TRANSPORTATION RESEARCH

RECORD

No. 1450

Planning and Administration

Pricing, Economic Development, Cost Analysis, Transportation Impacts, and Transportation Management Processes

A peer-reviewed publication of the Transportation Research Board

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY PRESS
WASHINGTON, D.C. 1994

Transportation Research Record 1450
ISSN 0361-1981
ISBN 0-309-06058-3
Price: $26.00

Subscriber Category
IA planning and administration

Printed in the United States of America

Sponsorship of Transportation Research Record 1450

GROUP 1—TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Chairman: Thomas F. Humphrey, Massachusetts Institute of Technology

Management and Administration Section
Chairman: Julie Hoover, Parsons Brinckerhoff, Inc.

Committee on Taxation and Finance
Chairman: Norman H. Wuestefeld, Wilbur Smith Associates
Secretary: Germaine G. Williams, FHWA
Andrea R. Bozzo, Thomas W. Bradshaw, Jr., Robert Clarke Brown, Mark A. Euritt, Enrico Fabi, David J. Forkenbrock, Martin J. Hemingway, Loyd R. Henion, Arthur C. Jacoby, Anthony R. Kane, Walter D. Kreutzen, Amy A. O'Leary, Shiva K. Pant, Elizabeth A. Pinkston, Clyde E. Pyers, Suzanne H. Sale, Roger L. Schrantz, Frank J. Smith, Fred L. Williams, Jenifer Wishart, Janice Turtora Zagardo

Committee on Management and Productivity
Chairman: Kathleen E. Stein-Hudson, Stein-Hudson Associates Howard
Secretary: Barbara Martin, Montana Highway Department
Luz B. Allende, Walter E. Bortree, John F. DiRenzo, Henry Droughter, Donald O. Eisele, Judy Guerrero, Barbara Thomas Harder, Jerry A. Hawkins, Laura A. Jibben, Robert C. Johns, Parviz A. Koushki, George T. Lathrop, Carol LeFevre, Arthur J. Morse, Daniel B. Pritchard, Ellin Reisner, Frankie G. Rodwell, Jane L. Shiatte, Roy Sparrow, William G. Stringfellow, Cindy M. Turvy

Committee on Transportation and Economic Development
Chairman: David J. Forkenbrock, University of Iowa
Chris P. Bertram, Donald J. Emerson, Norman S. J. Foster, Genevieve Giuliano, Terry L. Gotts, Sharon M. Greene, Randall Halvorson, Douglass B. Lee, Michael A. Lipsman, Debra L. Miller, Robert D. Owens, Wayne B. Placide, Marilyn Ragusa, Richard J. Reeder, Suzanne H. Sale, Frank J. Smith, Barbara W. Weiss, Bruce B. Wilson, Norman H. Wuestefeld, Robert J. Zuelsdorf

Transportation Forecasting, Data, and Economics Section
Chairman: Mary Lynn Tischer, Virginia Department of Transportation

Committee on Transportation Economics
Chairman: Ralph C. Erickson, Federal Highway Administration
Gary R. Allen, Kazem Attaran, Fredric S. Berger, Susan J. Binder, Jan L. Botha, Stewart E. Butler, Mark A. Euritt, Asif Faiz, Z. Andrew Farkas, David J. Forkenbrock, Edwin W. Hauser, R. Ian Kingham, Jeffery L. Memmott, Marcelo J. Minc, Ibrahim M. Mouaket, Bahar B. Norris, Farideh Ramjerdi, Christian Reynaud, Steven M. Rock, Aad Ruhl, Guillaume Shearin, Yorgos J. Stephanedes, Janice Turtora Zagardo, Robert J. Zuelsdorf

Committee on Social and Economic Factors of Transportation
Chairman: Thomas N. Harvey, Harvey Consultants, Inc.
Secretary: Mary R. Kihl, Iowa State University
William L. Ball, M. Lynn Bortel, Jesse L. Buffington, Burton Clifton, Matthew A. Coogan, Thomas A. Horan, William A. Hyman, Brian T. Ketcham, Brenda C. Kragh, Martine Micozzi, Arthur C. Nelson, Amy A. O'Leary, Michael L. Patten, Frank W. Pentti, Roslyn Carter Philips, Kathleen H. Quinn, Mary Donahue Stearns, Glen Weisbrod, Katie N. Womack, Norbert Y. Zucker

Transportation Research Board Staff
Robert E. Spicher, Director, Technical Activities
Kenneth E. Cook, Engineer of Planning and Administration
Nancy A. Ackerman, Director, Reports and Editorial Services
Norman Solomon, Editor

Sponsorship is indicated by a footnote at the end of each paper. The organizational units, officers, and members are as of December 31, 1993.

Transportation Research Record 1450

Contents

Foreword v

Part 1—Finance

Airport Congestion and Noise: Interplay of Allocation and Distribution 3
Wayne Brough, Edward Clarke, and Nicolaus Tideman

Freeway Congestion Pricing: Another Look 8
Herbert S. Levinson

Part 2—Economic Development

Integration of Financial and Construction Risks: A Simulation Approach 15
Ali Touran and Paul J. Bolster

Part 3—Economic Analysis

Cost-Benefit Analysis of a Rural Advanced Traveler Information System 25
Kazi Ullah, Wende A. O'Neill, and A. Bruce Bishop

Applying the Cashing Out Approach to Congestion Pricing 34
Patrick DeCorla-Souza

Application of a User Cost Model To Measure During and After Construction Costs and Benefits: Highway Widening Projects 38
Marie T. Wildenthal, Jesse L. Buffington, and Jeffery L. Memmott

Integrating Driver Information and Congestion Pricing Systems 44
Ibrahim El Sanhouri and David Bernstein

Part 4—Socioeconomic Impacts

Community Impacts of Local and Regional Railroads: A Kansas Case Study 53
Victor E. Eusebio and Stephen J. Rindom

Estimated Impact of Widening U.S. Highway 80 (Marshall Avenue) in Longview, Texas 59
Jesse L. Buffington and Marie T. Wildenthal

Part 5—Management and Productivity

Women in Transportation Management in Kuwait: Attitudes Toward Gender Bias 67
Parviz A. Koushki, Saleh Yaseen Ali, and Alison M. Larkin

Organization, Management, and Financing in a Road Agency 72
Antti Talvitie and Jukka Hirvelä

Developing and Implementing the Intermodal Surface Transportation Efficiency Act Management Systems: New York State's Approach 80
John J. Shufon, Clarence R. Fosdick, Barbara P. Gigliotti, and Joseph P. McClean

Foreword

This volume contains papers dealing with topics related to transportation finance, economic development, economic analysis, socioeconomic impacts, and the management and productivity of transportation systems.

The first paper provides a method for evaluating the allocation and distribution of takeoff and landing rights at airports while controlling noise pollution.

Several papers deal with congestion pricing. One paper sets forth the rationale underlying congestion pricing, and another proposes a system that requires an employer to provide a cash subsidy to employees who do not use employer-paid parking. A third deals with integrating driver information and congestion pricing systems.

Economic modeling is the theme of several papers. Using Monte Carlo simulation, one paper addresses the integration of financial and construction risks. Another uses a life cycle cost model to evaluate a proposed rural advanced traveler information system. A third uses a user cost model to measure the costs and benefits of a highway widening project.

Two papers examine community impacts of transportation systems. One provides a methodology to measure the impacts of local and regional railroads on small communities in Kansas, and the second estimates the impacts of widening a highway in Texas.

The final set of papers focuses on management and productivity issues. The issues considered include developing and implementing the Intermodal Surface Transportation Efficiency Act management systems; organizing, management, and financing in a highway agency; and gender bias in transportation management.

PART 1

Finance

Airport Congestion and Noise: Interplay of Allocation and Distribution

WAYNE BROUGH, EDWARD CLARKE, AND NICOLAUS TIDEMAN

The history of airport takeoff and landing rights is discussed, focusing on how distributive concerns have dominated the resolution of allocative issues. A mechanism is needed to separate allocation and distribution, to permit the simultaneous optimization of the use of scarce resources and minimization of the social cost of unintended redistribution. From this perspective, two allocative mechanisms are compared: a free market in transferable slots and an administered market, using compensated incentive compatibility (CIC), a version of the demand-revealing process. If the only concern is the efficient allocation of a specified number of slots, either mechanism will work. However, if the number of slots is to be optimized endogenously, CIC is needed. An additional important advantage of CIC arises from its capacity to provide optimal control of noise pollution. The CIC mechanism is useful not only for controlling public nuisances such as pollution, for which the mechanism was originally developed, but also for allocating a private good such as airport slots, where the government creates scarcity values in the process of controlling externalities such as noise and congestion. The conclusions extend to other settings in which allocation and distribution are intertwined and for which externalities need to be managed.

The decade following airline deregulation sparked great controversy over the role of the market, particularly in dealing with supply-side constraints (*1*). The growth in air travel put pressure on existing capacity and created increased congestion.

HISTORY OF SLOT MANAGEMENT

The creation of a market in airport takeoff and landing rights (slots) in 1986 was viewed as a significant, albeit limited, first step toward relieving an important constraint on the supply of airline services and improving the efficiency with which scarce airport capacity is used.

The slot trading (or buy-sell) program replaced a system of quotas for rationing capacity at some airports. The quota system was initially established by FAA in 1969 to allocate capacity at the four busiest airports—O'Hare, Kennedy, LaGuardia, and Washington/National. At these airports, the "high-density" rule established "slots" that represented the right to take off or land within an interval of typically 30 to 60 min. The high-density rule replaced a first-come, first-served rule that is still in effect at the majority of U.S. airports.

At the four high-density airports, slots for trunk carriers were originally allocated by scheduling committees. The scheduling committees met twice a year and were required to reach unanimous agreement, or the FAA would step in and impose its own allocation. Both incumbent carriers and new entrants served on these committees; the result was often extremely protracted negotiations. Trades in slots occasionally were possible, but generally only on a one-for-one basis for another slot at the same airport. In addition to inhibiting the most efficient use of existing slots, the quota system appears to have imposed considerable restraint on new entry.

FAA introduced the buy-sell program when scheduling committees were no longer able to reach unanimous agreement. This program, which became effective in April 1986, "grandfathered" existing users by allocating to them the slots they were using at the four airports as of December 1985. The rule also permitted the holders of slots to sell them.

INTERPLAY OF ALLOCATION AND DISTRIBUTION

The evolution of the buy-sell program, a system of de facto property rights in slots, illustrates the dominance of distributive considerations in the choice of allocative mechanisms. The evolution of the buy-sell rule and the reasons why it was adopted in lieu of other approaches, such as auctions or congestion fees, is discussed by Riker and Sened (*2*). The evolution of this market also illustrates the conflicts among three competing principles for settling distributive questions: efficiency, equality, and distributive stability.

When slots were not scarce, all three principles could be honored by allowing everyone who wished to do so to take off and land at airports, with charges only for the cost of managing the takeoff and landing process. However, when congestion and delays developed, the principle of efficiency was sacrificed. Equality was preserved. Distributive stability was compromised. It continued to be possible for everyone who wanted to take off or land to do so, but only at a cost of waiting in line.

The high-density rule of unanimously agreed quotas represented a compromise with all three principles. Unanimously agreed quotas were probably more efficient than the earlier congestion, but because only limited subsequent trading was permitted, slots often remained in the hands of carriers other than those that could use them most productively. A kind of equality was achieved by allowing all carriers to participate in the scheduling committees. However, to the extent that participants believed that a deadlock would lead FAA to impose an unequal allocation, the bargains they reached reflected that inequality. Distributive stability was sacrificed to the extent that existing carriers were obliged to agree to the assignment to new entrants of some slots that they had held previously.

W. Brough, Citizens for a Sound Economy Foundation, 1250 H Street, N.W., Washington, D.C. 20005. E. Clarke, Office of Management and Budget, 726 W. Jackson Place, N.W., Washington, D.C. 20503. N. Tideman, Virginia Polytechnic and State University, Department of Economics, Blacksburg, Va. 24061.

The introduction of the buy-sell rule in 1986 improved efficiency while preserving stability and sacrificing equality. The buy-sell rules permitted slots to be transferred to those carriers for whom they were more valuable, thereby promoting efficiency. The principle of stability was honored by setting initial allocation of slots according to usage at a time 4 months before the start of the buy-sell program. However, the assignment of slots only to those who had previously held them sacrificed the principle of equality. A variation on the buy-sell rules in which slots were initially auctioned would also have promoted efficiency while honoring the principle of equality, but would have sacrificed the principle of stability.

One alternative to the buy-sell program is a program of rationing slots by rental auctions or some other administered market. This has the potential to be at least as efficient as the buy-sell program, and possibly more efficient, because it may be easier under an administered market to vary the number of slots to take account of changes in the optimal number of takeoffs and landings. An administered market can honor the principle of equality by collecting the value of slots socially instead of assigning it to the carriers who had been using slots. However, by requiring carriers to pay for what they had previously received for nothing, an administered market sacrifices the principle of stability. Alternatively, an administered market can honor the principle of stability and sacrifice the principle of equality, if market-clearing fees are collected and allocated among carriers in proportion to their previous use.

The central distributive question with respect to slot management is as follows: When restrictions on takeoffs and landings are introduced at an airport for the sake of efficiency, should the value of exclusive takeoff and landing rights go to the carriers who had been using the airport (thereby honoring the principle of stability) or to the public treasury (thereby honoring the principle of equality), or should there be some compromise between these two principles?

The question may have no easy answer. We maintain that a history of use of common property does not create an exclusive right to privileged access when the opportunity to use such property becomes scarce. At the same time, it is reasonable to permit commitments of slots to carriers for some span of time—for example, in exchange for the carriers' investments in developing schedules. Accordingly, there could be a transition, at a rate that was appropriate in view of previous commitments, from entitlements based on past usage to social collection of the scarcity value of slots.

The important point here is that there is a tendency for distributive considerations to influence the choice of allocative mechanisms. To be confident that an allocative mechanism is chosen well despite the tendency of distributive considerations to influence the choice, it is desirable that the distributive issue be settled separately. For example, if the span of time for which existing carriers deserve special access is decided first, it is possible to assess alternative allocative mechanisms without the bias that comes from potential distributive consequences. Then, after the allocative mechanism has been chosen, one can adapt it to reflect the previously chosen rights of existing carriers.

ALLOCATION OF SLOTS BY TRANSFERABLE OWNERSHIP

We noted that the evolution of the buy-sell rule was strongly influenced by concerns for distributive stability. Efficiency considerations played an important role as well. The basic efficiency argument for the buy-sell program is that if the owner of a slot is unable to obtain as much value from it as some other carrier, then self-interest will lead the owner to sell it. Because people are also concerned about distributive stability, to many it will seem natural, if slots are to be owned, that initial ownership be assigned to the carriers that have been using the slots. Both efficiency and stability are thus completely satisfied.

This argument is valid for any specified number of slots, but it does not address the question of how many slots there should be. Allowing the wrong number of takeoffs and landings can be very costly. Morrison and Winston (*3*) have estimated that welfare gains of approximately $4 billion per year could be achieved by optimizing the number of takeoffs and landings. The attempt to schedule more takeoffs and landings in a given interval of time increases the expected delay for all of them. The number of slots in a given hour is optimal if and only if the rental value of a slot in that hour is equal to the cost of the expected additional delay that is caused by trying to squeeze one more slot into that hour. If the marginal delay cost were less than the rental value of a slot, then to achieve efficiency under a system of transferable ownership of slots, the airport authority would need to create new slots. If the marginal delay cost were greater than the rental value of a slot, the authority would need to eliminate one or more existing slots to achieve efficiency.

A need to change the number of slots can arise from a change in technology, a change in the number of runways, or a change in the estimate of the spacing required for safety. If carriers own slots, any increase in the number of slots reduces the market value of the assets of carriers, leading to pressure not to increase the number of slots. If efficiency is to be achieved, it is important that such pressure not be effective. Any reduction in the number of slots requires airport authorities to acquire slots from carriers. This would produce financial losses for airport authorities unless there were some provision for taxing the owners of slots to finance required reductions in the number of slots.

One of the consequences of takeoffs and landings is noise pollution. The cost of this pollution varies by time of day, type of day, type of aircraft, and how the aircraft are flown. To achieve proper incentives for reducing the costs of such pollution, those who take off and land must be charged with these costs. Thus efficiency requires that possession of a slot not insulate carriers from noise pollution charges.

To summarize, it is possible in principle to achieve efficiency through transferable slot ownership, but there are potential problems in adjusting the number of slots in each hour, in adapting to the redistributive consequences of changes in the number of slots in each hour, and in implementing efficient noise pollution charges. These problems are not insurmountable, but they demonstrate that transferable slot ownership has costs, which could be higher than the costs of an alternative allocative mechanism. An alternative mechanism could enhance allocative (and procedural) efficiency while making improved trade-offs between the principles of distributive stability and equality, in part by achieving a more effective separation between distributive and allocative issues.

ALLOCATION OF SLOTS BY A COMPENSATED INCENTIVE COMPATIBLE PROCESS

The origins of our proposal are Vickrey's concept (*4*) of a "second-price auction" and Clarke's idea (*5*) of levying charges on individuals for public goods according to the marginal social costs of accommodating their stated departures from standardized demand schedules, an idea to which Tideman and Tullock (*6*) gave the name "the demand-revealing process." The principal virtue of these mechanisms is that they motivate individuals to report their preferences honestly, thereby permitting efficient allocations to be identified and implemented. Dolan (*7*) described the way in which the demand-revealing process could be employed to optimize the use of a congested facility. Economics, Inc. (*8*) recommended that FAA use a second-price auction to motivate accurate revelation of willingness to pay for slots.

The authors' proposal involves a variation on second-price auctions and the demand-revealing process that was developed by Tideman (*9*). This variation, called compensated incentive compatibility (CIC), optimizes the use of a public resource while separating allocative efficiency from the distribution of the revenues generated by efficient pricing (in this case, of slots). Our proposal can also be considered a variant of the zero-revenue auction (ZRA) approach to emissions-rights allocation, which has appeared in the environmental literature (*10,11*).

In the remainder of this section, we introduce the CIC approach to slot allocation as a refinement of traditional auctions and ZRAs. We then introduce further refinements that take more precise account of congestion costs by better reflecting differences in priority status in a queue, building on Dolan's work (*7*). Finally, we develop a different application of CIC for dealing with the noise from takeoffs and landings.

Traditional Auctions

Under a traditional approach to the auction of slots, each carrier submits a demand schedule for slots (i.e., a statement of the quantity of slots that the carrier would wish to rent at each possible price). These individual demand schedules are added horizontally to construct an aggregate demand schedule for slots. There is an exogenous limit on the number of slots, set by legislation or regulation. If aggregate demand is less than this quantity at a price equal to the sum of noise and other external costs, then this price is the price of a slot. If aggregate demand is more than the limit at this price, then the price is such that aggregate demand is equal to the limit.

The theory of just distribution that is incorporated in a traditional auction is that slots are public property, so that if they are scarce, any carrier that wants to use slots ought to pay for them according to their market price.

A traditional auction is efficient if the number of carriers is so great that no carrier considers it worthwhile to take account of the effect of his reported demand schedule on the price. When the number of carriers is not so great, there is a modification of the traditional auction that is efficient. This is to require each carrier to pay for each slot it obtains according to the marginal social cost of that slot. That is, the price of a carrier's first slot would be the lowest price at which all other carriers had an aggregate demand for all but one slot, the price of the second slot would be the lowest price at which all other carriers had an aggregate demand for all but two slots, and so on. This method is an application of the principle behind Vickrey's second-price auction (*4*) and is the method of slot allocation recommended to FAA by Economics, Inc. (*8*). Because each carrier would pay for slots according to their marginal social cost, each carrier would have an incentive to report its demand schedule accurately. However, if the very considerable revenue that would be generated were to be returned to carriers, then there would be incentives to misstate demands.

ZRAs

In a ZRA, a system administrator assigns each carrier a provisional allocation of slots. As with a traditional auction, all carriers report their demand schedules. The intersection of aggregate demand with an aggregate quantity constraint determines the equilibrium price of slots. Each carrier's final allocation is its quantity demanded at the equilibrium price. Each carrier pays for slots at the equilibrium price and receives back an amount of money equal to the product of the equilibrium price and its provisional allocation. Net payments for all carriers taken together are zero. The theory of just distribution that is incorporated in the ZRA procedure is that each carrier has an entitlement to its initial allocation of slots, but this entitlement is protected by a liability rule rather than a property rule: each carrier may be required to sell some of its slots to any other carrier that values them more highly.

One problem with the ZRA procedure, noted by Hahn and Noll (*10*) and by others as well, is that when a carrier recognizes that it can affect the equilibrium price of slots, it will have an incentive to report something other than its true demand schedule. This problem can be remedied by the CIC method of auctioning slots.

CIC

Under CIC, a system administrator assigns each carrier a demand schedule as well as an initial quantity of slots. The assigned demand schedule should be the best estimate of that carrier's actual demand that the administrator can make without using information supplied by the carrier itself. (The use of that information would generate an incentive for biased reports.) The administrator can, however, use information supplied by similarly situated carriers to estimate any given carrier's demand. As with the other auction methods, carriers report their actual demand schedules. Assignment of slots to those who value them most highly leads to reallocations of some slots. But for any carrier whose assigned demand schedule is perfectly accurate, these reallocations occur without harm or benefit.

The amount that a carrier pays for its final allocation of slots is shown in Figure 1. Here D_1 is the administrator's estimate of the carrier's demand schedule, and D_2 is the schedule that the carrier actually reports. The schedule labeled S is the carrier's "derived supply schedule of slots." The quantity on this schedule at any price, p, is found by first determining the total number of slots that can be supplied to all carriers at a marginal social cost

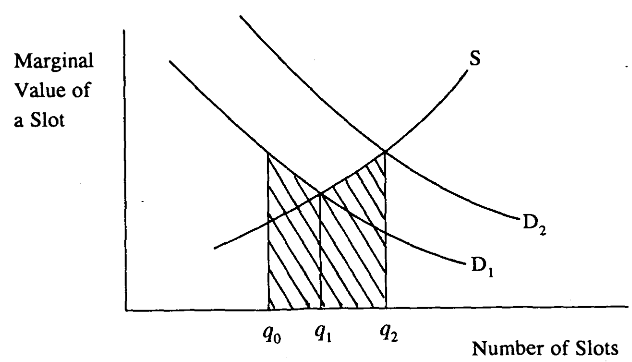


FIGURE 1 Compensated incentive compatibility.

of no more than p. (For the case of a regulated number of slots, one would simply use that number.) One then subtracts the quantities demanded at a price of p by all carriers other than the one whose demand is shown in the figure. The result is the quantity of slots that can be supplied to this carrier at a marginal social cost of no more than p, and the schedule of all such quantities is the derived supply schedule of slots for the carrier. The carrier's initially assigned quantity of slots is labeled q_0. The quantity of slots that the carrier would receive if it had reported a demand schedule of D_1 is labeled q_1. The quantity of slots that it actually receives, given that it reports a demand schedule of D_2, is labeled q_2.

The fee that is charged to the carrier whose demand is shown is the shaded area in Figure 1. This price is the sum of the integral of the carrier's assigned demand schedule from q_0 to q_1 and the integral of the carrier's derived supply schedule from q_1 to q_2. Either integral can be negative, in which case it represents a payment to rather than a payment from the carrier.

The reason that two different schedules are used to price different parts of one carrier's reallocation of slots is as follows: The movement from q_1 to q_2 is induced by the deviation of the carrier's reported demand schedule from its assigned schedule. To motivate an honest statement of the schedule, this movement must be priced according to marginal social cost, that is, according to the derived supply schedule. The movement from q_0 to q_1 is induced by the fact that q_0 is not the quantity of slots that would be efficient to assign to the carrier if it had reported that its assigned schedule were accurate. Using the assigned schedule to price this movement reduces unintended redistribution for this movement to the minimum amount feasible.

If the administrator were to estimate all demands perfectly and to assign quantities corresponding to the market-clearing ones, then each q_0 would equal the corresponding q_1 and q_2. Thus, there would be no charges on any carrier. The theory of just distribution that is incorporated in this approach to the allocation of slots is that every carrier has a right to receive, without charge, the quantity of slots that it would demand at a market-clearing price.

An efficient variant of ZRA is created by using CIC with any initial allocations of slots that sum to the total available quantity. At the other extreme, if all carriers are assigned quantities of zero and demand schedules that have zero quantity at all prices, then CIC reduces to the efficient auction procedure described above. But every intermediate distributive outcome can also be achieved efficiently through CIC. If one's theory of just distribution says (as the authors' does) that carriers have a temporary but not a permanent right to their initial usage of slots, this can be incorporated into the CIC approach by starting with initial allocations that correspond to prior usage and then reducing the initial allocations to zero quantities, either gradually or all at once after some chosen period of time.

In general, CIC does not achieve budget balance. To achieve the budget balance that must obtain in the end, the budget deficit or surplus could be allocated among carriers in proportion to their assigned quantities. This would induce a slight incentive for misstatements of demands, but it would be difficult to know what misstatements would be profitable. To eliminate the incentive for misstatements all but infinitesimally, the budget surplus or deficit could be assigned to the general funds of the government.

Noise pollution charges can be incorporated into the CIC simply by announcing the charges and asking carriers to report their demands given those charges. To incorporate the distributive premise that carriers are entitled to continue all or part of their past noise for some span of time, one would supplement the noise pollution charges with credits corresponding to those entitlements. With further refinements, priority status within queues could be incorporated as well.

CIC with Priority Pricing

Dolan (7, p. 432) developed a slot allocation method that incorporated congestion costs defined in terms of the demands of carriers (or passengers) for a guaranteed arrival or departure time or a higher priority in a queue. His static queuing model showed that the priority prices that would minimize congestion were equivalent to the taxes generated by a demand-revealing process. A corresponding modification of CIC is to ask each carrier to state, for each slot in which it expresses an interest, not just the amount of money that it is willing to pay for the slot, but rather the schedule of amounts they would be willing to pay for different priority status. The system administrator would assign not just initial quantities and demand schedules, but a priority status for each slot in each carrier's initial allocation and a priority demand schedule for each slot in which each carrier might have an interest. The final allocation would be the set of slot allocations, each with assigned priority status, that maximized aggregate reported value, subject to the constraints of available capacity. As with the earlier version of CIC, each carrier would pay, according to its assigned schedules, for the movement from its initial allocation to the allocation that it would have had, had it reported that its initial allocation was accurate. It would also pay the net cost to all other carriers that resulted from the deviation of its reported schedules from its assigned schedules.

MANAGING NOISE POLLUTION BY USING CIC

Properly set noise pollution charges will motivate carriers to invest efficiently in quieter airplanes, to operate them in such a way as to minimize noise, and to operate at times of the day when noise is less costly. The allocation of noise pollution fees to those who are adversely affected by the noise can neutralize unjustified redistribution that would otherwise result from variations in the level of noise. But what is the right level of charges for noise?

Noise is a "local public bad." That is, the harm that one person suffers from noise does not add or detract from the harm that his neighbors suffer from the same noise. But as with local public goods, the effect abates with distance from the source. The total cost of airplane noise is the sum of the harm experienced over all persons who are harmed by the noise. A CIC process can be used to motivate those who live in the vicinity of an airport to report this harm accurately and motivate carriers to economize on that harm. At the same time, the CIC process also manages distributive effects of airport noise within a prescribed theory of just distribution.

To manage noise, one must begin with a technology for measuring noise. A good measurement technology should achieve cardinally meaningful measurements. That is, if one plane is measured to produce twice as much noise as another at a given location, then all persons in that location should experience twice as much noise from the second plane as from the first. We will assume that such a measurement technology exists. We will also assume that it is easy to know how much noise any plane produces in any place.

To create a noise management system, one begins by dividing the total area that is affected by noise into subareas that each can be treated as experiencing a uniform level of noise for any pattern of airplane operation. One must also divide the week into time intervals in which noise has uniform costs. Let the number of subareas be S, and let them be indexed by s. Let I_s denote the set of individuals who are affected by noise in subarea s. Let the number of time intervals be T, and let them be indexed by t. Let there be J carriers, indexed by j.

In each subarea, s, in each time interval, t, there is a marginal social cost of noise:

$$C_{st} = \sum_{i \in I_s} f_{it}(Q_{st}) \quad (1)$$

where C_{st} is the cost of noise to subarea s at time t and f_{it} is a function that expresses the ith person's marginal cost of noise for time interval t as a function of Q_{st}, the amount of noise in subarea s in time interval t. If noise has neither economies nor diseconomies of scale, then the functions f_{it} will be constant functions. But these functions can also have regions over which they are increasing or decreasing.

The noise level in any subarea in any interval of time Q_{st} is the sum of the amounts of noise produced by individual carriers q_{jst}. That is,

$$Q_{st} = \sum_{j=1}^{J} q_{jst} \quad (2)$$

Each q_{jst} is a function of the matrix of prices of noise in all times and places:

$$q_{jst} = g_{jst}(\mathbf{P}) \quad (3)$$

where $\mathbf{P}$ is a matrix whose stth component is the marginal price of noise in subarea s in time interval t.

The efficient pricing rule is that the carrier operating any plane must pay the incremental noise costs that are caused by its plane. That is,

$$P_{st} = C_{st} \quad (4)$$

The practice of charging carriers the marginal costs of their noise will motivate them to economize efficiently on the production of noise. But it is also important to motivate individuals who are harmed by noise to report that harm accurately and to economize on the harm they experience. Economizing on harm can be achieved, for example, by insulating houses or, if people are particularly sensitive, by moving away from the airport area. Both the goal of motivating accurate reports and the goal of inducing efficient cost-reducing activity are accomplished by charging individuals for the net marginal costs to all others of the harms that they report. Such a net cost is the difference between the costs to carriers of reducing the amounts of noise they produce and the benefits to other individuals of the reduced amounts of noise.

What has been described so far is an example of an intricate but nevertheless standard application of the demand-revealing process. By utilizing the CIC, individuals can also be given entitlements to nonzero valuations of noise reduction. One reasonable way of doing this is to define those with entitlements as the possessors of land, with entitlements proportional to the assessed value of their land. (Landlords would have an incentive to take account of the concerns of tenants.) The entitlement to noise concern can then be defined as an entitlement to the median cost of noise per dollar of assessed value of land, in each interval of time. Each individual is then charged or credited for the concern he expresses by first computing the reduction in noise that results from the departure of his preferences from median preferences per dollar of assessed value of land. The cost of this reduction in noise to carriers (or benefit in the case of less-than-median concern) is computed, and from this the value of the noise reduction to other individuals is subtracted (or the cost of the increase in noise is subtracted from the benefit to carriers).

In the same way that individuals are given entitlements to noise concern, carriers could be given entitlements to produce noise. An initial level of entitlement could be determined as the level achieved when they have made the transition, for example, to all Stage 3 fleets. Departures from this status quo for further changes in the mix or level of operations would reconcile localized benefits with the costs to carriers expressed through a CIC process. Of course, except as a transitional accommodation, it can be argued that this would generally compromise the principle of equality and give carriers an unjustified privilege. The egalitarian application of CIC would be to give carriers entitlements to the amount of noise that the median person wishes to experience, which would be none.

REFERENCES

1. Hahn, R., and R. Kroszner. The Mismanagement of Air Transportation: A Supply-Side Analysis. *The Public Interest*, Vol. 95, Spring 1989, pp. 100–111.
2. Riker, W., and I. Sened. A Political Theory of the Origin of Property Rights: Airport Slots. *American Journal of Political Science*, Vol. 35, No. 4, Nov. 1991, pp. 951–969.
3. Morrison, S., and C. Winston. Enhancing the Performance of the Deregulated Air Transportation System. In *Brookings Papers on Economic Activity*, June 1989, pp. 61–123.
4. Vickrey, W. Counterspeculation, Auctions, and Competitive Sealed Tenders. *Journal of Finance*, Vol. 16, 1961, pp. 8–37.
5. Clarke, E. Multipart Pricing of Public Goods. *Public Choice*, Vol. 11, Fall 1971, pp. 17–33.
6. Tideman, T. N., and G. Tullock. A New and Superior Process for Making Social Choices. *Journal of Political Economy*, Vol. 84, Dec. 1976, pp. 1145–1159.
7. Dolan, R. Incentive Mechanisms for Priority Queuing Problems. *Bell Journal of Economics*, Vol. 10, No. 2, Fall 1979, pp. 421–436.
8. Economics, Inc. *The Allocation of Runway Slots by Auction.* Report No. FAA-AVP-3, Vol. I–III, FAA, April 1980.
9. Tideman, T. N. Liability Rules, Compulsory Exchange, and Compensated Incentive Compatibility: Toward Improved Management of Urban Externalities. In *COUPE Papers on Public Economics*, Vol. 3, 1979, pp. 105–134.
10. Hahn, R., and R. Noll. Tradable Permits. *Yale Journal of Regulation*, Vol. 1, 1983, pp. 63–91.
11. Hahn, R. Market Power and Transferable Property Rights. *Quarterly Journal of Economics*, Vol. 99, No. 4, Nov. 1984, pp. 753–766.

The paper represents the authors' views and not necessarily those institutions with which any of the authors are affiliated.

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

Freeway Congestion Pricing: Another Look

HERBERT S. LEVINSON

The rationale underlying congestion pricing is set forth. The level of congestion charges is based upon the freeway speed-flow curves contained in the 1985 *Highway Capacity Manual* and its 1994 update. Dollar values for the time costs incurred are developed on the basis of an annual household income of $33,000 and actual motorist studies using a time value of 15 cents per minute. The calculation results in congestion costs of about $0.35 to $0.87 per vehicle-kilometer ($0.61 to $1.40 per vehicle-mile) on the basis of the 1985 HCM speed-flow curves and about $0.04 to $0.06 per vehicle-kilometer ($0.06 to $0.09 per vehicle-mile) on the basis of the 1993 updated curves. Finally, some of the practical concerns associated with implementing freeway congestion pricing programs are discussed.

Growing congestion on urban transportation facilities has focused national efforts on congestion management—the management of both supply and demand to minimize congestion. Congestion pricing has received renewed attention as one means of rationalizing the use of congested roads by requiring motorists to pay for the costs they impose on others.

The concept of congestion pricing has been proposed by economists for more than three decades. Early studies by Vickery and Walters, among others, provided a conceptual and theoretical framework and attempted to quantify the levels of congestion charges through econometric analysis (*1–3*). More recent discussions, such as those set forth in *TR News* (*4*), describe the role, rationale, and limitations of congestion pricing.

The analysis and discussion that follows deals with one key aspect of congestion pricing: quantifying the actual congestion charges associated with freeway travel. The paper (*a*) presents the overall rationale underlying congestion pricing, (*b*) defines the basic concept of marginal (social) cost pricing, (*c*) quantifies the marginal costs on the basis of established speed-flow curves for freeways, and (*d*) sets forth emergent implications.

BACKGROUND AND RATIONALE

Congestion pricing has been used in several sectors of the economy for many years. Electric utility companies have set lower prices for off-peak use. Telephone calls are less expensive at night than during the day. Restaurants provide less expensive "early bird" specials.

There are also a limited number of examples in the transportation sector. The Washington Metro system has lower fares in off-peak periods. The Metro-North Commuter Rail system has lower off-peak round-trip fares (although the monthly commutation fares actually discount peak trips). Singapore has an automobile licensing scheme around its central area that involves charges for certain groups of road users during peak travel periods; its long-range plans call for an islandwide electronic road-pricing system.

40 Hemlock Road, New Haven, Conn. 06515.

Several public policy and economic reasons underly congestion pricing:

- Higher charges during peak travel periods can manage demand by reducing or spreading peaks or by shifting some travelers to other routes or modes.
- Peak travel demands require additional investments in transport capacity.
- Peak-hour travelers (especially automobile drivers) add to congestion and thereby impose congestion costs on the general traffic stream.
- Revenues obtained can be used to improve the transportation system.

MARGINAL COST PRICING

A key concern in congestion pricing is determining the appropriate level of congestion charges. People in vehicles on congested roads both incur and impose delays. Charging people for both of these counts would amount to double charging. Economic theory, therefore, calls for setting the congestion prices at levels that reflect the social marginal costs, that is, the marginal social costs imposed on others.

The various marginal costs concepts are shown in Figure 1 for a 1-km (0.62-mi) section of road. Volumes are shown on the X axis and costs (i.e., travel times) on the Y axis. At low volumes, up to V_0, there is no increase in travel costs (times) as volumes increase. Beyond this point, average costs increase with increasing volumes. Thus, for volumes 1 and 2, respectively, the average cost increases from C_0 to C_1 and C_2.

The marginal cost curve is designated by $M(V)$. This curve is always above the average cost curve when the average cost curve is increasing. This curve represents the increased cost per traveler resulting from an increase in the number of vehicles using the road, $\Delta C/\Delta V$. Thus, the addition of a Vth user imposes costs on all users, because all users travel at the reduced speed. The $M(V)$ curve exceeds the $C(V)$ curve by the amount of the increased costs imposed on other travelers by the Vth entrant. These differences are denoted by a_1, and a_2. The total marginal costs, MC (i.e., $a_1 + b_1$ or $a_2 + b_2$) are as follows:

$$MC = \frac{\Delta C_1}{\Delta V_1} = \frac{V_1C_1 - V_0C_0}{V_1 - V_0} \tag{1}$$

$$MC = \frac{\Delta C_2}{\Delta V_2} = \frac{V_2C_2 - V_1C_1}{V_2 - V_1} \tag{2}$$

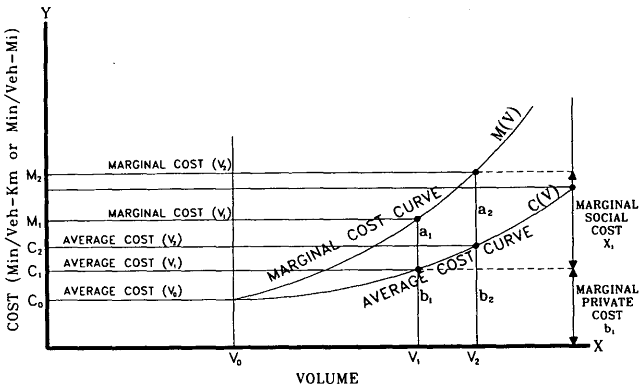


FIGURE 1 Average and marginal cost curves.

or, more generally,

$$MC = \frac{\Delta C_i}{\Delta V_i} = \frac{V_i C_i - V_{i-1}\, C_{i-1}}{V_i - V_{i-1}} \qquad (3)$$

where

V_{i-1} = initial volume,
V_i = final volume,
C_{i-1} = costs (or time) at V_{i-1}, and
C_i = costs (or time) at V_i.

