the early 1980s are still in use, and their maintenance is not an issue. At the time of repaving the main travel lanes, the rumble receives a fogseal treatment only (*6*).

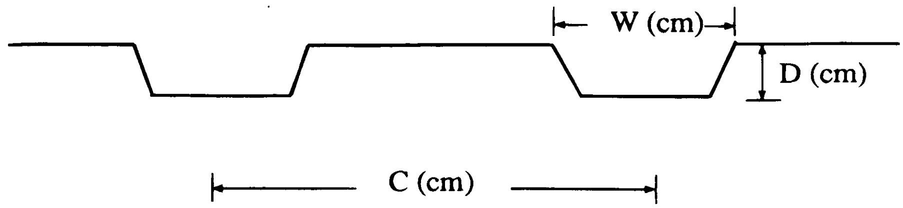
From the perspective of maintenance efficiency, compared with other shapes, the semi-circular shape and the cross section with sloped edges are more desirable because these are easier to clean (if necessary). Furthermore, because of a small number of sharp edges, these would resist the loss of aggregates.

EFFECT OF RUMBLE BARS ON PAVED SHOULDER SERVICE LIFE

Field reports do not indicate pavement damage due to grooves. On high speed highways, grooving shoulder pavements of two lifts does not become the cause of a weakness in structural terms (*7*). The shoulder pavement is subjected to a very small volume of traffic compared with travel lanes. Consequently, traffic-induced damage to shoulders at grooves is largely absent (*6,7*).

Field studies in Alberta revealed minor cracks at the top edges of triangular grooves. The age of the grooves is about 1 year or less, so these cracks are attributable to the method of construction.

Analytical studies were carried out to supplement field observations. The following steps were followed: (*a*) Shoulder pavement structures "with" and "without groves" were defined; (*b*) by applying the Ministry of Transportation (MTO) pavement design method [Ontario Pavement Analysis of Costs (OPAC)], the number of



Note: V is speed in km/h

Linear Form:

$$db_A = 53.636 + 0.585\,W + 3.284\,D + 0.161\,V$$

(7.0) (2.6) (6.3)

$R^2 = 0.87$ F-Ratio = 39.5

Non-Linear Form:

$$db_A = e^{3.412}\ W^{0.074}\ D^{0.048}\ V^{0.172}$$

(7.8) (3.5) (7.2)

$R^2 = 0.90$ F-Ratio = 49.9

Values in parentheses are "t" values.

Range of Values:
- W 5.1 - 17.8 cms
- D 0.64 - 1.27 cms
- V 64.4 - 96.5 km/h

For Constant C = 25.4 cms

FIGURE 4 Regression equation for shoulder rumble strip noise estimation for asphalt pavement.

equivalent standard axle loads (ESAL) were determined for the two shoulder pavement thicknesses (*10*). As a check on results obtained from the MTO method, the AASHTO and California design methods were used. These checks suggest that the MTO method gave logical answers; (*c*) from analysis results, the reduction in the ability of the shoulder pavement option "with indented rumble bars" to serve traffic without structural damage was found.

The calculations based on the OPAC are presented here for pavement thickness of 90 mm without rumble bars of 20 mm depth and 90 mm to 20 mm = 70 mm for pavement with rumble bars:

With Rumble Bar

Granular Thickness

$$H_e = 2h_1 + h_2 + (2/3)\,h_3 = 2 \times 70 + 1 \times 150 + 0.67 \times 450 = 592 \text{ mm}$$

where

h_1 = surface thickness (mm),
h_2 = base thickness (mm), and
h_3 = Subgrade thickness (mm).

Subgrade Deflection

$$w = (9000/\{2M_s Z\,[1 + (6.4/Z)^2]^{1/2}\})\ (\text{in.}) \times 25.4 = w \text{ in mm}$$

$$Z = [0.9H_e\,(M_2/M_s)^{1/3}\ (\text{in.}) \times 25.4 = Z \text{ in mm}$$

where

M_s = Subgrade Layer Coefficient, Assumed 5,000,
M_2 = Granular Layer Coefficient, Assumed 50,000, and
w = 0.503 mm.

P_T Loss in Riding Comfort Index due to traffic(n); Assumed $P_T = 0.2$

$$P_T = 2.4455\Psi + 8.805\Psi^3 \rightarrow \Psi^3 + 0.2777\Psi - 0.0227 = 0$$

where

$\Psi = 1000w^6N$ (w in in.),
$\therefore \Psi = 0.08$, and
$\therefore N = 1.3 \times 10^6$ (ESAL)

Without Rumble Bar

$$H_e = 2h_1 + h_2 + (2/3)\,h_3 = 90 \times 2 + 150 \times 1 + 450 \times 0.67 = 630 \text{ mm}$$

Subgrade Deflection

$$w = 9000/\{2M_s Z\,[1 + (6.4/Z)^2]^{1/2}\} = 0.0186\ (\text{in.}) \times 25.4 = 0.47 \text{ mm}$$

$$P_T = 2.44455\Psi + 8.805\Psi^3$$

where:

$$\Psi = 1000w^{6N}$$
$$\therefore N = 1.9 \times 10^6 \text{ (ESAL)}.$$

Therefore, a 20 mm of reduction in the thickness of the shoulder pavement will produce $(1.9 \times 10^6 - 1.3 \times 10^6) = 0.6 \times 10^6$ ESAL difference or a 31.6 percent reduction in ESAL or a 31.6 percent loss in carrying ESAL.

It should be noted that if rumble bars are applied on shoulder pavements of one lift of asphalt concrete of normally 40 mm thickness (or 50 mm max), the absence of one-half of the asphalt concrete might become a cause for concern. However, shoulder pavements that are designated for placement of grooves should receive two lifts. Under these conditions, shoulder pavements with indented rumble bars, even with their reduced ESAL capability, can serve their function for a long period of time because of only occasional traffic encroachments.