The social or external marginal costs represent the costs imposed on other vehicles by the additional traffic. These costs are noted as X on Figure 1. They can be defined as follows:

$$MSC = X = \frac{\Delta t V_2}{\Delta V} = \frac{t_2 - t_1}{V_2 - V_1} \qquad (4)$$

A simple numerical example illustrates its application: If the initial volume is 1,500 vph and the final volume is 2,000 vpm, then the change in volume is = 500 vph; and if the initial travel time is 0.74 min/km (1.2 min/mi) and the final travel time is 1.24 min/km (2.0 min/mi), then the change in travel time is 0.50 min/km (0.8 min/mi). Then

$$X = \frac{(0.5)\ (2000)}{500} = 2.0 \text{ min/km } (3.2 \text{ min/mi})$$

QUANTIFYING MARGINAL COSTS

Marginal costs associated with freeway traffic congestion depend on how travel speeds decline as traffic flows increase. Such speed-flow relationships vary by facility and location. Generalized relationships, assuming ideal conditions, are set forth in the 1985 *Highway Capacity Manual* (HCM) (*5*, Table 3-1) and in an update (*6*, Table 3-1).

Accordingly, the marginal social costs associated with freeway travel were quantified on the basis of established speed-flow relationships, assuming a 1-km road section. The costs based on the 1985 HCM speed-flow data are shown in Table 1 (*5*). The costs based on the approved revisions to the HCM are shown in Table 2 (*6*).

TABLE 1 Marginal Social Costs for Basic Freeway Sections, 1985 HCM (*5*)

LOS	Vehicles per Lane per Hour (V)	ΔV	Minutes per Vehicle Kilometer (t)	Δt	Marginal Social Cost $\frac{V_2\ \Delta t}{\Delta V}$
112.6-KPH (70-MPH) Design Speed					
A	700		.62		
		400		.03	.08
B	1100		.65		
		450		.04	.14
C	1550		.69		
		300		.12	.74
D	1850		.81		
		150		.43	5.73
E	2000		1.24		
96.6-KPH (60-MPH) Design Speed					
B	1000		0.75		
		400		0.05	0.17
C	1400		0.80		
		300		0.09	0.53
D	1700		0.89		
		300		0.35	2.33
E	2000		1.24		
80.5-KPH (50-MPH) Design Speed					
C	1300		0.87		
		300		0.06	
D	1600		0.93		0.32
		300		0.40	
E	1900		1.33		2.53

The following should be kept in mind:

- Data are given for 112.6-, 96.5-, and 88.5/80.5-kph design or operating speeds. These correspond to 70-, 60-, and 55/50- mph design or operating speeds, respectively.
- A 1-km section of road is assumed.
- Costs are given in terms of travel time for a 1-km section of road.
- Entries are presented for each break in the levels of service.

The marginal social costs, expressed in minutes per vehicle-kilometer, increase as the number of vehicles per lane per hour increases. The increases reflect the shape of the speed-flow curves (expressed in minutes per kilometer). The highest marginal social costs generally are experienced as freeway volumes approach or exceed 2,000 vehicles per lane per hour as usually happens when the level of service (LOS) changes from D to E. This is the point at which congestion normally occurs, as defined by both traffic engineers and driver perceptions.

The boundary between LOS D and LOS E describes operation at capacity. Any disruption to the traffic stream, such as vehicles entering from a ramp or changing lanes, can cause other vehicles to give way to admit the vehicle. This can establish a disruption that propagates throughout the upstream traffic flow. The traffic stream has no ability to dissipate; even the most minor disruption or incident can be expected to produce a serious breakdown in

TABLE 2 Marginal Social Costs for Basic Freeway Sections, 1994 HCM Update (*6*)

LOS	Vehicles per Lane per Hour (V)	ΔV	Minutes per Vehicle Kilometer (t)	Δt	Marginal Social Cost $\frac{V\,\Delta t}{\Delta V}$
112.6-KPH (70-MPH) Free Flow Speed					
A	700		0.53		
		420		0.00	0.00
B	1120		0.53		
		524		0.02	0.06
C	1644		0.55		
		371		0.04	0.22
D	2015		0.59		
		185		0.03	0.36
E	2200		0.62		
96.6-KPH (60-MPH) Free Flow Speed					
A	600		0.62		
		360		0.00	0.00
B	960		0.62		
		480		0.00	0.00
C	1440		0.62		
		384		0.03	0.14
D	1824		0.65		
		476		0.05	0.23
E	2200		0.70		
88.5-KPH (55-MPH) Free Flow Speed					
A	550		0.68		
		330		0.00	0.00
B	880		0.68		
		440		0.00	0.00
C	1320		0.68		
		440		0.00	0.00
D	1760		0.68		
		440		0.07	0.35
E	2200		0.75		

traffic flow and extensive queuing. Maneuverability becomes extremely limited, and the level of physical and psychological comfort afforded the driver is extremely poor (*5*).

Accordingly, the marginal social costs associated with operation at LOS E were assumed to best reflect congestion costs. These costs are summarized in Table 3 for various free-flowing speeds and speed-flow relationships. They define the limits for setting congestion prices. In summary:

- Congestion costs, based on the 1985 speed-flow curves, range from 2.33 to 5.73 min per vehicle-kilometer (3.80 to 9.33 min per vehicle mile). [The 5.73 min per kilometer figure is based on a sharp decline in the speed-flow curve as occurs when volumes increase from 1,850 to 2,000 vph for 112.6-kph (70-mph) free-flow speeds.]
- The updated speed-flow curves are much flatter than those for 1985. The flattening reflects factors such as greater driver familiarity with freeway driving and improved freeway designs. Consequently, the resulting congestion costs are considerably less, approximating 0.4 min per vehicle-kilometer (0.6 min per vehicle mile).

TABLE 3 Comparative Marginal Social Costs for Freeways

	Maximum Flow Conditions, Speed-Flow Curve	
Free-Flowing Speed	1985	1993
112.6 KPH (70 MPH)	5.73	0.36
96.6 KPH (60 MPH)	2.33	0.23
80.5–88.5 KPH (50–55 MPH)	2.53	0.35

Note: Measurements given in minutes per vehicle kilometer.

The dollar costs of freeway congestion were estimated by assigning dollar values to the time costs incurred. The actual value of time depends upon the location involved and the proportion of commuter trips made for work purposes. Thus, there is wide variation in congestion costs from area to area.

The values of time were estimated by two basic methods: (*a*) allocating varying proportions of the national average household income to peak-hour travelers and (*b*) applying values of time actually used in toll road financial feasibility studies.

Median household income in 1990 reportedly was approximately $30,000. Assuming a 10 percent growth to 1993, results in an annual median household income of $33,000, about $.26 per minute. This value then was discounted to reflect nonwork travelers in the peak hour traffic (i.e., 25 to 50 percent).

Table 4 presents the 1993 values of time used in recent toll road studies. The final weighted value of time ranges from about $0.14 to $0.20 per minute.

The resulting dollar costs of congestion are set forth in Table 5. A time cost of about $0.15 per minute, a value commonly used in toll road studies, results in congestion costs of about $0.38 to $0.86 per vehicle-kilometer ($0.57 to $1.40 per vehicle-mile) on the basis of the 1985 speed-flow curves. The 1994 speed-flow curves yield costs of about $0.03 to $0.05 per vehicle-kilometer ($0.06 to $0.09 cents per vehicle-mile).

IMPLICATIONS

Congestion prices derived reflect assumed values of time, and, above all, the shape of the speed-flow curves. Moreover, the speed-flow curves represent idealized conditions that rarely exist on most urban and suburban freeways, especially those with design and operating problems.

Lane drops, grades, points of route convergence, and areas of heavy merging or weaving will tend to result in congested operations at volumes considerably less than those identified in the idealized relationships. For these reasons, many older freeways such as the Long Island Expressway and I-95 in Southwestern Connecticut have peak-hour speeds of less than 55 kph (about 35 mph). In such cases, congestion costs average 2.2 to 2.5 min per kilometer (3.5 to 4.0 min per mile), or about $0.37 per vehicle-kilometer ($0.60 per vehicle-mile).

Thus, in reality, the speed-flow curves will vary from freeway to freeway and along different sections of the same freeway, resulting in a range of facility-specific congestion prices. Therefore, the actual operating conditions of any freeway should be taken into account in establishing appropriate congestion prices.

TABLE 4 Value of Time Comparisons

Project/Location:	Sumner/Callahan Tunnel Boston, Massachusetts	S.R. 91 Riverside-Orange County California	Creek Turnpike Extension- Tulsa, Oklahoma	Conway Bypass, Horry County, South Carolina
Year of Study:	1992	1992-93	1993	1993
Median Household Income in Primary Area of Demand: (estimated in current 1993 dollars)	$34,662	$64,800	$27,558	$30,560
Unweighted Value of Time: (cents per minute)	25.1	(B)	23.8	25.0
Final Weighted Value of Time: (cents per minute) (A)	19.8	Peak: Single Occupant Vehicle - 20.0 Multiple Occupant Vehicle - 28.8	14.0	Seasonally Calculated: Winter - 15.0 Summer - 19.0
Assumptions Related To Final Weighted Value:	1. Average annual household worker hours assumed at 2,300 hours/year 2. Trip Purpose Distribution: a - To/from work = .750 b - During work = .150 c - Soc./Rec./Other = .100	1. Average Annual Household worker hours census derived 2,300 hours/year 2. Peak Hour Trip Purpose Distribution: a - To/from work = .700 b - Other work = .100 c - Non work = .200	1. Average Annual Household worker hours assumed at 2,080 hours/year (ASHTO Standard) 2. Trip Purpose Distribution: a - To/from work = .321 b - During work = .182 c - Soc./Rec./Other = .497	1. Average household worker assumed at 2,080 hours/year (ASHTO Standard) 2. Trip Purpose Distribution: Summer a - To/from work = .182 b - During work - Negligible c - Soc./Rec./Other = .818 Winter a - To/from work = .340 b - During Work = .164 c - Soc./Rec./Other = .496

SOURCE: Jeff Byer, Wilbur Smith Associates, New Haven, Connecticut

NOTES: (A) Final weighted value of time reflects trip purpose distribution and path choice factors. Path choice factors range from 0.4 to 0.8 for work, 1.0 during work and 0.4 for other purposes.

(B) Median Household Income not used. Method of calculation based on Stated Preference Survey Methodology.

TABLE 5 Estimated Marginal Social Costs of Freeway Congestion (Dollars per Vehicle Kilometer)

	$33,000 Annual Household Income				
	Percent of Hourly Wage Rate Applied			Toll Road Studies	
	50	75	100		
Dollars/Hour	7.94	11.90	15.87	9.00	10.20
Cents/Minute	13.22	19.84	26.45	15.00	17.00
Design/Operating Speed	Actual Costs				
1985 HCM					
112.6 KPH (70 MPH)	0.76	1.14	1.52	0.86	0.97
96.6 KPH (60 MPH)	0.31	0.46	0.62	0.35	0.40
80.5 KPH (50 MPH)	0.33	0.50	0.67	0.38	0.43
1994 HCM					
112.6 KPH (70 MPH)	0.05	0.07	0.10	0.05	0.06
96.6 KPH (60 MPH)	0.03	0.05	0.06	0.03	0.04
88.5 KPH (55 MPH)	0.05	0.07	0.09	0.05	0.06

Peak-hour speeds can be used as a basis for determining appropriate congestion prices:

- If peak-hour speeds exceed 70 to 80 kph (about 45 to 50 mph), the 1993 speed-flow curves can be used, resulting in a congestion cost of about $0.06 per vehicle-kilometer ($0.10 per vehicle-mile).
- If peak-hour speeds are under 65 kph (about 40 mph), the 1985 HCM speed-flow curves [for 96.6 and 80.5 kph (60 and 50 mph) operating conditions] can be used resulting in congestion costs of about $0.37 per vehicle-kilometer ($0.60 per vehicle-mile).

These are the congestion prices suggested by economic theory. However, because of the magnitude of the costs involved [daily charges of $1.00 to $6.00 per 16-km (10 mi) trip], downward adjustments may be needed in practice to minimize adverse impacts on the journey to work.

The practicality of implementing congestion pricing is another issue. Two important concerns must be addressed: (*a*) political acceptability and (*b*) a practical means of collecting tolls, that is, the technology issue. The first concern might be minimized by dedicating the collected revenues to highway transportation improvements. Use of improved automatic vehicle identification systems would probably address the technology issue.

Other key concerns that must be recognized include (*a*) possible shifts of traffic to city streets, thereby transferring problems; (*b*) encouragement of locational shifts in economic activity to the detriment of particular communities; and (*c*) clear definition of the extent and periods of operation. Finally, there is the equity issue —the cost of the journey to work would increase. This is particularly important in corridors where there is no viable public transportation alternative.

Consequently, other approaches may be more practical from a policy perspective, at least in the short run. These include (*a*) elimination of commuter discounts and possible institution of some form of congestion pricing on existing toll bridges, tunnels, and highways; (*b*) peak period parking surcharges; (*c*) land use controls that limit office developments away from transit corridors; and (*d*) ramp metering and related actions to reduce recurrent congestion. Finally, a program to eliminate key bottlenecks on urban freeways would further reduce the extent of congestion, and, in turn, the level of appropriate congestion charges.

ACKNOWLEDGMENT

The help of Jeff Byer of Wilbur Smith Associates, who furnished the value-of-time studies, is sincerely appreciated.

REFERENCES

1. Joint Committee on Metropolitan Washington Problems, *Statement on the Pricing of Urban Street Use*, 86th Congress, 1st sess., Nov. 11, 1959.
2. Fitch, L. C., et al. *Urban Transportation and Public Policy*. Chandler Publishing, New York, 1964.
3. Walters, A. The Theory and Measurement of Private and Social Cost of Highway Congestion. *Econometrics*, Vol. 29, No. 4, 1961, pp. 676 –699.
4. Point of View: Congestion Pricing. *TR News*, No. 167. TRB, National Research Council, Washington, D.C. July/Aug. 1993.
5. *Special Report 209*: *Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1985.
6. *Special Report 209*: *Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1994.
7. *Statistical Abstract of the United States—1992*. Bureau of the Census, U.S. Department of Commerce, 1992.

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

PART 2

Economic Development

Integration of Financial and Construction Risks: A Simulation Approach

ALI TOURAN AND PAUL J. BOLSTER

A general approach for quantifying construction and financial risks of a major capital transit project was developed. The methodology relies on Monte Carlo simulation. The technique was used to estimate the probability of time and cost overruns in construction projects. The value of integrating both financial and construction risks into such an analysis was emphasized because these risks are interrelated and, in many cases, cannot be separated. When the two sources of risk are examined in isolation, there is the possibility that some risks at the intersection may be omitted or double counted. With an integrated approach, however, the potential impact of project cost overruns can be assessed consistently and completely. The proposed methodology can be used by the planners and owners of capital transit projects to help them decide on the levels of funding needed to meet construction and design costs, given various uncertainties. Rather than providing a safety factor to guard against unfavorable scenarios, the simulation approach allows the planner to define a consistent confidence level in regard to achieving project objectives. The approach is illustrated with an example involving a hypothetical capital transit project.

Cost and schedule overruns are common in large construction projects. Thompson and Perry report that out of 1,778 projects financed by the World Bank between 1974 and 1988, 63 percent experienced cost overruns (*1*). In the United States, cost overruns have been common in large, complex projects such as power plants. Major capital transit projects are not an exception in this regard. For example, Pickrell studied 10 large transit projects and found that 9 out of 10 of these projects suffered from budget overruns. The amount of overrun ranged from 11 to 106 percent (*2*).

Several parameters are responsible for such huge overruns. Scope changes, optimistic scenarios yielding low estimates of costs and high estimates of benefits, estimation error, incomplete information about project objectives, faulty design, and delay of the construction start date are some of the more important factors contributing to overruns. Whereas some of these parameters are strictly technical in nature, others depend on the political atmosphere surrounding the decision makers and the condition of the economy. Although these political and social factors sometimes prove to be the most important, we do not deal with them in this paper. Instead, we focus on developing guidelines to incorporate technical difficulties and economic uncertainties into project budget estimating.

On the basis of research and discussion with FTA experts, we believe that project uncertainties can be divided into two main categories: design and construction and financial. Hence, risks associated with either of these broad categories are either design and construction risks or financial risks. Design and construction risks relate to the process of construction and to the parameters that affect the construction budget or schedule. Financial risks tend to affect the project at a more macro level; they may include unfavorable changes in interest rate, the state of the economy and its impact on project financing, or uncertainty regarding a project's cash flows. An example of a risk checklist tailored to transit projects can be found elsewhere (*3*).

The traditional approach in calculating the impact of cost uncertainties has been to add a contingency of between 5 and 15 percent of the estimated cost of the project to the budget (*2*). Most of the time, the calculation of this contingency is based on incomplete data or on the intuition of experts. In some cases, an overall contingency rate is calculated and added without due analysis of project details. The accuracy of cost estimates is directly related to the clarity of the project's scope and the amount of information available at the time of the estimate. Figure 1 shows this situation. Horizontal bars show the steps required in FTA planning and engineering phases and their average duration (*3*). Distributions are used to show that a lack of knowledge of project details in the early phases of a project, leads to larger uncertainty in the budget estimates (*1*). Therefore, it makes sense that, in the earlier phases of a project, the contingency sum tends to be larger than the contingency estimate in later phases. The larger contingency estimate is needed to provide the same level of confidence.

In more recent projects probabilistic risk analysis has been applied. In such cases, the expected range for each major parameter contributing to the project's uncertainty is input into a computer program. A Monte Carlo simulation analysis is conducted for several hundred to several thousand iterations, and a cumulative distribution function (CDF) is calculated for the total project cost. Using the CDF, the planner can choose a probability of cost overrun with which he or she is comfortable. In other words, the planner may choose a budget for which the probability of actual cost exceeding that level would only be, say, 20 percent (*4*).

INTERRELATIONSHIP BETWEEN FINANCIAL AND CONSTRUCTION RISKS

A contractor of a transit system is interested in construction risks. The owner or the sponsor is interested in financial risks, design and construction risks, and the combined effect of these risks on the project. Financial and construction risks are interrelated. If the construction phase suffers schedule overrun (quite common for large public projects), that adversely affects the project budget. An increase in project cost will influence the level and cost of financing. The owner develops a financial plan by considering a reasonable construction budget. If the budget's financial contingency is not sufficient, the owner faces the uncertainty of lining up additional financing at a potentially unfavorable rate and time.

A. Touran, Department of Civil Engineering, Northeastern University, 420 Snell Engineering Center, 360 Huntington Avenue, Boston, Mass. 02115. P. J. Bolster, College of Business, Northeastern University, 413 Hayden Hall, 360 Huntington Avenue, Boston, Mass. 02115.

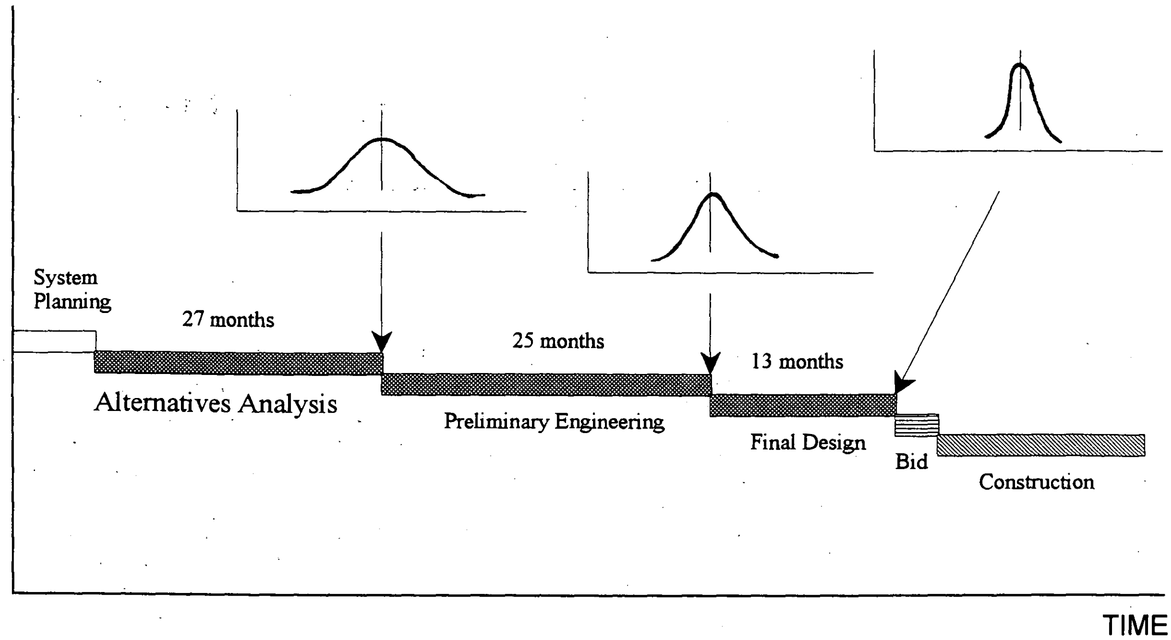


FIGURE 1 Change of project uncertainty with level of information.

Hence, an owner or sponsor of a project must consider the impact of design and construction risks on a project's financing picture as well as uncertainties related to the cost of project financing. Availability of financing will be directly influenced by expectations of future sources of revenues, interest rates, and financial markets. The authors emphasize an integrated approach to dealing with these risks and provide a simple approach for evaluating a project's financial plan and budget.

INTEGRATION OF FINANCIAL AND CONSTRUCTION RISKS

A better understanding of a project's overall risks can be gained by incorporating financial and construction risks into a single analysis. Whereas separate analyses of financial and construction risks can pinpoint specific problem areas, an integrated analysis shows the project's overall chance of success. The approach is especially useful from a project sponsor's or owner's point of view because it evaluates the adequacy of funding and the impact of a potential shortage of local funds and increases in construction costs on the project. The use of a probabilistic risk assessment approach in contingency calculation is advocated because it allows a planner to define a consistent confidence level in regard to achieving project objectives.

The Monte Carlo technique for arriving at the statistical distributions of objective functions was used. Whereas an analytical solution to the problem of calculating the cost distribution is attractive, the complexity of its derivation under general conditions remains a major obstacle. Widespread use of the Monte Carlo technique in similar applications has increased users' familiarity with the method. Also, a former obstacle to performing Monte Carlo analysis, lack of access to expensive hardware and software, has been removed. Several powerful software packages, designed as add-ins to popular microcomputer spreadsheets, have facilitated the use of Monte Carlo, especially in cost estimating and financial applications—areas in which spreadsheets have long been used. In the following example, we have used @RISK by Palisade, which works with a Lotus 1-2-3 spreadsheet and allows the user to generate random numbers from a host of different statistical distributions (*5*). A detailed discussion of the benefits and the shortcomings of the Monte Carlo approach, along with the typical cost models used in construction, is presented elsewhere (*4*).

HYPOTHETICAL EXAMPLE

To illustrate the probabilistic approach to evaluating project financial and construction risks a hypothetical transit project was used. It was assumed that feasibility studies and alternatives analysis phases were complete and that a sponsor had decided to go forward with construction of a fixed guideway transit project consisting of 19.3 km (12 mi) of elevated tracks and related stations and equipment (*3*).

Construction Costs

Total project cost is modeled as the sum of several cost items, some of them random variables. Obviously, if one wants to consider cost variations in every small cost component that goes into a detailed estimate, the approach would be impractical. Because of this, only cost items that have a significant impact on the total project uncertainty are modeled as random variables. In a large project, most of the total cost variation is due to the variability of a limited number of components.

Monte Carlo simulation can be used for modeling cost items with a high potential for variability as random variables and for generating random numbers according to their assumed cost distributions. These items are added up, the fixed costs are added to these, and the total project cost is computed. The procedure is repeated at least several hundred times, and every time a value for the total cost is computed. A histogram and, later, a CDF can be constructed for the total cost. The CDF can then be used to estimate the probability of completing a project at or below a certain budget and to arrive at a reasonable contingency sum for the project.

The process of identifying major risk items in a transit project, choosing a proper statistical distribution for modeling the data, and developing an appropriate cost function for the total costs is the subject of another research project by the authors (*3*). There is considerable literature on the choice of distribution for various cost components. It appears that most cost variables may be modeled using a unimodal, unsymmetrical distribution, preferably with confined positive limits (*6,7*). Another mathematical complexity involves modeling of correlations that exist between cost variables. It has been shown that many construction cost items are correlated (*7*). Correlations between economic factors, such as interest rates and inflation, have been established. An analyst cannot disregard correlations, because in general they tend to affect the variance of the total cost and this, in many cases, underestimates the risk of cost overrun. Generating correlated random numbers is possible, but the analyst has to be aware of mathematical constraints. Developing joint density functions is generally difficult, and if data are not normally distributed, it is not always feasible. Many Monte Carlo simulation software packages use rank correlations. This allows generation of correlated random variables, even when marginal distributions are not normal (*8*). It should be noted that each of these issues deserves extensive discussion in its own right. This paper emphasizes the interaction and integration of financial and construction risks.

Assume that, in the present example, the project's budget (or target estimate), including escalation factors, is estimated at $1,205 million. Further assume that the project's critical cost components with potential for large variation have been identified, their distributions and parameters specified, and a Monte Carlo simulation conducted to compute the total cost. A CDF for the project was developed and is presented in Figure 2. It shows that there is almost a 50 percent chance that the project cost will exceed the target estimate of $1,205 million. If the owner is not comfortable with that confidence level and prefers one of 80 percent, for example, then the budget required would be approximately $1,300 million. In other words, a $95 million contingency reserve is needed to assure, with a level of confidence of 80 percent, that the project will not suffer cost overrun.

The project spans a 5-year period, and the overall cost has been distributed over these years using the project schedule (see spreadsheet provided in Table 1). It was assumed that each of the annual budgets follows a lognormal distribution and that for every year a contingency budget would be calculated, such that the probability of cost overrun would be kept to less than one-third (33 percent). The total project contingency is $97.5 million (8.1 percent of target estimate), providing a confidence level of 81.7 percent against cost overrun. In other words, there is one chance in six that a cost overrun will occur if the total budget considered is $1,205 million + $97.5 million, or $1,302.5 million.

Project Financing

The project would be financed through three primary sources: federal grants, excise tax revenues, and proceeds from bond issues. The amount derived from federal sources is assumed to be certain and is distributed as indicated in Table 1. It is assumed that FTA will provide $765 million distributed over a period of 5 years, or about 60 percent of the total construction estimate plus contingency. The ratio appears to be reasonable given current circumstances. The serial bonds issued are revenue bonds; $490 million is planned to be raised by issuing a series of them. The sales tax revenues are assumed to service the repayment of principal and interest of the bonds issued. These revenues are assumed to grow at a mean annual rate of 2.5 percent. Growth rates are drawn from a truncated normal distribution with a mean of 2.5 percent, standard deviation of 2.5 percent between −2.5 percent and 7.5 percent. The growth rate reflects assumptions regarding the income of the underlying regional economy, population trends, and expansion of the regional job base.

Interest Rates

Interest rates are modeled as the inflation rate plus a time premium that increases with the bond's maturity. The inflation rate itself is assumed to follow a truncated normal distribution with a mean of 3.25 percent and a standard deviation of 3.25 percent, truncated between 0 and 6.5 percent (*9*). Mean interest rates for the serial bond issues used in this example are given in Table 2. Another

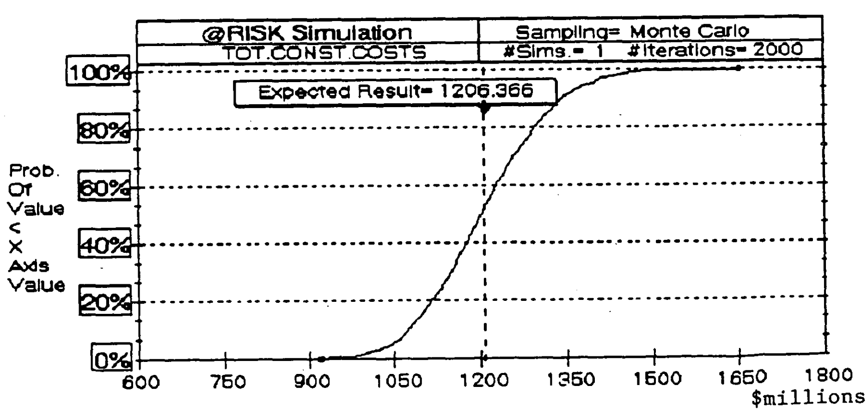


FIGURE 2 CDF for the total construction costs.

TABLE 1 Capital Financial Plan

YEAR	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	TOTAL
FUNDING:												
FTA	120.00	175.00	175.00	175.00	120.00							765.00
Sales tax	45.00	47.62	50.40	53.34	56.45	59.74	63.23	66.91	70.81	74.94	79.31	667.77
Interest Income	3.63	4.74	5.66	7.84	8.86	9.92	9.18	9.21	8.01	5.38	3.00	75.44
Bond Proceeds	100.00		200.00		190.00							490.00
TOTAL REVENUES	268.63	227.36	431.07	236.18	375.31	69.66	72.40	76.13	78.83	80.33	82.32	1998.21
COSTS:												
System Contract	90.00	325.00	230.00	255.00	225.00	80.00						1205.00
Contingency	2.50	16.00	23.00	26.00	22.00	8.00						97.50
Bonds Debt Service	5.26	5.26	15.43	15.43	20.05	40.05	49.10	97.60	113.80	169.18	105.50	636.65
TOTAL COSTS	97.76	346.26	268.43	296.43	267.05	128.05	49.10	97.60	113.80	169.18	105.50	
NET SURPLUS/DEFICIT	170.87	-118.90	162.64	-60.24	108.26	-58.39	23.30	-21.47	-34.97	-88.85	-23.18	
Beginning Cash Balance	0.00	170.87	51.97	216.61	154.36	262.62	204.24	227.54	206.06	171.09	82.25	
Additions to cash	170.87	-118.90	162.64	-60.24	108.26	-58.39	23.30	-21.47	-34.97	-88.85	-23.18	
Ending Cash Balance	170.87	51.97	214.61	154.36	262.62	204.24	227.54	206.06	171.09	82.25	59.06	
Debt Coverage Ratio	9.24	9.95	3.63	3.97	3.26	1.74	1.47	0.78	0.69	0.47	0.78	

TABLE 2 Debt Service Schedule for Project Bonds

Bond Series	Bond Amount	Bond series	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	
	($millions)													
1(a)	20.00							20.00						
		4.75%	0.95	0.95	0.95	0.95	0.95	0.95						
1(b)	30.00								30.00					
		5.00%	1.50	1.50	1.50	1.50	1.50	1.50	1.50					
1(c)	50.00												50.00	
		5.63%	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	2.81	
2(a)	80.00									80.00				
		4.75%			3.80	3.80	3.80	3.80	3.80	3.80				
2(b)	70.00											70.00		
		5.25%			3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68		
2(c)	50.00												50.00	
		5.38%			2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	2.69	
3(a)	100.00										100.00			
		4.63%					4.63	4.63	4.63	4.63	4.63			
3(b)	90.00											90.00		
		4.75%					4.28	4.28	4.28	4.28	4.28	4.28		Totals
		Principal						20.00	30.00	80.00	100.00	160.00	100.00	490.00
Total Issued	490.00	Interest	5.26	5.26	15.43	15.43	20.05	20.07	19.12	17.62	13.81	9.18	5.50	146.65
		Debt Service	5.26	5.26	15.43	15.43	20.05	40.05	49.10	97.60	113.80	169.18	105.50	636.65

relevant interest rate is the rate the owner can achieve from the surplus cash balances generated during the project's life. This rate is modeled as the inflation rate plus 1.0 percent.

Timing of Bond Issues

In this example, three serial bond issues are provided in 1995, 1997, and 1999. The issues are timed to provide positive cash flows during the construction phase of the project. Bonds are issued according to the schedule in Table 2 and have a total face value of $490 million. Interest rates for the bond issues are tied to their issue dates and to variations in inflation rates. The model assumes an upward-sloping yield curve, the prevailing structure in 11 of the past 16 years and one described by current interest rates (*10*). This means that longer-term bonds carry a higher interest rate than shorter-term bonds. However, the model is sufficiently flexible to allow an alternative yield curve definition (flat or inverted, for example). This flexibility is important, because the owner may choose to alter the timing of market financing on the basis of the prevailing term structure of interest rates. Tax revenues are not large enough to provide sufficient financing during construction. After construction, bond principal and interest are offset by sales tax revenues. The cash flows that result from this financing strategy are robust in early years and sufficient in later years. In practice, more complex bond issues would be used to minimize the surplus cash balances in early years. However, the simplified financing structure in this model captures the essence of cash-flow management reasonably well.

Simulation Analysis

Several items in Table 1 have potential for chance variations. Construction expenditures for every year are modeled according to lognormal distributions, as discussed earlier. Sales tax is a function of growth rate and inflation; interest income and debt service are modeled as functions of interest rate, which itself is a function of inflation. Because the inflation and growth rates are modeled probabilistically, sales tax, interest income, and debt service become probabilistic variables too.

A Monte Carlo simulation analysis was conducted on the spreadsheet. This was accomplished by generating random numbers according to specified probabilistic models for 2,000 iterations. The number of iterations chosen was sufficiently large to allow the simulation results to converge to their theoretical values.

Analysis of Results

There are several important issues that have to be studied in Table 1. First, planners have to make sure that the construction budget is sufficient and the contingency reserve is large enough to meet unexpected cost variations. Second, the ending cash balances should be positive throughout the spreadsheet. A negative value in any year means a cash shortfall that can create financial hardships and complications, either in the construction process or in meeting financial obligations to lenders. Simulation helps to assess the probability of having negative cash balances at any time in the project.

Figure 3 shows a distribution summary graph for the ending cash balances. Table 3 provides summary statistics for this parameter. The probability of having a negative cash balance increases in the later years. This is expected because of the modeling approach used in the example. For every iteration, a random value for inflation and growth rate is generated for the first year. In subsequent years, the values generated for the previous year will serve as the mean of the normal distribution used to model growth rate and inflation rate. In other words, the value of the growth and inflation rates will depend on their values in the previous year and will show a variance around the previous year's value. Tax revenues, interest income, and bond proceeds are updated in every iteration on the basis of the generated growth and inflation rates. More complicated models based on probabilistic treatment of population trend, local income, and so forth also can be conceived.

As indicated in Table 3, there is a 33.6 percent chance that the project will sustain a cash shortfall in 2005. This probability is 26.4 percent for 2004. For earlier years, the probability is significantly lower and never exceeds 9.4 percent. The planners could respond to this problem in several ways, depending on their tolerance for risk. One option is to issue more bonds. That option should be considered only in conjunction with the local economy's ability to repay the debt. An alternative is to increase the sales tax rate. Either option could be pursued before the project is undertaken or as funds are needed.

The growth of sales tax and its variations is another item of interest. Because sales tax is the major funding source for servicing the debt in this example, the project's sensitivity to varia-

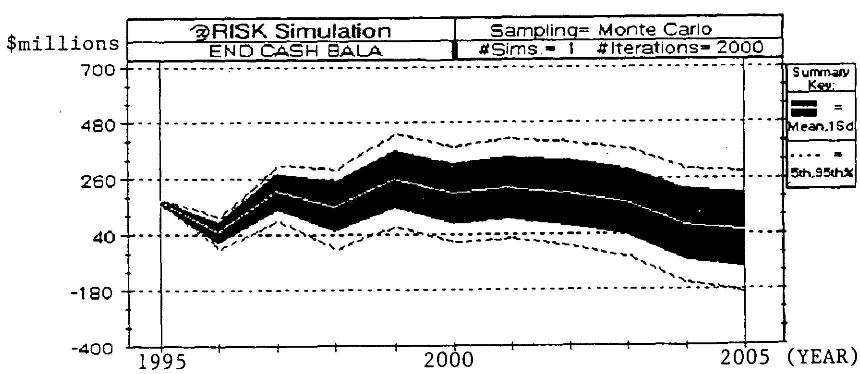


FIGURE 3 Distribution for ending cash balances, 1995 to 2005.

TABLE 3 Ending Cash Balances Statistics for Various Years

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Result of 2,000 Iterations											
Maximum Result	191.31	154.87	427.85	394.77	600.67	577.40	632.56	645.53	637.45	574.94	572.75
Minimum Result	150.27	-84.15	-117.76	-213.04	-147.05	-208.12	-197.37	-240.76	-296.60	-402.99	-443.93
Chance of Positive Result	100.0%	90.6%	99.6%	94.2%	98.7%	95.7%	96.8%	94.9%	90.8%	73.6%	66.4%
Chance of Negative Result	0.0%	9.4%	0.4%	5.8%	1.4%	4.3%	3.2%	5.1%	9.2%	26.4%	33.6%
Standard Deviation	6.28	38.20	67.05	93.69	109.01	114.08	118.00	122.90	128.64	135.13	142.74

NOTE: All figures except percentages are $ millions.

tions in cash inflows from this source should be studied. That can be done two ways. One method involves changing the values of growth rate and studying the impact on the project's viability. Another method involves a sensitivity analysis that can be conducted while assuming a probabilistic model for the growth rate. The second model, though a bit more complex, is more realistic because it provides a measure of uncertainty for every scenario studied.

SUMMARY

Cost and schedule overruns are common in large construction projects. In this paper, the process of measuring and analyzing construction and financial risks in construction were described. Probabilistic methods for estimating project contingency and for modeling financial factors affecting project budgets were reviewed. Emphasis was placed on the integration of financial and construction risks and on analysis of the impact of their interaction on a project's successful completion. The methodology used was based on Monte Carlo simulation. A hypothetical project was used to illustrate the modeling concepts and the process of risk quantification. It was shown that one can quantify the impact of variations in construction costs and financial fluctuations on the ending cash balances of project funds. Also, problem areas in the financial plan were pinpointed and the extent of their impact was quantified.