ECONOMIC FEASIBILITY

Cost of Rumble Strips

Because of the nature of the rolling method, the state of California achieved texturing in an economical fashion. The rumble strips were constructed as a part of resurfacing of the highway at a cost of US$0.16/m (1982$) (*11*). The milling-in method is costlier than the rolling method. The Pennsylvania Turnpike experience shows US$1,243/km (1992$) as the cost of milling-in rumble strips (*5*). A more expensive estimate suggested by the Washington State experience amounts to US$1,429.50/km by the grinding method (1993$). The NCHRP Report on Synthesis of Highway Practice indicates that 0.61- to 1.52-m rumble bars rolled-in during resurfacing would cost US$93.20 to 360.50/km (per one shoulder). In this research, the following costs are used: Canadian $1,906/km for two shoulders and Canadian $3,812 for four shoulders. These cost estimates are based on US$1,429.50/km for two shoulders or US$2,859.00/km for four shoulders.

Cost-Benefit and Sensitivity Analysis

Decision making regarding the installation of rumble bars on highway shoulders may take place in conjunction with the assessment of the economic feasibility of paving shoulders. On the other hand, for shoulders that are already paved, the investigation of incremental cost and benefit of adding rumble bars would be required. In this section of the paper, following a description of the effectiveness of rumble strips, results of both types of analyses are illustrated.

Studies in California, Washington, and elsewhere have revealed that shoulder rumble strips of the indented type, when used at high ROR sites, have been successful in reducing such accidents. The state of California study showed that, at high ROR accident sites on Interstate routes, a 16 percent reduction in overall accidents and a 52 percent reduction in ROR accidents were achieved (*12–14*).

The Pennsylvania Turnpike experience with rumble strips was even more impressive in terms of reducing drift-off-road accidents. As a result of the first five rumble strip installation projects, a 70 percent reduction in ROR accidents was reported (*5*).

In the state of Washington, rumble areas were placed on highway shoulders in response to a large number of ROR accidents. A high proportion of these involved trucks. These rumble areas have been successful in reducing ROR type of accidents. According to Washington State Department of Transportation officials, before and after studies have shown a 37 to 50 percent reduction in ROR accidents. The overall accident rates dropped by 33 to 42 percent. Their success clearly suggests that the high engine noise levels of trucks do not significantly decrease their effectiveness.

In addition to the primary function of shoulder textured treatments, namely reducing ROR accidents, another advantage of using rumble strips on highway shoulders relates to bicyclist safety. Should bicyclists be allowed to use paved shoulders, the rumble strips can serve as a buffer, separating bicyclists from motorized traffic.

As for disadvantages of grooving shoulders, the rumble areas may interfere with smooth snow ploughing operation if placed next to the edgeline. Also, long rumble bars become a problem at the time of using the shoulders as travel lanes while the main lanes undergo repair. However, short bars placed on full width shoulders overcome this disadvantage.

In this research, the quantification of the economic value of reducing ROR-type accidents started with the accident rates for various types of highways. For Ontario, these are "Other King's Highways" (i.e., two-lane and multilane): 1.08 accidents/million vehicle-km; and freeways: 0.74 accidents/million vehicle-km. Available information indicates that depending on the site, 2 percent to 20 percent of highway accidents are of the single vehicle ROR type and that shoulder rumble strips could potentially reduce at least 20 percent of such accidents. Here, it was assumed that the lower estimate (i.e., 2 percent) was used.

The economic value of reducing a highway shoulder-related accident was recently estimated for Ontario conditions to be $76,638.84 (1994 Canadian $). This cost to society of saving an accident compares well with an estimate of saving/accident developed by using the FHWA approach, which amounts to $75,982.90 (1994 Canadian $).

The benefit-cost analysis results for paving shoulders on all types of highways "with" and "without rumble strips" are presented in Table 1 and Figure 5. In this research, sensitivity analysis of economic feasibility with respect to traffic volume was used to find threshold traffic levels for the feasibility of paving shoulders without rumble strips. Both partially paved and fully paved shoulder options were covered. The benefits are the sum of savings of travel lane and shoulder maintenance expenditures plus the economic value of reducing accidents.

In Table 1, threshold annual average daily traffic (AADT) values for the economic feasibility of paving shoulders are presented. Additionally, the cost of shoulder pavement and the benefit/cost ratio are noted. Given that the option of installing rumble bars has to be analyzed, the design of pavement is based on two lifts of asphalt concrete. The life of rumble bars is assumed to be the same as for shoulder pavement. All analyses were performed in the 1994 constant (Canadian) dollars, and an interest rate of 6 percent (real) was used. The identification of threshold AADT to the nearest thousand has resulted in benefit/cost ratios (B/C) of more than 1.0 in a number of cases.

Here, the example of two-lane highway and 1.5-m shoulder pavement is presented to describe the process of estimation of costs and benefits. For an AADT of 8,000 (both directions), roadway surface

TABLE 1 Benefit-Cost Analysis of Paving Shoulders Without and With Rumble Strips (1992 Canadian Dollars)

	Two Lane	Four Lane Undivided	Multilane With Median	Freeway
Shoulder Pavement 1.5m on Both Sides			NA	NA
Without Rumble Bars				
AADT Threshold	8000	8000		
Cost	$54,144	$54,144		
Benefit/Cost Ratio	Appr.1.0	Appr.1.0		
With Rumble Bars @AADT = 8000				
Cost	$56,050	$56,050		
Benefit/Cost Ratio	1.09	1.09		
1.5m Outside, 0.5m Median	NA	NA		
Without Rumble Bars				
AADT Threshold			16000	20000
Cost/Km			$72,192	$79,112
Benefit/Cost Ratio			Appr.1.0	1.01
With Rumble Bars @AADT = 16000				
Cost/Km			$76,004	
Benefit/Cost Ratio			1.15	
With Rumble Bars @AADT = 20000				
Cost/Km				$82,924
Benefit/Cost Ratio				1.16
3.0m Both Sides			NA	NA
Without Rumble Bars				
AADT Threshold	9000	9000		
Cost/Km	$108,288	$108,288		
Benefit/Cost Ratio	1.07	1.06		
With Rumble Bars @AADT = 9000				
Cost/Km	$110,196	$110,196		
Benefit/Cost Ratio	1.13	1.12		
3.0m Outside, 1.0m Median	NA	NA		
Without Rumble Bars				
AADT Threshold			18000	20000
Cost/Km			$144,384	$147,317
Benefit/Cost Ratio			1.05	1.05
With Rumble Bars @AADT = 18000				
Cost/Km			148,196	
Benefit/Cost Ratio			1.15	
With Rumble Bars @AADT = 20000				
Cost/Km				$151,129
Benefit/Cost Ratio				1.13

Notes: (1) Shoulder pavements for two lane, 4 lane undivided and multilane highways are 80mm depth (two lifts) and life is 12 years. Freeway shoulder pavement is full strength (more than 80mm depth) and life is 15 years. (2) Interest rate is 6% (real). (3) NA Not applicable.