ACKNOWLEDGMENTS

The research described in this paper was sponsored by FTA, whose contribution is gratefully acknowledged. The authors would also like to thank Edward L. Thomas, Marina Drancsak, and Elizabeth Solomon of FTA for their support.

REFERENCES

1. Thompson, P., and J. Perry. *Engineering Construction Risks.* Thomas Telford, London, England, 1992.
2. Pickrell, D. H. *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs.* Report DOT-T-91-04. Urban Mass Transportation Administration, U.S. Department of Transportation, 1990.
3. Touran, A., P. J. Bolster, and S. W. Thayer. *Risk Assessment in Fixed Guideway Construction.* Report FTA/MA-26-0022-94-1. FTA, U.S. Department of Transportation, 1994.
4. Touran, A. Risk Modeling and Measurement in Construction. *Civil Engineering Practice*, Vol. 7, No. 1, Spring 1992, pp. 29–46.
5. *@RISK: Risk Analysis and Modeling User's Guide.* Palisade, Inc., Newfield, N.Y., 1992.
6. Spooner, J. E. Probabilistic Estimating. *Journal of Construction Division*, ASCE, Vol. 100, No. CO1, March 1974, pp. 65–77.
7. Touran, A., and E. P. Wiser. Monte Carlo Technique with Correlated Random Variables. *Journal of Construction Engineering and Management*, ASCE, Vol. 118, No. 2, June 1992, pp. 285–272.
8. Iman, R. L., and W. J. Conover. A Distribution-Free Approach To Inducing Rank Correlation Among Input Variables. *Communications on Statistics: Simulation and Computing*, Vol. 11, No. 3, 1982, pp. 311–334.
9. Bodie, Z., A. Kane, and A. J. Marcus. *Investments.* Irwin, Inc., Boston, Mass., 1992.
10. Sears, R., and G. Trennepohl. *Investment Management.* Dryden Press, Inc., Fort Worth, Tex., 1993.

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

PART 3

Economic Analysis

Cost-Benefit Analysis of a Rural Advanced Traveler Information System

KAZI ULLAH, WENDE A. O'NEILL, AND A. BRUCE BISHOP

A life-cycle cost model is developed to evaluate a proposed rural Advanced Traveler Information System (ATIS). Costs used in this model include capital investment (in equipment and facilities as well as installation), operation, and maintenance costs. A cost-benefit analysis is reported. System benefits are equated to potential reduction in the number of accidents that occur while the ATIS is in place. Sensitivity analysis is performed on both its costs and benefits. The approach is useful for evaluating Intelligent Vehicle Highway System applications as well as for exploring trade-offs among proposed technologies for the application.

The Advanced Traveler Information System (ATIS) is one component of the Intelligent Vehicle Highway System (IVHS) applications currently sweeping the nation. The IVHS program's goal is to improve the efficiency and safety of surface transportation (*1*). ATISs are information-based applications designed to provide roadway users with accurate and timely information on travel conditions. A major assumption underlying these systems is that this information affects a person's decisions as to where, when, and how to travel. The purpose of ATIS is to mitigate traffic congestion problems by either (*a*) informing an en route driver of traffic incidents ahead and suggesting alternative routes or (*b*) allowing pretrip travel information to prompt someone to delay trip starts or to choose alternative routes or modes of transportation. ATIS applications have been made primarily in urban areas, where congestion and traffic delays are major cost factors. Rural applications of ATIS, on the other hand, focus on single corridors of travel (usually a section of Interstate) that have high accident rates or other operational problems.

Design of ATIS incorporates several technologies that (*a*) collect data on current traffic conditions, (*b*) interpret the information, and (*c*) communicate it to the public. The most common technologies for these applications include video, satellite, radio, and computers. These hardware components are combined with specialized software into an integrated traveler information system. Most rural systems are designed to provide information to a motorist on weather, road, or traffic conditions downstream from his or her location, using visibility sensors, pavement sensors, and variable message signs (*2*).

PROBLEM STATEMENT

This paper focuses on evaluating proposed technologies and application of a rural ATIS. The prototype system differs from other rural applications of ATIS in the following ways:

K. Ullah and W. A. O'Neill, Department of Civil and Environmental Engineering, Utah State University, Logan, Utah 84322-4110. A. B. Bishop, College of Engineering, Utah State University, Logan, Utah 84322-4110.

- The system is designed for a regional application, incorporating a network of rural roads.
- Pretrip information is important.
- Improved safety is the primary concern; however, an additional benefit associated with improved statewide maintenance management is realized.
- Roadway environment, as well as weather conditions, influences design parameters for the system.

This system differs from other rural weather information systems in that real-time data are collected for the entire region and along each road traveled by maintenance crews. Data from point source systems are less reliable in mountainous areas because conditions change as frequently as the roadside environment. Research conducted in Wyoming for the I-80 corridor indicates that weather and road information from point source systems rarely coincides with motorists' perceptions of the conditions (*3*).

Rural canyon roads in Utah have high traffic volumes in the winter because they provide access to several ski resorts and recreational areas used for Nordic skiing, snowmobiling, sledding, hunting, and ice fishing. Average annual daily traffic (AADT) for two of these canyons is shown in Figures 1 and 2. Traffic accidents during the winter months are a major problem in rural Utah. The magnitude of winter weather accidents is described in detail later in this paper. Not only is there a heavy cost associated with loss of life and property damage, but also many hours are wasted by stranded motorists waiting for tow trucks to help them back onto the road.

An ATIS is proposed that monitors roadway conditions and uses dynamic mapping techniques to communicate the information to the public. The potential market for this system is as follows:

- Tourists who stay in the urban areas and drive to different resorts during their vacation,
- Resort workers who commute from the city to the resorts because they cannot afford the high cost of living in the resort communities,
- Private shuttle services from the airport to resorts,
- Rural school bus operators, and
- Anyone using the rural road system for work, recreational, or sustenance-related reasons.

The proposed system basically operates as follows:

- Maintenance vehicles involved with plowing and salting activities are equipped with vehicle-tracking devices.
- Location information is sent to a central traffic control center where it is processed and integrated with other information (data on fog, wind, avalanches, accidents, etc.).

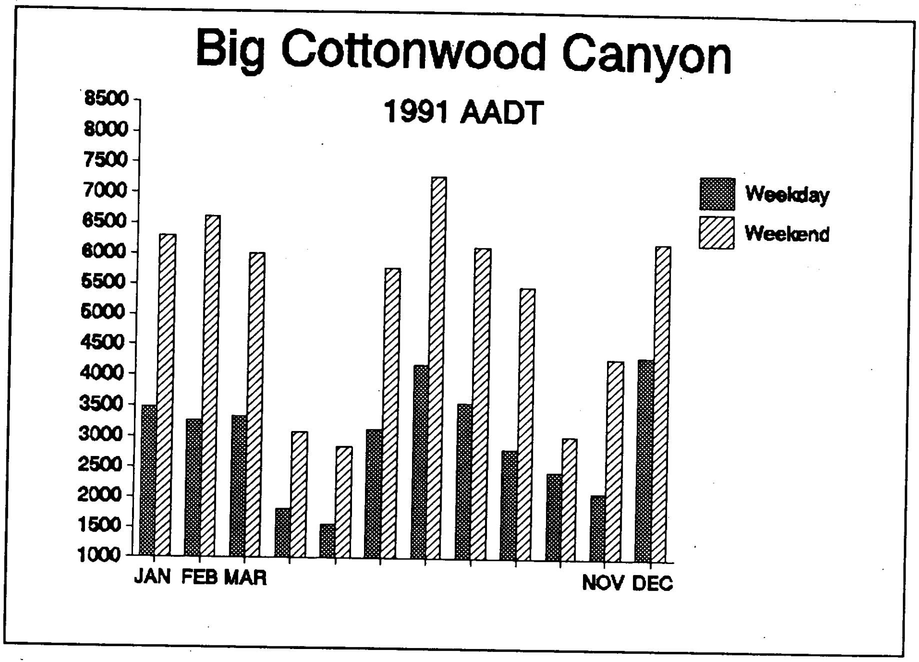


FIGURE 1 Traffic volume on a rural canyon road: Big Cottonwood Canyon, 1991 AADT.

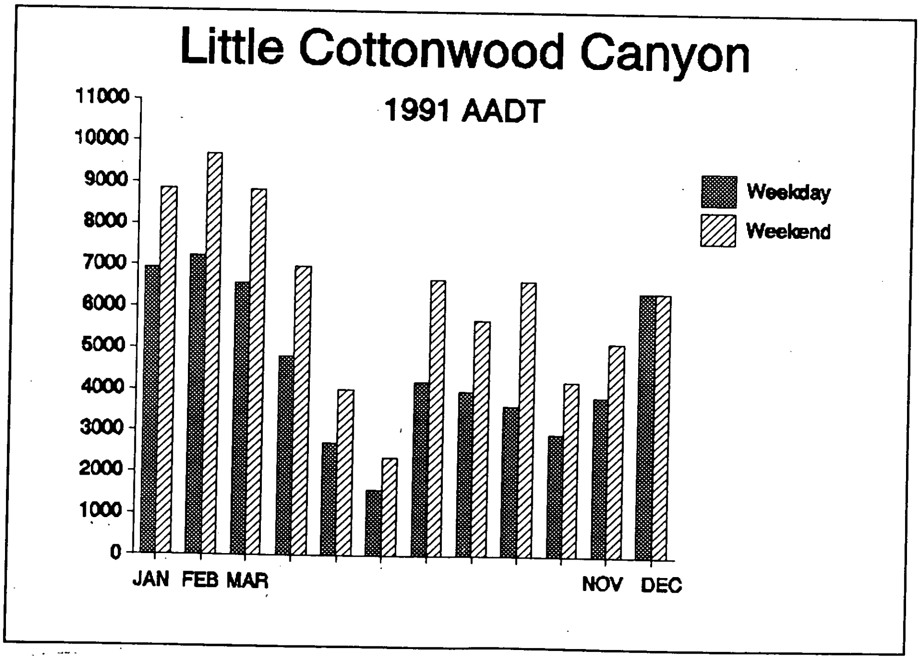


FIGURE 2 Traffic volume on a rural canyon road: Little Cottonwood Canyon, 1991 ADDT.

- Roadway condition information is communicated to the public via television, telephone, radio, and interactive display terminals placed at strategic locations (resort lobbies, hotel lobbies, car rental agencies, and employment and shopping centers).

A substantial financial investment is required to implement this system. In addition, a long-term financial commitment is required to maintain and operate the system. A decision must be made on whether the potential benefits of this system are worth the cost. One way to answer this question is described below.

COST MODEL

The exact cost of the proposed system is difficult to determine. However, a cost estimate can be derived on the basis of a few simple assumptions. The cost of high-technology equipment and software changes from year to year. As the number of high-technology applications and users grows, instrument costs should continue to decrease in the future. The dollar value of future equipment and services is not the same as it is in the present. To account for this behavior in our cost estimation model, future year costs are discounted to present value equivalents, called present worth of cost (PWOC). A discount rate of 7 percent is used in calculating PWOC. Instrument life is assigned a value of 10 years. Finally, the proposed ATIS is expected to operate during the winter months, from November to March.

PWOC is calculated from the following equation (*4–6*):

$$\text{PWOC} = I + \sum_{j=1}^{n} A\, PW_j - T\, PW_n \qquad (1)$$

where

I = initial cost = $(\Sigma_{k=1}^{8} IC_k)$, and IC_k is the initial cost of item k;
A = annual cost = $(\Sigma_{k=1}^{5} a_k)$, and a_k is the annual cost of item k;
T = salvage value; and
PW_j = present worth factor for year $j = 1/[(1 + r)^j]$, and r is the discount rate (7 percent) and j varies from 1 to 10 years.

Cost analysis of the proposed ATIS considers both global positioning system (GPS) and radio technology for tracking locations of maintenance vehicles.

Nonrecurring Costs

The first step in estimating the cost of the proposed system is to determine the initial investment or nonrecurring (one-time) costs. All costs associated with installation of equipment and preparation for its operation are included as a part of this investment. One-time costs include such items as system design, programming, system testing, equipment acquisition, and training. The costs may occur at any time during the life cycle of the system. For the sake of simplicity, an assumption is made that nonrecurring costs occur only during the first year of the cycle. Table 1 gives initial cost estimates for this model. The following assumptions are made in deriving these figures.

TABLE 1 Nonrecurring Costs

COST ITEM	NOTATION	AMOUNT
Construction/Renovation of Roadway Management Center (RMC)	IC_1	$ 12,000
Hardware/software for location finding	IC_2	
GPS		$100,800
Radio		$ 84,000
RMC Hardware	IC_3	$ 8,000
Remote site hardware (60 sites)	IC_4	$192,000
RMC data transmission modem	IC_5	$ 200
Remote site modems	IC_6	$ 12,000
Display software at remote sites	IC_7	$ 60,000
Interactive hardware at remote sites	IC_8	$ 20,100

Cost of Roadway Management Center

A centralized roadway management center (RMC) will be used to receive, collect, and monitor information sent from maintenance vehicles. This information will be integrated with accident and weather information, then dispatched to remote sites for use by the public. This center will also produce maintenance data for monitoring and tracking maintenance activities. Initial cost for this center includes construction or renovation fees. In this study, construction of a one-room addition to the existing regional maintenance headquarters is assumed. Cost depends on the size of the extra room as well as internal plant requirements (temperature control, additional floor support for mainframes/equipment, etc.). Construction cost is estimated to be approximately $12,000 for this purpose.

Cost of Location Finding (GPS/Radio) Instrumentation

This is one of the largest costs for the proposed system. Two technologies have been investigated, namely GPS and radio communication networks. GPS equipment, with mobile satellite communication for tracking, costs about $1,200.00 for each maintenance vehicle. It is assumed that these systems provide one-way communication only, since the vehicles are already equipped with two-way radio communication.

A radio-based tracking system requires small, in-vehicle mobile data terminals or PCs interfaced with a vehicle's radio modem. The cost of this equipment is $1,000 for each maintenance vehicle. This cost is based on the assumption that a sufficient radio network has been established by private industry in the region. Companies currently marketing this technology are focusing on large urban market areas. Even though this technology seems less expensive to implement, a delay of several years can be expected before it is available in rural areas.

Eighty-four state maintenance vehicles provide service to the study area. Total cost of in-vehicle location-finding equipment is calculated by multiplying the number of vehicles by the cost per vehicle.

Hardware and Software Costs

To send data files from the RMC to remote sites for use by the public, the following equipment is needed:

- IBM, Intergraph 6000, or equivalent work station with a c400 processor in the RMC (the initial cost is estimated as $8,000);
- One IBM 486 PC having a memory of at least 30 megabytes at each remote site for graphic display of road conditions;
- One 9,600- or 14,400-band modem at the RMC and one at each other location, each costing $200; and
- Micro-station 32 software and some custom C programs to show the paths of maintenance vehicles using locational data received in the RMC. Location data are placed in a graphic control file. Once sent to remote computers, it is ready to be displayed. Software costs should not exceed $1,000 per site.

There are more than 60 hotels and motels in and around Salt Lake City where visitors may stay during winter months. If PCs are used and 50 of them and 10 information centers (resorts, malls, employment centers, etc.) are considered for display of roadway conditions during snowy weather, at least 60 PCs would be required for this study. (It is not possible to sell this system as a service to these remote sites because information is being gathered by the state and is therefore public.) Cost is calculated per unit site. Each 486 PC costs about $3,200, including a monitor.

Other Equipment Costs

Video converters may be used to display roadway conditions on a large screen instead of a small computer screen in each location. Different types of equipment can be used for this purpose. One approach is to use a projection monitor connected to the computer and a projection screen. For a color display, the cost of this equipment is $2,800. Another approach uses a videoconverter hooked to the computer and a color television to show the map display on a large TV screen. The cost of this equipment is $399, excluding the TV. So the total cost will be $2,100 including a large television, which is less expensive than the previous approach mentioned. Another method that provides an interactive system uses touch-screen equipment instead of a keyboard. A touch screen is affixed to the computer monitor and then plugged into the computer. The equipment is considered in the present study. Touch-screen interactive capabilities add approximately $335 to the cost of each remote-site monitor.

Recurring Costs

The second step in the cost-estimation process is to determine recurring costs (annual costs), those associated with maintenance and operation of the system. Data communication costs, personnel services, space occupancy, supplies, and utilities are examples of recurring costs. Table 2 contains information on recurring costs used in this model. The following assumptions are made in deriving these figures.

Operating and Maintenance Cost of RMC

An assumption is that the RMC will operate with two staff persons. Both people are paid a gross salary of $3,000 per month in the first year. A 5 percent increase in the salary is assumed for subsequent years.

TABLE 2 Recurring Costs

COST ITEM	NOTATION	AMOUNT
Roadway Management Center Staffing (first year, 5% annual increase)	a_1	$ 72,000
Spatial database maintenance	a_2	$ 2,000
Satellite use fee Radio access fee	a_3	$ 50,400 $ 10,080
Telephone fee for remote sites	a_4	$2,304
Maintenance cost at remote sites	a_5	$ 60,000

Purchase Cost of Road Network Data Base

A graphic-based system is proposed that uses maps to convey road-condition information as well as accident and weather information. This spatial data base must contain roads in the region to accommodate interactive queries by users on optimal routes. An updated road network data base may be purchased from a private organization each year due to construction of new roads or closing of existing roads. The Utah Department of Transportation (UDOT) itself may be able to supply these data, so base map update costs could be insignificant. However, it is assumed that $2,000 is required each year to purchase these data.

Access Fees for Vehicle-Tracking Equipment

In the current market, an access fee of $10 per vehicle per month is estimated for a radio-based system. If more than 200 position fixes per vehicle per month are required, a higher cost will be incurred. An extra cost of $50 per vehicle per month may be necessary when using satellites for data communication. This cost is based on estimates from freight companies using this technology as well as vendor price quotes.

Telephone Fee

Data files are sent through existing telephone lines. The service fee is comparable to a monthly telephone bill. Fees depend on time of day (highest during peak hour, lowest during off-peak hour) and length of time needed to send data files. In the proposed study, maintenance vehicles are assumed to work early in the morning in most cases. But this varies depending on the weather. A plowing period may not be more than 2 hr, because it is Utah's policy to clear snow from roads within 2 hr. However, in case of continuous snow, this period may be much longer.

In the present study, a snow removal period is taken as 8 hr a day. There are 152 days from November through March. A 10-year weather history from the Utah Climate Center indicates that it snows more than $^1/_2$ in. in the study area for an average of 24 days during this period. Maps at remote sites are updated every 15 min. In an 8-hr period, data transmission occurs 32 * 60 times. Assuming 15 sec per site to send information, it will take 480 min per day. Using a cost of $0.20 per minute, the total cost per day is $96; that is, 2,304 per year.

Maintenance Cost at Remote Sites

Each facility where current roadway conditions are shown has potential maintenance needs, related to hardware failure or vandalism, for example. The maintenance cost is estimated to be $1,000 per year.

Additional Model Assumptions

Salvage or terminal value is defined as the expected value of hardware and software at the end of its useful life, which is 10 years in this study. This value is denoted as T in Equation 1. To determine the salvage or terminal value, the most important criterion is whether the item will be sold, reused, or continue in operation for another cycle. If the asset is sold or reused, the value is the actual market value less the cost of sale or redistribution. If an asset is to be scrapped, the only value is the scrap value less costs of dismantling and selling. For the sake of simplicity, in this study all hardware and software is considered to be dismantled after 10 years. Hence, salvage value of the proposed ATIS is considered zero after 10 years, as a conservative approach.

During the 10-year life, new technology is expected to become available that can be incorporated into the system. The ATIS described here may become obsolete by that time; however, with the addition of some new features the basic principal will remain the same.

In doing a cost analysis of both GPS and radio technology for the next 10 years (from 1993 to 2002), all cost estimates for each year were expressed in current dollar value. A discount factor of 7 percent is applied to convert future dollar value into present value. The value of this factor varies from project to project and is based on good judgment. Studies have shown that a 6 to 10 percent rate is practical in most cases (*6,7*).

Results of the Cost Analysis

PWOC for ATIS using GPS and radio-based technology is given in Table 3. The number of remote sites receiving this service is assumed to be 60 in this analysis. Radio technology will cost slightly less than GPS technology over a 10-year period. However, the cost figures do not take into account the cost associated with delayed implementation of the system using radio technology. GPS design may be implemented almost immediately, whereas a sufficient radio network must be installed before implementing a radio-based tracking system.

TABLE 3 Cost Analysis of ATIS over 10 Years

	Cost of GPS-based System	Cost of Radio-based System
Year 1	579,590	525,108
Year 2	166,219	131,002
Year 3	158,430	125,517
Year 4	151,094	120,334
Year 5	144,180	115,433
Year 6	137,664	110,798
Year 7	131,519	106,410
Year 8	125,723	102,256
Year 9	120,253	98,321
Year 10	115,090	94,593
TOTAL	$1,829,761	$1,529,770

BENEFITS ANALYSIS

IVHS is supposed to provide various benefits, such as reductions in congestion, pollution, energy consumption, and accidents, as well as improved mobility. An additional benefit of ATIS is improved data for winter maintenance management; however, to follow a conservative approach, only benefits due to reductions in accidents are considered.

Accident data for different roads leading to ski resorts are used in the analysis. Only accidents that occurred during winter months or snow and icy, wet conditions are selected from the data base. A shortcoming of the data is that they did not provide information on delays of stranded motorists (waiting for tow trucks) stuck in heavy snow during bad weather. In such incidents, there is typically no damage to vehicles or drivers, although lost time and towing expenses can result. Historic trend information is used to estimate the number of future accidents that would occur in the study area if the proposed technology is not implemented.

Accurately estimating the benefits of this technology is difficult because of drivers' potential responses.

1. Some drivers will not use information supplied by the system. Many drivers currently do not call designated telephone numbers for up-to-date road and travel information. Some people will choose not to activate in-vehicle devices or observe information kiosks in hotels or employment centers. Accident potential for drivers ignoring travel information is the same after implementation of the system as it is before.

2. Some drivers will ignore system information received, because of the importance of their trip or their lack of confidence in the system or technology. Technology breakdowns may lead people to disregard available information in the future. Secondly, if inaccurate or outdated information is presented, drivers may come to distrust all such information in the future. Such drivers will then be classified in Category 1. Accident potential for drivers in Category 2 will not change.

3. Finally, some drivers use the information provided by the system. Studies indicate that informed drivers travel more cautiously and are more likely to cancel trips (*3,8*). In this case, the following three conditions may result (*a*) Drivers will proceed cautiously or avoid hazardous routes, reducing accident potential. (*b*) Drivers will delay trips; these drivers' chance of becoming involved in an accident is reduced, but it is difficult to estimate the potential accident reduction. (*c*) Drivers will cancel their trips. In such cases, there will be no accidents. However, cancellation of trips may result in a loss of revenue at the intended destination.

To better understand driver acceptance of ATIS, surveys on driver response to ATIS should be conducted in hotels and at other appropriate locations. Such surveys were not conducted in the present study because of resource limitations.

The prototype system is evaluated by assuming different percentages of accident reduction and calculating corrresponding benefits. These benefits include reductions in the number of fatal accidents, personal injuries, and property damage only (PDO) accidents on roads within the study area. Percentage of accident reduction in relation to the cost-effectiveness of the system is evaluated later in this paper.

Analysis of Data

Accident data for the 5 months, November through March, during a 5-year period from 1987 to 1991, were analyzed. During this period, only accidents occurring in snow were considered in the analysis in order to relate the number of accidents with the effectiveness of snow-removal activities.

Despite the availability of data from UDOT, there was a problem with data quality and completeness. Accident data files must be integrated with traffic and road inventory data for the analysis. No data were available for three roads in the study area for 1987. Unfortunately, AADT data on some roads were not consistent at all.

Other research using accident data bases indicated that other problems with the data could occur. For instance, not all accidents are reported, particularly in urban areas where PDO accidents often are not reported. In general, the more severe an accident, the more likely it is that the accident will be reported. Also a multivehicle accident is more likely to be reported than a single-vehicle accident of equal severity. Accidents are probably less likely to be reported during bad weather than during good weather (*9*).

The interrelationship of various accident causal factors makes data analysis and interpretation difficult. Usually, the number of road accidents should have some relation to traffic volume. Several studies show that this relation is more complex than a simple proportion (*10*). In this study area, AADT is analyzed separately both for rural and urban roads for the last 5 years, from 1987 to 1991. Each road studied is found to have several sections with different AADT. The percentage change in AADT for each section is calculated. Weighted change in AADT is then calculated by considering the change in different sections and corresponding lengths. The percentage change in AADT for the last 4 years is determined separately both for rural and urban roads. No general pattern is identified from these calculations. This may be because of bad data or the uncertain behavior of travelers along those road segments. Because of the lack of trend in AADT change, only the number of accidents is analyzed for the purpose of prediction of accidents.

Accidents on rural and urban roads are analyzed separately because the manner of occurrence of traffic accidents varies greatly in these areas. Accidents can be classified into various categories depending on severity, cause of accident, type of collision, for example. Accidents have been classified into five types based on severity for an FHWA study (*11*):

1. PDO: those accidents in which only damage to the vehicle or roadside property results;
2. Minor injury: those injuries that require minor treatment, such as treatment for abrasion, pain, nausea, or hysteria;
3. Medium injury: those which may include a lump on head, minor lacerations, bruises, or crushed finger, for example;
4. Serious injury: any injury other than fatal injury that prevents a person from walking, driving, or performing normal activities; and
5. Fatal injury: any injury that results in death within 30 days.

A variety of methods exist to quantify accidents, such as accident rate per mile, accident based on population, accident rate based on vehicle-miles of travel, number of accidents based on severity. In the present case, analysis is done according to number of various types of accidents based on severity. Table 4 summarizes the number of PDO, minor injury, medium, serious, and fatal injury accidents on rural urban roads during snow or snowstorms during winter months, for the past 5 years. Whereas there is no uniform pattern for the number of accidents on separate road segments, an increased pattern is observed for total accidents within the last 5 years.

On average, a 10 percent increase in accidents occurred in the past 5 years on rural roads. The percentage is used to estimate any increase in future accidents on rural roads. On average, a 31 percent increase in accidents on urban roads occurred over the past 5 years. In this study, an average, conservative increase of 10 percent is applied to predict future urban accidents.

Table 5 gives percentages of different types of accidents with respect to total accidents for rural and urban roads. A one-way analysis of variance test was conducted to determine whether the percentages of various accident types among different years were similar or not. A conclusion from this test is that the percentage of accidents by type does not vary significantly from year to year. On average, 72.84 percent of accidents are PDO, 12.64 percent are minor, 7.5 percent are medium, 6.75 percent are serious, and 0.28 percent are fatal injury accidents for rural areas. For urban roads in the study area, it is assumed that 71.64 percent of accidents are PDO, 15.33 percent minor, 7.55 percent medium, 5.24 percent serious and 0.24 percent are fatal injury accidents.

Assuming a 10 percent annual increase in the number of accidents in the study area, total accidents for the next 10-year period may be calculated (Table 6).

Analysis of Safety Benefits

Safety benefits vary from year to year throughout the service life because of variation in the dollar value assigned to different types of accidents. Benefits are converted to present value using a discount rate for comparison purposes. Present Worth of Benefit (PWOB) is calculated as follows (*4–6*):

$$\text{PWOB} = \sum_{n=1}^{10} B_n PW_n \qquad (2)$$

where

B_n = benefit varying from year to year,
PW_n = present worth factor = $1/(1 + r)^n$, and
r = 7 percent.

Safety benefit B_n is estimated from the following formula (*4*):

$$B_n = N_f \sum_{i=1}^{5} P_i S_i C_i \qquad (3)$$

where

N_f = total number of expected future accidents,
P_i = percentage of accidents of type i,

TABLE 4 Total Accidents During Winter Months and Under Snowy Conditions Within Study Area

	1987	1988	1989	1990	1991
Rural Roads in Study Area					
Property Damage Only	307	452	328	356	401
Minor Accidents	47	83	46	60	84
Medium Accidents	54	40	23	32	42
Serious Accidents	25	31	33	39	42
Fatal Accidents	0	2	2	3	0
TOTAL	433	608	432	490	569
Urban Roads in Study Area					
Property Damage Only	336	860	551	571	622
Minor Accidents	86	118	130	137	158
Medium Accidents	31	55	60	76	88
Serious Accidents	13	64	46	38	54
Fatal Accidents	0	3	1	0	6
TOTAL	466	1100	788	822	928

S_i = expected reduction in type i accidents, and
C_i = average cost of type i accidents.

Now the problem boils down to estimating the expected reduction in PDO, minor, medium, serious and fatal injury accidents. Until the system is installed and used for an extended period of time, a reasonable estimate of accident reduction is difficult to make. The expected reduction may depend on the various drivers' reactions as mentioned before. It may vary for different types of accidents and result in greater reduction in fatal accidents than PDO accidents. To simplify the estimate, therefore, accident reduction is considered to be uniform for all types of accidents.

TABLE 5 Percentages of Accidents by Type and Year on Rural and Urban Roads in the Study Area

	1987	1988	1989	1990	1991
Rural Roads					
Percent Property Damage Only	70.9	74.3	75.9	72.6	70.5
Percent Minor	10.9	13.7	10.7	12.2	14.8
Percent Medium	12.5	6.6	5.3	6.3	7.4
Percent Serious	5.8	5.1	7.6	8.2	7.4
Percent Fatal	0	0.3	0.5	0.6	0
Urban Roads					
Percent Property Damage Only	72.1	78.2	69.9	69.5	67.0
Percent Minor	18.5	10.7	16.5	16.7	17.0
Percent Medium	6.7	5.0	7.6	9.3	9.5
Percent Serious	2.8	5.8	5.8	4.6	5.8
Percent Fatal	0	0.3	0.1	0	0.7

NOTE: Numbers are rounded to the nearest tenth.

TABLE 6 Estimated Number of Accidents During Winter Months and Under Snowy Conditions on Rural and Urban Roads

	'92	'93	'94	'95	'96	'97	'98	'99	2000	2001	2002
Rural	626	683	740	797	854	910	967	1024	1081	1138	1195
Urban	1021	1114	1206	1299	1392	1485	1578	1670	1763	1856	1949

To further complicate the analysis, methods used to determine costs for different accident types are not yet standardized. The average cost of the various types of accidents varies according to different organizations. Cost estimates are composed of various components, such as wage loss, medical expenses, insurance administration costs, and motor-vehicle repair or replacement costs. According to the National Safety Council (*12*), estimated costs for different types of accidents in 1992 are as follows:

- Fatal injury, $450,000;
- Serious injury, $42,400;
- Medium injury, $10,700;
- Minor injury, $3,300; and
- PDO accident, $1,100.

These costs are used in the benefit analysis. Given the assumptions and data described above, the safety benefit is calculated such that $S_i = S_j$ for i and j. Safety benefits and corresponding PWOB for both rural and urban roads are calculated using several values for percent of accident reduction, namely 1 percent, 2 percent, and 3 percent, as indicated in Table 7.

Another type of benefit achieved by this system is improved data for budgeting and planning maintenance operations. The system will help the maintenance division keep track of road mileage plowed or salted and other pertinent information. Improved decision making may result in more efficient planning routes for snowplow crews as well as in better inventory practices. The system should help achieve lower costs for maintenance work and provide improved service to the public. The system may also be used, during other seasons, to track the maintenance crews during their routine work. It is very difficult to quantify this type of benefit, and it is not considered in the study.

SENSITIVITY ANALYSIS

Net present value (NPV) and benefit/cost ratio are used to evaluate the proposed systems. NPV and B/C ratio are calculated as follows:

$$\text{NPV} = \text{PWOB} - \text{PWOC}$$

$$\text{B/C ratio} = \text{PWOB}/\text{PWOC}$$

TABLE 7 Safety Benefits for Various Accident Reduction Values

PWOB	S_i = 1%	S_i = 2%	S_i = 3%	S_i = 4%
Rural	$391,453	$ 782,907	$1,174,360	$1,565,813
Urban	$561,615	$1,123,231	$1,684,646	$2,246,461
Total	$953,068	$1,906,138	$2,859,206	$3,812,275

Table 8 gives the value of these statistics for the proposed system at different accident reduction rates. NPV is positive and the B/C ratio is greater than one when the accident reduction rate is 2 percent or more. The break-even period for different accident reduction rates is indicated. With a 2 percent reduction in accidents, the GPS-based ATIS would pay itself off in 9 years. The amount decreases significantly with a 3 percent accident reduction rate.

Costs are based on estimates of different equipment costs, fees, and so forth and often represent best judgment. To compensate for uncertainty, sensitivity analysis was done to evaluate the impact of changes in data.

The variables considered in the sensitivity analysis are (*a*) staff salary, (*b*) GPS instrument cost, (*c*) telephone fee for data transmission, and (*d*) the discount factor. The relative sensitivity of these variables for ±20 percent variation is in Figures 3 and 4 for 2 percent and 3 percent accident reduction, respectively. Both figures indicate that staff salary is the most sensitive factor. Other factors are relatively insensitive.

CONCLUSIONS

A prototype ATIS for a rural regional application is proposed to improve winter weather safety. The system provides pretrip information to travelers during snowy weather in the winter. Information on current road conditions allows drivers to make their own decision about their trip or alternate routes. Other information, such as wind speed or pavement temperature, can be sent to the RMC depending on the technology used in the future. However, this is not considered in this study.

In the study, both GPS and radio systems are found to be cost-effective when the accident reduction is as low as 2 percent for

TABLE 8 Cost/benefit Statistics for Proposed ATIS

System	NPV	B/C Ratio	Break even point
1% Accident Reduction			
GPS	-876,693	0.52	N.A.
Radio	-576,701	0.62	N.A.
2% Accident Reduction			
GPS	76,376	1.04	8.85 yr
Radio	376,368	1.24	5.61 yr
3% Accident Reduction			
GPS	1,029,444	1.56	3.26 yr
Radio	1,329,436	1.86	2.48 yr

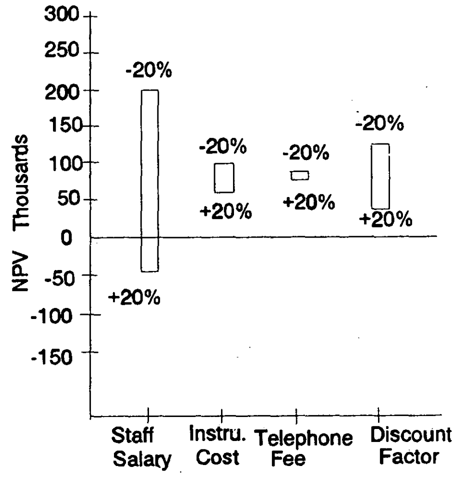


FIGURE 3 Sensitivity analysis at a 2 percent accident reduction rate.

all types of accidents. Sensitivity analysis of the cost variables indicates that the NPV is still positive with more expensive hardware than what was used in the study.

Only benefits related to accident reduction are considered here. However, there are other nonmonetary benefits of this system that are difficult to quantify. The proposed ATIS has a great impact on planning and budgeting maintenance operations, as mentioned before. It will save time for estimating maintenance cost each year

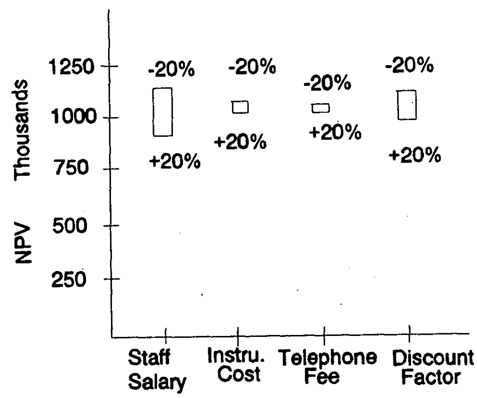


FIGURE 4 Sensitivity analysis at a 3 percent accident reduction rate.

and provide improved data for effective forecasting and decision making. The system would be more cost-effective than what was shown here.

A survey on travelers' behavior should be conducted to understand their perspective if this type of system is implemented. This survey would help to estimate the percentage of travelers using system information to change their route or delay trips. Such behaviors may offer better data with which to estimate the percentage reduction in accidents.

A better method for predicting future accidents is needed. Other factors such as population change, vehicle registration, employment activity, road surface condition, and law enforcement in the surrounding area of each road also need to be considered to better estimate the number of accidents in the future.

ACKNOWLEDGMENT

Funding for this research was received from the Mountain Plains Consortium of University Transportation Centers.

REFERENCES

1. Euler, G. W. Intelligent Vehicle/Highway Systems: Definitions and Applications. *ITE Journal*, Nov. 1990, pp. 17–22.
2. Yamin, M. H. Analysis of the Integrated Weather Monitoring System in Indianapolis, Indiana. Presented at 1991 North American Snow Conference, Montreal, Canada, April 1991.
3. French, K. A., and E. M. Wilson. Evaluating the Potential of Remote Sensing Rural Roads and Travel Conditions. Presented at the 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., 1993.
4. *NCHRP report 162*, 1975.
5. *Cost-Benefit Analysis Handbook*, Department of Veterans Affairs, Aug. 1989.
6. Abelson, P. *Cost Benefit Analysis and Environmental Problems*, Saxon House, Fairborough, England, 1979.
7. Sassone, P. G., and W. A. Schaffer. *Cost-Benefit Analysis: A Handbook*. Academic Press, New York, 1978.
8. Russam, K., and D. J. Jeffery. Route Guidance and Driver Information Systems; An Overview. *Electronics and Power*, April 1986, pp. 295–299.
9. Brinkman, C. P. Toward Improved Highway Safety Analysis. *Public Roads*, Vol. 50, No. 2, Sept. 1986, pp. 49–53.
10. Frantzeskakis, J. M. Accident Analysis on Two Non-Controlled Access National Highways in Greece. *ITE Journal*, Feb. 1983, pp. 26–32.
11. *The Costs of Highway Crashes*. Report DOT-RD-91-055, FHWA, U.S. Department of Transportation, 1991.
12. National Safety Council, 1992.

Publication of this paper sponsored by Committee on Transportation Economics.

Applying the Cashing Out Approach to Congestion Pricing

PATRICK DECORLA-SOUZA

Congestion pricing is extremely difficult, perhaps impossible, for the public to accept in the form in which it is currently being proposed, for a variety of reasons. First, there are too many people who perceive themselves as big losers under congestion pricing. Second, congestion pricing is viewed by some as "just another tax increase" that will lead to bigger government. Third, others perceive congestion pricing as having a disproportionate impact on low-income groups, taking a larger share of their incomes. Interestingly, all of these objections to congestion pricing may be overcome and pricing made more acceptable by taking the cue from recent developments in parking pricing. Pricing of commuter parking has been made more acceptable through policies that "cash out" employer-paid parking subsidies (i.e., if an employer offers a parking subsidy to an employee, the employer is required to give the employee the option to receive, in lieu of the parking subsidy, the fair market value of the parking subsidy in cash). The "cashing out" concept could be extended to peak period road pricing, either to an entire regional system or to a specific corridor or bridge location. It would work as follows: Peak period tolls would be imposed on free roads, and all peak period commuters would be provided with a credit or a "smart card," which they could use to pay tolls during the peak periods. The value of the credit or the amount encoded on the smart card would be equal to the peak period toll each commuter would be required to pay each month after congestion pricing is implemented. Credits or smart cards could be exchanged for transit farecards or cash, thereby providing an inducement to solo drivers to carpool and pocket the cash or to take transit. Noncommuters, who would not be eligible for "free" credits or smart cards, would provide sufficient funds through their toll payments to fund all cash payments. Discussed are various implementation aspects of such a policy and its probable impacts on travel demand. It is demonstrated that sufficient funds would be received from noncommuters to pay those who want to "cash out" their credits. Fairness issues are discussed. Finally, a method to test the concept on a limited basis on an existing congested toll facility is suggested.

Recently, interest in congestion pricing has increased in the United States (*1*). The interest stems from three recent developments: (*a*) the recognition that, because of funding and environmental limitations, urban areas will not be able to "build their way out of congestion"; (*b*) the emphasis on reductions in vehicular travel demand, environmental considerations, and economic efficiency in recent federal legislation, such as the Clean Air Act Amendments of 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA); and (*c*) electronic toll collection (ETC) technology, which eliminates the need for toll booths and allows tolls to be collected without the vehicle having to stop or slow down.

In spite of the increase in interest, however, only one urban area (San Francisco) is proceeding to implement congestion pricing on roadways or bridges. In November 1992, FHWA solicited congestion pricing projects for funding with 100 percent federal funds under ISTEA's Congestion Pricing Pilot Program, but only one project met the eligibility criteria that FHWA had set. Most of the projects submitted for consideration did not propose to increase the price of travel on congested mixed-flow traffic lanes or bridges, and therefore little or no change in motorist behavior could be expected. The only acceptable project was one that involved increasing tolls on the San Francisco Bay Bridge during peak periods.

FHWA, 400 Seventh Street, S.W., HEP-22, Washington, D.C. 20590.

WHY CONGESTION PRICING IS CURRENTLY UNACCEPTABLE

It is not surprising that only one project involving true congestion pricing was proposed. This is because, in spite of its many economic and environmental benefits, congestion pricing is extremely difficult and perhaps impossible for the public to accept in the form in which it is currently being proposed, for a variety of reasons.

First, there are too many people who perceive themselves as big losers were congestion pricing to go into effect. The very few who perceive themselves as winners do not see themselves gaining much. Only a few high-income travelers and commercial road users value the time savings from reduced congestion somewhat more than the toll price. Second, congestion pricing is viewed by many as "just another tax increase" that will lead to bigger government. Third, many are against congestion pricing because it is perceived to have a disproportionate impact on low-income groups, taking a larger share of their incomes. Finally, it is difficult to tell the commuting public that they will be charged for something that they currently get free, especially when they have already made long-term decisions, such as where to live, on the basis of the current price structure for transportation.

MODEL TO FOLLOW IN OVERCOMING OBJECTIONS

Interestingly, the preceding objections may be overcome and congestion pricing made more palatable by taking the cue from recent developments in parking pricing. Currently, well over 90 percent of U.S. commuters receive free or subsidized parking from their employers. Pricing of commuter parking has been made more palatable through an ingenious idea developed by Donald C. Shoup of the University of California at Los Angeles (*2*). Shoup proposed a policy to cash out employer-paid parking subsidies. The policy was passed into law by California recently. Under the law, if an employer offers a parking subsidy to an employee, the employer is required to give the employee the option to receive, in lieu of the parking subsidy, the fair market value of the parking subsidy in cash. (Recently, the Clinton Administration has proposed revision to the U.S. tax laws to encourage employers to provide cash out options to their employees, as part of its plan to reduce emission of greenhouse gases and combat global warming.)

There are no major losers from the cash out policy. The employer does not spend any more than before, but simply pays the employee who chooses not to drive the amount previously paid the parking operator. Employees who continue to drive do not pay any more than they did before.

However, there are many who gain: (*a*) employees who decide to switch to a carpool get extra cash in their pockets; (*b*) employees who switch to transit have all or part of their fares subsidized; and (*c*) the government gets additional tax dollars, because cash payments to employees are taxable as income. The benefits to those who switch are progressive, that is, the poor who take cash get a larger percentage increase in their incomes.

CASHING OUT FREE ROADS

Shoup's idea can be extended to peak-period road pricing, through a concept that may be called "cashing out free roads." One study (*3*) has shown that future public highway infrastructure costs to serve peak-period travelers range from 12.5 to 19.8 cents per peak period vehicle mile of travel (VMT), whereas user taxes and tolls average only 2.0 cents per VMT. Thus the subsidy to peak period travelers amounts to 10 to 18 cents per VMT, or $2.00 to $3.60 for a 20-mi round-trip during peak periods. This subsidy, like parking subsidies, could theoretically be cashed out. In other words, funding proposed to provide infrastructure for free peak-period travel could theoretically be offered in cash to would-be peak-period drivers as an inducement to shift to other modes, thus reducing the need for additional infrastructure. However, this would be difficult if not impossible to do in practice for a variety of reasons. For example, the funding necessary to provide for new highway infrastructure needs may actually be nonexistent.

The paper discusses a way in which the concept could be made more practical through a modification in the source of funds for cash payments and a change in criteria for determining who is eligible for the cash-out option. The concept could be applied either to the entire regional system or to a specific corridor or bridge location. Implementation on a regional basis is discussed first. Later, implementation on a single facility or set of facilities during the testing phase is discussed.

The concept would work as follows: Peak period tolls would be imposed on all free roads, and tolls on existing toll roads would be raised during peak periods. If tolls are equated to the subsidy to peak period travelers on the basis of long-run highway infrastructure costs (*3*), they may be more acceptable to the public than congestion-based tolls. All peak-period commuters would be provided with a credit or a "smart card" to pay the tolls. The smart card would be similar to transit farecards currently provided for travel on rail transit systems. The value of the credit or the amount encoded on the smart card would be equal to the peak-period toll (or toll increment, on existing toll roads) that each commuter would be required to pay each month after congestion pricing is implemented in the urban area. Information on the employee's home and work location, obtained through the employer, would be used to calculate the total toll value to be credited to the employee or encoded on the smart card. (A similar system is currently being used by the U.S. Department of Transportation to distribute transit farecards to its Washington headquarters employees.)

Credits or smart cards could be exchanged for cash. Noncommuter traffic, which would not be eligible for free credits or smart cards, would provide sufficient funds through their toll payments to fund all cash payments. Cash could be obtained from ATM-like machines at rail stations or carpool park-and-ride lots. Alternatively, unused credits could be periodically rebated to the employee like income tax refunds. This would be a significant monetary incentive for singe-occupant vehicle (SOV) drivers to share rides and for high-occupancy vehicle (HOV-2) commuters to increase the number of riders in the carpool. If adequate transit service is available, some SOV drivers or HOV users might be induced to switch to transit.

Note that there are two conceptual differences between congestion pricing and the parking cash-out approach. First, market prices already exist in the case of parking (at least in downtown locations), whereas the imposition of tolls creates a new market. Second, noncommuters will lose, whereas in the parking cash-out case few if any will lose.

IMPACTS OF CASHING OUT FREE ROADS

What would be the impact of such a policy? Shoup's case study analysis (*2*) has shown that when drivers pay for parking, the number of cars driving to work per 100 employees drops from 72 to 53—a drop of about 26 percent. Many economists believe that there is no difference between the travel demand impacts of cashing out policies and simply raising prices, because drivers are put in a position of having to forego cash to continue their previous travel behavior. Responses to California's cashing out policy should provide data to make comparisons between the two approaches.

Assuming that peak-period tolls for a commuter's trip would roughly equal the parking cost differential in Shoup's analysis (equivalent to an average toll of about 15 cents per mile), we could estimate that a regionwide system of congestion pricing would result in a similar drop of about 26 percent in the number of commuter vehicles driven during peak periods. Larger reductions could occur if commuters have the flexibility to shift their time of travel to off-peak periods.

Recent data from the 1990 Nationwide Personal Transportation Study (*4*) suggest that commute trips represent about half of the total number of VMT during peak periods. The reduction in peak-period VMT that could be expected from the policy would thus be 26 percent of the 50 percent commuter VMT, or about 13 percent.

PAYING FOR IMPLEMENTATION COSTS

Would there be sufficient funds from paying noncommuters to pay those who want to cash out their credits? First, let us estimate the amount of credits that will be cashed out. On the basis of estimates discussed in the previous section, only about 26 percent of former drivers would cash out their credits. However, previously existing nondriving commuters (e.g., carpool passengers, transit passengers, and bicycle commuters) are potential drivers. They would also be eligible for credits or smart cards, which they would cash in. On the basis of current carpooling, transit, and other mode usage for commuter trips (5), the pool of potential drivers represents an additional 14 percent of base commuter drivers. The total number of commuters cashing in their credits or smart cards would thus represent about 40 percent (i.e., 26 percent plus 14 percent) of commuter drivers. Assuming that nondrivers and drivers have roughly the same trip lengths (in miles), the amount to be paid out would represent about 40 percent of the 50 percent of base peak-period VMT represented by commuter travel, or about 20 percent of base peak-period VMT.

The remaining 50 percent noncommuter share of base peak-period VMT represents nonwork travel, commercial travel, travel through the urban area by outsiders, and travel into or out of the urban area by visitors. These travelers would pay tolls that would provide the funds to pay those commuters who want to cash out their credits or smart cards. Elasticity of highway travel relative to price generally ranges from 0.1 to 0.4. In other words, a doubling of price (i.e., a 100 percent increase) would reduce highway travel by 10 percent to 40 percent. Assuming an extreme case drop of about 40 percent in noncommuter VMT as a result of tolls, about 30 percent of base peak-period VMT (i.e., 60 percent of the 50 percent base noncommuter VMT) would pay tolls. The funds collected from the 30 percent of base VMT who were paying tolls would be more than enough to pay for the 20 percent of base VMT who would use the cash out option. In other words, even under a very pessimistic rate of revenue recovery from noncommuters, there would be a balance of funds equivalent to tolls from 10 percent of base peak-period VMT.

The balance of funds (i.e., funds from the 10 percent of base peak period VMT) could be used, in part, to pay for toll transaction costs (e.g., ETC, enforcement, administration, and billing). Toll transaction costs perhaps could be reduced by instituting tolls only in the afternoon peak periods at twice the rate that would otherwise be charged. Such a strategy should not change the impact on commuter behavior and will maximize the impacts on noncommuter travel, which represents a much larger share of afternoon than of morning peak-period travel. Toll transaction costs can be expected to be about 5 percent of toll charges when ETC is implemented on a massive scale. Looked at another way, tolls paid by 5 percent of peak-period VMT would be sufficient to pay for all toll transaction costs. Because after implementing the policy peak-period VMT would represent about 67 percent of base peak-period VMT (i.e., a 13 percent reduction from commuter VMT and an extreme-case 20 percent reduction from noncommuter VMT), toll transaction costs would equate to tolls paid by about 3.3 percent of base peak-period VMT.

The remaining balance of tolls collected (i.e., funds from about 6.7 percent of base VMT) could be used to subsidize any noncommuter travelers with particular hardships (e.g., by providing discount toll rates for low-income groups).

PUBLIC ACCEPTABILITY

The concept of cashing out free roads can overcome most of the major objections from the public that have stymied implementation to date.

First, the most vocal opponents of peak-period pricing (i.e., commuters) under the traditional approach do not lose anything under this approach. All gain from reduced delays and frustration as a result of lower congestion levels, and some in fact gain in monetary terms if they decide to switch modes. Second, the concept can easily be sold to fiscal conservatives as being both revenue-neutral and economically efficient. Third, those concerned about impacts on the poor will clearly see the benefits to low-income commuters—who are more likely to "take the cash" and carpool or ride transit. Finally, commercial users will find it appealing (because their transportation productivity will increase) and will not mind paying for the benefits of time savings and reliability. (For example, commercial travel time is valued at about \$30.00 per hour; this means that commercial travelers should be willing to pay as much as \$2.50 in tolls if the pricing policy saves them just 5 min per trip from reduced congestion.)

Some will remain losers. For example, nonwork travelers will lose money. However, they will have smaller losses if they decide not to travel regularly during peak periods or shift their time of travel to avoid the toll. Proponents of the pricing policy should expect to draw substantial opposition from this group, which may pose a significant political stumbling block. However, the magnitude of the opposition would be far less than the outrage that a traditional approach would elicit from commuters. Besides, support for the policy could be expected from commuter groups because highway commuters would benefit from reduced congestion levels, and transit commuters and carpoolers would in effect get a commuter subsidy. This support could be used to counter any opposition from noncommuters.

Whereas most commercial travelers will have net benefits despite the new tolls they will have to pay, it may be hard for the policy proponents to convince commercial travelers that congestion levels will indeed drop drastically and that their time savings from reduced congestion will be enough to compensate them for the tolls. However, if pilot tests of the concept (as discussed in the next section) are carefully crafted and prove it to be successful, the concept will be a lot easier to "sell" to commercial groups.

Occasional travelers, such as visitors to the area or those passing through, may lose. However, many visitors and those who pass through the urban area will not mind tolls since they make longer trips and therefore value time saved. In any case, these travelers have a limited ability to organize any substantial opposition because they do not live in the area. However, if the economy relies on tourism, some opposition could be expected from the tourist industry.

Despite additional administrative burdens that employers will have to face if they are to be tapped for verification of employee data and for distribution of smart cards, they may be expected to support the approach because (*a*) a commuter subsidy would become available to employees who carpool or ride transit; (*b*) the promise of lower congestion would reduce the psychological toll on their employees and thus make them more productive; and (*c*) employers who have instituted transit fare subsidy programs may be in a position to terminate those programs, with consequent savings. In air quality nonattainment areas classified as severe, this approach may be a substitute for the requirements of the Employer Commute Options program, whose burdens on larger employers are greater than those under this approach. On the basis of these considerations, area employers might be expected to support the congestion pricing policy.

FAIRNESS ISSUES

Fairness issues are sure to be debated by policy makers. First, is it fair to have noncommuters pay to keep commuters off the roads? Some could argue that commuters and noncommuters have equal rights to the use of roads during peak periods, and therefore noncommuters should not be discriminated against. However, off-peak noncommuters are already paying an unfair share of the costs of building highway capacity improvements needed primarily for peak-period commuters through their fuel taxes, property taxes, sales taxes, and even income taxes (*3*). With the proposed congestion pricing policy, unfairness to noncommuters will simply be more blatant.

A second fairness issue sure to concern policy makers is as follows: Is it fair to pay existing carpoolers and transit riders simply to continue socially good behavior that they have already opted for supposedly in their own best interest? Do they deserve the windfall from free credits or smart cards? Perhaps one way to counter this concern would be to suggest that existing carpoolers and transit riders could give up their rights to existing and future planned HOV lanes in return for the windfall. (Note that HOV lanes would be unnecessary under congestion pricing, because tolls would be designed to eliminate most congestion, that is, there would be no time advantage in using HOV lanes.) There would be no need to build the massive HOV lane systems being proposed in some urban areas. The resources that the government might have otherwise expended may be likened to the resources that might have otherwise been expended by employers on parking leases and so forth if Shoup's parking cash-out program were not in place. Just as it is fair that the freed-up resources from unneeded parking are returned in cash to employees, it is also fair for freed-up resources that would otherwise be expended on unneeded HOV lanes to be returned to those who help make them unnecessary. Of course, since sufficient cash should be available from tolls on noncommuters, there is no need to dip into the pool of "saved" resources.

The saved resources could instead be expended to maximize total transportation system efficiency or for any other purpose deemed fair by policy makers. One great advantage of the pricing polity is that policy makers would get a clear signal as to when further investment in the transportation system would be more efficient. If tolls needed to optimize traffic flow are higher than the public and social costs for providing added capacity, it would clearly signal to policy makers that investment in added capacity would be warranted on grounds of economic efficiency.

TESTING THE CONCEPT

Before full implementation on a regionwide basis, the concept can be tested on any congested facility, preferably a facility with existing tolls—a toll road, bridge, or tunnel—where opportunities for diversion of traffic are limited. Likely candidates are the Bay Bridge of San Francisco or the set of bridges and tunnels connecting New York City and New Jersey. Peak-period tolls could be raised, and at the same time all commuters could be provided with bonus coupons whose value would be equivalent to the toll increase. Thus, in effect, only noncommuters (nonwork travelers, commercial traffic, visitors, and through traffic) would pay the higher toll. The coupons would be redeemable for cash.

Eligible commuters would be identified through mail-back postcards distributed as they drive through toll booths. To enroll in the coupon program, commuters would use the postcard to provide information on their employer's address, their home address, and their work schedule. To reduce temptation for fraud, the postcard would warn of criminal penalties that might apply to fraudulent claims.

The coupons could be sent to the commuters' employers for distribution to eligible employees. Along with the coupons, the employee would be provided with a carpool match list derived from the initial postcard survey, providing an additional incentive to those who would like to cash out their coupons but don't know who they could ride with. If adequate transit service between the commuter's home and office is available, the route schedules would also be enclosed.

Note that existing transit riders and carpool passengers would be eligible for the coupons. During the postcard survey, all occupants of buses and carpools, as well as transit passengers on rail lines in the corridor, would be provided with the postcards. If transit riders form a large share of corridor commuters, funds from paying road users may be insufficient to pay for coupons cashed out by transit users. Peak-period fares in the corridor may have to be raised sufficiently to provide the needed cash. However, raising transit fares would reduce the incentive for solo drivers to shift to transit. The incentive to shift to carpools would remain.

CONCLUSIONS

This paper has presented a new concept that could improve the political acceptability of congestion pricing, either at the facility level or systemwide. The concept of cashing out free roads would eliminate the major objections of policy makers and the public to the concept of congestion pricing. Urban areas with existing toll facilities that are congested have a unique opportunity to test the concept on a limited basis on those facilities before commitment to larger-scale implementation.

ACKNOWLEDGMENTS

The author wishes to acknowledge the valuable comments on an earlier draft by Anthony R. Kane, Sheldon Strickland, Donald Shoup, Tom Higgins, Kiran Bhatt, and anonymous reviewers of the TRB Committee on Transportation Economics.

REFERENCES

1. Kane, A., and P. DeCorla-Souza. Urban Mobility, Environment and Transportation Financing: The Role of Tolls. Presented at the ITE 1992 International Conference, Monterey, Calif., March 1992.
2. Shoup, D. Cashing Out Free Parking. *Transportation Quarterly*, Vol. 36, pp. 351–364.
3. DeCorla-Souza, P., and A. R. Kane. Peak Period Tolls: Precepts and Prospects. *Transportation*, Vol. 19, 1992, pp. 293–311.
4. Shoup, D. Cashing Out Employer-Paid Parking: A Precedent for Congestion Pricing. Presented at the Congestion Pricing Symposium, Washington, D.C., June 22–24, 1993.
5. *New Perspectives in Commuting.* U.S. Department of Transportation, July 1992.

The views expressed in this paper are those of the author alone and do not represent the policies of the FHWA or the U.S. Department of Transportation.

Publication of this paper sponsored by Committee on Transportation Economics.

Application of a User Cost Model To Measure During and After Construction Costs and Benefits: Highway Widening Projects

MARIE T. WILDENTHAL, JESSE L. BUFFINGTON, AND JEFFERY L. MEMMOTT

Because many highways in Texas are being widened to expedite traffic, motorists are asking questions about the cost impacts of such highway improvements. This study is designed to determine the user costs and benefits, both during and after construction, of widening a highway located in an urban area. A 10.79-km (6.7-mi) section of U.S. Highway 80 in Longview, Texas, a city with a population of 70,311 in 1990, was selected for study. The highway section was upgraded recently with a two-way continuous left-turn lane and curbs and gutters within the existing right of way. In addition, a new interconnecting signal system was installed. The total cost of the project was $9.5 million. The Heem-III benefit-cost model was used to determine the benefits to motorists. Benefits were calculated as the sum of delay savings, accident reductions, and vehicle operating cost savings, discounted over a 20-year period. Instrumented vehicle runs indicated that motorist delay was reduced as a result of optimal signal timing implemented during the widening construction and reduced stops as lanes were no longer blocked by left-turning vehicles. The accident rate fell steadily from the time that construction began. Projected maintenance costs were subtracted from projected benefits, and the resulting difference is divided by the cost of construction to obtain the benefit-cost ratio. The total benefit-cost ratio for the whole project is $7.82, which means that motorists are receiving benefits worth $7.82 for every dollar spent on the project.

The Texas Department of Transportation (TxDOT) continually is faced with the responsibility of providing safe and congestion-free highways. One of the principal ways that TxDOT is accomplishing this task is by widening and adding travel lanes to existing highways. In many cases, these highways are widened enough to install a continuous two-way left-turn lane in the median, and curbs and gutters at the margins.

The benefits to motorists of an improved highway can be classified into three general categories: delay savings, accident reductions, and vehicle operating cost savings. Many methods and techniques are available to calculate these benefits, but, in general, such calculations are based on some change in the before and after situation the motorists face, putting a dollar value on those changes, and calculating those dollar values over the life of the improvement. These benefits are then discounted to the present and compared with the construction cost. If the user benefits are greater than the costs, then it is a beneficial project. This study is unique in that impacts of the proposed improvements during construction are also calculated.

Texas Transportation Institute, Texas A&M University, TTI/CE Building, Suite 609, College Station, Tex. 77843-3135.

The study focuses on the widening of U.S. Highway 80 (Marshall Avenue) in Longview, Texas. To reduce traffic congestion, three major intersections were widened in 1974. Two additional major intersections were widened in 1986. In 1987, a continuous left-turn lane was proposed between Fisher and Eastman roads along Marshall Avenue, which includes the five widened intersections. That same year, a study was conducted to estimate the benefits of creating a continuous left-turn lane on Marshall Avenue (Buffington et al., unpublished data). Travel times, speed changes, left-turning movements, and lane volumes were documented fully. The study estimated a benefit-cost ratio of $3.47 for the proposed improvement. The proposed improvement was approved and went to contract in fall 1989, and it was completed in fall 1991. The current study is a follow-up study and was initiated before construction so that the construction period could be monitored and the cost impacts to users before, during, and after construction could be estimated. Similar data were collected during and after construction. Also, construction activity, such as lane closures and expenditures, were monitored. Therefore, a complete impact analysis of costs and benefits before, during, and after construction can be performed.

CALCULATION OF DELAY SAVINGS

Delay savings are calculated as the dollar value of motorist time savings resulting from the highway improvement. They are calculated using the following formula as a guideline:

$$\text{Savings} = \text{length} \times \text{volume} \times \left(\frac{1}{\text{speed}_{\text{No Median}}} - \frac{1}{\text{speed}_{\text{With Median}}}\right) \times \text{value of time}$$

where

savings = hourly delay savings ($1,000/hr);
length = section length (1.61 × km) (mi);
volume = hourly traffic volume by lane (thousands of cars);
$\text{speed}_{\text{No Median}}$ = speed under previous conditions, no median [1.61 × km/hr (mph)];
$\text{speed}_{\text{With Median}}$ = speed under current conditions, with median [1.61 × km/hr (mph)]; and
value of time = the weighted average of truck and car value of time ($/hr).

Traffic Volume

Traffic volume is calculated as average daily traffic (ADT). Detailed ADT for 1986 was collected from TxDOT maps along the section of U.S. Highway 80 that was widened. Also, the Texas Transportation Institute (TTI) collected ADT data annually before, during, and after construction for calculating construction-period impacts. In addition, TxDOT provided a projected ADT for 2006 for this section of highway. Because there was no indication that the traffic would follow a specific growth pattern in the future, the difference between the 1986 and 2006 values was divided by 20 to obtain an annual increase in ADT. Various multiples of this value were added to the 1986 figure to obtain an estimated ADT for more recent years.

The estimated ADT is slightly higher than that established by the TTI counters, which show the ADT remaining nearly flat during the construction period. The construction period benefits may be slightly overstated, but TxDOT projections for the long term seem reasonable.

For the major route, which is Marshall Avenue, the ADT for the segment with the least volume was used as the current through ADT, and the difference between the actual segment volume and the current ADT was entered as local ADT. The ADT calculated for the minor routes, or cross streets, was put in directly as estimated. In addition to the current ADT, a projected ADT is required for calculating future benefits.

The ADT was further broken down into hourly volumes by lane using traffic counters placed in several locations along the highway. The number of vehicles passing each location over a 24-hr period was counted. These were accumulated into hourly totals and applied to the overall average ADT along the section to give average hourly traffic volumes by lane.

Traffic Speed

Speeds before, during, and after construction were determined by instrumented vehicle runs along the study section of U.S. Highway 80. To compare speeds before and after construction, speeds were compared with the default speeds of the HEEM-III model, a benefit-cost computer program developed by TTI (*1*). If they differed, default speeds were changed to represent actual measured speeds. The HEEM-III model then was used to calculate vehicle operating costs and savings. Speeds used in the model reflected the effects of construction activities, including increased congestion caused by the lane closures.

Value of Time

On the basis of a TTI study using a speed-choice model and the latest data for Texas, the HEEM-III model assumes that the car value of time is $9.52 per hour per person and that the truck value of time is $22.63 per hour per person (*2*). Intersection or interchange delay is calculated using the delay equations for selected highway situations discussed by Memmott (*1*).

The model calculates the delay on an hourly basis for each direction on both the major and minor routes for each route segment. These calculations are repeated for a 24-hr period for both the unimproved and newly widened road sections. The difference between the sum of the before and after costs is the motorist benefit. These calculations are repeated for each year of the analysis. Unreasonable delays are precluded by calculations that modify the lower and upper parts of the curve. Delay equations are based on optimal signal timing and phasing, and the calculated delay can be modified for less than ideal conditions by using an intersection delay adjustment factor. These factors are modified on the basis of vehicle travel time and the number of stops recorded by instrumented vehicles, which are summarized in Table 1.

Additional delay can be caused by vehicles that are queued behind a vehicle waiting to make a left turn from the median lane. Without a median, vehicles attempting to make left turns at mid-block driveways or intersections without a left-turn bay will have to wait for a gap in the oncoming traffic to make the turn. Vehicles may have to wait behind the turning vehicle if there is insufficient space within the shoulder lane to pass the vehicle. These situations could be eliminated with a continuous left-turn median.

Reduction in delay stops from queuing vehicles was estimated using several runs with an instrumented vehicle through the length of the study highway section. The number of stops made by an

TABLE 1 Instrumented Vehicle Travel Time, Speed, and Stops on Runs Through Study Project[a]

		Stops		Travel		
Year	Runs	At Lights	Mid-Block[b]	Time (min)	Speed (km/h)[c]	Approach Speed (km/h)[c]
1987	99	10	3	14.91	43.44	58.57
1990	93	16	1	15.30	42.29	52.08
1991	76	19	1	14.60	44.32	57.49
1992	90	4	0	12.30	52.61	67.35

[a] An average of 30 runs per day on Thursday, Friday, and Saturday Between 6:00 a.m. and 10:00 p.m. each day of each year studied.

[b] Stops per run rounded off to appropriate whole number.

[c] 1 mi. = 1.61 km.

TABLE 2 Number of Accidents per Year, Study Area, 1984–1992

Year	Fatal	Injury	Property Damage Only	Total
1984	2	165	300	467
1985	2	171	251	424
1986	2	157	271	430
Average	2	164	274	440
Percent	0.45	37.27	62.28	100.00
1989	1	88	122	211
1990	1	109	132	242
1991	0	93	107	200
1992 (January - August)	1	50	63	114
1992 Annualized	1	75	95	171
Average	1	91	114	206
Percent	0.49	44.17	55.34	100.00

instrumented vehicle decreased with the addition of a continuous left-turn lane, as can be seen from the information in Table 1. The runs were not sufficient to estimate the effects on an hourly basis, however, so daily traffic using the median lanes was used to estimate the savings. It was assumed that all of this delay would be eliminated with continuous left-turn medians.

VEHICLE OPERATING COSTS

Additional vehicle operating costs are incurred when motorists slow down and stop at intersections, including costs associated with running and idling as vehicles wait for a signal to turn and the queue to dissipate. Average running speed is the most important variable in the latter calculation, and HEEM-III's calculation for it is based on the 1985 *Highway Capacity Manual.* Speed calculations for volume/capacity above capacity are taken from a TTI study on delay (*3,4*). Equations are presented by Memmott (*1*).

The vehicle operating cost equation for the segments and intersections were estimated from Zaniewski et al. (*5*) and updated in 1990. The vehicle operating costs were summed and then adjusted for the pavement condition using the formula presented by Memmott (*1*), taken from the *Highway Performance Monitoring System Analytical Process* (*6*). A pavement condition of 4.5 is used as the base for the adjustment.

ACCIDENT REDUCTION SAVINGS

The numbers and types of accidents on Marshall Avenue between 1984 and 1986 and from 1989 to 1992 are given in Table 2. The table indicates that there were fewer accidents between 1989 and 1992 than there were between 1984 and 1986.

Present research assumes that the continuous left-turn lane will reduce the number of accidents involving turning vehicles. Table 3 gives the number of accidents involving turns during the construction period and almost a year after the construction period. The postconstruction period data resemble that for 1990, and it is not clear that turning accidents were affected by the construction.

There is also a question of whether the construction caused additional accidents. In Table 4, accidents in the construction zone are divided into those that were construction related and those that were not. Only a small percentage of the construction zone accidents were construction related.

With the HEEM-III model, accident costs are calculated by multiplying the accident rate by the cost per accident. The accident rate, which is given in Table 5, is then adjusted by the accident adjustment factor. The accident adjustment factor is based on the total accident rate of the study area over various time periods, with the preconstruction period (1984 to 1988) representing the base rate of 1.0. Accident rates for highway segments are taken

TABLE 3 Number of Accidents on Marshall Avenue Involving Turning Vehicles

Year	Left-Turn	Right-Turn
1989	19	14
1990	34	16
1991	18	21
1992 (Jan - Aug)	20	10
1992 (Annualized)	30	15

Source: TxDOT

from the *Highway Performance Monitoring System Analytical Process* (*6*). Accident rates for intersections, interchanges, and railroad grade crossings were estimated from Texas accident rate tapes from 1981 to 1986 (Table 6). Costs per accident were taken from a TTI study of accident costs by Rollins and McFarland (*7*). All operating and accident costs are updated to July 1990 and are presented in Table 7. The model estimates that accident costs will be reduced by $4,276,420 over a 20-year period between 1993 and 2012.

CALCULATION OF MOTORIST BENEFITS OVER THE ANALYSIS PERIOD

Three types of benefits are analyzed. The first type is the benefit or lack of benefit associated with the construction. Benefits related to early completion of the project (in 2 years instead of the estimated 3 years) are a second type. The last type is those benefits received after construction, as compared with those received before construction. Benefits calculated following project completion are presented in Table 7.

HIGHWAY IMPROVEMENT COST

Two types of costs are associated with highway construction: the construction costs themselves and the costs of maintaining the highway. The actual cost of the Interstate 80 widening construction was $9,544,420. Future highway costs are associated with overlays, striping, and routine maintenance. These costs are projected to be $350,000 for this project; they are presented in Table 7. There may be additional costs for maintaining traffic control devices that were not included in this analysis, so total costs may be understated.

SUMMARY OF BENEFITS AND COSTS

The benefit-cost ratio for the continuous left-turn lane is the total discounted user benefits less maintenance costs divided by the

TABLE 4 Distribution of Accidents in Construction and Maintenance Areas

Year	Construction Zone		Maintenance Zone	
	Non-Construction Related Accident	Construction Related Accident	Non-Maintenance Related Accident	Maintenance Related Accident
1989	2	0	0	0
1990	94	3	1	0
1991	55	2	0	0

Source: TxDOT

TABLE 5 Urban Accident Rates and Costs in Texas

	Freeway	Divided	Undivided
Accident Rates[a]	244	565	616
Cost per Accident	13,360	12,570	9,170

Source: HEEM-III: Revised Highway Economic Evaluation Model Version 1.0

[a] Accident Rates per 161 Million Vehicle Kilometers

TABLE 6 Urban Accident Rates in Texas

Accident Rates	PDO	Injury	Fatal
At Grade Stop	0.9393	0.5165	0.0102303
At Grade Signal	0.4648	0.2145	0.0020001
Interchange	0.0879	0.0518	0.0014806

Source: HEEM-III: Revised Highway Economic Evaluation Model Version 1.0

[a] Accident rates per urban intersection per 1,610 vehicle lane kilometers

TABLE 7 Summary of Discounted Benefits, Costs, and the Benefit-Cost Ratio, 1992

Motorist Benefits	Construction Period	Early Completion	Before vs. After	Total
	(Thousands of Dollars)			
Delay Savings	-3,969.43	6,695.95	61,563.10	64,289.62
Reduced Vehicle Operating Cost	191.85	193.22	5,532.95	5,918.02
Accident Reduction	317.35	162.04	4,276.42	4,755.81
Total	-3,460.23	7,051.21	71,372.47	74,963.45
Less Maintenance Costs	-50.00	-30.00	-270.00	-350.00
Benefits - Maintenance Costs	-3,510.23	7,021.21	71,102.47	74,613.45
Construction Costs				9,544.42
Benefit-Cost Ratio				7.82

construction costs:

$$\text{B/C ratio} = \frac{(\text{benefits} - \text{maintenance costs})}{\text{construction costs}}$$

The discount rate used in this study is 8 percent. The benefit-cost ratio estimated in 1992 is

$$\text{B/C ratio} = (\$74{,}963{,}450 - \$350{,}000)/\$9{,}544{,}420 = \$7.82$$

$$\text{Net present value} = \$74{,}963{,}450 - \$350{,}000 - \$9{,}544{,}420 = \$65{,}069{,}030$$

A benefit-cost ratio of $7.82 means that the motorists are receiving $7.82 of benefit for every dollar spent on the project. This is a beneficial project from the standpoint of the motorist because the benefits are greater than the costs by a substantial margin. As indicated in Table 7, finishing the construction a year earlier created benefits of $7,021,210, which more than compensated for the negative user-cost impacts incurred during the 2 years of construction, which totalled $3,510,230.

As indicated earlier, the preliminary study estimated a benefit-cost ratio of $3.47 using an earlier version of the HEEM benefit-cost model. This study used HEEM-III, which gives more accurate estimates of vehicle delays and operating costs.

SUMMARY

The addition of a continuous left-hand turn lane can result in three types of motorist benefits: delay savings, accident reductions, and vehicle operating cost savings. This report includes estimates of motorist benefits related to the widening of Marshall Avenue in Longview. Delay savings were estimated using the reduced number of stops along the study section as recorded by instrumented vehicle runs. Vehicle operating savings were calculated using the HEEM-III benefit-cost model. The number of accidents along the study section fell as the construction started, and this trend continued during and after construction. Overall, the findings indicate considerable user benefits over the cost of highway improvement, even after subtracting the negative impacts of construction.

ACKNOWLEDGMENTS

The authors want to thank several officials of District 10 of the Texas Department of Transportation for their assistance in this study as well as the preliminary report: James R. Evans and Harold C. Waggonner provided support and guidance during this study, and Robert E. Ward and J. Walter Lehmann furnished data and provided valuable assistance.

The authors are indebted to Edlyn Vatthauer and John H. Russell of the City of Longview for the data and valuable assistance they provided during the study.

Further, the authors want to express their sincere thanks to L. C. Woods of the Netherton Company, Inc., the general contractor for the widening project, and the officials of the subcontractors for their help in determining the amount of the construction expenditures that were made in the Longview area and for logging lane closure data.

Other members of the Texas Transportation Institute's Transportation Economics Program gave valuable assistance to the study. W. F. McFarland assisted with the highway user cost analysis. Darrell Borchardt and Gerald Ullman and their data collection staffs collected the traffic data for the study. Craig Smith and George Rose helped to reduce the study data base. Finally, Linda Buzzingham helped with compiling and sorting the data base as well as with the report preparation.

REFERENCES

1. Memmott, J. L. *The HEEM-III Benefit-Cost Computer Program.* Research Report 01128. Texas Transportation Institute, Texas A&M University, College Station, Tex., Nov. 1990.
2. McFarland, W. F., and M. K. Chui. *The Value of Travel Time: New Estimates Using a Speed-Choice Model.* Research Report 396-2F. Texas Transportation Institute, Texas A&M University, College Station, Tex., May 1986.

3. *Special Report 209: Highway Capacity Manual*. TRB, National Research Council, Washington, D.C., 1985.
4. Memmott, J. L., and J. L. Buffington. *A Model To Calculate Delay Savings for Highway Improvement Projects*. Research Report 327-1. Texas Transportation Institute, Texas A&M University, College Station, Tex., Oct. 1983.
5. Zaniewski, J. P., et al. *Vehicle Operating Costs, Fuel Consumption, and Pavement Type and Condition Factors*. Report FHWA/PL/82/001. FHWA, U.S. Department of Transportation, March 1982.
6. *Highway Performance Monitoring System Analytical Process*, Vol. 2. Office of Highway Planning, FHWA, U.S. Department of Transportation, Jan. 1986.
7. Rollins, J. B., and W. F. McFarland. *Costs of Motor Vehicle Accidents in Texas*. Research Report 396-1. Texas Transportation Institute, Texas A&M University, College Station, Tex., May 1985.