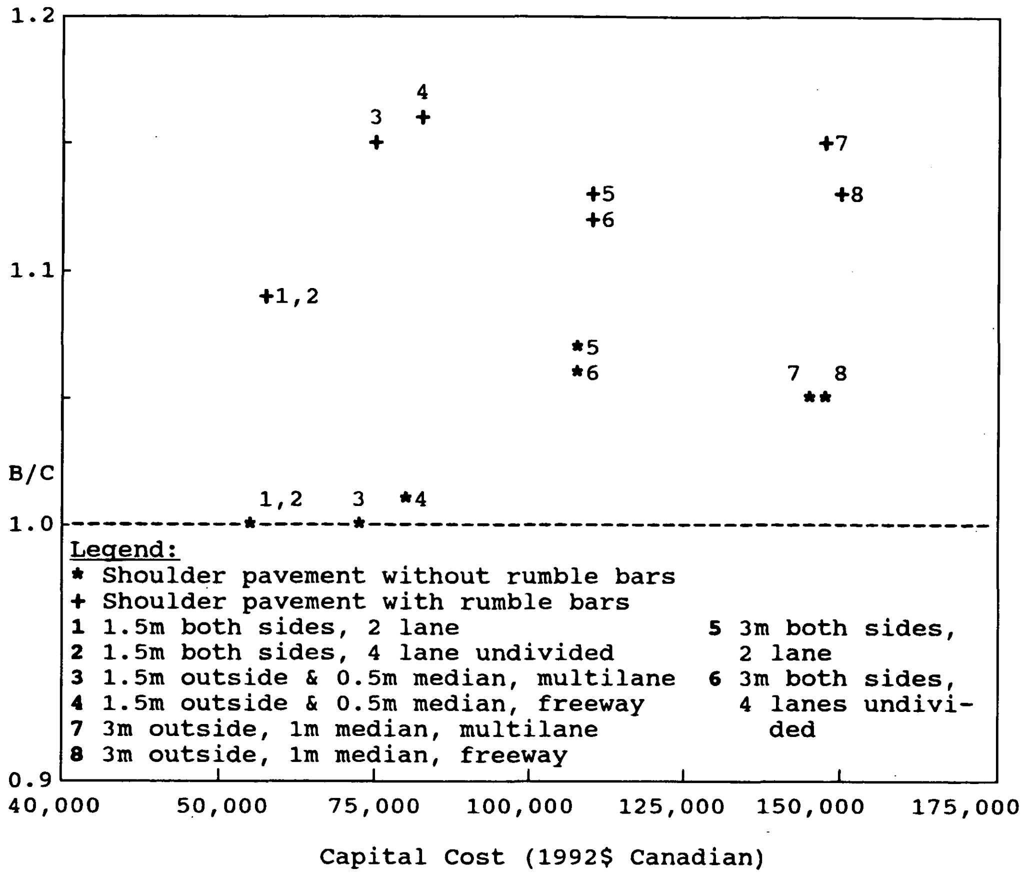


FIGURE 5 Cost-effectiveness of partially/fully paved shoulders with and without rumble strips.

patching and shoulder maintenance cost per year are found in constant dollars for the cases of without paved shoulders and with paved shoulders. Regression equations developed in this research were used for cost estimation. The difference between these costs is maintenance cost reduction attributable to 1.5-m paved shoulders. The present worth of maintenance cost saving/km is found to be equal to $1,530 for pavement life of 12 years and an interest rate of 6 percent (real).

Next, safety benefits were found by estimation of accident reduction due to paved shoulders and converting accident reduction into dollar benefits/year (in constant dollars). These savings amount to $51,709 in terms of their present worth. A safety model reported by Zegeer is used for the estimation of accident reduction due to 1.5-m paved shoulders (*15*). The addition of maintenance cost reduction and safety benefits amounts to $53,239/km of total benefits. The cost/km of 1.5-m paved shoulder for two sides is $54,144. At an AADT of 8,000, the B/C = 0.98 (approximately 1.0) (Table 1). It should be noted that at an AADT of 9,000, the B/C = 1.11.

At an AADT of 8,000, the benefits of rumble bars in present worth is $8,100/km, and the costs of rumble bars/km is $1,906. This gives a B/C of 4.25 (Table 2). The net present worth is $6,914/km. The benefits of 1.5-m paved shoulders with rumble bars is $61,339, and costs is $56,0507. This gives a B/C of 1.09 (Table 1). Further details of the costs and benefits of paving shoulders are reported in Khan and Holtz (*16*).

As illustrated in Tables 1 and 2, because of high incremental savings attributable to rumble bars for every dollar invested, the B/C ratios for shoulder pavements with rumble bars improve considerably. Figure 5 presents the cost versus B/C ratio information for partially/fully paved shoulders with and without rumble strips. The B/C ratio is being used as an indicator of effectiveness. The information presented in Figure 5 clearly shows that the addition of rumble bars improves the economic feasibility of shoulder pavements. A related observation would be that shoulder pavements with rumble bars become feasible at lower AADT threshold levels than those for pavements without rumble strips.

On the assumption that rumble bars are to be applied on existing shoulder pavements or that the decision to install rumble bars is separated from that of shoulder pavement feasibility, it is useful to study the economic desirability of investment in this safety measure. The benefit-cost analysis results shown in Table 2 suggest that despite extremely conservative estimates of accident reduction and the use of high cost estimates for milling-in rumble bars, the B/C ratio exceeds 4 in all cases.