Publication of this paper sponsored by the Committee on Transportation Economics.

Integrating Driver Information and Congestion Pricing Systems

IBRAHIM EL SANHOURI AND DAVID BERNSTEIN

A great deal is known about both congestion pricing systems and driver information systems in isolation. Unfortunately, very little is known about the joint implementation of such systems. This is particularly troubling because a number of integrated systems are now being considered. Questions that must be answered when designing an integrated driver information and congestion pricing system are discussed. The reason why it is important to consider interactions between the two component subsystems is illustrated using a simple example.

Currently, interest in congestion pricing appears to be particularly intense, despite failed attempts at it during the past 30 years. Many believe that congestion pricing may turn out to be very important to the ultimate success of intelligent vehicle/highway systems (IVHS) and vice versa. There are at least three reasons for this.

First, it is clear that demand management strategies must be included in IVHS. Efforts to develop IVHS technologies usually have been justified on the grounds that they would increase the efficiency and capacity of the existing transportation network and thereby reduce congestion, fuel consumption, and related environmental impacts. However, there is increasing concern that the benefits of IVHS may not be as great as originally anticipated. For example, any increase in capacity—whether the result of electronic toll collection, traffic control (such as ramp metering or in- or out-of-vehicle route guidance), or improved incident management—will be met by an increase in the number of trips and vehicle miles traveled. The likelihood that people will take more trips or change their mode of travel has created concern that augmenting supply via IVHS will conflict with the Clean Air Act Amendments. As a result, many have begun to argue for IVHS-related demand-management techniques (i.e., techniques aimed at influencing the intensity, both over time and space, of transportation demand). One of the most important of these techniques is congestion pricing.

A second reason is that congestion pricing may improve the performance of IVHS. IVHS policies that should work well in an ideal world may be ineffective where there is unpriced congestion. To the extent that tolls properly price congestion, they could improve the performance of IVHS overall.

Finally, congestion pricing may be more palatable as part of an integrated IVHS. Recent attempts to market congestion pricing to the public have relied on introducing congestion pricing for new highways or bridges that are already planned as toll facilities, adding time-of-day variation to the toll structure of an existing bridge or place where traffic bottlenecks. Options include electronic toll collection technology and opening high-occupancy vehicle lanes to nonqualifying vehicles that are willing to pay a fee (*1–3*). It may be easier, however, to get people to accept congestion pricing if it is introduced along with an advanced traffic management system or an advanced driver information system (ADIS). That way people would think they are receiving something concrete in return for additional tolls.

For these reasons, people have argued for integrating congestion pricing and IVHS. Advocates of integration include users of the highway system, environmentalists, traffic engineers, and policymakers. In fact, several integrated systems recently have been or are about to be proposed.

Although there have been some papers written on the topic, little is known about how congestion pricing should be integrated into IVHS or what the impacts of it will be. It has been argued intuitively that information systems would perform better in the context of congestion pricing, because the latter would lower congestion levels and thereby increase capacity on routes for rerouting (*4*). Similarly, combining information and pricing could result in synergistic effects; greater improvements may result than would have if each policy were implemented alone (*5*). Only two examples of quantitative work on this topic were found in the literature (*6,7*). Although interesting, the analyses are somewhat limited; primary attention is given to examining whether gains from joint pricing and information are greater than gains that would follow if the policies were applied separately. The results are either greater (superadditive), less (subadditive), or independent.

Several key assumptions were made, including the following:

- Information is supplied before any travel begins.
- Capacity is constant on a give day (i.e., incidents last throughout the peak period), and
- The system is in equilibrium every day (even given the day-to-day changes in capacity).

The purpose of this paper is to explain (*a*) why it may be possible to use integrated driver information and congestion pricing systems to reduce congestion and its negative impacts, (*b*) what types of decisions need to be made when designing such a system, and (*c*) why it is important to consider interactions between the two subsystems. First, the role of driver information systems and congestion pricing systems is discussed. Various types of systems that can be used, and the possible advantages and disadvantages of each are considered. Then a simple analytic model is used to illustrate the importance of considering interactions between the two subsystems. Finally, future topics for research are outlined.

DESIGN OF AN INTEGRATED DRIVER INFORMATION AND CONGESTION PRICING SYSTEM

When designing an integrated driver information and congestion pricing system, it is necessary to consider the role of each of the two component subsystems and the details of how each works.

Massachusetts Institute of Technology, Room 1-138, Cambridge, Mass. 02139.

Roles of Subsystems

The best way to design an integrated system follows three steps: First, consider the specific goals of the system (i.e., what type of congestion is to be reduced). Second, consider what changes in behavior could achieve those goals. Third, consider how the two component subsystems could be used to bring about the desired changes in behavior.

The first step involves distinguishing between two different types of congestion, nonrecurring and recurring. Nonrecurring congestion, which does not follow a regular day-to-day pattern, is caused by incidents, such as accidents or breakdowns. In contrast, recurring congestion follows a regular pattern; it is caused by the normal dynamics of traffic flow.

The composition of congestion has been investigated by several researchers; most of their figures indicate that both types of congestion are substantial. According to one study, 64 percent of the total delay due to congestion is incident related and 36 percent is due to recurring congestion (*8*). It is generally believed that an integrated system should be developed to reduce both types of congestion, if possible.

The second step involves distinguishing between default behavior and adjustment behavior. Default behavior is that which is exhibited by a majority of travelers who make a particular trip repeatedly, such as a trip from home to work. Under those circumstances, travelers are likely to develop a habit with regard to the various choices related to that trip, including the decision to travel and the choice of destination, mode, route, and departure time. These habitual choices, in the short-run, will be adhered to with little variability from day to day. On occasion, however, immediate or real-time adjustments will be made to the default pattern that do not arise simply from natural fluctuations in travelers' behavior and their environment. Travelers make adjustments in response to severe weather, for instance, or to reports of excessive congestion or accidents on their default routes. Adjustment behavior includes pretrip changes regarding decision to travel or the choice of destination, mode, route, or departure time as well as en route changes in destination, mode, and route.

At least in principle, changes in both default and adjustment behavior can affect both nonrecurring and recurring congestion. Of course, all changes in default behavior affect recurring congestion, and many changes in adjustment behavior can influence nonrecurring congestion. What is less obvious is that changes in default behavior can have an impact on nonrecurring congestion in a number of ways. For example, the frequency and the magnitude of incidents (and hence the level of nonrecurring congestion) is probably a function of the level of recurring congestion and therefore can be influenced by changes in default behavior. Furthermore, changes in adjustment behavior can have an impact on recurring congestion because people do not always behave in their own self-interest. Some travelers may, for example, routinely choose a slower route to work because they are unaware of a better alternative.

With this in mind, the third step involves determining how congestion pricing and information subsystems can be used to influence default and adjustment behaviors. In general, both subsystems can be used to influence both types of behavior.

The most popular application of such information systems is their use in influencing adjustment behavior. Indeed, it is clear that information can be used to influence pretrip and en route adjustments (*9*).

Less widely discussed is the fact that information systems can be used to influence default behavior. How information might be used to affect default behavior, total travel costs, and the travel costs of individuals has been examined by several researchers (*10*).

Traditionally, discussions of congestion pricing have focused on how it might be used to influence default behavior. Tolls can be used to alter individuals' decision to travel and their choice of destination, mode, route, or departure time. A majority of early studies avoided the task of modeling these various responses using a generic demand curve. Papers that analyze actual responses include a seminal work that investigated the departure time response to a time-varying toll (*11*). This study is of particular relevance given current interest in congestion pricing, which is largely based on pricing certain times of the day. Another paper studied the route-choice response to pricing (*12*).

Finally, it is easy to see how, with the advent of various new technologies, congestion pricing might be used to influence adjustment behavior. First, if drivers are made aware of the toll levels before they begin their trips, they can make various pretrip adjustments. In addition, applying differential pricing to several alternative routes could be used to modify en route decisions.

Types of Congestion Pricing Systems

Congestion pricing systems vary in both their spatial and temporal structure. The authors summarize some of the more important characteristics of these systems; a more complete discussion is available elsewhere (*13*).

In terms of spatial structure, congestion pricing schemes can be either areawide or facility based. The most popular approach to implementing congestion pricing outside of the United States has been areawide. The Singapore system charges for entry into the central business district (CBD) during the morning peak and for exit in the afternoon. The well-known (though short-lived) Hong Kong experiment with congestion pricing subdivided the city districts into several zones, and commuters were tolled as they crossed zone boundaries according to a time-varying schedule. The Norwegian cities of Oslo and Bergen constructed cordons around their CBDs that charge time-invariant tolls but are able to implement peak-period price differentials. Moreover, planned schemes in London and Cambridge, England, and Stockholm are based on one form or another of areawide pricing (*14*). In the United States, on the other hand, much more attention is being given to facility-based approaches to congestion pricing. One reason is that such approaches are believed to have the best chance of gaining public acceptance, because with such an approach toll-free options are preserved. Another reason is that much of the congestion occurs on suburban connectors, which are not well suited for being charged under areawide schemes.

In terms of temporal structure, congestion pricing systems can be static or dynamic. Static tolls repeat themselves from day to day (or from week to week, if for example the Monday travel pattern is observed to differ strongly from the Friday pattern), even though they may be time-varying (i.e., have different values at different times of the day). Dynamic tolls include all forms of pricing; their temporal toll structure on a given day depends on actual traffic flow or congestion levels. Systems of all three types have been proposed to date, but only static systems have been implemented this far.

It is also important to observe that both static and dynamic systems can be either continuously varying, interval based, or constant within a given day. That is, the toll can change continuously over time (e.g., second by second), can change a few times and remain constant for the intervals between such times, or can remain constant throughout the day. All of the static systems implemented to date have been interval based.

In our view, not all types of congestion pricing systems can be used to influence all types of behavior. For example, using congestion pricing to influence en route choices is very different from using it to influence pretrip choices. A continuously varying dynamic toll is probably not an appropriate way to influence pretrip adjustment behavior. If tolls change continuously, people would expect the tolls to change from what they were before they reach the toll facilities and might ignore them. On the other hand, congestion pricing in principle can be used to influence en route decisions almost continuously. It is not clear, however, whether such a system would be acceptable to the majority of travelers, who might object to not being able to know in advance what they will be required to pay for using a particular route.

Using congestion pricing to influence en route decisions is very different from using it to modify default behavior. In the case of default behavior, it makes sense to consider the response to the toll in the long term. In the case of adjustment behavior, it only makes sense to consider the immediate response. As a result, en route adjustments can be elicited in a variety of different ways. First, one might consider marginal cost pricing. One determines the financial impact of each driver's behavior on the total cost to society and charges accordingly. Because it is not clear that charging marginal fees on a one-time basis results in the adjustment desired, one can consider what tolls would effect the desired behavior. One could charge a toll that no one would be willing to pay on all of the alternatives that are being discouraged at a particular time. Or, one could charge a toll that is meant to encourage desired adjustment behavior by charging a toll that is placed appropriately within the value of time distribution (so that the right number of people go each way).

Types of Driver Information Systems

Just as there are several ways to implement congestion pricing, many different driver information systems also have been proposed. To some extent, the differences among them are determined by the technologies they employ. For purposes of this study, however, it is more important to consider the four functional differences (*10,15,16*) among them.

First, driver information systems may vary in the information they provide. That is, they can provide either status or guidance information. In addition, the information they provide can be historical, current or predictive. The exact nature of the information influences how people respond to them in real time and during the long run.

Second, the spatial structure of driver information systems can vary in important ways. In particular, they can vary by geographic extent or coverage (including whether both pretrip and en route information is available) and in their specificity (i.e., whether information is provided to individual vehicles or whether the same information is provided to all of the vehicles in a given area). The spatial structure will largely determine the resolution of the ADIS (i.e., how specific the system can be in influencing traffic patterns).

Third, different driver information systems may have different temporal structures. Most important, the frequency with which the information is updated can vary, which too can affect resolution of the ADIS. One study has shown that temporal structure can have a considerable effect on whether the system experiences overreaction effects (*15*).

Finally, it is possible to design driver information system with a variety of different objectives. The general objective usually is to minimize some individual's or group's travel cost. However, how the group is defined can significantly affect the ultimate operation of a system. Possible groups include those vehicles at a particular information provision point; all vehicles within x km of a particular point; all vehicles currently within the network; and all vehicles currently within the network, plus those forecast to be within it in the next t min.

Possible Advantages and Disadvantages

With all of this in mind, it is important to compare driver information systems and congestion pricing systems in view of the fact that either can be used to influence both default and adjustment behavior. Which system should be used in each case? It is not yet possible to answer this question with certainty; however, the authors present some of the advantages and disadvantages of each.

Influencing Default Behavior

Information systems are only likely to have a significant impact on default behavior if travelers lack perfect information on alternatives to their current choices. Hence, the extent to which an information system will continue to influence default behavior for the longer run depends in large part on how long it takes people to remember the information they are regularly given. Commuters and other regular travelers may learn relatively quickly or be very well informed already; thus the information system may be necessary in this regard for a relatively short period of time.

From a technical standpoint, however, congestion pricing is likely to influence default behavior effectively. Travelers have demonstrated a sensitivity to prices because almost everyone has alternatives to their default choices. Yet failed attempts to implement congestion pricing in the past have shown that political difficulties remain. One issue is congestion pricing's inequitable impact on the poor. If fairness theory (*17*) is applied, congestion pricing is at a disadvantage compared with other traffic restraint policies, such as blanket prohibitions on driving in city centers (*13*).

Influencing Adjustment Behavior

Although information systems can have a significant impact on both pretrip and en route adjustment behavior, they cannot achieve every desired response pattern. The most important reason for this is that there is no guarantee that travelers will comply with information directives. In particular, an information system can be effective only if the information being provided is perceived as reliable (in that what is predicted occurs) and useful (in that it is in a traveler's own best interest). Otherwise, it may be ignored, rendering it ineffective (*15*). Therefore, it probably is not possible to minimize congestion directly using an information system, because to do so would require that some travelers be given information that is not in their own self-interest.

On the other hand, congestion pricing is useful in influencing adjustment behavior, particularly when it is used in conjunction with an information system, because the tolls reinforce information.

However, if the information is both reliable and useful, it should not be necessary to reinforce it. Congestion pricing is necessary only if the information offered is unreliable or it is not useful (in a traveler's self-interest). If the information is unreliable, any tolls are not likely to be accurate. However, if the information simply is not useful, then congestion pricing may be able to achieve objectives that cannot be achieved with information alone. In particular, if information must be "fair," (that is, affect all travelers equally) then information alone is not apt to achieve optimal adjustment behaviors, because such adjustments are likely, to be bad for some drivers and good for others. Congestion pricing, on the other hand, can be used to achieve the optimal adjustments, although it may not be widely accepted.

EXAMPLE OF THE IMPORTANCE OF INTEGRATED DESIGN

Thus far, the authors considered why it might be advantageous to implement an integrated driver information and congestion pricing system and what decisions must be made in the design of such a system. To illustrate why it is important to design the two subsystems simultaneously, a simple numerical example is given to show problems that can arise if the two subsystems are designed independently.

Consider a facility-based congestion pricing system that has static, interval tolls and a driver information system that attempts to minimize the cost of the vehicle currently receiving information by providing predictive, vehicle-specific guidance that is updated continuously. The specific design issue is the location of the toll stations (at either points of entry or exit).

In the absence of incidents, the location of the toll station will have no impact on traffic flow given the static nature of the tolls. However, in the event of incidents and with the use of an information system, vehicles may be advised to switch routes when incidents occur. That may have an impact on the number of people that pay the toll, who pays the toll, and their satisfaction with the system.

Network

Figure 1 shows the network under consideration. Commuters travel from A to C and have the choice of two routes, using either Links 3 and 1 or Links 3 and 2. The free-flow travel times on Links 3, 1, and 2 are 15, 12, and 18 min, respectively. There are potential bottlenecks, modeled as deterministic queues, on Links 2 and 3, which have capacities of 780 and 300 vehicles/hr, respectively. Toll stations are located either at the entrances of Links 1 and 2 (at *B*), or just after the bottlenecks on those links (at *C*). The origin-destination flow from *A* to *C* is 2,200 vehicles. The capacity of Link 3 is set arbitrarily high; in effect, it is a two parallel-route network, with Route 1 consisting of Links 3 and 1 and Route 2 consisting of Links 3 and 2. Modeling Links 1 and

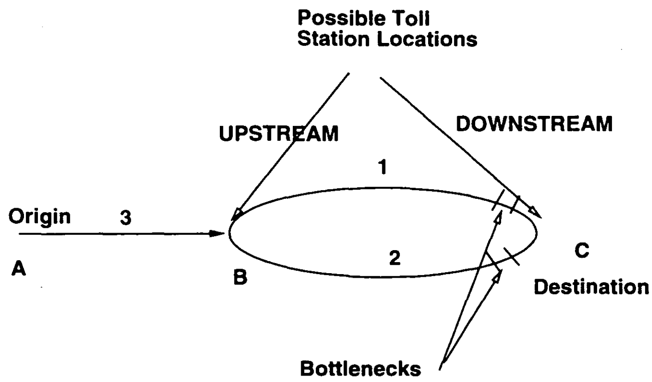


FIGURE 1 Integrating congestion pricing and information systems.

2 as a combination of a free-flow component of fixed time and a bottleneck of variable time (depending on queue length) is useful and has some empirical validity (*18*). Such behavior has been observed on urban freeways. In addition, the fixed time component brings the travel time function on a link closer in shape to that of popular speed-density curves. Thus T_1^f = 27 min and T_2^f = 33 min. The desired arrival time, t^*, is 8.0 hr.

The performance of the system is examined in the presence of incidents. A conditional analysis is carried out that looks at the effects of a single incident, that is, a random, limited time reduction in network capacity. No assumptions are made about the frequency of occurrence of such one-incident days. Furthermore, the impact of the incident on the capacity of the link is modeled as a constant reduction in the capacity of the affected link. The reduction factor, the duration, and the location of the incident are all assumed to be uniformly distributed random variables.

The effect of toll station location on performance is evaluated by examining two situations: one in which the toll stations are upstream of the bottleneck (i.e., at *B*), and one in which they are located between the bottleneck and the destination (at *C*). The information system is located at *B*, in the sense that route guidance is provided at this point to direct travelers to one of the two routes.

Behavioral Model

The behavioral model is based on the assumption that travelers adopt a default behavior that is described by an equilibrium travel pattern. The equilibrium will adjust as a result of the imposition of a congestion pricing policy. Specifically, an extension of the traditional network equilibrium model (*19*) is used. It is assumed that in equilibrium no traveler can improve his or her total travel cost by unilaterally switching to a new departure time or route (*20,21*).

An essential feature of this model is the notion of a trade-off between travel time and schedule delay. Those commuters who arrive on time or close to the desired arrival time will have longer travel times than those who arrive early or late. In particular, it is assumed that the travel cost function is given by

$$C(t) = \alpha \cdot (\text{travel time}) + \beta \cdot (\text{time early}) + \gamma \cdot (\text{time late}) + \text{toll} \quad (1)$$

where $C(t)$ is the cost for a commuter leaving at time t, and α, β, and γ are the values of travel time, time early, and time late, respectively.

It is also assumed that demand for travel is fixed and that the population is homogeneous. Further, it is assumed that travel time on Link i is the sum of the time spent traveling at constant velocity along the link, T_i^f, plus the time spent queuing in bottlenecks at the end of the link, T_i^v. The bottleneck at the end of the link is represented as a deterministic queue. Thus, if the arrival rate at the bottleneck exceeds the capacity or service rate s_i of that link, queuing will occur. Given these assumptions, it is possible to find analytic representations of the equilibrium departure rates both with and without tolls (*11,22,23*). Throughout the analysis, values of time estimated in a previous study (*24*) are used. It is assumed that α = \$6.40/hr, β = \$3.90/hr, and γ = \$15.21/hr.

When an incident occurs, the information system, if in place, begins operation. It is assumed that travelers follow the route guidance provided at B, which may or may not result in a change in their default route choices.

Congestion Pricing Scheme

The authors assume that the optimal single-step toll is charged (*22,23,25*). With such a toll in place, commuters pay a toll, τ, when arriving at the toll station between the period $[t_i^+, t_i^-]$; at other times during the period of departures, no toll is charged. The equilibrium solutions are identical for the two toll stations, except for the timing of the toll period. The optimal step-toll on each route consists of the set $\{\tau_i, t_i^+, t_i^-\}$ that minimizes total cost.

There are two noteworthy features of the equilibrium travel patterns that arise from the discontinuities in cost introduced by the step-toll. First, at the time that results in arrival at the toll station just before a toll period begins, a gap in departures begins. It lasts until queue lengths have diminished to the point at which travel costs, including the toll, are equal to that of the last commuter. In addition, there is a bulk departure of $2s_i\tau_i/(\alpha + \gamma)$ commuters just after the end of the toll period, assuming that the position is random in the bulk (i.e., it averages out over a number of days). Thus, equilibrium is achieved only on the average.

For two routes in parallel, it is necessary to optimally split the N commuters and maintain equilibrium between routes. This is achieved by applying a uniform toll τ_s on one route in addition to the step toll.

Applying these results to our example gives the results in Table 1. The uniform toll is applied to Route 1, which has the shorter free-flow travel time, and equals \$0.22.

TABLE 1 No-Toll Equilibrium and Equilibrium with Optimal Step-Toll

Regime & Route	N	EC	Toll($)	T^+	T^-
Untolled 1	1634	9.38	0	N/A	N/A
Untolled 2	566	9.38	0	N/A	N/A
Tolled 1 Upstream	1620	9.28	3.00	6:33	7:59
Tolled 2 Upstream	580	9.28	3.22	6:32	7:53
Tolled 1 Downstream	1620	9.28	3.00	7:16	8:12
Tolled 2 Downstream	580	9.28	3.22	7:18	8:11

Information System

Again, it is assumed that there is a route guidance system located at Node B and that this system is perfect in the sense that it "knows" (i.e., can predict perfectly) the end of an incident after it begins. No delay is assumed between the incident's occurrence and the provision of information (i.e., the incident reporting delay is assumed to be zero). Also, it is assumed that all travelers receive information and comply with it. Guidance is based on minimum predicted cost. For simplicity, the effect of the various guided probabilities that represent the fraction of travelers who follow guidance directives is not considered. Because the information system is updated continuously, possible problems related to overreaction are eliminated (*16*). However, higher benefits could be obtained with lower guided probabilities, because the system, despite its perfectness, does not attempt to minimize system costs. In the case of congestion pricing, the information is provided on the basis of the total cost, including tolls.

When an incident occurs on Link 1 or 2, the information system begins operation. At that point, the number of vehicles on both of these links and the queue lengths are known. Thus, the exit time of the last vehicle on each link to have passed B before the incident can be computed. Because the duration of the incident also is known, the exit time for a vehicle arriving at B on each link can be predicted accurately in the following manner. First, the sum of the arrival time of the vehicle and the free-flow travel time on the link results in the arrival time at the queue. If the last vehicle to exit is still in the queue, then the predicted exit time for the vehicle now at B is the exit time of the last vehicle plus the service time of the queue. Otherwise, the total service time for the queue is added to the arrival time at the queue. The time of the last vehicle to exit each link is then updated according to the route choice made. If the predicted cost of travel on the default route is greater than that of the alternate route by more than a small threshold (to avoid excessive sensitivity), the vehicle is directed to that route.

Results

A macroscopic simulation model was used to evaluate the effectiveness of both a driver information system alone and the integrated driver information and congestion pricing system (*26*). The default route and departure time patterns were calculated using the equilibrium model described above and made discrete for use in the simulation. For each simulation run, a single incident is assumed to occur on either Link 1 or Link 2, which is assumed to affect the capacity of the respective bottlenecks for simplicity. (Alternatively, the free-flow travel time could be assumed to increase as a result of an incident.) The main objective is to evaluate the impact of toll station location on total travel costs, including and excluding toll costs. Because toll stations are placed either at the beginning (B) or end (C) of Links 1 and 2, the objective of modeling random increases in travel time on these links is served adequately by restricting the impact of incidents to capacity reductions in the bottlenecks. This restriction on the location of the incident is somewhat unrealistic because, in practice, incidents may occur anywhere along a highway, but the restriction should not affect the results beyond making the incidents more severe than if their location were allowed to vary. (For a given magnitude and duration of incident, more people are affected if the location is at the bottleneck instead of upstream of it.) Only summary results corresponding to 100-run simulations for each of the different scenarios are provided here; more detail on the simulation results can be found in other work (*13*) in which modifications to both the pricing and the information systems are discussed.

With regard to upstream toll station locations, general conclusions based on the 100-run simulation experiments include the following:

- In the presence of incidents, and without information, toll costs are not affected by the incident, because delays due to the incident arise from queuing in the bottleneck, which is located after (downstream of) the toll stations.
- Information always produced improvements in total costs, excluding tolls. In contrast, providing information may result in negative net benefits when toll costs are included. The main reason is that a net increase in the number of toll-paying commuters results from giving information. The net increase occurs when some travelers on Route 1, whose toll period ends several minutes before it does on Route 2, switch to Route 2 (reducing their number compared with those who had no information), followed by the switching to Route 1 of a subset of the bulk on Route 2, which increases the number of toll-paying travelers. Depending on the magnitude of the benefits in total costs excluding tolls, this increase in toll costs may result in negative benefits including tolls.

General conclusions regarding downstream toll station locations include the following:

- An incident may reduce the total number of toll-paying travelers. Incidents reduce the rate at which travelers exit the bottleneck. If the period during which the incident is in progress overlaps the toll period, fewer travelers pass through the toll station during the toll period. Total revenues decrease in this case. Thus, a certain number of commuters who would pay a toll in the incident-free case now exit the bottleneck late enough to avoid the toll. As a result, the costs, including tolls without information, were generally higher for upstream than downstream toll station locations. When information was supplied, these differences were accentuated because information in the upstream case generally increases revenue as well as increases costs compared with the downstream case. In the latter case, the authors observed a negligible increase in the number of toll-paying travelers because of information. Thus, total travel costs, including tolls, invariably decreased with information. Note that because the toll station location is just before the destination at *C*, equilibrium requires that the ends of the toll period are close to each other, differing only enough to make up for differences in the toll levels on each route. Hence, there is little opportunity to switch to a tolled route from one that is not, or vice versa.
- On the other hand, the time shift in arrivals at the bottleneck caused by the incident may draw travelers into the toll period who do not usually pay the toll, resulting in significantly increased costs for them. This occurs when the incident begins before the start of the toll period and may occur even when information is provided, because some travelers will be between *B* and *C* on the incident route when the incident occurs. If the incident ends before the toll period, the number of travelers passing through the toll station is the same as it would be in the case of no incident, because some travelers are drawn into the toll period who do not pay in the latter case, and an equal number of travelers who usually pay arrive at the toll station after the toll period ends.
- Similar to the upstream case, total travel costs excluding tolls always decreased with information.

The observation that higher costs result from giving information, as sometimes occurred with upstream toll stations, supports the authors' original claim that combining pricing and information systems must be done with an eye to the issues that are unique to the combined systems. Although results may be model sensitive, they provide an incentive to look for such phenomena even when modeling conditions are different. The same can be said for the more robust findings regarding downstream station locations, which emphasize the need to consider possible interactions between the two systems. The impact of incidents on revenues, which in turn might spawn acceptability problems on the part of travelers who face unpredictable travel costs, would all have to be taken into account when designing an actual system. Otherwise, independent design of pricing schemes might fail to consider the role of incidents, which are responsible for both the variability in arrival times at the toll stations and the reduced throughput through the station.

CONCLUSION AND DIRECTIONS FOR FUTURE RESEARCH

The authors have discussed decisions that must be made when designing an integrated driver information and congestion pricing system and have attempted to illustrate the importance of careful design using a simple numerical example. However, it is important to realize that many other issues might arise when driver information systems and congestion pricing systems are implemented together. Future work will examine other issues, whether temporal (i.e., related to how systems are designed to behave in time), spatial (i.e., concerning how systems are designed to behave in space), or demographic (i.e., regarding how systems are designed to behave for different people and vehicles). Various systems will be evaluated on the basis of their acceptability before implementation and their operatability after implementation.

REFERENCES

1. Giuliano, G. An Assessment of the Political Acceptability of Congestion Pricing. *Transportation*, Vol. 19, 1992, pp. 335–358.
2. Poole, R. Introducing Congestion Pricing on a New Toll Road. *Transportation*, Vol. 19, 1992, pp. 383–396.
3. Small, K. Guest Editorial for Special Issue: Congestion Pricing. *Transportation*, Vol. 19, 1992, pp. 287–291.
4. Goodwin, W. The DRIVE Programme, Transport Policy and the Problem of Congestion in Europe, Advanced Telematics in Road Transport. *Proc.*, DRIVE Conference, 1991, pp. 585–593.
5. Van Vuren, T., and M. B. Smart. Route Guidance and Road Pricing—Problems, Practicalities, and Possibilities. *Transport Reviews*, Vol. 10, 1990, pp. 185–203.
6. De Palma, A. A Game-Theoretic Approach to the Analysis of Simple Congested Networks. *AEA Papers and Proceedings*, Vol. 82, No. 2, 1992, pp. 494–500.
7. De Palma, A., and R. Lindsey. *The Potential Benefits of a Combined Route Guidance and Road Pricing System: An Economic Analysis.* Research Paper 92-10. University of Alberta, Alberta, Canada, 1992.
8. Lindley, J. Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions. *ITE Journal*, 1989.
9. Spyridakis, J., W. Barfield, L. Conquest, M. Haselkorn, and C. Isakson. Surveying Commuter Behavior: Designing Motorist Information Systems. *Transportation Research A*, Vol. 25, 1991, pp. 17–30.

10. Mahmassani, H., and R. Jayakrishnan. System Performance and User Response Under Real-Time Information in a Congested Traffic Corridor. *Transportation Research A*, Vol. 25, 1991, pp. 293–307.
11. Vickrey, W. Congestion Theory and Transport Investment. *American Economic Review*, Vol. 59, 1969, pp. 251–260.
12. Dafermos, S., and F. T. Sparrow. Optimal Resource Allocation and Toll Patterns in User-Optimized Transport Networks. *Journal of Transport Economics and Policy*, Vol. 5, 1971, pp. 184–200.
13. El Sanhouri, I. *Evaluating the Joint Implementation of Congestion Pricing and Driver Information Systems*. Ph.D. dissertation. Massachusetts Institute of Technology, Cambridge, 1994.
14. Hau, T. *Congestion Charging Mechanisms: An Evaluation of Current Practice*. World Bank Policy Research Working Papers, World Bank, Washington, D.C., 1993.
15. Kaysi, I. *Framework and Models for the Provision of Real-Time Driver Information*. Ph.D. dissertation. Massachusetts Institute of Technology, Cambridge, 1992.
16. Ben-Akiva, M., A. de Palma, and I. Kaysi. Dynamic Network Models and Driver Information Systems. *Transportation Research*, Vol. 25A, 1991, pp. 251–266.
17. Baumol, W. *Superfairness*. MIT Press, Cambridge, Mass., 1986.
18. Lisco, T. Procedure for Predicting Queues and Delays on Expressways in Urban Core Areas. In *Transportation Research Record 944*, TRB, National Research Council, Washington, D.C., 1983, pp. 148–154.
19. Wardrop, J. G. Some Theoretical Aspects of Road Traffic Research. *Proc., Institution of Civil Engineers*, Part II, Vol. 1, 1952, pp. 325–378.
20. Friesz, T. L., D. Bernstein, T. E. Smith, R. L. Tobin, and B. W. Wie. A Variational Inequality Formulation of the Dynamic Network User Equilibrium Problem. *Operations Research*, Vol. 41, 1993, pp. 179–191.
21. Bernstein, D., T. L. Friesz, R. L. Tobin, and B. W. Wie. A Variational Control Formulation of the Simultaneous Route and Departure-Time Equilibrium Problem. *Proc., International Symposium on Transportation and Traffic Theory*, Elsevier, New York, 1993, pp. 107–126.
22. Arnott, R., A. de Palma, and R. Lindsey. Economics of a Bottleneck. *Journal of Urban Economics*, Vol. 27, 1990, pp. 111–130.
23. Arnott, R., A. De Palma, and R. Lindsey. Departure Time and Route Choice for the Morning Commute. *Transportation Research B*, 1990, pp. 209–228.
24. Small, K. The Scheduling of Consumer Trips. *American Economic Review*, Vol. 72, 1982, pp. 467–479.
25. Bernstein, D., and I. El Sanhouri. A Note on Departure Time and Route Choice for the Morning Commute. *Transportation Research B* (forthcoming).
26. Mukundan, A. A Real Time System for IVHS Traffic Modeling. M.S. thesis. Massachusetts Institute of Technology, Cambridge, 1992.

Publication of this paper sponsored by Committee on Transportation Economics.

PART 4

Socioeconomic Impacts

Community Impacts of Local and Regional Railroads: A Kansas Case Study

VICTOR E. EUSEBIO AND STEPHEN J. RINDOM

A methodology to measure the direct economic impacts of local and regional railroads on small communities in Kansas is provided. An economic model is used to evaluate the economic impacts of decreased transportation costs on a community as a result of rail-using firms contracting with local and regional railroads instead of Class I railroads. Relative changes in employment, payroll, value added, and nonlabor income are estimated for individual counties in Kansas. A majority of the counties can expect slight to moderate (0 to 2 percent) increases in employment, payroll, nonlabor income, and value added. However, there are some counties for which the expected increases in economic activity are substantial. These counties should be examined in greater detail when rail financial assistance programs are considered. The estimated economic benefits from the establishment and continued operation of local and regional railroad systems need to be considered when allocating limited public resources among competing interest groups and development assistance programs.

As Class I railroads continue to downsize their systems, local and regional railroads have acquired rail lines that otherwise would have been abandoned or that major carriers wanted to spin off. From 1970 to 1992, 294 local and regional railroad enterprises with 33 350 km (20,714 mi) were formed in the United States (*1*). At present, they operate 42 665 km (26,500 mi) of road, or roughly a quarter of total U.S. trackage.

The Association of American Railroads defined regional railroads as non-Class I, line-haul freight railroads that operate at least 565 km (350 mi) of road or earn at least $40 million in revenue. Local railroads are freight railroads that are not Class I or regional railroads. They operate less than 565 km (350 mi) of road and earn less than $40 million annually. Local railroads that primarily perform terminal and switching services for other railroads are excluded from the analysis. In this report, the term "short line railroads" is used interchangeably with local and regional railroads.

The short line railroad industry in Kansas has experienced remarkable growth in recent years. In 1989 there were three local railroads in Kansas with total trackage of 678 km (421 mi). In 1993 Kansas had two regional and five local railroads operating 3616 km (2,246 mi) of road (*2*). More may be formed in the future.

Due (*3*) has identified state or local government assistance as one of the determinants of success for short line railroads. Many states and local governments have played an active role in the formation of successful short lines, particularly through the purchase of track. However, the severe budget restrictions facing many states and localities may force them to reevaluate their role in future financial assistance programs.

Although local and regional railroads have proven to be viable transportation alternatives for most rural branch lines, the precise linkage between successful short lines and local economic development is not clear. Further, other interest groups competing for limited public resources (educators, highway users, social welfare programs, tax relief advocates, for example) may question the cost-effectiveness of state aid to short line development as a means of achieving the desired gains in employment, income, and production in rural areas. Therefore, there is a need for more rigorous examination of the impact of short lines on local job creation, income growth and distribution, and increased value-added production, before scarce public funds are allocated to the local short line industry. Estimating the community impacts of local and regional railroads can help redefine the nature, scope, and degree of assistance state and local governments should give to the short line industry in the interest of economic development.

OBJECTIVES

The primary objective of this paper is to provide a methodology to measure the economic impacts of local and regional railroads on small communities in Kansas. The specific objectives are

- To provide a theoretical framework identifying the nature of economic impacts on local communities of local and regional railroads;
- To develop an empirical model to measure the economic impacts of local and regional railroads on income, employment, and production levels in the affected communities; and
- To test the accuracy of the model at the county (community) level.

This study benefited from previous research by Rogstad et al. (*4*), Ferguson et al. (*5*), and Eusebio et al. (*6*) regarding methodology and estimation techniques.

SCOPE OF STUDY

A community or local economy is defined as a county. The analysis given here deals with estimating the economic impacts of successful local and regional railroads on individual counties. It is assumed that the benefits of short line railroad operations are

Kansas Department of Transportation, Docking State Office Building, Topeka, Kans. 66612-1568.

spread proportionately among all firms in the industry and among all affected industries in a county.

Total benefits from short line rail service at the state level do not necessarily equal the sum of the estimated benefits locally. An increase in economic activity in communities with successful short line rail service may be partly offset by declines in other communities. However, a statewide net gain in investment and jobs is the more likely result.

This study provides an estimate of the community impacts of successful short line rail service using available secondary data at the local and state level. In cases requiring a more refined analysis, the same model can be used with the relevant local primary (field survey) data incorporated.

THEORETICAL BACKGROUND

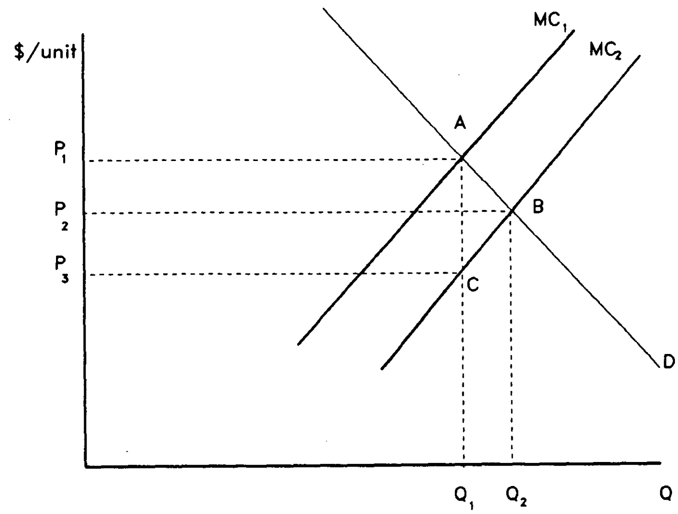
There is evidence that short line railroads have benefited local shippers. A 1989 joint staff study by the U.S. Department of Transportation and the Interstate Commerce Commission (*7*) compared rate levels and quality of service provided to shippers by Class I railroads in the past with those currently provided by short line railroads. Eighty-eight percent of respondents from a nationwide survey of short line railroad shippers reported that their rate levels decreased or remained the same. The same survey also indicated a clear pattern of shipper satisfaction regarding quality of service, with over 94 percent of survey respondents believing that service levels had been maintained or improved.