CONCLUSIONS

1. Rumble strips of indented type installed on highway shoulders are effective in reducing ROR accidents and show highly favorable economic feasibility results. The B/C ratio exceeds 4 for a

TABLE 2 Benefit-Cost Analysis of Shoulder Rumble Strips (1992 Canadian Dollars)

Shoulder Pavement	Two Lane	Four Lane Undivided	Multilane With Median	Freeway
1.5m on Both Sides				
AADT Threshold for Shoulder Pavement Feasibility	8000	8000	NA	NA
Cost of Rumble Bars per Km (2 shoulders)	$1,906	$1,906		
Benefit/Cost Ratio	4.25	4.25		
1.5m Outside, 0.5m Median	NA	NA		
AADT Threshold for Shoulder Pavement Feasibility			16000	20000
Cost of Rumble Bars per Km (4 shoulders)			$3,812	$3,812
Benefit/Cost Ratio			4.25	4.22
3.0m Both Sides			NA	NA
AADT Threshold for Shoulder Pavement	9000	9000		
Cost of Rumble Bars per Km (2 Shoulders)	$1,906	$1,906		
Benefit/Cost Ratio	4.78	4.78		
3.0m Outside, 1.0m Median	NA	NA		
AADT Threshold for Shoulder Pavement Feasibility			18000	20000
Cost of Rumble Bars per Km (4 shoulders)			$3,812	$3,812
Benefit/Cost Ratio			4.78	4.22

Notes: (1) Shoulder pavements for two lane, 4 lane undivided and multilane highways are 80mm depth (two lifts) and life is 12 years. Freeway shoulder pavement is full strength (more than 80mm depth) and life is 15 years. (2) Interest rate is 6% (real). (3) NA Not applicable.

number of cases tested. The addition of rumble bars on highway shoulders improves the economic viability of partially or fully paved shoulders.

2. Rumble bars can be designed to produce satisfactory noise levels for passenger and freight vehicles. These can be applied on partially and fully paved shoulders of all rural highways. In the case of freeways and multilane highways rumble bars should be placed on both outside and median shoulders. These pavements should receive two lifts of asphalt concrete. Rumble bars can serve as a buffer between bicyclists and vehicular traffic.

3. Short rumble bars are effective, and they enable the use of full width shoulder pavement for maintenance vehicles or serve as temporary lanes.

4. The technologies for installing bars on asphalt shoulder pavement with a roller or by the milling-in method are well developed.

5. There are no appreciable maintenance problems associated with indented rumble strips even in areas within the snow belt.

6. A 20-mm reduction in thickness of the shoulder pavement results in a loss of 31.6 percent in carrying EASL. However, for two-lift shoulder pavements, there would be no appreciable service life reduction because of only occasional traffic encroachments.

ACKNOWLEDGMENTS

This paper is based on a study sponsored by the Ministry of Transportation, Ontario. Opinions expressed are those of the authors.

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Publication of this paper sponsored by Committee on Transportation Economics.

Allocating Pollution Costs Using Noise Equivalency Factors

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Noise pollution associated with roadway traffic and methods of reducing its negative impacts has been a research issue for over 30 years. One of the more popular approaches to reducing noise pollution has been to install noise barriers along the sections of roadway where noise levels exceed some acceptable standard. The cost of these barriers, however, is usually borne by the transportation authorities and not those who directly cause the problem. With the advent of ITS, and electronic toll pricing in particular, there exists a unique opportunity to recover the costs of noise pollution directly from the people who produce it. The focus of this paper will be to identify methods by which the financial cost of noise pollution may be equitably allocated to those vehicles that cause the noise. The first section of the paper will briefly examine different types of cost allocation methodologies. Subsequently, the methods by which noise pollution is quantified and predicted will be explored and discussed. The concept of noise equivalency factors will be introduced and used to calculate a responsibility measure for different vehicle classes. Lastly, a simple example will be used to outline the concepts developed in the paper.

With the recent advances in ITS, particularly in the areas of electronic toll collection, there has been renewed interest in demand management techniques such as peak hour pricing to reduce congestion in urban areas. There also has been a significant amount of interest on the part of both the driving and nondriving public to reduce the level of pollutants emitted from vehicles. One of the proposed methods of achieving both of these aims is to set the electronic toll prices to capture not only congestion costs but also pollution costs. Consequently, there is a requirement to identify the level of responsibility of each vehicle type in order to set the pricing strategy in a fair and equitable manner.

It is the intent of this author to demonstrate some of the potential methods for allocating pollution costs in situations in which those responsible can be identified and their relative levels of responsibility can be assessed. Noise pollution only is examined in this paper although the techniques can be applied to any type of pollution. The section on cost allocation techniques (below) examines typical cost allocation techniques and identifies the methods most appropriate for highway transportation agencies. The section on sound and noise gives a brief overview of traffic noise, and the section on noise equivalency factors (NEF) illustrates approximate NEF for various vehicle types using the concepts discussed in the previous sections.

COST ALLOCATION TECHNIQUES

Within the field of highway agency cost allocation there is currently much debate over the appropriate methodology for allocating costs. Traditionally highway agencies have attempted to recoup their financial outlays through some type of average cost strategy in which the principle debate consists of defining the most "equitable" manner of doing this. More recently marginal cost pricing has been touted as the more economically efficient and therefore more desirable strategy. The problems with this approach include the high probability of excessive administration costs and the fact that many highway projects are not based solely on economic criterion, which means that the full cost of the project might not be recovered. Perhaps more importantly, from an implementation standpoint, is that there is no consensus on what the marginal cost would be. For example, it is easy to argue that if highway pavement thickness were designed for the expected environmental conditions and the expected truck traffic (which it is in Canada), then the marginal cost of the pavement thickness for automobiles is effectively zero. Conversely, if it is argued that the roads are built solely for automobile usage, then the marginal cost to trucks for the additional pavement is relatively low (*1*). In either case, a marginal cost strategy would be unacceptable both to the trucking firms in the former case and to the automobile associations in the latter case. For these reasons highway agencies have tended to use some type of equitable, as opposed to efficient, cost allocation strategy, as discussed in the next few paragraphs.

Public policy makers are primarily interested in the equitable allocation of highway costs in order to ensure that taxes (or user charges) are fair and that, ideally, they recoup their expenditures. Typically it is direct agency costs such as pavement construction and maintenance that are analyzed. In this paper a technique for allocating the agency costs of traffic noise pollution will be examined. These agency costs will only involve the capital cost of noise attenuation barriers, although the concepts may be used for other costs as well.