Babcock et al. (*8*) developed several performance indicators to compare the rate and service levels of current short lines with those of previous Class I railroads. In a survey of 264 shippers in Iowa and Kansas, 85 percent of Iowa shippers and 100 percent of Kansas shippers reported that their outbound freight rate levels (a performance indicator) either decreased or remained the same.

How transportation cost savings that are gained by rail-using firms as a result of rate reduction and improved service quality translate into benefits for the community is an empirical issue addressed in the study.

With the establishment of successful local or regional railroad service in a community, transportation costs, and hence the total costs of rail-using firms, are likely to decrease. The magnitude of decrease depends a lot on the volume of outbound and inbound rail traffic that the firms generate. Conversion from Class I to short line rail operations may mean substantial cost reductions for rail-using firms. Furthermore, the decrease in transportation cost can result in the following: (*a*) an increase in real income of residents in a community arising from lower prices paid for goods and services and (*b*) gains in income or wealth by resource owners in the community in the form of higher factor prices or higher factor usage.

Distribution of transportation savings in terms of gains in real income for rail-using firms, consumers, and resource owners will depend on the nature of product demand and resource supply (Figures 1 and 2). Figure 1 shows a hypothetical example in which a representative rail-using firm faces a fairly elastic product demand curve. A decrease in the cost of rail transportation will enable the firm to decrease its production costs, causing a rightward shift (MC_1 to MC_2) in its supply curve. Rail-using firms benefit by decreasing product price (P_1 to P_2) and increasing sales (Q_1 to Q_2). Consumers benefit from the price decrease by buying more of the commodity rather than higher-priced substitutes. In the example,



Transportation Savings/unit: $P_1 - P_3$

Total Gain: P_3CBAP_1

Consumer Gain: P_2BAP_1

Firm Gain: P_3CBP_2

FIGURE 1 Consumer and firm gains.

both the firm and consumers benefit from the decrease in transportation cost with the distribution of benefits swaying in favor of the firm as product demand becomes more elastic.

Figure 2 shows a hypothetical example in which a representative rail-using firm faces a fairly elastic factor supply curve, S. An increase in the quantity of a product demanded by consumers will require the firm to increase production. This in turn will increase the firm's demand for a factor (labor) and hence a rightward shift (D_1 to D_2) in the factor demand curve. Faced with an increase in demand for their services, resource owners will provide their labor at a higher price (wage rate). In the example, both the firm and resource owners benefit from a reduction in rail transportation cost with distribution of benefits swaying in favor of the firm, as factor supply becomes more elastic.

At the community (local economy) level, gains in income for rail-using firms, consumers, and resource owners translate to changes in output, employment, and wage levels as well as changes in returns to capital and land.

EMPIRICAL MODEL

An economic model is used to evaluate the impacts of a decrease in transportation cost on the local economy. The six-equation model is based on the traditional competitive model, which assumes that each rail-using firm within an industry is identical and follows profit-maximizing behavior in a perfectly competitive market setting. Mathematical derivations of the economic model are available from the authors on request.

The model estimates the impact of a decrease in transportation cost on changes in employment, payroll, value added, and nonlabor income at the county level. Change in employment relates to possible decreases in unemployment rates, whereas change in payroll is associated with increases in the income levels of the

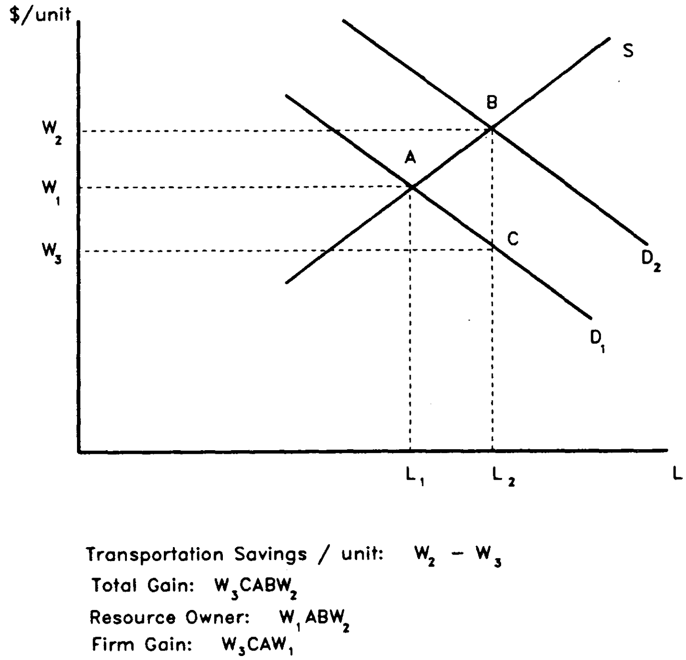


FIGURE 2 Resource owner and firm gains.

indigenous population. Change in value added takes into account possible increases in the value of the contribution to production due to labor and capital services employed in the locality. Change in nonlabor income is the difference between the change in value added and the change in payroll, and it is associated with increases in the amount of "property-type" capital services used.

Changes in employment, payroll, nonlabor income, and value added are multiplied by an income multiplier of 1.9 to capture the first-round impacts of increased spending on consumer and investment goods on the local economy. Earlier transportation studies cited by Ferguson et al. (*5*) suggest that the local portion of household expenditure may be as high as 50 percent. That translates into a community spending income multiplier of 1.9, assuming a marginal propensity to consume of 0.95. Secondly, changes in all output variables are reduced by a factor to reflect the general importance of short line rail service in the community. The factor is defined as the ratio of carloads handled by short lines to total rail carloads handled in the county.

Components of the Model

Six industries judged to be users of rail transportation are included in the model. These industries are agriculture, agricultural services, mining, construction, manufacturing, and wholesale and retail trade.

The key economic (nontransportation) parameters include share of payrolls in value added (α), elasticity of substitution (σ), price elasticity of (product) demand (η), supply elasticity of labor (ϵ_L), and supply elasticity of capital (ϵ_K) (Table 1).

Lastly, the model includes several transportation parameters, including rail input coefficients I(I), rail inbound/outbound coefficients O(I), and ratios of short line rail operating costs to Class I rail operating costs F(I) (Table 1).

Model Simulations

Two simulations are done: (*a*) the current network of local and regional railroads in Kansas and the trackage they operate and (*b*)

TABLE 1 Economic and Transportation Parameter Estimates by Industry Group

Industry	ϵ_K	ϵ_L	α	η	σ	I(I)	O(I)	F(I)
Agriculture	.1	6.9	.27	-2.8	1.01	.000	.035	0.67
Ag. Services	.1	6.9	.63	-2.8	1.01	.002	.000	0.67
Construction	.1	10.4	.53	-0.2	1.01	.002	.000	0.67
Manufacturing	.1	7.1	.56	-1.2	1.01	.009	.005	0.67
Mining	.1	10.4	.37	-0.5	1.01	.004	.001	0.67
W & R Trade	.1	4.9	.45	-1.6	1.01	.011	.001	0.67

an expanded network of local and regional railroads, operating lines with traffic density between 0.03 million and 8.0 million gross ton-km per km (0.02 million and 5.0 million gross ton-mi per mi) per year. The FRA criterion for rail line rehabilitation funds is arbitrarily used as the standard for lines that may be candidates for future short line railroad industry expansion.

Fifty-two counties have rail lines operated by local and regional railroads. Only short lines performing line-haul operations are included in the analysis. They are the Central Kansas Railroad; Garden City Western Railway; Kansas Southwestern Railway; Kyle Railways, Inc.; Northeast Kansas & Missouri Railroad; Southeast Kansas Railroad; and Southern Kansas & Oklahoma Railroad.

Eighty-one counties have light-density lines that meet the traffic criterion. This scenario also implies that not all line segments currently operated by local or regional railroads may survive into the future, because a few of the line segments may have traffic below the set minimum.

Data Sources

Data regarding employment, income (payroll), value added, and value of shipments in Kansas were obtained from the Department of Commerce publication series *County Business Patterns* (*9*) and *Census of Industries* (*10*). Employment and wage data by county and by industry were provided by the Kansas Department of Human Resources (*11*).

Elasticity estimates were obtained from the following sources: Rogstad et al. (*4*), Ferguson et al. (*5*), Eusebio et al. (*6*), Berndt and Wood (*12*), and Wohlgenant (*13*).

Class I and short line transportation coefficients by industry were calculated using the following reports: Tolliver (*14*), Emerson (*15*), the Association of American Railroads (*16*), Dooley (*17*), and the U.S. Department of Commerce (*18*).

Estimates of rail traffic tonnage and revenue by shipping and receiving point were obtained from the 1989–1991 Interstate Commerce Commission Carload Waybill Data and from marketing and management personnel of local and regional railroads in Kansas.

RESULTS

Table 2 gives frequency distributions of percent changes in county employment, payroll, nonlabor income, and value added for two scenarios: (*a*) the present network of local and regional railroads in Kansas and their existing systems of branch lines and (*b*) an expanded network of local and regional railroads operating light-density branch lines meeting the FRA traffic criterion.

The growth in economic activity for rural communities is attributed to conversion of marginally profitable lines previously operated by Class I railroads to financially viable lines operated by local and regional railroads.

The following generalizations can be made: First, a majority of the counties can expect slight to moderate (0 to 2 percent) increases in employment, payroll, nonlabor income, and value added. There are, however, some counties in which the expected increases in economic activity are substantial. These counties should be examined in greater detail when rail financial assistance programs are considered. Second, lower-paying jobs will be created as employment growth outpaces any increase in payroll for most counties. Third, increases in the value of contribution of local resources to production will largely come from capital or "property-type" services and not from labor. This is certainly true for most farming states (including Kansas) where large-scale and highly mechanized agricultural systems dominate. Lastly, even bigger economic benefits are possible if the short line railroad industry in Kansas expands operations to take over rail lines currently operated by Class I railroads that meet the predetermined traffic density criterion.

Impacts on Low- and High-Population Counties

Community impacts of local and regional railroads are compared for low- and high-population counties for both scenarios (Table 3). Results indicate that less populated counties (those with a population less than 2,500) stand to benefit more than the more populated counties (those with populations greater than 25,000). Less populated counties seem to have greater reliance on rail service than more populated counties, where other transportation options are available. Consequently, the smaller communities are the most

TABLE 2 Change in Employment, Payroll, Nonlabor Income, and Value Added: Present and Expanded Short Line Networks

Simulation/ Economic Indicator	Percent Increase			Total Counties
	0-1%	1-2%	>2%	
Present Network				
1. Employment	30	18	4	52
2. Payroll	52	0	0	52
3. Non-Labor Income	26	22	4	52
4. Value Added	32	19	1	52
Expanded Network				
1. Employment	27	39	15	81
2. Payroll	80	1	0	81
3. Non-Labor Income	26	45	10	81
4. Value Added	37	42	2	81

TABLE 3 Average Percentage Increase in Employment, Payroll, Nonlabor Income, and Value Added Comparisons

Category/ Simulation	Number of Counties	Ave. Percentage Increase			
		Employ	Payroll	Non-Labor	Value-Added
1. Population					
<u>Present Network</u>					
Low Pop'n	4	1.8	0.7	1.4	1.1
High Pop'n	9	0.4	0.2	0.6	0.4
<u>Expanded Network</u>					
Low Pop'n	7	2.0	0.7	1.4	1.2
High Pop'n	15	0.6	0.3	0.9	0.6
2. Sector					
<u>Present Network</u>					
Agric.	10	0.5	0.2	0.9	0.6
Non-Ag.	4	1.7	0.5	1.0	0.9
<u>Expanded Network</u>					
Agric.	13	0.5	0.2	0.9	0.6
Non-Ag.	7	2.2	0.7	1.3	1.1
3. Shipment					
<u>Present Network</u>					
LDCs	12	1.2	0.5	1.1	0.8
HDCs	3	0.4	0.2	0.6	0.5
<u>Expanded Network</u>					
LDCs	20	1.8	0.6	1.3	1.0
HDCs	5	0.5	0.5	1.3	1.0

positively affected by the conversion from Class I to short line railroad operations on rail branch lines.

Impacts on Agricultural and Nonagricultural Counties

Community impacts of short line railroads are compared for agricultural and nonagricultural counties for both scenarios (Table 3). Results indicate that counties that are largely agricultural (payroll share from agriculture as a percentage of total six-industry payroll greater than 75 percent) stand to benefit more from short lines than nonagricultural counties (payroll share less than 10 percent). This outcome is hardly surprising considering agriculture's historic dependence on the railroad system to deliver products to local or national markets. This dependence will likely continue with the emergence of local and regional railroad systems on lines previously operated by Class I railroads.

Diversification and Local Economic Development

The impacts of the short line railroad industry on local economic development in highly diversified counties (HDCs) are compared with the impacts in less-diversified counties (LDCs) for both scenarios (Table 3). A diversification index is calculated as the inverse of the sum of the squared value of shipment ratios for individual industries in a county. Results indicate that counties that are highly diversified (diversification index > 4.0) stand to benefit less from short lines than counties with less-diversified economies (index < 2.0).

Studies by Babcock et al. (*8*) and Wolfe (*19,20*) have reported the benefits to local and regional railroads of a diversified traffic stream to minimize the downturns and degree of dependence within individual industries. Whereas traffic diversification may be essential to the success of a local or regional railroad, its benefits do not extend as well to local economic development.

The following explanations are offered: (*a*) Short line railroads, when transporting commodities that have relatively elastic transportation demand (like grain and coal), decrease rail rates to increase rail revenue. The fact that the railroad's fortunes may be so closely linked to these commodities (and industries) may serve as an added incentive to cut rates to keep the traffic base from switching to alternative modes of transportation. As a result, railroad profits may have been passed on to rail-using firms and to the local community in the form of reduced rail rates. (*b*) Faced with a diverse traffic base from HDCs, short line railroads can exercise price discrimination between low-valued commodities, with relatively elastic transportation demand, and high-valued commodities, with relatively inelastic transportation demand (such as manufactured goods). Also, loss in traffic from one commodity or industry can be made up by traffic gains in other industries. As a result, short line railroad industry profits may have been maximized with less benefits passed on to rail-using firms and the local community.

CONCLUSIONS

The major railroads continue to downsize their rail networks. There is a need to preserve vital rail service, especially in rural areas, through the creation or expansion of local and regional railroads.

This paper provides evidence that local and regional railroads in Kansas have direct and positive economic impact on local-community income, job growth, and value-added production. Consequently, economic benefits from the establishment and continued operation of short lines need to be considered when allocating limited public resources among competing interest groups. Not only does the conversion of marginally profitable Class I lines to short lines positively affect local communities, it also avoids the alternative of rail abandonment and the adverse effects abandonment has on these communities.

ACKNOWLEDGMENTS

This study was supported by the Kansas Department of Transportation Bureau of Rail Affairs.

The authors acknowledge the helpful comments of Orlo Sorenson of Kansas State University and John R. Scheirman of the Kansas Department of Transportation.

REFERENCES

1. Due, J. F., and S. D. Leever. *The Post-1984 Experience with New Railroads Formed To Take Over Lines Spun Off or Abandoned by Railroads.* Bureau of Economic and Business Research Working Paper 22, University of Illinois at Urbana-Champaign, Sept. 1992, 46 pp.
2. *Kansas Rail Plan, Update 1992.* Kansas Department of Transportation, Bureau of Rail Affairs.
3. Due, J. F. New Railroad Companies Formed To Take Over Abandoned or Spun-Off Lines. *Transportation Journal,* Vol. 24, No. 1, 1984, pp. 30–43.
4. Rogstad, B. K., et al. *Analysis of Alternative Subsidy Programs: Impact on Regional Development.* U.S. Department of Commerce, Aug. 1973, 305 pp.
5. Ferguson, A. R., et al. *Community Impacts of Abandonment of Rail Service.* U.S. Department of Commerce, Dec. 1974, 219 pp.
6. Eusebio, V. E., S. J. Rindom, and A. Abderrezak. Community Impacts of Abandonment of Rail Service in Kansas. *Kansas Business Review,* Vol. 15, No. 3, 1992, pp. 23–33.
7. *A Survey of Shipper Satisfaction with Service and Rates of Shortline and Regional Railroads.* Joint Staff Study, U.S. Department of Transportation and the Interstate Commerce Commission, Aug. 1989, 29 pp.
8. Babcock, M. W., E. R. Russell, M. Prater, and J. Morrill. *State Short Line Railroads and the Rural Economy.* Midwest Transportation Center, Ames, Iowa, 215 pp.
9. *County Business Patterns, 1987: Kansas.* U.S. Department of Commerce, Bureau of Census, 1988.
10. *1987 Census of Industries.* Kansas and Area series. U.S. Department of Commerce, Bureau of Census, 1988.
11. *Kansas Employment and Wages 1989.* Kansas Department of Human Resources, Labor Market Information Services, 64 pp.
12. Berndt, E. R., and D. O. Wood. Technologies, Prices and the Derived Demand for Energy. *The Review of Economics and Statistics.* Vol. 57, 1975, pp. 259–268.
13. Wohlgenant, M. K. Demand for Farm Output in a Complete System of Demand Functions. *American Journal of Agricultural Economics,* Vol. 71, 1989, pp. 241–252.
14. Tolliver, D. T. *The Adoption and Use of the Uniform Railroad Costing System: Ex Parte 431.* Upper Great Plains Transportation Institute Paper 55, Sept. 1983, 24 pp.
15. Emerson, M. J. *The Kansas Input-Output Model: A Study in Economic Linkages.* Bulletin 655, Agricultural Experiment Station, Kansas State University, Manhattan, 9 pp.
16. *Railroad Facts: 1991 Edition.* Association of American Railroads, Economic and Finance Department, Washington, D.C., 64 pp.
17. Dooley, F. J. *Economies of Size and Density for Short Line Railroads.* Mountain-Plains Consortium Report 91-2, April 1991, 118 pp.
18. *Standard Industrial Classification (SIC) to Standard Transportation Commodity Classification (STCC) Code Equivalence Table.* U.S. Department of Commerce, Bureau of Economic Analysis, 1991.
19. Wolfe, K. E. The Downside Risk: An Analysis of Local and Regional Railroad Service Failures. *Journal of the Transportation Research Forum,* Vol. 29, No. 1, 1988, pp. 124–137.
20. Wolfe, K. E. Financial and Demographic Conditions Associated with Local and Regional Railroad Service Failures. *Transportation Quarterly,* Vol. 43, No. 1, 1989, pp. 3–28.

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Kansas Department of Transportation.

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

Estimated Impact of Widening U.S. Highway 80 (Marshall Avenue) in Longview, Texas

JESSE L. BUFFINGTON AND MARIE T. WILDENTHAL

The effects during and after construction of a highway widened to install a continuous two-way left-turn lane with curbs and gutters are documented. A 10.89-km (6.7-mi) section of U.S. Highway 80, known as Marshall Avenue, in Longview, Texas, was widened in this manner between 1989 and 1991. Before the addition of the continuous left-turn lane, five intersections were widened. A study of the effects of the latter construction was completed in 1987, and the data collected at that time serve as the "before construction" data for the present study. Data were also collected during and after construction of the two-way continuous left-turn lane. The data collected included information on abutting businesses' assessments of the impact of construction on their businesses, estimates of parking availability and use, and the impacts of the construction expenditures on the local area or city. Most businesses' number of usable parking spaces, customers per day, full-time and part-time employees as well as gross sales and net profits were unaffected, either during or after construction. Over half of the 1987 abutting businesses experienced no change in their number of parking spaces. Longview land and property values peaked in 1986 and fell until Marshall Avenue construction started. Subsequent increases in values were not necessarily related to the construction. Construction expenditures in Texas totaled $8.1 million. The Texas input-output model estimates the impacts of these expenditures to be $29.9 million in additional output and 514 jobs for the statewide economy.

Departments of transportation (DOTs) continually are faced with the responsibility of providing safe and congestion-free highways. One of the ways that the DOTs are accomplishing this task is by widening and adding travel lanes to existing highways. In many cases, these highways are widened enough to install a continuous two-way left-turn lane in the median and curbs and gutters at the margins. Additional right-of-way has to be acquired from owners of abutting property to make these improvements on some highways.

Many business and property owners who potentially may be affected by the construction ask questions about the negative economic impacts. Some are concerned about losing shoulder and private parking space for their customers, the ability of their customers to safely turn into their parking lots if curbing restricts continuous access to their parking lots, and the economic impact, specifically on land value, land use, and their businesses, of such an improvement. Unfortunately, the only studies found in the literature dealing with any of the impacts of highway widening projects that add a two-way continuous left-turn lane discuss the benefit-cost and land use impacts.

This paper provides a complete economic impact study, encompassing land use, land value, business, and parking impacts. Texas Transportation Institute (TTI) has another highway widening study under way that will provide additional findings for use in estimating the positive and negative impacts of the same type of improvement on other highways. Even so, there is a need for several more case studies of different types of widening projects to establish a minimal data base for estimating all related economic impacts of such improvements on those directly affected as well as the city as a whole. Also, the results could be used as supporting data for the environmental assessment (EA) required for proposed projects before approval can be obtained from FHWA. Need for supporting data for EAs was dramatized in the case of the proposed widening of U.S. Highway 80 in Longview, Texas. As a result, the Texas Department of Transportation (TxDOT) asked TTI to estimate the expected economic impact of the proposed improvement. The initial study was completed in September 1987. The findings were based on traffic counts, instrumented vehicle runs, parking surveys, and the opinions of businesses, especially those located along five short sections widened to install protected left-turn lanes at major intersections. These findings were submitted as part of the EA to FHWA for approval, which was granted.

Before construction, parking space availability and use, business volumes, and employment levels were fully documented. The proposed improvement was approved and went to contract in fall 1989; it was completed in fall 1991. Then, a follow-up study was authorized by TxDOT, and similar data were collected during and after construction. Construction activity and expenditures were monitored. In short, a complete impact analysis, covering before, during, and after construction, was performed.

METHODS

Four aspects of the construction are evaluated: Mail and interview surveys of businesses abutting the construction were conducted to determine impacts on sales, employment, number of customers, and number of parking places. Additional parking surveys were conducted for businesses that were expected to have a parking availability problem. Land and property values were studied to determine construction impacts. Input-output analysis was used to determine the employment and output impacts of the construction expenditures on Texas.

ESTIMATED IMPACT ON BUSINESSES

By 1987 five intersections had already been widened to include a left-turn lane. Three intersections were widened in 1974, and the

Texas Transportation Institute, TTI/CE Building, Suite 609, Texas A&M University, College Station, Tex. 77843-3135.

other two were widened in 1986. The impacts of these widenings were discussed in an unpublished report in 1987 (Buffington et al., unpublished data). The five widened intersections included 45 businesses, 39 of which were willing to respond to a 1987 in-person survey on the impacts of widening the intersection (87 percent response rate). In the following discussion, the 1987 actual impacts during and after construction for these five intersections (hereafter referred to as previously widened sections of the highway) are compared with those impacts of widening construction for a continuous left-turn lane for the unwidened sections.

The previously widened sections were minimally affected by the widening of the remaining portions of Marshall Avenue. Realignment of the curbs, new surface treatment, and new pavement markings were the principal improvements made in these sections during the latter construction. Also, widening of the remaining sections was anticipated, as portions most distant from the intersection were already being used to some extent to make left turns into parking spaces of businesses on the opposite side of Marshall Avenue.

In 1992 each business abutting the previously and newly widened section of U.S. Highway 80 (Marshall Avenue) was surveyed by mail to determine the impacts of the construction on the businesses. The completely widened section extends between Eastman and Fisher roads. Three hundred seventy-one operating businesses were located on this section when the survey was administered in August, 1992, compared with 331 in 1987, a 10.08 percent increase during the period. Most 1992 businesses were involved in retail sales and service. Forty-six businesses (12 percent) completed all or part of the 1992 survey. The 1992 results are reported only for those who answered the question, not for those who left the question blank. There were no respondents from gas stations, convenience stores, motels, food and liquor stores, or house-trailer businesses. Between 6 and 29 percent of other types of businesses responded to the survey. Seven (16 percent) of these respondents were located along sections at the five major intersections that were widened before 1991, representing 10.5 percent of all businesses operating along the 10.89-km (6.7-mi) previously and newly widened sections.

Note that because of the low response rate of the 1992 survey, the survey results may contain nonresponse errors. This means that the final sample may not fully represent what happened to the whole population of businesses. However, 100 percent of the whole population of operating businesses had an opportunity to respond. Also, because the number of 1992 respondents is greater than 30, the chance of nonresponse errors or nonrepresentativeness of the findings is low (*1*). Further, the sampling error can be estimated adequately by the size of the sample (*2,3*). Finally, the findings of the 1992 survey are logical. Similar surveys are now conducted in person with almost a 100 percent response rate for the new widening study.

The business owners were surveyed about changes in their number of usable parking spaces, gross sales, net income, the number of full-time and part-time employees, and the number of customers per day. Respondents were asked to indicate impacts both during and after construction.

There was little difference between survey responses about the impacts during construction versus after construction for a single year. However, the answers differed between the years. A possible explanation for this is that 1987 data combined responses of "don't know" with responses of "no answer," whereas 1992 data eliminated answers from nonrespondents. The responses to individual questions are summarized below.

Usable Parking Spaces

Longview's businesses generally did not experience increases in usable parking spaces either before or during construction in either 1987 or 1992. Only 3 percent of the 1992 respondents, during or after construction, responded with "don't know," whereas 44 percent gave this response in 1987. Approximately one-third of the 1987 respondents experienced no change in number of parking places, whereas approximately three-fourths of the 1992 respondents experienced no change. Roughly 20 percent of the businesses experienced a decrease in parking spaces for both years. Therefore, most respondents did not experience a change in number of parking spaces during or after construction. However, if they did experience a change, it was for the worse.

Customers per Day

Generally businesses did not experience an increase in the number of customers per day either before or during construction for either of the two survey years. In 1992 the number of customers for most businesses did not change, whereas the number of customers for approximately 20 percent of 1987 businesses did not change. More businesses had fewer customers during the construction than afterwards, although the percentage of responding businesses experiencing a decrease in 1987 (41 percent) was twice the percentage of those with similar experiences in 1992 (27 percent). After construction, only 16 percent of the 1987 businesses and 9 percent of the 1992 businesses experienced a decline. Approximately 47 percent of the 1987 respondents did not know or did not answer, compared with roughly 8 percent of the 1992 businesses.

Therefore, because the number of parking spaces generally was not affected, construction might have hurt business accessibility. Finished construction may not improve or may hinder accessibility as compared with accessibility before construction. Also, people get out of the habit of going to a place if it is difficult to gain access. When a business is accessible again, former customers may not think about coming back.

Full-Time and Part-Time Employees

Although the businesses were asked about full-time and part-time employees in different questions, their answers for each were basically the same. None of the businesses increased its number of employees either during or after construction for either study year. Approximately 40 percent of the 1987 businesses and 90 percent of the 1992 businesses had the same number of employees during and after construction. Approximately 13 percent of the 1987 businesses hired fewer employees during or after construction, whereas roughly 5 percent of the 1992 businesses did so. Although approximately 47 percent of the 1987 businesses said that they did not know, or simply did not respond to the question about employees, only 3 percent of the 1992 businesses responded that they did not know. In sum, few businesses laid off any employees, and most tried to retain them.

Gross Sales and Net Profit

Businesses also were asked about gross sales and net profit separately, as they were for full-time and part-time employees, but their responses for both were very similar. Less than 3 percent of the 1987 businesses experienced increased sales or profit, whereas approximately 5 percent of the 1992 businesses had such an experience. The sales and profit of roughly 22 percent of the 1987 businesses did not change, although approximately 72 percent of the 1992 businesses experienced such changes. More businesses experienced decreased sales and profit during the construction than afterwards, although the percentage of responding businesses experiencing a decrease in 1987 (41 percent) was twice as much as the percentage with similar experiences in 1992 (19 percent). This fact could be related to the decrease in the number of customers experienced by many businesses during the construction. After construction, only 18 percent of the 1987 businesses and 3 percent of the 1992 businesses experienced a decline. This situation could be related to customers getting out of the habit of shopping at a certain store during construction and not going back once the construction was completed. Whereas approximately 47 percent of the 1987 respondents did not know or did not respond to the question, only 12 percent of the 1992 respondents did not know how their sales and profit were affected.

ESTIMATED IMPACT ON PARKING

In 1987 Buffington et al. indicated that many of the businesses along Marshall Avenue in the 10.79-km (6.7-mi) study area were concerned that widening the sections of the highway that had not been widened previously at intersections would have a negative impact on available customer parking (unpublished data). Exacerbating the problem was the fact that many of the businesses were housed in older buildings located too close to the right-of-way. Many did not have the minimum number of parking spaces required by the city's zoning ordinance at that time. Some businesses depended on Marshall Avenue's sloped paved shoulders for much of their parking.

In the last section, the parking problem was addressed through the eyes of the businesses. To further determine the magnitude of the parking problem, surveys on parking space availability and use were conducted. A parking-space availability survey was done with the use of a 1986 aerial photograph, a detailed design schematic, and an on-the-ground inspection of the premises of each business. An estimate of the number of available parking spaces before and after construction was established. Annual parking space use surveys of selected businesses were done by on-the-ground inspection.

Before the highway widening construction, both parking space availability and use included space on the paved shoulder in front of the premises of each business. All of the paved shoulder is on the highway right-of-way, and parking on the shoulder is illegal. However, the standard dimension of 2.75 by 6.10 m (9 by 20 ft) for each parking space was used to estimate the number of passenger vehicles that could park on the paved shoulder in front of each business.

Effects on Parking Space Availability

The results of the 1987 parking space availability survey are summarized. The survey did not include the side and back spaces of businesses that had adequate front, side, or back parking. None of the shoulder spaces available to the businesses before construction were available after the construction started on a particular section of the project. Projections in 1987 forecast a 2 percent loss of the front parking spaces of all businesses and a maximum loss of 9.7 percent of all available shoulder and front parking spaces. More than half were expected to experience no change in their number of parking spaces, and only four (1 percent) would lose more than eight parking spaces. A higher percentage of the open businesses would experience no more change in available parking spaces than would be the case for closed businesses.

The study focused on the parking spaces available before and after construction for 118 of the 1987 businesses (open and closed) that were expected to experience a parking space availability problem. A total of 300, or 22 percent of the parking spaces, would be lost because of the construction. The average number of available parking spaces per business would drop from about 11.5 spaces to 9 spaces, a reduction of 2.5 spaces per business.

Effects on Parking Space Use

Since 1987, parking demand for a selected group of businesses that were expected to have a parking availability problem has been studied on an annual basis. by 1992, the number of businesses or parking lots monitored for parking demand had been reduced, partially because a small shopping center, structurally damaged by the explosion of a nearby railcar, had been demolished and some businesses closed. (Parking capacity data were unavailable for one business.) About 24 of the 114 businesses surveyed in 1987 already were experiencing a shortage of available parking spaces. Following construction, the number has not changed, but some businesses now have a smaller parking surplus, and other businesses have closed.

To analyze further the severity of the parking space availability versus use problem, all businesses having 10 or fewer spaces after construction were identified and classified according to levels of parking space use. Eleven parking loss levels were used for comparison. In 1992, the same percentage of businesses were under capacity as in 1987, a higher percentage were over capacity, and a lower percentage either were closed or did not know their status. Overall, a higher percentage of the businesses lost all of their available spaces in 1992 than did so in 1987. However, a lower percentage of the businesses with overcapacity lost all of their available parking spaces in 1992 than did so in 1987. Even so, more of these businesses experienced a deterioration in parking use and availability during and after construction.

ESTIMATED IMPACT ON PROPERTY VALUES AND USES

A limited amount of data were collected to provide some indication of the extent of property value and use impacts. Data were collected from the Gregg County Appraisal District, local real estate appraisers, and the city of Longview to estimate abutting property value and land use impacts of the widening project. Property values, building permits, and property uses were the three types of data collected.

Property Values

During the years before the widening of U.S. Highway 80, specifically between 1985 and 1989, property values fell in Longview. The decline, which was observed in both land and building values, was partly caused by the oil recession. One appraiser also noted that Longview property values peaked in 1985 because of overbuilding. Land and building values on Marshall Avenue fell similarly to the decline in Longview property values overall. The overall decline was exacerbated by the continuation of the late 1960s to early 1970s trend of building north of U.S. Highway 80.

By the time that the widening construction of U.S. Highway 80 began, Longview land and building values had leveled off and were beginning to rise. Land values on U.S. Highway 80 were behaving similarly. One appraiser noted that the construction slowed down the traffic on U.S. Highway 80, thus making it a more desirable location. He indicated that property values were related to the condition of the property but were generally falling because of the earlier neglect of buildings.

Only one year of after-construction property value is available. Trends evident during construction are still present. The increase in value between 1991 and 1992 is not as great as the increase between 1990 and 1991, however. Obviously, more time is needed to assess even the short-run after-construction impacts.

Building Permit Data

Demolition Permits

Earlier neglect of buildings can be traced through building demolition data available from the city of Longview. Between 1984 and 1989, there were only a few building demolitions each year. During the construction period, there were more demolitions. However, there were more commercial demolition permits issued the first year after construction than in any previous year. This increase supports the contention that Marshall Avenue property had been neglected, requiring demolition of existing buildings to take advantage of the renewed interest in building in this location. It is important to note that many kinds of work, including petroleum tank removal, are classified as building demolition.

Building Permits

The highest value of construction occurred between September 1984 and August 1985. Sixteen permits were issued between 1984 and the start of construction, and three permits were issued during the construction period. This decline supports the appraisers' view that Longview is overbuilt or that businesses are building north of Highway 80. Whereas $1.64 million in new construction permits was issued in the last year of construction, only $12,300 worth of permits was issued after the construction was completed. The building permits for new construction neither support nor refute the contention that there is renewed interest in building on Marshall Avenue. Note that the permits filed are for installation of signs, offices, and electrical plugs and are not necessarily related to the highway construction.

Remodeling Permits

City residents faced with the possibility of highway widening feared they would lose part of their property for highway right-of-way. For this reason, permits for remodeling purposes were investigated. The permits applied for after the construction was completed were related mainly to routine improvements such as installing electrical outlets, signs, lavatories, air conditioning, heating furnaces, roofing, or sprinkler systems. It appears that Longview residents did not have to do extensive remodeling in the aftermath of U.S. Highway 80 widening.

Property Uses

Most properties had the same use throughout the study period. Property use changes that did occur included the addition of new retail outlets built on previously vacant land toward the end of the construction period. The new highway improvement may have influenced these use changes.

In 1991 more than 40 percent of the properties abutting Marshall Avenue were used as sites for retail businesses. Another 14 percent were being used for other commercial, office, and industrial purposes. About 25 percent of the properties were still vacant land. The remainder of the properties were used to house public activities, religious activities, or single- and multiple-family dwellings.

ESTIMATED ECONOMIC IMPACT ON THE LONGVIEW AREA

The general economic impact on Longview and the surrounding area of the proposed change in Marshall Avenue is estimated on the basis of the impact on businesses along the facility and multiplier effects of the project expenditure on the Longview area.

Impact on Business

In 1987 a few small businesses were expected to go out of business because of the loss of parking and the negative effects of construction. Less than one-third of the responding businesses thought that the long-term business effects would be negative, and businesses along previously widened sections expected that fewer jobs would be lost than did businesses abutting newly widened sections. Temporary effects on the businesses' number of employees, gross sales, and net profits were expected to be negative.

Fewer businesses had negative expectations in 1992 than in 1987. Most businesses experienced no change in the number of usable parking spaces, the number of customers per day, or the number of full-time and part-time employees. Gross sales and net profit received a less negative response, with 3 percent of the respondents noting a decline and 79 percent indicating no change. Some smaller businesses closed, but that is normal on Marshall Avenue and cannot be directly attributed to the widening construction.

Impact of Project Expenditure

U.S. Highway 80 construction costs totaled $9,544,420.01, more than half of which was spent in the Longview area; $2,616,400.48

was spent on Longview area construction materials, $1,448,503.77 went to Longview area laborers, and $1,526,559.31 in overhead expenses was paid to Longview area businesses. Longview area businesses appeared to receive the most patronage for each type of expenditure because less—$2,331,028.84 worth of materials, $783,837.65 worth of labor, and overhead expenditures of $838,089.96—was purchased from businesses not located in Longview.

Employment and output multipliers were developed from the 1986 Texas input-output model to produce statewide estimates of the impacts of widening expenditures for U.S. Highway 80. Note that there are many limitations to using input-output models; these models are only mechanisms for gauging impacts. Impact estimates are made using the most applicable expenditure category in the input-output model, which is Category 20, new road/highway construction. The estimated employment multiplier for new road/highway construction is 53.7601 people per $1 million of expenditures. This includes the direct impact of the construction expenditures, the indirect impacts on the suppliers, and the induced effect of increased consumer spending. Because costs have risen since 1986, the multiplier can be adjusted using the TxDOT construction cost index, which gives an adjustment factor of 1.1191 for 1991. An adjusted employment multiplier of 63.5 is generated by dividing the 1986 employment multiplier by the 1991 construction cost index. Applying this multiplier to the $8.1 million construction costs spent in Texas indicates that widening Highway 80 generated about 514 jobs for the statewide economy. It is unknown how much employment was generated in the Longview area.

The total output multiplier is $3.69 of output per dollar of expenditures. Applying this multiplier to the $8.1 million of construction expenditure in Texas indicates that widening Highway 80 generated about $29.9 million in additional output. Again it is unknown how much of this increase benefited the Longview area.