Highway agency expenditures may be classified as belonging to three distinct categories for cost allocation purposes. The first types are known as uniquely occasioned costs or long term separable costs. These are costs that may clearly be assigned to one vehicle class. An example of this would be truck weigh stations. The second types are known as common costs and these are costs that may not reasonably be assigned to one vehicle class. The cost of land acquisition for roadway right-of-way is an example of a common cost. Lastly, there are joint costs in which all vehicle types have some responsibly, but this responsibility varies by vehicle type. An example of this is pavement costs, which all vehicle user classes are responsible for incurring, although obviously with differing levels of responsibility. It will be shown in subsequent sections that the agency costs of traffic noise fall into this category.

Once the costs have been identified they have to be allocated or assigned to the different vehicle classes. Traditionally there have been three equity concepts that may be used as a basis for highway

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cost allocation (*2*). The first is the received benefit equity concept, in which user charges are proportional to the benefits received by the users. The second is the occasioned cost equity concept, in which the users are charged in proportion to the cost for which they are directly responsible. Lastly, there is the ability to pay equity concept, in which the users are charged in proportion to their ability to pay.

Most highway agencies have adopted the occasioned cost concept, whereby the users are assigned the average costs that are expended by the highway agency for each of their trips. The challenge in this technique is to identify a suitable responsibility measure that captures the occasioned costs and that may allow the joint costs to be allocated to the different vehicle classes. For highway pavements, it has been shown that a suitable responsibility measure is the load equivalency factor (*1*). In this paper the focus will be on developing a similar responsibility measure for traffic noise.

SOUND AND NOISE

The problem of vehicle and traffic noise associated with traffic networks has been gradually gaining public attention over the past 40 years. Although not as great an issue in North America as in Europe (which has a much larger population density), it is still one of the most easily recognized environmental disbenefits associated with automobile transportation (*3*).

Traffic Noise

The sound pressure and the sound pressure level (*4*) are easily measured and calculated and may be used to categorize traffic noise quantitatively. However, the effects of noise on the auditory systems of human beings are a little more complex, and consequently traffic noise is usually defined in a subjective manner. Sound may be ordered on a scale from soft to loud, and from this the "loudness" of a sound may be derived. Loudness depends not only on the sound pressure level but also on the frequency and wave form of the stimulus. Sound meters used in traffic noise measurement identify only the actual sound pressures of a traffic stream and not the subjective loudness rating. For this reason they are equipped with internationally defined weighting filters that attempt to translate the sound pressure level into measurements of the subjective sound level. The sound level is defined in decibels. There are three standard weighting factors, but the A range is generally used for traffic applications, and it has been shown to have a reasonable correlation with objectively determined rankings (*5*).

Although the unit of noise is relatively easy to define, other subjective measures associated with noise also need to be quantified. For example, as the flow and traffic composition on the roadway changes, the noise level also changes. There are a number of common methods of quantifying the variability of the resulting noise. One measure is the mean sound interval (L_n), which is defined as the mean sound level exceeded n percent of the time. Various values of n have been used to quantify noise, with the most common being 10, 50, and 90 percent. The equivalent sound unit (L_{eq}) was developed in Sweden. It is effectively an average noise level that equates the actual noise to the same A weighted sound energy over the same period of time. The formula used to calculate the equivalent sound unit is indicated in Equation 1 (*6*).

$$L_{eq} = 10 \log_{10}\left(\frac{1}{100}\sum_{i=1}^{n} f_i \, 10^{l_i/10}\right) \quad (1)$$

where

l_i = the sound level corresponding to the midpoint of class i;
f_i = the time interval for which the sound level is in the limits of class i; and
n = the number of classes.

Traffic Noise Prediction Methods

There are many traffic noise prediction models that are used worldwide. These models are used primarily for assessing the potential noise levels for new roadways or noise levels in the future because of traffic increases. The majority are based on empirical measurements and have been extensively calibrated and validated. This paper will focus on a model that is used in the province of Ontario, although the procedures adopted will be applicable to any model.

The FHWA traffic noise prediction model, STAMINA, is one of the more widely used models in North America, and has been used by the Ontario Ministry of Transportation for traffic-related noise studies (*6*). The central feature of the model is the use of reference noise emission levels for various classes of vehicles that use the traffic network. These reference levels are subsequently adjusted for particular situations. In the general case, the vehicle stream is assumed to be composed of three vehicle types: automobiles, medium trucks, and heavy trucks. Medium trucks are defined as two-axle vehicles which generally weigh less than 5500 kg and typically have a pickup or van body type. Any truck that exceeds these minimum standards is considered a heavy truck.

The actual noise level at any point varies with many factors. For instance, traffic volume, percentage trucks, average speed, distance to highway, shape of road, ground cover, height of roadway, height of receiver, as well as environmental factors (wind, etc.) all may be important. Based on these inputs and the FHWA equations, the total hourly equivalent sound level $L_{eq}(h)$ in $dB(A)$ may be calculated for actual or forecast conditions.

Ontario has developed a simplified method of predicting traffic-related free field noise in $L_{eq}(h)$, based on a modified version of the STAMINA model (*7*). Although the model is not as complicated as the original STAMINA program, it does give some general insight into traffic noise. The predicted noise level is a function of traffic volume, equivalent distance to the roadway, ground cover coefficient, and equivalent subtending angle. The general relationship is indicated in Equation 2.

$$L_{eq} = 10 \log\left[\frac{\Phi}{15} VK\left(\frac{15}{D_E}\right)^{1+\alpha}\right] \quad (2)$$

where

V = volume of traffic (veh/h);
K = parameter representing effect of different vehicle classes;
D_E = equivalent lane distance [average distance to nearest and furthest lane (m)];
ϕ = equivalent subtending angle; and
α = site parameter (land-dampening coefficient).

The parameter ϕ is the equivalent subtending angle and is used to model the decrease in noise level caused by intermediate obstructions. When the place at which the sound level is being estimated is unobstructed, the noise emanating along the entire roadway needs to be accounted for. In this situation ϕ may be found by using Equation 3.

$$\Phi = \frac{180}{1 + .58\alpha^{0.9}} \tag{3}$$

In the modified STAMINA model the energy emission models for each vehicle type are combined into a direct energy expression. This combination is defined as K in Equation 2. K may be calculated using Equation 4.

$$K = K_A + K_{MT} + K_{HT}$$

$$K_A = \frac{N_A}{442.53V} S_A^{2.81}$$

$$K_{MT} = \frac{N_{MT}}{5.83V} S_{MT}^{2.39}$$

$$K_{HT} = \frac{N_{HT}}{3.59721 \cdot 10^{-2}V} S_{HT}^{1.46} \tag{4}$$

where

N_A = number of automobiles on roadway (veh/h);
N_{MT} = number of medium trucks (veh/h);
N_{HT} = number of heavy trucks (veh/h);
V = total volume of vehicles (veh/h);
S_A = average speed of automobiles (km/h);
S_{MT} = average speed of medium trucks (km/h); and
S_{HT} = average speed of heavy trucks (km/h).

It may be observed in Equation 2 that the volume parameter V occurs in both the numerator and denominator (through the K factor) and hence may be canceled out. The volume is thus represented explicitly by the number of automobiles, medium trucks, and heavy trucks. It may be observed that as the number of vehicles increases so does the value of L_{eq}. It should be noted that an increase of X automobiles would lead to a smaller increase in noise than would an increase of X heavy trucks. That is, a heavy truck will cause more traffic noise than an automobile, all other factors being equal. This last point will be examined further in the next section.

NEF

It is clear from Equation 4 that the different vehicle classes are responsible for differing amounts of the estimated noise. That is, the responsibility of traffic noise pollution cannot be deemed the sole responsibility of one vehicle class and consequently an individual vehicle for one vehicle class will contribute a different amount to the total noise produced than an individual vehicle from another vehicle class. As discussed in the section on cost allocation techniques, a responsibility measure is required in order to allocate joint costs based on the occasioned cost methodology. In this section a method for developing NEF for the various vehicle classes will be illustrated.

The Load Equivalency Factor (LEF) is used in highway design to assess the impact of a heterogeneous traffic stream on the pavement. The basic technique is to reduce the truck load damage to an equivalent number of passes of a standard load: the so-called ESAL (equivalent single axle load). Therefore, any vehicle may be defined as a fraction or multiple of the ESAL by means of a LEF. As an example, a truck with a LEF of 1.5 would cause 1.5 times the damage of a standard ESAL. In effect, the LEF is used to transform a heterogeneous measure (vehicles in a traffic stream) to a homogeneous one (number of ESALS in a traffic stream) in order to facilitate the design process. The concept of a NEF is similar to the LEF. In this case a standard vehicle is chosen, and the NEF represents the number of standard vehicles a particular vehicle would be equivalent to with respect to noise production. As an example, a truck with a NEF of 10 indicates that the truck produces the same amount of noise as 10 standard vehicles.

If it is assumed that the automobile is the standard vehicle, then the NEF for a heavy truck (denoted here as $NEF_{HT\text{-}A}$) may be calculated using Equation 5. It may be observed that the $NEF_{HT\text{-}A}$ is simply the ratio of the derivative of the L_{eq} function with respect to the number of heavy trucks and the derivative of the L_{eq} function with respect to the number of automobiles.

$$NEF_{HT-A} \frac{dL_{eq}(N_A, N_{MT}, N_{HT})}{dN_A} = \frac{dL_{eq}(N_A, N_{MT}, N_{HT})}{dN_{HT}} \tag{5}$$

If the traffic noise production follows that of the modified STAMINA model, the resulting $NEF_{HT\text{-}A}$ is indicated in Equation 6 below.

$$NEF_{HT-A} = 12{,}302 \frac{S_{HT}^{1.46}}{S_A^{2.81}} \tag{6}$$

In summary, Equation 6 identifies the number of automobiles that would give rise to the same increase in traffic noise as that caused by the addition of one heavy truck for a given set of roadway conditions. The large value of the constant implies a relatively high trade-off between cars and heavy trucks with respect to noise responsibility, all other things being equal. However, the NEF will tend to decrease with an increase in average speed, as evidenced by the relative difference in the exponents of the speed parameters. It is important to note that for this example only the ratio of the vehicle classes has an effect on the NEF and not the traffic volume. The volume will, of course, affect the estimated L_{eq} value. A similar procedure may be used to derive the NEF between medium trucks and automobiles, as indicated in Equation 7. The NEF between heavy trucks and medium trucks may be found in the same manner and is indicated in Equation 8.

$$NEF_{MT-A} = 75.85 \frac{S_{MT}^{2.39}}{S_A^{2.81}} \tag{7}$$

$$NEF_{HT-MT} = 162.185 \frac{S_{HT}^{1.46}}{S_{MT}^{2.39}} \tag{8}$$

Assuming that all the vehicle types travel at the same speed, Figure 1 may be developed from the above equation, which indicates the different NEF as a function of the average speed on the roadway. It can be observed that at a speed of 50 km/h, one heavy truck is responsible for the same amount of noise as approximately 63 automobiles. This ratio decreases with increasing speed and at 100

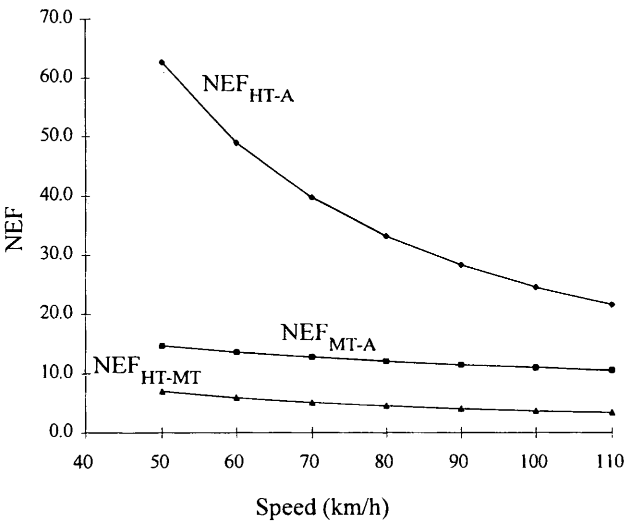

FIGURE 1 NEFs from the modified stamina model.

km/h it may be observed that 25 cars are equivalent to one heavy truck. The NEF for medium trucks as compared to automobiles ranges from approximately 2 to 16. The relatively large constant in Equation 8 would appear to imply that there is a large difference in truck noise accounted for by heavy as opposed to medium trucks. However, the relationship between the speed parameters is such that for realistic situations, the NEF varies from about 5 to 2, as indicated in Figure 1.