Local impacts of construction expenditures are difficult to determine because the Texas input-output model is designed to average the economic relationships for all communities in Texas. Therefore, it is not representative of any specific city. Estimates of the economic benefits from the Longview area expenditures can be made, but extreme caution should be exercised in the use of the estimates provided in this report. The total amount of expenditures made to Longview area vendors was $5.59 million. Applying the Texas input-output multipliers to this value yields an estimated impact on Longview employment of 355 new jobs and $20.6 million of additional output.

A benefit-cost model was also used to analyze the benefits and costs to motorists of the highway widening construction. The model and its implementation are presented in the paper by Wildenthal et al. in this Record. The benefit-cost ratio was 7.82, which means that the motorists are receiving $7.82 in benefits for every dollar spent on the project.

SUMMARY

Estimated Business Effects

Abutting businesses were asked about the impacts of widening Marshall Avenue on various aspects of their businesses, including the number of parking spaces, customers, and employees as well as sales and profits. For the most part, the 1987 survey respondents' experiences were much more negative than those of the 1992 respondents. A lower percentage of the 1992 respondents experienced a negative impact during and after construction on all aspects of their businesses except for usable parking spaces. A much lower percentage of the 1992 respondents experienced a negative impact on their business after construction than during construction. Had the construction period been a year longer and had there been less cooperation between all concerned—the businesses, the contractor, and TxDOT—the negative impacts, at least during construction, could have been greater.

Parking Impacts

In 1987, more than half of the businesses abutting the widened section of Marshall Avenue were expected to experience no change in their number of parking spaces. Firms that were expected to have inadequate front, side, or shoulder parking were selected for a follow-up study through 1992. The number of businesses expected to have a serious parking problem increased during and after construction. However, a higher percentage of these businesses than anticipated had adequate parking after the construction.

Property Value and Use Impacts

Longview's land values peaked in 1986 and fell until Marshall Avenue construction began. Land values began to rise at that time but still have not reached their 1985 and 1986 levels. Property along Marshall Avenue was affected by the land value trend as well as the trend toward building north of Marshall Avenue. Property was neglected, and building demolitions increased during and after the construction period. Building permits for new construction were issued more frequently in the last year of construction and after construction but not as frequently as before construction began. Property owners did not have to do extensive remodeling after the construction was completed, and few property use changes occurred during the study period.

Economic Impact

Longview, and motorists using the widened section of Highway 80, have benefitted from the construction. Business sales and property values along the highway are increasing. Construction expenditures of $5.59 million are still felt in the local economy. The construction period's negative impacts were kept to a minimum by early completion of the project.

ACKNOWLEDGMENTS

The authors would like to thank the following officials of District 10 of TxDOT for the data they furnished and their valuable assistance with this study: James R. Evans, Harold C. Waggonner, Robert W. Ward, and J. Walter Lehmann.

The authors also are indebted to Edlyn Vatthauer and John H. Russell of the City of Longview for data and valuable assistance. The authors express sincere thanks to the Netherton Company, Inc., the general contractor for the widening project, in particular to L. C. Woods. The company's assistance in determining construction expenditure data for the Longview area and logging lane closure data was greatly appreciated.

Their thanks also go to the following Transportation Economics Program personnel for their valuable assistance: W.F. McFarland, J. L. Memmott, and Katie N. Womack, who conducted the parking survey, and Darrell Borchardt, Gerald Ullman, and their staff. Craig Smith and George Rose helped to reduce the study's data base. Finally, Linda Buzzingham helped to compile and sort the data and to prepare the report.

REFERENCES

1. Ezekiel, M., and K. A. Fox. *Methods of Correlation and Regression Analysis: Linear and Curvilinear* (3rd ed.). John Wiley and Sons, Inc., New York, 1959, pp. 14–31.
2. Bailey, K. D. *Methods of Social Research* (3rd ed.). MacMillan, Inc., New York, 1987, pp. 162–167.
3. Alevijos, J. P. *Marketing Research: Application, Procedures, and Cases.* Prentice Hall, Inc., Englewood Cliffs, N.J., 1959, pp. 80–103.

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

PART 5

Management and Productivity

Women in Transportation Management in Kuwait: Attitudes Toward Gender Bias

PARVIZ A. KOUSHKI, SALEH YASEEN ALI, AND ALISON M. LARKIN

Gender bias may be the single most significant contributor to the current worldwide escalation of both poverty and population. Whereas sex discrimination can be found universally, its effects are most pronounced in developing nations. The greatest obstacle to the development of policies for the curtailment of gender bias is lack of information on the scope and effects of the problem. An attempt is made to quantify attitudes toward gender bias among professional women working in the field of transportation management in Kuwait. The major findings that emerged from the study were as follows: (*a*) Since 1970, Kuwaitis have witnessed an enormous growth in the number of women in higher education; (*b*) with respect to job-related factors such as salary scale, professional treatment, responsibility, benefits, and vacation, nearly 80 percent of professional Kuwaiti women surveyed expressed a feeling of equality with or even superiority to their male counterparts; and (*c*) with respect to one job-related criterion, promotion to upper management positions, the women under study felt they were treated "less than equal" to their male colleagues. Perceptions of employment equality reported by the survey population were found to be positively correlated with level of education, years of work experience, grade point average, and field of specialty. The relationships were all significant statistically. Among the job-related factors contributing to the feeling of equality were, in order of importance, professional treatment, promotion, level of responsibility, and the opportunity to reach upper management positions. Interestingly enough, salary scale contributed least to the feeling of equality.

Despite enormous changes in the world's socioeconomic, political, and environmental conditions in recent years, gender bias remains a universal problem. This paper reports the findings of a recent study undertaken to determine attitudes toward gender bias among professional women working in the administration, planning, design, operation, and supervision of transportation systems in Kuwait.

Gender bias exists in every nation, at virtually every income level and social stratum. It is especially pervasive in poor countries, where it is often compounded by discrimination based on class, caste, or race. Its impacts include exclusion of women from social and educational development programs, wage and mobility discrimination, and systematic violence against women (*1*).

Gender bias is a primary cause of poverty in subsistence economies. It prevents hundreds of millions of women from obtaining the needed education, training, health services, child care, and legal status to improve productivity and escape from the cycle of poverty (*2,3*).

Gender bias has also been identified as the single most important factor contributing to rapid population growth (*4,5*). As environmental degradation and impoverishment continue to reduce women's access to productive resources, their responsibilities in terms of demands on their time and energy increase. When they can no longer increase their own labor burdens, they depend more heavily on the contribution of their children, especially girls, to alleviate time constraints and improve economic security (*6*). The increasing tendency in many subsistence economies to keep girls out of school to help with their mothers' work virtually ensures that another generation of females will grow up with fewer options than their brothers to improve their life styles and narrow the gender gap.

Gender bias is not confined within the borders of developing nations. As economies develop, existing gender gaps in the allocation and distribution of wealth and access to resources usually persist, although their dimensions are likely to decrease with increasing sociopolitical awareness. For example, during the period stretching from the 1950s through the 1980s, worldwide standards of living—as measured by common indicators such as life expectancy, per capita income, and education—rose significantly, especially in the developed nations. Although women's rights were defined and broadened during this period, women never achieved complete parity with men, even in the developed economies (*1*). According to the "human development index" (HDI), a measure developed by the United Nations Development Program (UNDP) to gauge the level of resources needed by a human to attain a decent standard of living, women lagged behind men in every nation for which compatible data were available (*7*). As indicated by the HDI, women's HDI as a share of men's was 96 percent in Sweden, 86 percent in the United States, 83 percent in Italy, 77 percent in Japan, 65 percent in South Korea, and 58 percent in Kenya (*7*). Whereas those indices reflect the universality of gender bias, they also demonstrate that it is more pronounced in developing countries.

Gender-desegregated data recently collected on a small scale have been instrumental in the recognition of the gender gap (*4*). However, there is an enormous informational void on gender bias worldwide, especially in the developing world (*1*). Such data are essential for the development of policies and plans to ensure women's equal access to economic, health, and educational opportunities.

Compared with other Persian Gulf countries, Kuwaiti women rank very high on the scale of equality with their male counterparts in terms of socioeconomic and educational benefits, and access to recreational opportunities. Kuwaiti women are extremely mobile and independent. They enjoy a wide range of choice in clothing, from traditional Islamic clothing to the most current European and American fashion. And the two extreme styles, and everything in between, coexist harmoniously.

The appointment of a woman as rector of Kuwait University reflects a standard of achievement that can be attained by Kuwaiti women.

P. A. Koushki and S. Y. Ali, Department of Civil Engineering, Kuwait University, P.O. Box 5969, Safat, Kuwait, 13060. A. M. Larkin, Language Center, Kuwait University, P.O. Box 5476, Safat, Kuwait 13060.

This paper reports the results of a study of gender bias in the region. Its target population is professional women involved in the management of transportation systems in Kuwait. The specific aims of the research are to provide answers to the following questions:

- To what extent does gender bias exist in the management of transportation systems in Kuwait?
- Which job-related factors are most affected by this phenomenon?
- What personal factors affect attitudes toward gender bias?

RESEARCH SURVEY

More than 95 percent of the total population of Kuwait lives in Kuwait City. Because of the country's small population (631,818 people, 1993) and the concentration of the population in one urban area, the survey sample includes almost all professional Kuwaiti women involved in the management (administration, planning, design, operation, and maintenance) of transportation systems. Organizations employing these women include the ministries of Public Works, Communication, Defense, Industry and Commerce, and Social Welfare; Municipality; Public Transit Company; Kuwait Institute for Scientific Research; and a number of private companies.

Women involved in the management of transportation systems at each organization were identified, interviewed, and asked to fill out a pretested, simple, yet structured questionnaire. Two types of information were sought in the questionnaire: (*a*) sociodemographic and educational data and (*b*) gender-bias information on job-related factors. Altogether 244 professional women, nearly the total population, completed the questionnaire. Only seven questionnaires (2.9 percent) contained missing information, with the exception of the question regarding degree type, which 7 percent of the respondents did not complete.

The data were coded and compiled on a VAX computer system at the College of Engineering and Petroleum; SAS was used to process the data (*8*).

ANALYSIS AND RESULTS

Detailed statistical analyses were carried out to determine the extent of gender bias among transportation management professionals in Kuwait. Possible cause and effect relationships between gender bias and sociodemographic and educational characteristics of the surveyed population were also investigated. Mean and frequency statistics were used to determine distributions and deviations; cross-classification analysis was performed to evaluate trends. A correlation analysis was performed to identify degrees of associations, and the *t*-test and R^2 were applied to examine the magnitude of the associations.

Educational characteristics of professional women in transportation management in Kuwait are presented in Table 1. Only 1.6 percent of the study population had graduated from institutions of higher education before 1970. This figure increased to 9.4 percent in the decade of the 1970s, to 59.8 percent in the 1980s, and to 29.1 percent in the 1990s. The statistics reflect the enormous growth rate of women's participation in higher education in recent decades. Since 1970, women in Kuwait have been enrolling in institutions of higher learning at a mean annual growth rate of 261 percent.

TABLE 1 Graduation Year, Degree Type, and Field of Specialization

Variable	Frequency	Percent
Graduate Year:		
< 1970	4	1.6
1970-1979	23	9.4
1980-1989	146	59.8
> 1990	71	29.1
Degree Type:		
Institute/Junior College	20	8.2
College	191	78.2
Masters	11	4.5
Doctorate	5	2.1
Missing	17	7.0
Field of Specialization:		
Civil Engrg.	105	43.2
Chemical Engrg.	7	2.9
Elec./Computer Engrg.	41	16.9
Mechanical Engrg.	14	5.8
Petroleum Engrg.	1	0.4
Mgt./Eco./Business	13	5.3
Sciences	6	2.5
Other	56	23.0

The largest percentage of the study population had college degrees (78.2 percent). Sixteen had successfully pursued graduate studies, 11 had a master's degree and 5 had a Ph.D. degree. Of the study population, 8.2 percent were graduates of technical institutes in Kuwait.

Civil engineering was the most common field of specialization among the professional women interviewed (43.2 percent). Other specializations were electrical or computer engineering (16.9 percent), mechanical engineering (5.8 percent), and management, economics, and business administration (5.3 percent). The remaining women specialized in chemical and petroleum engineering, one of the sciences, or other fields.

Nearly 42 percent of the professional women in transportation management in Kuwait graduated with a grade point average (GPA) of between 2.00 and 2.99. The second largest percentage (37.3 percent) had a GPA of less than 2.00. Those who achieved a GPA of 3.00 or above at graduation represented 20.9 percent of the group under study (Table 2). The mean population GPA was 2.34.

A majority of the study population were married (66.4 percent), and nearly a quarter (24.2 percent) had been employed for 1 year or less. Approximately 60 percent had been working for 2 to 10 years, 8.2 percent for 10 to 15 years, and 5.3 percent had more than 15 years of work experience (Table 2). These statistics reflect the growth in recent years of the number of women graduating from institutions of higher education and participating in the labor market. The mean number of years of work experience was 5.9 for the study population as a whole.

Table 3 presents responses to the following question: "In comparison with the men engineers in your organization who have

TABLE 2 Grade Point Average, Marital Status, and Work Experience

Variable	Frequency	Percent
GPA:		
1.0 - 1.9	91	37.3
2.0 - 2.9	102	41.8
3.0 - 4.0	51	20.9
Marital Status:		
Single	82	33.6
Married	162	66.4
Years of Experience:		
< 1 year	59	24.2
2 - 4	55	22.5
5 - 7	50	20.5
8 - 10	47	19.3
11 - 15	20	8.2
> 16	13	5.3

similar characteristics (education, years of experience, and other qualifications), do you receive the same salary, . . . , job benefits?'' Nearly two-thirds of the respondents said they were treated equally with respect to salary (60.3 percent), promotion (58.7 percent), professional treatment (65.7 percent), level of responsibility (62.1 percent), job benefits (61.8 percent), and vacation (78.5 percent). See Table 3.

The only significant inequality reported was related to the question about reaching upper management positions; 39.3 percent of respondents said women were not treated equally on that basis. This figure suggests that it is still a man's world at higher echelons of transportation management in Kuwait. However, the great respect for motherhood that characterizes Middle Eastern cultures is reflected in the study's vacation statistics. A significant percentage of the professional women surveyed had enjoyed longer vacations and times off the job than their male counterparts (e.g., 2 months of paid vacation for each child's delivery).

Although no comparable data were found in the literature concerning job equality for women professionals working in transportation in western industrialized nations, statistics presented in Table 3 indicate a significant lack of gender bias among Kuwait's transportation management professionals. In fact, in a surprising response to the question ''Do you, in every respect, feel equal to the men engineer colleagues?'' a majority (68.8 percent) said ''yes.'' Of those who said ''no,'' 81.3 percent (61 individuals) stated they actually felt ''superior'' to their male colleagues. That response may not be so surprising after all. Academic records of students enrolled in transportation courses indicate that in the category of ''A'' and ''B'' grades, female students outnumber their male counterparts by a ratio of nearly three to one (*9*).

The women's expression of ''feeling equal'' to their male colleagues followed certain expected patterns. The most pronounced relationship was between this ''feeling of equality'' and the type of degree that they held. As the level of education increased (from the institute level to the doctoral level), the percentage of those who felt equal to their male colleagues also increased. Increases in feelings of equality from that of the graduates of institutes (2-year programs) to those with bachelor's, master's and doctoral degrees were 11.7, 51.7, and 66.7 percent, respectively (Table 4).

The factor of years of experience also correlated positively with the feeling of equality. An increase in years of experience was followed by an increase in the feeling of equality (Table 4). The relationship between the grade point average and the feeling of equality, although positively related, peaked for those with a GPA between 2.00 and 3.00 (Table 4). Perhaps higher levels of expectation on the part of individuals with very high GPAs may partly explain the diminished feeling of equality experienced by this group.

All of the study's professional women with a degree in electrical and computer engineering felt equal to their male counterparts. Of those with mechanical engineering degrees, 79 percent felt equal, of chemical engineers, 76 percent. Ironically, only 58 percent of female civil engineers in the study population felt equal to their male colleagues.

Correlation Analysis and the *t*-test

A correlation analysis was performed to determine the degree of association between the socioeducational traits of the study pop-

TABLE 3 Study Population's Responses to Job-Related Factors

Job-Related Factor	Compared to Men Colleagues in Your Organization, is your: The Same:		If No:	
	Yes	No	More	Less
Salary Scale :	60.3	39.7	4.5	95.5
Promotion :	58.7	41.3	7.6	92.4
Professional Treatment :	65.7	34.3	21.1	78.9
Level of Responsibility :	62.1	37.9	30.1	69.9
Reaching Upper Management :	39.3	60.7	7.8	92.2
Job Benefits :	61.8	38.2	13.6	86.4
Vacation :	78.5	21.5	38.3	61.7

TABLE 4 Cross-Classification of Educational Traits and Feeling of Equality

Variable Name	Feeling of Equality (%) Yes	No
Degree Type:		
Institute	60	40
College	67	33
Master	91	9
Doctorate	100	0
Years of Experience:		
< 6	67	33
7 - 11	70	30
12 - 16	72	28
> 17	83	17
GPA:		
< 2.00	58	42
2.00 - 2.99	76	24
3.00 - 4.00	72	28

ulation and their attitudes toward gender bias. The resulting coefficients of correlation were subjected to a t-test to quantify their significance (*10*).

The t-test rejects the hypothesis $H_0{:}r_{xy} = 0$, that a given value of coefficient of correlation is equal to zero (indicating insignificant statistical association between any two variables x and y if

$$|T| = [r_{xy}/(1 - r_{xy}^2)^{1/2}]\,(N - 2)^{1/2} \geq t_{\alpha/2};\ N - 2$$

where

T = percentage point of the T distribution,
r_{xy} = coefficient of correlation, N sample size,
$t_{\alpha/2}$ = the 100 − $\alpha/2$ percentage point of the T distribution for $N - 2$ degrees of freedom, and
α = tolerance limit.

Type of degree was correlated positively and significantly with the factor of equal professional treatment ($r_{xy} = 0.2359$, $T = 2.16$, $\alpha = 0.05$), with the level of equality in job responsibility ($r_{xy} = 0.2607$, $T = 2.52$, $\alpha = 0.05$), and with equality in vacation ($r_{xy} = 0.2728$, $T = 2.81$, $\alpha = 0.01$). In other words, women with higher educational degrees were more numerous among those who expressed equality in professional treatment, job responsibility, and vacation options.

The GPA was also positively and significantly correlated with equality in salary scale ($r_{xy} = 0.2899$, $T = 3.00$, $\alpha = 0.01$), with equality in promotional criteria ($r_{xy} = 0.3374$, $T = 3.79$, $\alpha = 0.01$), and with job benefits ($r_{xy} = 0.2147$, $T = 2.79$, $\alpha = 0.01$). Those with higher GPAs tended to feel equal to their male counterparts.

Ironically, women engineers with non–civil engineering degrees (especially electrical and computer engineers) were more apt to experience equality in the upper management of transportation systems. This relationship was statistically significant at the 95 percent significance level ($\alpha = 0.05$). This finding does not necessarily mean the non–civil engineers outpaced civil engineers in reaching civil engineering–related management positions. It may indicate that female engineers in electrical and computer, mechanical, and chemical engineering jobs experienced less competition in climbing the ladder to upper management levels.

Of particular interest is the finding that gender bias is a declining trend in Kuwait. The number of years of employment experienced by professional women in transportation was negatively and significantly correlated with equality of salary scale ($r_{xy} = -0.2162$, $T = 3.26$, $\alpha = 0.01$) as well as equality in promotion ($r_{xy} = -0.2188$, $T = 3.31$, $\alpha = 0.01$). In other words, most of the women professionals who stated equality with men in the salary scale and promotional criteria, were from among those who had recently been employed by transportation organizations.

To examine how job-related factors contribute to the feeling of equality expressed by the professional women in the management of transportation systems in Kuwait, coefficients of determinations, R^2, were computed for the data. As presented in Table 5, important points include the following: (*a*) all of the job-related factors were positively associated with the feeling of equality; (*b*) the magnitude of these associations were all statistically significant at the 99 percent confidence level (except for the salary scale, which is significant at the 95 percent level); and (*c*) all of the nonmonetary job factors outweighed the salary scale component by significant margins in contributing to respondents' feeling of equality. The factors, were, in order of importance, professional treatment, promotion, level of responsibility, job benefits, and opportunity to reach upper management positions.

TABLE 5 Correlation Coefficients, *t*-Test, and Coefficients of Determination for Feeling of Equality and Job-Related Factors

Job-Related Factor	Coefficient of Correlation (r_{xy})	Degrees of Freedom (N-2)	Computed T Value	Test of Hypothesis: $H_0 : r_{xy} = 0$	Contribution to the Feeling of Equality (R^2%)
Salary	0.1472	236	2.59	Rej., α=0.05	2.2
Promotion	0.3545	236	5.82	Rej., α=0.01	12.6
Professional Treatment	0.3568	236	5.87	Rej., α=0.01	12.7
Level of Responsibility	0.3342	237	5.44	Rej., α=0.01	11.5
Job-Benefits	0.3395	235	5.54	Rej., α=0.01	11.2
Management Position	0.2970	236	4.78	Rej., α=0.01	8.8

Study Implications

These findings have some interesting implications for working women in Kuwait. On the scale of professional equality described in the introduction of this study, Kuwaiti women in transportation management rank on a par with professional women in western countries. Considering the situation of women in neighboring Saudi Arabia, to which Kuwaiti society has deep cultural as well as geographical ties, this is a surprising achievement. Moreover, it may challenge a stereotype of Arab women as less than equal. It is hoped that this study will generate comparative research in the area of gender bias in the Middle Eastern and other societies.

CONCLUSIONS

The study identified significant trends. Since the early 1970s, there has been an enormous growth rate in the number of women who participate in higher education and employment opportunities in Kuwait. The feeling of equality with male colleagues prevails among Kuwait's professional women involved in the management of transportation systems. In addition, nearly 80 percent of the study population expressed feelings of equality or superiority to their male colleagues with respect to a number of job-related factors.

The contribution of job-related factors to the feeling of equality, as expressed by the Kuwaiti professional women under study, were, in order of importance, professional treatment, promotion, job responsibility, job benefits, and the opportunity to reach upper management positions.

ACKNOWLEDGMENTS

The authors are indebted to Dina Al-Ali, Haifa Al-Mohanna, Abrar Al-Hammad, Dhia Al-Jassem, Majedah Al-Safy, Nawal Al-Brikan, Ayesha Al-Marzoogh, Dhaia Al-Jaber, Suhaila Ben-Shaaban, Sabikah Al-Khalid, Lamya Al-Nassar, Amal Al-Hosaini, Hajar Al-Sabt, Jehad Al-Hulail, Leyla Safari, Leyla Hasan, Latifa

Towfighi, Iman Al-Mail, and Sana Al-Haddad for their valuable efforts in the research survey and data processing.

Thanks are also due to Mini Kora, who typed the manuscript.

REFERENCES

1. Jacobson, J. L. *Gender Bias: Roadblock to Sustainable Development.* Paper 110. World Watch Institute, Washington, D.C., Sept. 1992.
2. Smith, D. L., and C. H. Trujillo. The Struggle To Legitimize Subsistence: Women and Sustainable Development. *Environment and Urbanization*, Vol. 4, No. 1, April 1992.
3. Agrawal, B. Rural Women, Poverty and Natural Resources: Sustenance, Sustainability, and Struggle for Change. *Economic and Political Weekly*, Washington, D.C., Oct. 28, 1989.
4. *The World's Women: Trends and Statistics 1970–1990.* United Nations, Department of International Economics and Social Affairs, New York, 1992.
5. *The State of the World Population.* United Nations Population Fund, New York, 1991.
6. Chatterjee, M. *Indian Women: Their Health and Productivity.* World Bank, Washington, D.C., 1991.
7. *Human Development Report.* United Nations Development Program, Oxford University Press, New York, 1992.
8. *SAS/STAT Procedure Guide.* Version 6, 4th ed., Vol. 2. SAS Institute, Inc., Vary, N.C., 1989.
9. Koushki, P. A. *Students Performance in Transportation Courses.* Internal Report. Department of Civil Engineering, Kuwait University, Kuwait, 1992–1993.
10. Bowker, A. H., and G. J. Lieberman. *Engineering Statistics* (2nd ed.). Prentice Hall, Englewood Cliffs, N.J., 1985.

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

Organization, Management, and Financing in a Road Agency

ANTTI TALVITIE AND JUKKA HIRVELÄ

Issues and concepts involved in the organization, management, and financing of road administration are discussed. Road agency organization is analyzed using a cost function that supports a decentralized "fractal organization." Several road management systems are discussed and it is argued that for a management system to be useful it must be compatible with the agency's organizational structure. Finally, road funds and road user charges are discussed, and their importance to road administration management is elaborated.

A country's transport system is an enormous national asset. As the circulation system of the body politic, it facilitates commerce, communication, and economic and social growth. Management of the system is a highly sensitive and complex task, entrusted to a country's road administration and shaped by political, technical, environmental, managerial, and historical forces. Because of a transport system's complexity, the mission of a country's road administration is typically stated in broad terms (e.g., effectively manage the transport system that serves the country). In addition, serving clients, delivering quality products, protecting the environment, and valuing employees are increasingly recognized concerns, and they add to the managerial dimension of a road administration's mission.

Operational objectives to which a road administration's professional staff attaches importance include the following: traffic safety, increasing capacity to sustain or enhance current operating speeds as well as to respond to changing traffic demand, rehabilitation of existing roadways, and environmental amelioration. In some countries and regions, improved farm-to-market accessibility, congestion management, and promotion of carpooling and public transit are also important objectives.

Issues and problems surrounding these objectives constitute a familiar, well-trodden ground for transportation professionals in every country, and most transport managers anticipate them in the course of their work. However, what makes accomplishing the objectives technically difficult is their intricate relationship with a full range of socioeconomic parameters and nearly every facet of life, and the complications they may introduce into road management.

What might appear to be a contradiction is not; the "big picture" or vision of a country's road system can only be implemented by attending to a multitude of small details, both technical and social, and accomplished by various means, including good administrative management, optimal resource allocation, technical improvements, personnel training, and well-designed financing and attendant user charges. This paper focuses on issues and concepts involved in a road administration's organization, management, and financing.

A. Talvitie, The World Bank, 1818 H Street, N.W., Washington, D.C. 20433. J. Hirvelä, Finnish National Road Association, Opastinsilta 12A, PL33, 00521 Helsinki, Finland.

ORGANIZATION AND ADMINISTRATION: A BRIEF INTERNATIONAL REVIEW

Organizational development is not an exact science; it simply is a certain arrangement for human cooperation. Organizational structure alone does not determine the effectiveness or success of an administration. There are "soft" factors involved: motivation, leadership, and culture. The management of a highway system, including ways of doing road work and overseeing roads, influences the ways road administrations are organized. The historical and political organization of a country also forms the framework for organizing countries' road administrations.

A recent survey of resource allocation practices in the Organization for Economic Cooperation and Development countries (*1*) showed a remarkable communality in these practices and managerial approaches despite substantial differences in organizational structures. Three observations are relevant here. First, organizations reflect the governmental structures prevailing in each country. Thus a federal as well as a state level for road administration is relevant in Germany, Italy, Spain, Switzerland, and in the United States. Canada's federal government is not involved in allocating road budgets. In other countries, the federal/state hierarchy is either missing or has been replaced by another administrative organizaton or procedure. Interestingly, even when countries' governmental levels and the road administrative bodies are similar, they do not have similar responsibilities. Second, extensive traffic or financing problems are motivations for creating totally new kinds of institutions. Motorway concession companies in France are a good example. Third, two main types of organizational structures can be detected: the functional line organization and the fractal organization (to be discussed later). In the former, responsibilities are divided functionally, among construction, maintenance, planning and design, and administration. This is the most common type of organization. In the fractal organizational model, there is a comprehensive delegation of responsibility such as is found in the organizations in Sweden and Finland.

Managerial approaches to road administration among countries show great similarity and encompass the planning and execution involved in the development, maintenance, and operations of a road system. Development consists of construction of new roads, increases in road capacity by adding lanes, and substantial realignment of a road that may or may not increase capacity. Maintenance involves periodic resurfacing or strengthening of roads' structural capacity. Operations involves snow and ice removal (in certain countries); care of roadside and service areas, guardrails, and traffic signs and markings; and other minor repairs that keep pavements and shoulders smooth and safe for motorists. Traffic safety, environmental protection, congestion management, and other ends that do not directly affect transport may affect these three main activities (Figure 1). The three-part division of development, maintenance, and operations corresponds to the policy and budget-making practices of most public agencies. The divisions relate to the time horizon of decisions: development decisions are long range, maintenance decisions are made for the intermediate range, and operations makes short-range decisions and emergency interventions. The threefold division, observed in most countries, is a useful management aid; as a management tool it is likened to the functional classification of roads.

Similarly, there are three administrative decision-making levels: the network, program, and project levels. They are shown as rows in Figure 1, which illustrates, in compact form, the domains of management and resource allocation for road administration. The network level, which is first, deals with policy and usually involves actions by central management in the agency or ministry. The lowest or project level normally is performed by the regional office's engineers, who are charged with execution of the policies and design. In between is the program level; this level's function is to program the actions and implement the policies set at the network level, for example, a multi-year road program.

MANAGEMENT, PERFORMANCE, AND ORGANIZATION OF A ROAD AGENCY

Literature Review

There is a shortage of literature on state or federal road administration organizations and their performance as well as comparisons of different countries' or regions' road agencies. Larson and Rao's (*2*) seminal study of U.S. state highway agencies illustrates the complexity of management and financial practices and the variance that exists in them among states. Talvitie and Sikow (*3*) have studied productivity growth in Finland's road administration (FINNRA); Heggie (*4*) presents a comprehensive proposal for improving management and financing of roads (in sub-Saharan Africa, although the proposal has wider applicability). According to Heggie, the key managerial challenge includes fundamental reforms for organization, management, and financing; the process of these reforms; and the strategy to be followed in accomplishing them. Hartgen (*5*) uses a number of indices to compare the productivity and effectiveness of state highway agencies in the United States over time. Finally, Humphrey et al. (*6*) report on the methods used to assess U.S. state DOTs' performances in response to Hartgen's bold attempt to rank them in terms of performance.

Agency Performance and the Management Effect

The remainder of this section reports on a Finnish study (*7*) whose original aim was to study an agency's productivity and management. The study proved important from the point of view of the administration's organization.

Method

A review of literature (*8,9*) indicates that the cost function is a versatile way of addressing questions related to productivity and efficiency. To assess efficiency, the method involves calculating average cost differences, through time or between regions, and decomposing them, in the present case, into input, output, and management effects and productivity or trend effects. The innovation was to introduce management variables to the cost function and to gauge their importance.

It was assumed that road production can be described indirectly as a cost function of the following form:

$$C = g(W_i, Q_j, M_k, T, D_i) \tag{1}$$

where

C = total cost of production,
W_i = vector of input prices,
Q_j = vector of outputs,
M_k = vector of management variables,
T = binary time variable or a proxy for technology, and
D_i = vector of dummy variables to specify the 13 different highway regions in Finland.

Data

Road construction and maintenance can be viewed as acquiring, moving, disposing, and treating materials. The volume of this work, measured in m^3, is defined as output. In order to test for a multiproduct production process, four classes of roads were specified to allow for the possibility of different production technologies.

Input prices include wages, capital service, haulage, and material. There are three management variables that the road agency, or management of a project, controls. The effects on costs of speed of construction and percentage of contract work both give valuable information about past decisions that aids future planning. The amount of "own fixed manpower" is defined as the third management variable, which, in the short run, is often beyond the management's control. Several other variables were tried.

Maintained Hypothesis

Rigorous statistical tests (*3*) indicate that input prices are separable from outputs and management variables, but outputs are not separable from management. The road agency is a multiproduct agency whose output cannot be aggregated into a consistent scalar number. There appears to be no specific regional difference; however, if a single output is used to characterize the works, then regional differences in this single output are wrongly ascribed to region-specific variables. The cost function was reduced to the following form:

$$\ln C = f(\ln W_i) + g(\ln Q_j, \ln M_k) \tag{2}$$

The result is fortuitous: the management and output levels are separable from prices. At least, the result did not contradict the assumption of functioning factor markets. Inseparable management and outputs suggest, even require, that managers of the output (vector) also formulate it. This has clear implications for organizational structure.

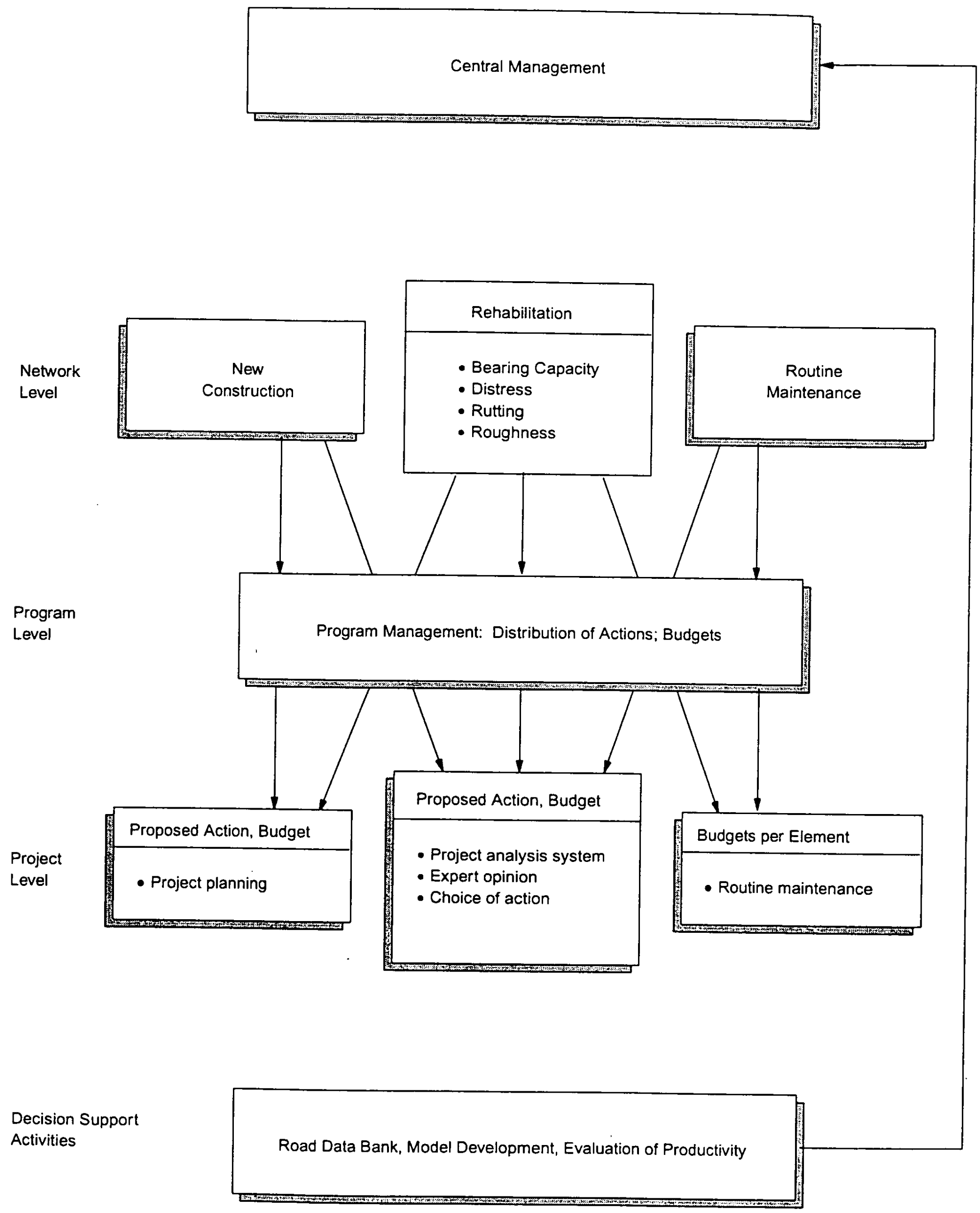


FIGURE 1 Road management system.

There were economies of scale. Also, management had an important bearing on costs. An increase in the speed of construction would have reduced costs in every highway region. Elasticity of cost with respect to percent of contract work was positive. The reason might be that the fast increase in the share of contract work had not been followed by a similar decrease in regions' own fixed manpower, thus, it had a negative impact on cost. Because direct labor was also required to make a bid, it was easy to establish whether the mandated competition had reduced costs. It had. It was also evident that contracting increased productivity and reduced costs. An increase of 1 percent in the fixed labor force raises total costs 0.88 percent on the average, whereas the share of labor is only about 35 percent of the costs. A change in costs with respect to the amount of direct labor is therefore elastic.

Measuring Performance

After manipulation, the cost function can be used to obtain the following basic formulas:

Total factor productivity

$$= \text{change in outputs/change in inputs} \quad (3)$$

Total factor productivity

$$= \text{management effect} + \text{time trend} \quad (4)$$

Change in unit costs

$$= \text{change in input prices} - \text{productivity} \quad (5)$$

(In Equation 3, inputs = total costs/weighted input price.) The total factor productivity measure differs from the traditionally used time effect by the management variables' effect. This is an important difference: management affects agency performance. The above equations enable analysis of the changes in TFP from two different angles: from the production process, which compares input and output quantity levels and their changes (Equation 3); and from the differences in the management factors and the rate of technical change (Equation 4). A third interpretation is possible: the background variables can be seen as the sources of variations in the production process. For example, changes in the level of input factors can be motivated by a technological innovation, and a change in the speed of construction can affect both input usage and output levels and thus the productivity development of road construction and maintenance (*3,10*).

The cost function begs the question What is the output? The properties of this output are important to efficiency and productivity. For example, the efficiency of contract maintenance should not, cannot, be analyzed simply by taking one output, say overlaying, and examining its costs if there are economies of scope and the costs of overlaying are affected by other outputs of the road agency. The labor force of a modern road agency is trained to have multiple skills, and the question of economies of scope cannot be ignored (*3*). The cost function also can be used for intercountry comparisons (*8*). The fact that some measures have been found efficient in one context does not mean that they will be so elsewhere. For example, cost reductions achieved by contracting out maintenance may simply be a sign of inefficiency in that particular country, which may not be present in another country.