As stated previously, the above technique could be used to calculate NEF from other noise prediction models as well. For example, a noise prediction model for arterial roadways that operate with speeds in the range of 10 to 60 km/h has been developed (*8*). Heavy trucks were defined as trucks weighing over 1525 kg. The NEF (again using the automobile as the standard vehicle) for heavy trucks and medium trucks for this model are calculated as 13 and 9, respectively. These values are very different from those indicated in Figure 2. Two points need to be addressed. It is impossible to simply compare the parameters of two models without an in-depth study of the data collection, assumptions, definitions, and techniques used to create the models. It is not the intent of this author to identify the best NEFs, but rather to identify the technique used to calculate them. Secondly, the NEF is calculated so that it may be used in the cost allocation process. The following sections will illustrate how the NEF may be used to allocate noise barrier costs. An example of the cost allocation technique for a noise barrier will be performed along with a sensitivity analysis to illustrate the effect that different NEF values will have on the results.

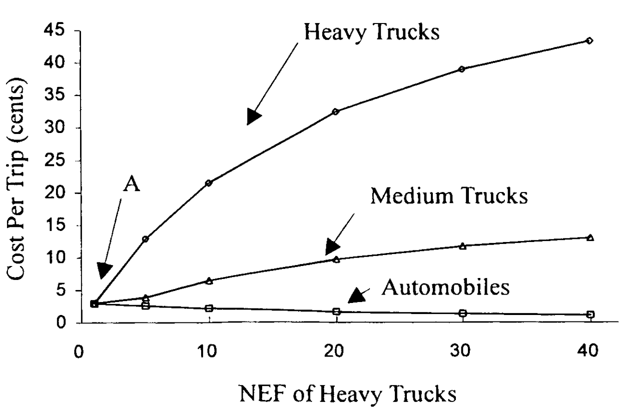

FIGURE 2 Sensitivity analysis of example problem (3 percent heavy trucks, 5 percent medium trucks).

Allocation of Noise Barrier Costs

As discussed in the section on cost allocation techniques, highway agencies have typically used the occasioned cost principle to allocate the construction, maintenance, and operating costs of their facilities. In the remainder of this section, an examination of how the costs associated with noise barriers may be allocated to the different vehicle classes that use the traffic network will be presented. It should be kept in mind that although this analysis pertains to noise pollution, the principles and techniques would apply to any negative externality.

A number of additional items need to be addressed at this point. The first is the matter of economic rights with regard to who is ultimately responsible for the cost of noise mitigation: the homeowners who are affected by the noise or the vehicle owners who produce the noise. Typically, if a noise barrier is being constructed in a developed residential area, the cost is absorbed by the transportation agency, which collects its monies through various taxation schemes. The decision of whether to construct a noise barrier is based on established guidelines, and these guidelines relate to the measured noise levels in the area. For example, in Edmonton, Alberta, once the noise level reaches 65 dBA, a community is eligible for a noise barrier. In new residential areas, the decision to build a noise barrier depends on projected noise levels, for both the base and future years, which are calculated using noise prediction models, as discussed in the section on cost allocation techniques. The cost is absorbed by the developer, who subsequently passes the cost onto the homeowner in the purchase price of the lots. In this paper it is assumed that the noise barrier is being built in a developed area and the transportation agency wishes to recoup the cost directly from the drivers who cause the noise instead of from general revenues.

The second point concerns the manner in which a cost recovery scheme could be implemented. Until recently this exercise would have been more of an academic exercise because it would have been infeasible to charge vehicles on a per use basis. However, with the advent of electronic toll pricing, noise barrier costs may be easily recouped on a per use basis. In this paper the responsibility measures used will be the NEF, as discussed earlier. Therefore, the costs will be allocated on a vehicle class basis in which each vehicle is classified according to the definition of the STAMINA model.

Lastly, it should be kept in mind that this paper is seeking only to demonstrate the procedure instead of attempting to define the optimal pricing strategy. For example, it may be hypothesized that in actual practice each vehicle would be tested annually to determine the various emission levels of different types of pollution (hydrocarbons, noise, etc.). From these measurements the equivalency factors could be calculated for each individual vehicle. These equivalency factors could then be used to price roadway trips according to criteria such as how much pollution they produce, where they produce it, and when they produce it. In areas that currently undergo such testing, the additional cost would be minimal. This scheme would have the desirable feature of allowing vehicle owners to explicitly trade-off the costs of vehicle improvements (i.e., quieter tires) versus the increased cost of electronic tolls associated with not investing in noise attenuation improvements. If time-of-day pricing were instituted, it may also have the effect of spreading the peak pollution periods. Regardless, the analysis in the next section will give an approximate estimate of the allocated costs to each vehicle type, which may be useful in determining whether current pricing techniques are equitable for all vehicle classes.

Sample Problem

The following is an example of how the NEF concept may be used to allocate the cost of a noise attenuation barrier. Consider an arterial roadway where a noise barrier has been constructed along both sides in order to reduce the noise to an acceptable level during the peak periods. The cost of this barrier is approximately $1,000 per m, which results in a total project cost of $1 million. If the project life is assumed to be 20 years and a real interest rate of 4 percent prevails, the transportation agency would have to recover $73,581 dollars per year in order to recoup the construction costs.

During the morning and afternoon peak periods (1-h length), the hourly flow is 4,800 vehicles per hour, which is composed of 92 percent automobiles, 5 percent medium trucks, and 3 percent heavy trucks. If it is assumed that there are 260 days in a year when the acceptable noise level is exceeded, then there are approximately 2.5 million vehicles per year that should be charged the cost of the noise barrier. If the agency charged all vehicles the same then the cost per vehicle to use this section of road would be 2.95 cents ($73,581/2,496,000) per trip. Note that travelers during the off-peak times would not be charged, as they are not responsible for the noise that makes the noise attenuation barrier necessary.

If the transportation agency decided to recover the capital cost of the barrier based on the occasioned cost principle with the NEF used as the responsibility measure, then the toll prices would be somewhat different. If the average speed on the arterial is 70 km/h, the NEF for the three vehicle classes would be 1, 12.7, and 39.7, respectively, as indicated in Figure 1. This implies that the noise caused by the current peak hour traffic stream would be equivalent to that produced by approximately 6.85 million cars—2,496,000 [1(0.92) + 12.7(0.05) + 39.7(0.03)]. The cost per automobile would decrease to 1.1 cents per trip, the cost per medium truck would increase to 13.6 cents per trip, and the cost per heavy truck would increase to 42.6 cents per trip. This pricing strategy would result in the heavy trucks paying approximately 40 percent and medium trucks paying approximately 20 percent of the capital cost of the noise barrier.

Of course, the results of the above example are based on all of the assumptions of the example problem, in particular the NEF values. Figure 2 illustrates a sensitivity analysis of the NEF values. The x-axis represents the NEF for heavy trucks. It is assumed that a NEF ratio 1-12-40 applies for the different vehicle classes such that a NEF for heavy trucks of 20 implies a NEF for medium trucks of 6. The y-axis represents the cost per trip for the different vehicle classes that would have to be charged in order to recover the cost of the noise barriers.

Point A in Figure 2 represents the situation in which all vehicles are charged the same rate (i.e., both heavy trucks and medium trucks have a NEF of 1). As would be expected, as the NEF for heavy trucks increases so too does the cost per trip for the trucks, whereas the cost per trip for automobiles declines. Note that the slope of all of the curves depends not only on the NEF but also on the number of vehicles in each vehicle class. At a NEF of 10 the heavy trucks would pay a relatively high cost of 20 cents per trip, which is still significantly higher than the average vehicle cost method. Under this pricing strategy the heavy trucks would pay approximately 25 percent of the cost of the noise barrier and the medium trucks approximately 5 percent.

The example problem was subsequently analyzed when the percentage of trucks doubled with all other factors being held equal. The graph of this scenario is indicated in Figure 3. Point A in Figure 3 represents the cost per trip when all vehicles are charged at the same rate. The cost per trip for this scenario is the same as in Figure 2 because the volume on the roadway has not changed. It may be observed in Figure 3 that the cost per trip for all vehicle types decreases when the percentage of trucks increases. The reason for this is that although the cost responsibility of the trucks increases there are now more of them, leading to a decrease in the average cost per trip. For example, at a LEF of 40 the cost of the barrier paid by automobile users drops from approximately 40 percent in the first scenario to 25 percent in the second scenario.

CONCLUDING REMARKS

It was not the intent of this author to provide a definitive answer to the question of cost allocation of noise pollution to the different vehicle classes. Rather, the objective was to provide insight into some of the issues involved and to demonstrate some of the more promising techniques for setting pricing strategies for pollution. However, a number of interesting points have been illustrated in this paper.

It is possible to use the existing traffic noise prediction models, such as the modified STAMINA model, to assign responsibility to the different vehicle classes as long as the models explicitly account for the effects of each vehicle class on the noise level. Based on the modified STAMINA traffic noise prediction model, it was shown that the relative responsibility levels or NEF for trucks was much higher than for automobiles. As an example, it was illustrated that at a speed of 100 km/h one heavy truck was equivalent in noise responsibility to 25 automobiles whereas one medium truck was equivalent to 11 automobiles. Although the original noise prediction models were not developed for cost allocation purposes, the

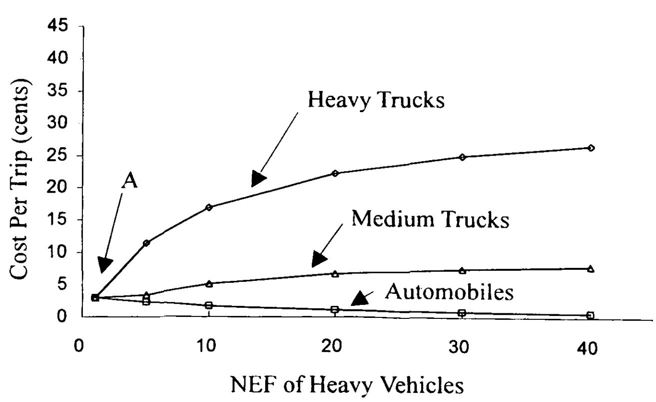

FIGURE 3 Sensitivity analysis of example problem (6 percent heavy trucks, 10 percent medium trucks).

fact that they have been used extensively in numerous noise studies provides some validity to the results. However, as illustrated in the section on NEFs, different noise prediction models can provide different results, and it is currently unclear which model (and hence NEF) is the most appropriate to use.

Once the relative responsibility measures or NEF have been identified, they may be used to allocate pollution costs to the various vehicle types. It was shown in a relatively simple example that the actual amount allocated to each vehicle in this method could be significantly different from that achieved by allocating the cost simply on a per vehicle basis. For example, when the cost was allocated in the sample problem on a per vehicle basis, the cost of a noise attenuation barrier was approximately 3 cents per trip. However, when the cost was allocated on a standard vehicle basis using a NEF of 10 for heavy trucks, the cost per trip for heavy trucks increased to approximately 20 cents per trip. It was shown that the actual charge for a particular vehicle type depends on many factors including the number of vehicles, the percentage of trucks, and the responsibility measure used.

Although the concepts developed in this paper are relatively straightforward, there are a number of further questions that also need research attention. In particular, what are the optimal NEFs for cost allocation procedures? What are the equivalency factors for other pollution costs? Could a cost recovery system based on the occasioned cost principles be implemented given the recent advances in electronic toll collection techniques? Lastly, and perhaps most importantly, if such a cost recovery system were implemented, what would be the implications in terms of system users reducing their noise production by buying quieter cars, driving slower, changing their routes, or driving during different periods of the day? These questions will form the basis of further research on this topic.

ACKNOWLEDGMENTS

Funding for this project was supplied by the Natural Science and Engineering Research Council of Canada and is gratefully acknowledged. The author would also like to thank the referees of this paper for their thoughtful and useful comments.

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Publication of this paper sponsored by Committee on Transportation Economics.