Cost function is a good method for assessing a road administration's productivity and efficiency trends. It is a particularly useful tool for the management. For instance, it soon became apparent that FINNRA's excess manpower and slow speed of construction with many ongoing projects were detrimental to efficiency. Remedies were taken to correct these problems after studies from different starting points confirmed the cost function results.

Traditional price orientation of productivity studies need to be shifted to transaction costs to consider What is the management environment? Why is one organization better than another? What is the role of a management philosophy, of technology, and of the managers themselves?

In sum, the cost function, together with a road management system and periodic audits of road condition, provide the necessary information for performance assessment of a road agency. In all phases the people responsible for the project must be involved in this analysis because they can supplement and explain the things that a model cannot.

Organization and Performance

Good organizational structure is necessary for effective road management including good results in production and meeting customers' needs.

Current Situation

Typically, a country's road administration has a centralized decision-making and functional line organization. Its regional offices are also organized along functional lines. Decision making that takes place at the regional level deals with straightforward work planning and not with program planning. This organizational structure is based on the technocratic idea that each line has its own separate product and that within the line output (e.g., a rehabilitated road), inputs (e.g., factor prices), and management (e.g., the number of projects) are separable from each other.

However, this may not be the most efficient organization. There are several problems: unclear and mixed functions and objectives, excess of organizational needs over "optimal" needs, a loss of information due to top-down micromanagement, and so forth.

Approach for Restructuring

There are several approaches to resolving resistances in public organizations and providing for the conflicting objectives of accountability, direction, control, flexibility, freedom, and creativity. One of these is organizational restructuring to enable management to manage efficiently. From the point of view of organization structure, the key results of FINNRA's cost function analysis were separability of prices from output and management, nonseparability of management and output, multiproduct nature of the firm, economies of scale, irrelevance of region-specific characteristics, and the importance of scheduling (programming) of projects and the effect of their optimal timing on costs (*11*).

Without proving the matter here, separability is a necessary condition for decentralization and delegation of decision making. Accordingly, FINNRA's output should not be defined by the central administration to be managed by the regional administration. Decentralization was a must. On what scale should the decentralization be done? According to the model, optimally FINNRA should be divided into 4 to 5 regions instead of the previous 13. Because there were no unique regional differences beyond the output, they could not be cited as evidence against restructuring. Still, restructuring of the regions proved to be enormously difficult both professionally and politically. Although decisions were made after a process of about 2 years, they have taken effect gradually, the first ones in 1991. From idea to implementation restructuring took 3 years.

When these findings are translated into practical terms they mean that, given its budget, the executing regional office must have comprehensive responsibility regardless of the size of the region to creatively manage all its outputs. That is, the regional director should be accountable for the design, construction, rehabilitation, and maintenance of the region's roads, once policy and the overall program goals have been established. For example, a regional director could be accountable to a director general and the board of the road administration.

What then is the role and composition of the central administration? Following the results and reasoning above, the central administration must have comprehensive responsibility of recommending to the board or Ministry policies to be followed, and the distribution of monies within the country. It must be accountable for the road agency's performance. Many advantages can be gained if the directorate of the agency is composed of the director general and the regional directors and forms a general purpose management team. Advantages include formulation of goals in a manner that is uniform for all regions, commitment to distribution of allocated monies, possibility of monitoring performance in a consistent manner, and cohesion within the agency. If the country is divided into numerous regions, the size of the directorate could become too big and unmanageable. It is important that the number of regions is optimally small.

At the regional level, the same reasoning and rules apply. Instead of line organization, the regional director should have an area organization under which the area chief is responsible and accountable for the roads in the area as well as planning, design, safety, construction, maintenance, and environmental safety. He or she may employ experts, but the manager has general responsibility.

The organizational structure outlined above, represented in Figure 2, can be called a fractal organization, because each lower level is a replica of the higher level. This organizational structure does not mean that everything is delegated. Activities that are best performed at the regional level (e.g., programming and executing road condition surveys) need not be delegated. Centralization, decentralization, and delegation depend on technology and available expertise, not solely on organization structure.

Concurrently, other administrators arrived at these conclusions by means other than an econometric study. At least two FINNRA regional directors expressed similar thoughts about the organization and, in particular, how to organize the regional road agency. Comprehensive managerial responsibility and delegation of authority were timely concepts. Studies in the United States echoed similar themes. Larson and Rao (*2*) propose that "in a more competitive environment for resources, highway capital programs will likely require a new focus and broader ranging goals," but they maintained that there was no "right way" to manage the highway capital program and argued for "directed autonomy" to allow creative approaches to be developed by individual states. Larson and Rao suggested that the best results are achieved when there is a "balance between the need for direction and control on the one hand and freedom and flexibility on the other, depending on the political, cultural, and demographic circumstances" of each state (country). These ideas are certainly not contradicted by ideas that were commonly held in Finland and Sweden at the time (both countries were undertaking reorganization as Larson and Rao's study was published). Thus, model results were reflected in the current thinking of professionals in transportation.

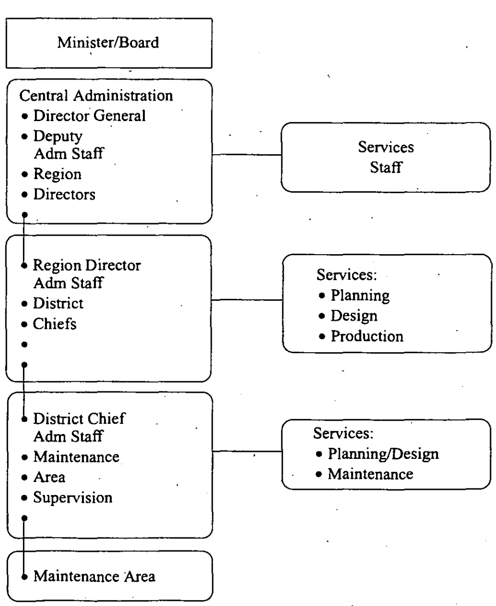


FIGURE 2 Fractal organization.

It is hoped that studies will be undertaken to determine how many regions a country should have for purposes of transport administration. One hypothesis is that a functionally organized line organization is more efficient with low-level technology and insufficient information systems. A fractal organization only becomes possible with the use of more advanced technologies and information systems. Some speculate that the functional and fractal organizations need to be used in a cyclical manner: the functional line organization to push forward specialization and advanced technology, the fractal organization to consolidate the technological gains made in the organization. That the line organization has been in effect up to recent times in most countries shows its viability; it may well be the best organizational model for most developing countries for some time to come. An organization's structure is important to the fulfillment of its mission. It is also important that organizational restructuring keep pace with technological development. Needless to say, the issue of organizational structure and the number of subdivisions has political importance; an organizational restructuring is always a political process. More research and experimentation is needed on these matters.

IMPLICATIONS FOR MANAGEMENT SYSTEMS

Management systems are a necessary element of good management. Not everyone appreciates that organizational structure and decision making style are important factors in the design of the management systems. The design of FINNRA's road management system (*10,12,13*) was critically affected by organizational considerations and by the weakness of the then practiced budgeting and output formulation processes, which, among other things, permitted serious leakage of funds and nonoptimal choices of projects.

The road management system (RMS) must be consistent with the management structure reflected in Figure 1. Network level decisions, exercised by the central administration, deal with policy and resource allocation. Project level decisions, performed by the regional offices, deal with design and work planning. Program level decisions to implement policies for many years are the joint responsibility of the central administration and the regional offices. This organizational system is called a "top-down" method, as opposed to a "bottom-up" method, which builds the multiyear program from individual projects. The system developed and adopted by FINNRA is both.

Key ideas in the top-down method's (Figure 1 as read top down) network-level RMS are the following:

- All investment, maintenance, and operations monies are accounted for.
- Central management distributes monies to regions, normally by functional classification (or volume class), and may recommend an action.
- Central management has many other considerations and constraints that it needs to value when distributing the budget.
- Budget and other constraints are considered explicitly and their importance assessed and communicated in terms of tradeoffs between competing programs.
- Central management operates in a "virtual" reality.

These thoughts are consistent with contemporary practice and thinking in road management, which emphasizes the role of the chief administrative officer and the top-down authority of the central management. In that context, transportation is perceived and used by policymakers as a means to ends other than affecting transportation; the approach is compatible with Larson and Rao's (*2*) thoughts on a "competitive environment for resources," or "new focus and broader ranging goals," or "the need for direction and control on the one hand and freedom and flexibility on the other."

Key ideas of the bottom-up method (Figure 1 as read from bottom up) project-level design system are the following:

- Even a single project consists of many tasks.
- There are many centrally unavailable but locally available variables that affect the final design and the final program, such as "historical memory."
- A design engineer must have both direction (budget constraint, a recommended action) and control (e.g., conduct an audit of the road conditions). But he or she must also have the freedom to exercise creativity in designing the project.
- A design engineer operates in a "concrete" reality.

The bottom-up approach ensures that regional management conceives the output vector it is responsible for managing for cost and level-of-service. In doing so, project-level scale and other effects, involving project size, construction time, and scheduling—all of which yield clear monetary benefits to road agency and users alike—are used to advantage. In a companion study (*11*), these benefits are calculated to range from 11 to 25 percent of project costs, depending on the demand volume on the road.

In conclusion, compatibility between the management systems is important. For example, had a bottom-up RMS been adopted all the way, the central management would not have been able to exercise direction and control or consider broader ranging goals and manage successfully in a competitive environment for resources. Similarly, if the top-down model was used exclusively, freedom and flexibility and creative approaches would have been compromised.

FUNDING AND ROAD USER CHARGES

In many countries, the national road budget is allocated from the country's general budget. Increasingly, there are examples of systemwide earmarking (as in Switzerland, the United States, and some African countries) and of toll roads (Austria, France, Italy, Norway, Spain, Mexico, and the United States.

Financing road administration from general budget revenues coincides with the old road agency model: centralized administration and heavy producer organizations. More autonomous road organizations, even with general budget financing, tend to be more flexible and business oriented, leaning heavily toward contracting out and willing to develop user charges, a road fund based on user tariff. Road funding, be it earmarking a user tariff or developing toll roads or a combination of the two, is an integral element of road agency reform, as Heggie (*4*) points out. At the same time macroeconomists contest this point; they see no relation between cost recovery and user charges on theoretical grounds. They see autonomous road agencies limiting the maneuvering room of the country's Ministry of Finance.

This paper will not attempt to resolve this dispute. It merely seeks to lay out the issues of importance and not to ignore the fact that there can be no accountability in management and no customer-oriented service delivery without a degree of control of income and without appropriate user charges.

Basis of Road User Contributions

The framework used for deciding road budget allocation and distribution (between regions and road classes) to minimize total transportation costs determines the optimum size of the network and the optimal condition standards of roads (Figure 3). Today, few countries employ user costs to help determine the road condition standard. Instead, the road condition standards are determined by engineering and other considerations.

The issue is not, as road users maintain, that they already contribute more to government revenues than is spent on roads. The issue is that governments do not have surpluses; instead they experience shortages of tax revenues. But taxing road users is not

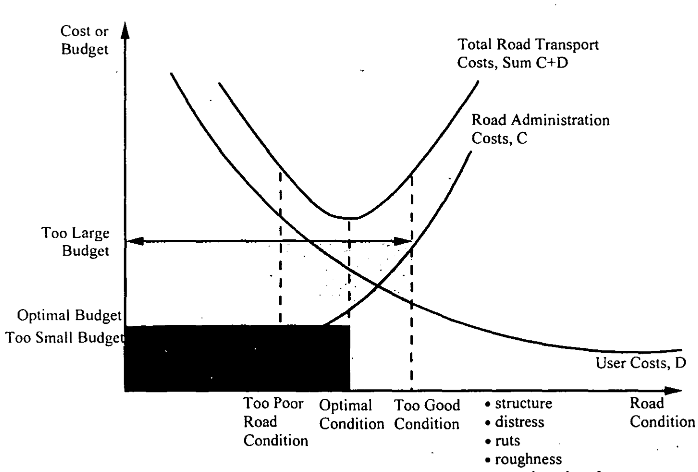


FIGURE 3 Optimal road condition and budget.

necessarily the best way to make up the shortage. Even if it is debatable whether road users pay too much, road transport incurs external costs in terms of pollution, noise, and congestion for which there is no market value at present; taxing behavior that incurs these external costs may not be good policy. There is also considerable evidence of cross-subsidization from cars to trucks, especially to heavier trucks.

Road users claiming they pay too much and the government allocating too little monies to roads point to the need for an appropriate road management system and analytical procedures for recommending road budgets and standards. There is also the need to pay for the costs of roads, which means well-reasoned user charges, such as a road tariff, and a road fund.

Pros and Cons of the Road Fund

A road fund is created by collecting road user charges. The fund is dedicated to roads. The advantages of a road fund most often cited are the following:

- It provides for a stable road budget and avoids political diversion of road user charges.
- It promotes efficient programming and contributes toward lower contracting costs.
- It makes higher user charges more acceptable because their use can be identified and monitored.
- It facilitates cost recovery and equity, because beneficiaries and those who pay can be matched.
- It constitutes a link between payments and benefits, which promotes more efficient management of funds and increases the sense of accountability, because the programs can be easily monitored and a clear system of performance indicators can be developed.
- It is essential for commercializing the road agency.

The most commonly cited disadvantages of a road fund are the following:

- It is said to entail a cost in terms of loss of budgetary freedom, especially if unforeseen fiscal difficulties arise.
- It could lead to distortions between different sectors of the economy and overspending in the road sector.
- It has not been successful in ensuring adequate monies for maintenance; there has been a tendency to use road fund monies for new construction.

Lessons from earmarked road fund experiments, and the "cons" identified, suggest that the following factors are important if a dedicated road fund is being contemplated:

- The planning process and the types of expenditures and functional classes for which a road fund can be used must be clearly specified.
- The yearly level of expenditure, the road sector allocation and its distribution between the major activities—new construction, maintenance, and operations—should be determined by reliable, periodically updated data and appropriate analytical procedures.
- The road management, in addition to auditing and accounting safeguards, which cover both the money usage and the performance of the road administration, should be under proper political control.
- The road fund authorization should be periodic (e.g., set 4 years at a time, to maintain efficiency and avoid monopoly pricing).

It appears that the pros of road funds outweigh the cons, if appropriate safeguards are observed. The matter of funding is an important part of road agency management, and research should be undertaken to clarify the issues surrounding road funds.

Proposal for Road Fund Based on Road User Charges

Customarily, public finance principles of economic efficiency, administrative cost, and equity, in addition to cost recovery, are applied in developing road user charges. The following compromise proposal is designed to achieve these conflicting objectives and yet provide a transparent system that allows straightforward political oversight of agency performance.

- Variable charges, such as fuel charges and axle load charges, are levied to pay for maintenance and operations. Both charges are related to usage and inexpensive to collect. Fuel charges relate to both road wear and to many externalities. Heavy-vehicle charges, those based on the axle loads and distance driven, relate to road damage and a road's structural capacity. Electric cars and bad driving habits, as reflected in the drive cycle, are not covered and may require substituting tolls for fuel charges or other measures in the future.
- Fixed annual charges, vehicle charges, may influence the movement toward a less polluting and damaging vehicle fleet and, most importantly, may be applied to pay for the expansion (or contraction) of the network and pay interest on the capital invested in highways.
- Congestion tolls, made feasible by recent technological advances and restricted to congested facilities, are considered for demand management and for paying for capacity expansion or other acts on any transport mode to alleviate congestion. (If fuel charges on vehicles using alternative fuels become difficult to collect, such charges also can be collected as a toll.)

Any or all the above charges may contain a component to ameliorate environmental harm, provided the harm is, in fact, compensated. There may also be sales taxes or value-added taxes on fuel and vehicles that would accrue to the general tax fund.

CONCLUSION

Each of the sections offer conclusions; however, if there is one matter the authors want to emphasize it is the importance of a road agency's organization, management, and funding to its accountability and performance.

REFERENCES

1. Resource Allocation for Road Rehabilitation and Maintenance Programmes. Draft. Organization for Economic Cooperation and Development, Paris, France, 1993.

2. Larson, T., and K. Rao. Process for Recapitalizing Highway Transportation Systems, Synthesis of Current Practice, NCHRP Project 20-5, Washington, D.C., 1989.
3. Talvitie, A., and C. Sikow. Econometric Analysis of Highway Construction Technology. Proc. 5th World Conference on Transport Research, Volume II, 1989, pp. 69–84.
4. Heggie, I. Improving Management and Financing of Roads in Sub-Saharan Africa. Sub-Saharan Africa Transport Policy Program, The World Bank, Washington, D.C., 1992.
5. Hartgen, D., et al. *Comparative Performance of State Highway Systems 1984–1989*. Transportation Academy, University of North Carolina at Charlotte, 1991.
6. Humphrey, T., M. Meyer, and C. M. Walton, Exploring Methodologies for Comparing State Highway Performance. NCHRP Project 20-24(6)A, Washington, D.C., 1993.
7. Talvitie, A., and C. Sikow. Analysis of Productivity in Highway Construction Using Different Definitions of Average Cost. *Transportation Research*, Vol. 26B, No. 6, 1992, pp. 461–478.
8. Jorgenson, D. W., and M. Nishimizu. U.S. and Japanese Economic Growth 1952–1974; an International Comparison. *American Economic Journal*, Vol. 88, 1978.
9. Caves, D. W., L. R. Christensen, M. W. Tretheway, and R. J. Windle. Network Effects and the Measurement of Returns to Scale and Density for U.S. Railroads. In *Analytical Studies in Transport Economics*, (A. F. Daughety, ed.), Cambridge University Press, Cambridge, England, 1986.
10. Talvitie, A. The Issues: Accountability, Management, and Organization. Presented at a World Bank Conference on Road Agency Organization, 1993.
11. RWA/Projektikonsultit, *Optimal Duration and Implementation of Highway Projects*. FINNRA Research Report (in Finnish). Helsinki, Finland, 1986.
12. Talvitie, A., and R. Olsonen. Selecting Asphalt Concrete Condition States for Highways. Presented at 67th Annual Meeting of the Transportation Research Board, Washington, D.C., 1988.
13. *Infrastructure Management System; Preparation of a Case Study*. Final Report. FinnRA Research Reports, Finnish National Road Administration, Helsinki, April 1993.

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

Developing and Implementing the Intermodal Surface Transportation Efficiency Act Management Systems: New York State's Approach

JOHN J. SHUFON, CLARENCE R. FOSDICK, BARBARA P. GIGLIOTTI, AND JOSEPH P. MCCLEAN

Section 1034 of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) mandates that states develop six management systems and an associated traffic monitoring system. Whereas states have direct responsibility to implement these systems, ISTEA requires that each system be developed in cooperation with other agencies receiving federal highway or transit funds, and with metropolitan planning organizations in urban areas. Federal regulation further requires that a mechanism be established to coordinate development and implementation of the systems administratively, functionally, and technically. Described are the steps that the New York State Department of Transportation (NYSDOT) is taking to ensure compliance with these requirements and to integrate the management systems into the state's program planning and development process. The management structure implemented to oversee system development is detailed, as are the procedures that have been put in place to coordinate these activities among NYSDOT system developers and other affected transportation providers. In addition, guidance provided to system developers to ensure timely implementation is presented. The guidance focuses on the appointment of formal technical committees and the development of concept plans, which carefully define system scope, at the same time building on existing processes and technical tools. Staged system implementation is also recommended, the January 1995 certification deadline being a major milestone.

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) is seen as marking a change in philosophy from building the Interstate highway system to managing the nation's entire transportation system as effectively and efficiently as possible. Section 1034 of ISTEA mandates that each state develop six management systems and an associated traffic monitoring system to meet this charge. Each state is to engage in a multiyear effort to develop and certify implementation of the following management systems by January 1, 1995:

System	*Responsible Organization*
Pavement (PMS)	Planning Division
Bridge (BMS)	Structures Division
Safety (SMS)	Traffic Engineering and Safety Division
Congestion (CMS)	Planning Division
Public Transportation Facilities and Equipment (PTMS)	Transit Division
Intermodal Transportation (IMS)	Commercial Transport Division
Traffic Monitoring (TMS)	Planning Division

As stated in the proposed federal regulation (23 CFR Part 500) governing ISTEA management system implementation:

> The primary purpose of the management systems is to provide additional information needed to make effective decisions on the use of limited resources to improve the efficiency of, and protect the investment in, the nation's existing and future transportation infrastructure at all levels of jurisdictional control.

Thus, those under development within the New York State Department of Transportation (NYSDOT) are decision-support systems for use by public and private transportation entities in objectively evaluating performance, identifying deficiencies, and helping construct and evaluate alternative solutions and investment strategies. For NYSDOT, the systems will support and enhance the decision-making process, in particular the goal-oriented programming (GOP) element of that process.

Although envisioned as separate systems or subsystems of an overall transportation management system, all six systems have several important elements that run throughout (*1*):

- Cooperation: The state is the responsible agency for developing and implementing each management system. In metropolitan areas, this must be accomplished in cooperation with metropolitan planning organizations (MPOs). Transit agencies and local governments must also be involved.
- Objectives: The fundamental purpose of the management systems is to improve the efficiency of transportation systems and to protect public and private investment in those systems through more effective decision making.
- Implementation: Transportation needs and improvements identified by a management system must be considered by the states and their MPOs in their planning and programs and in making project-selection decisions.

It should be recognized that although systems' outputs must be considered, the systems themselves will not be the end products— their implementation and use will not force particular program or project decisions. NYSDOT will continue to function in a decentralized decision-making environment. Project decisions will be

Systems and Program Planning Bureau, Planning Division, New York State Department of Transportation, Building 4, Room 111C, State Campus, Albany, N.Y. 12232.

made in the 11 regional offices; policy guidance and goals will be determined in the central office. Current responsibility and authority will not be diminished. The systems will simply provide decision makers with more structured and comprehensive data, along with necessary analytical tools that can be used to develop a quality program that is balanced and integrated.

The purpose of this paper is to introduce the concept of management systems and to address how they will function within NYSDOT's decentralized decision-making culture. Administrative, functional, and technical processes to be used to coordinate and integrate management systems development and implementation are defined. In addition, guidance is provided to assist individual system developers in implementing a system consistent with the federal regulation by the January 1, 1995, deadline.

BUSINESS OF THE DEPARTMENT: AN OVERVIEW

The opening paragraph of ISTEA states:

> . . . it is the policy of the United States to develop a National Intermodal Transportation System that is economically efficient and environmentally sound, provides the foundation for the nation to compete in the global economy, and will move people and goods in an energy efficient manner.

NYSDOT's goals and objectives certainly support this policy, as affirmed by the department's mission statement: "It is the mission of the New York State Department of Transportation to provide adequate, safe, balanced, and efficient transportation at reasonable cost to the people of the State."

The department's business, broadly speaking, is to achieve this mission by performing numerous direct and supporting tasks aimed at maintaining and improving the state's transportation infrastructure and its operation. These range from planning, design, and maintenance of the highway system to various administrative activities, both fiscal and organizational, which are required to support capital construction and operational programs across all program areas. The management systems are central to these activities and will provide the connecting framework for a consistent approach and criteria to judge competing priorities among the state's surface transportation systems.

The concept of management systems is not new to the department. Pavement and bridge management systems have provided valuable input to the program development process for several years. The Highway Safety Improvement Program has for two decades provided a systematic process for selecting safety projects and evaluating the effectiveness of safety treatments. Computerized systems maintained throughout the central office and the regions have been developed to assist in managing congestion and financing transit operators. ISTEA requires that these systems be enhanced and their coverage expanded; however, their function will remain the same: to provide input to program development decision making, particularly that of the department's GOP process.

The GOP process is the primary mechanism for planning, evaluating, implementing, and monitoring the department's transportation program efforts. Originally designed to address the capital program, it was broadened in 1992 to reflect such noncapital activities as maintenance and operational work performed by state forces. GOP provides a method to manage the program by establishing goals, setting clear measurable objectives, and then measuring program performance in attaining those goals and objectives. The GOP product is a recommended program of projects explicitly balancing needs, priorities, and resources.

Historically, the GOP process has addressed the department's bridge, pavement, capacity, and safety programs. Implementation of the ISTEA management systems provides the opportunity to sharpen decision making for those program areas and, for the first time, to include transit and intermodal elements in the programming process. Ultimately, the management systems are intended to provide the consistent data, analysis tools, and administrative procedures to assist decision makers in making the best decisions, within and across all functional areas. The development of multimodal solutions to transportation problems is a goal of ISTEA. The department's GOP process serves as the framework to achieve that goal.

Figure 1 shows a simplified flowchart of the GOP process. Data from the existing management systems are used by executive management to set statewide goals and to establish policies. They are also used to develop performance measures and selection criteria and as input to the allocation of capital and operating funds to the department's 11 regions. Working within their allocations and given their goals, each regional office uses data from the management systems for annual development of 5-year programs of capital and operations projects, including maintenance. It is here, at this early stage in the process, that each regional office works with MPOs, local governments, and transit providers. Technical tools such as the department's pavement, bridge, and congestion forecasting models are used by the regions to evaluate the impact of alternative construction, operational, and preventive program strategies on "end conditions." Trade-offs are made and programs are selected that explicitly balance needs, priorities, and resources.

Each region then prepares a report detailing the programs selected, describing the rationale used in arriving at program choices, both among transportation programs and within each program, and comparing the results with regional conditions. This report is transmitted to the central office, where it undergoes technical review to ensure that proposed programs are consistent with goals and policies established by executive management.

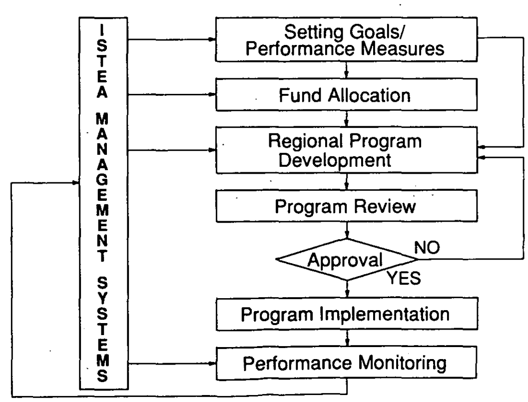


FIGURE 1 Integrating management systems into the NYSDOT GOP process.

Once programs are approved, implementation commences. The data collection component of the management systems is used to monitor performance and update the data bases, which in turn provide feedback for the next year's goal-setting activity.

INTEGRATION AND COORDINATION OF THE MANAGEMENT SYSTEMS

ISTEA clearly cites Congress's intent for coordination of management systems' implementation. The legislation requires that management systems be developed and implemented in cooperation with MPOs and other affected agencies. In addition, system outputs must be considered in developing metropolitan and statewide transportation plans and improvement programs and in making project selection decisions under both Title 23 and the Federal Transit Act. Federal regulation emphasizes and expands upon this intent by requiring each state to have

> procedures within the State's organization, for coordination of the development, establishment, implementation and operation of the management systems. The procedures must include:
>
> - An oversight process to assure that adequate resources are available for implementation;
> - Complementary target dates of the systems to ensure that outputs of all systems can be given timely consideration in development of metropolitan and Statewide transportation plans and programs;
> - The use of data bases with a common or coordinated reference system and methods for data sharing methodology; and
> - Interrelationships among the systems to address outputs and issues related to the purposes of more than one management system.

The steps NYSDOT has taken to ensure the required coordination and integration will now be discussed from three perspectives—administrative, functional, and technical.

Administrative Coordination

Administrative coordination of the ISTEA management systems involves policy development and project management, such as agency resource allocation. The management structure designed to ensure administrative coordination of the ISTEA systems is shown in Figure 2 and consists of the following components:

- Executive steering committee (ESC): General oversight of the system development effort is provided by an ESC consisting of the first deputy commissioner; the director of the planning and program management group; the assistant commissioners for management and finance, operations, engineering, and public transportation; and two regional directors. The committee meets approximately quarterly to be briefed on the status of each management system and to address high-level issues affecting relationships among the systems. Among issues to be addressed are annual budgetary allocations to each system development team, adjustment of resource allocations as necessary, ratification of policy proposals, and resolution of policy disagreements.

Because of the advanced stage of implementation of the department's bridge management system (BMS), its steering committee, although quite similar to the ESC, will continue as currently constituted. The BMS will be developed and coordinated in a manner consistent with ISTEA requirements and federal regulations.

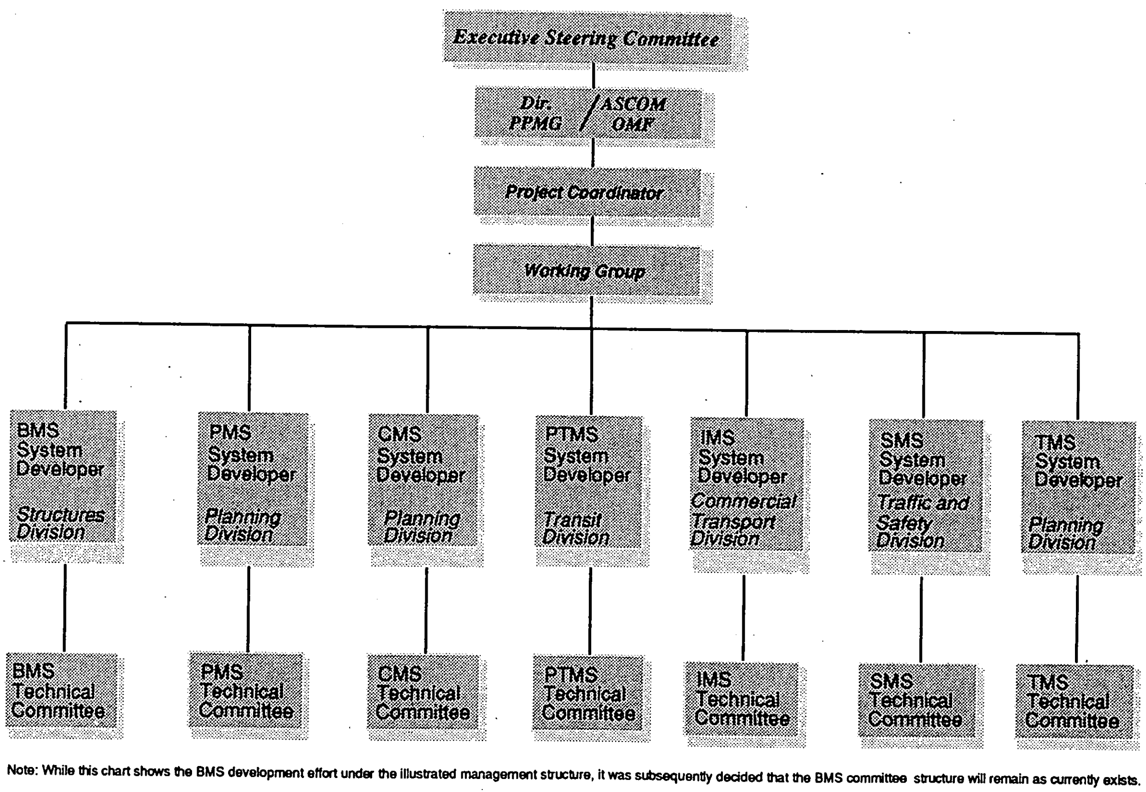


FIGURE 2 NYSDOT management structure for management system development.

• Executive directors: The assistant commissioner for management and finance (OMF) and the director of the planning and program management group (PPMG) have joint responsibility for overseeing coordination and progress of the systems development effort. As the organization responsible for automation standards and policies and for providing systems development services, OMF is responsible for ensuring that each effort is consistent with these policies and standards. As manager of planning and implementation of the department's program, PPMG has specific responsibilities to ensure that these systems meet the state's program planning and development needs.

• Project coordinators: The Systems and Program Planning Bureau of the planning division of the PPMG has been designated project coordinator for development and implementation of the management systems. Under supervision of the executive directors, the project coordinator is responsible for the following administrative activities: ensuring that the project is placed on the department's priority list and that adequate resources are devoted to development; assisting system developers to ensure that the project is progressing at an acceptable pace and that systems are designed using appropriate systems-development methodology; acting as staff to the ESC by scheduling meetings, arranging agendas, and so forth; resolving conflicts and raising issues to the joint directors with recommendations for remedial action; working with system developers to address individual problems in conjunction with staff from the information management division and strategic planning and management systems division; and attending technical committee meetings and disseminating information to the various system developers.

• Technical committees: Their role is to provide system developers with expertise as well as to outline customer needs to be considered during management system development. ISTEA is specific about the interests that must be involved in developing the management systems. The department decided that the technical committees would act as forums for that involvement. The committees are chaired by the system developers; membership is consistent with federal regulation and must be approved by the ESC. The recommended composition of each technical committee is discussed later.

• System developers: System developers are responsible for developing management systems that satisfy ISTEA requirements for function, performance, schedule, and customer involvement, as well as department requirements for compatibility, customer access, and information management. The system developer is required to outreach to MPOs and other customer groups to ensure meaningful input and buy-in from all affected parties and to fulfill obligations under the law and regulation.

Functional Coordination and Integration

Functional coordination and integration addresses program interrelationships among the systems. For example, output of one system may serve as input to another. The department's SAFEPAVE program illustrates functional coordination. Safety evaluation findings have suggested that a simple resurfacing with high-friction asphalt will reduce wet-weather accidents by 50 percent at locations where wet-weather accident rates are significantly above the mean. Locations identified by the pavement management system are now matched with high wet-weather accident locations, and project lists are developed that address both considerations. Thus, a PMS output serves as an input to the SMS.

Currently, functional coordination is achieved by the regional offices as part of the GOP development process. Each regional program committee, which is a formal group consisting of functional group managers chaired by the regional director, meets regularly to discuss proposals for the pavement, bridge, safety, and capacity programs. Trade-offs among these programs are discussed and, within fiscal constraints, a program of projects is selected that best meets the goals established by executive management. Formal subcommittees specializing in each program area provide ongoing technical input to this process. Implementation of the management systems will broaden and enhance this input.

Functional integration involves development of policies and procedures so that various programs are coordinated to promote effective and efficient deployment of resources to achieve the agency's mission. For instance, all systems performing economic analyses of project proposals should be bound to the same policy premises. Thus, all benefit-cost work should use the same discount rate for invested funds, the same value for user costs, and so on. In addition, if life-cycle cost is a corporate investment policy, then all systems should be capable of providing such assessments.

The management structure described in the preceding section ensures functional coordination and integration in developing management systems. Important policy issues that are strategic in nature will be discussed and resolved by the ESC. On a day-to-day basis, the project coordinator works with system developers so that each system's needs are addressed while the other systems are being developed.

In addition, a working group has been formed consisting of system developers, the coordination team, FHWA, MPOs, and other department personnel with a direct interest in the management systems. This working group will advise and assist the project coordinator to facilitate discussion, share information, develop common definitions, ensure coordination in system scoping, and develop staff-level consensus on issues affecting development and implementation.

Technical Coordination

Federal regulation is very specific on the need for technical coordination in developing the management systems, specifically in using common data bases with a common or coordinated reference system, and for data-sharing methodology. Certainly, the aforementioned management structure (along with the working group) aids the coordination of management systems from a technical standpoint. In addition, NYSDOT has decided that this coordination will be achieved, in part, by implementing a geographic information system (GIS) to link data components of the management systems. GIS technology permits assimilation, integration, and presentation of data collected and stored in each of the management systems, regardless of the referencing system used to locate the data elements (e.g., reference markers, mile points, and coordinates). Figure 3 illustrates conceptually how the GIS will operate.

The department has taken several steps to implement GIS technology. A GIS selection committee has been appointed to evaluate software and recommend a GIS solution to system integration. A technical subcommittee has been designated to work with the regions in assessing proposed applications using various GIS plat-

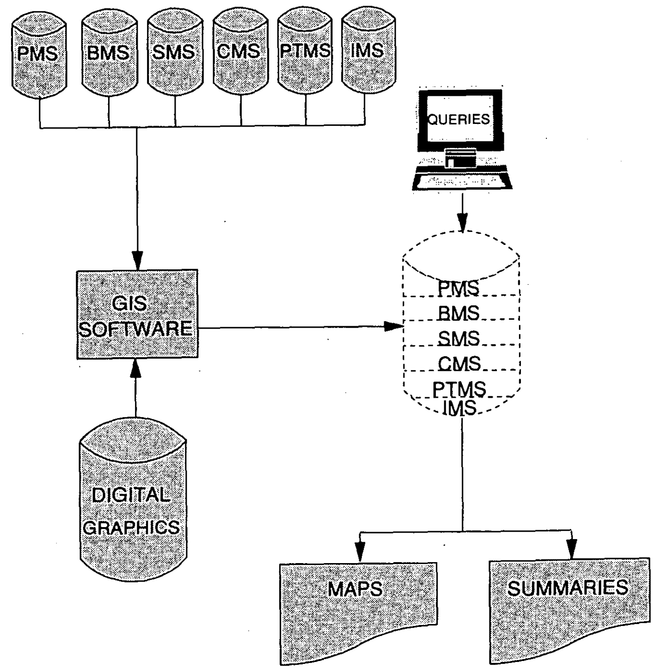


FIGURE 3 GIS and the management systems.

forms. In addition, a detailed work plan to implement GIS has been prepared by the information management division and approved by the deparment's Management Information System Steering Committee (*2*). It is anticipated that the GIS selection committee will complete the required work and make a final recommendation by early 1994. It is well recognized that GIS implementation, although important, is only one step in ensuring technical coordination. A GIS is not a substitute for traditional systems analysis. Much work must be done in technical design of the management systems, for example, determining user needs, identifying relationships among the systems for data-sharing purposes, and developing common data definitions. To accomplish these tasks, the information management division has assembled a team of computer analysts to work full-time with the systems developers, GIS specialists, and other data-processing staff from the user groups in developing and integrating automation elements of the management system project.

GUIDELINES FOR MANAGEMENT SYSTEM DEVELOPMENT

This section provides system developers with guidelines for developing their respective management systems. The following discussion is a generic overview applying to all systems. System developers should refer to the federal regulations for details specific to each system and work with FHWA and the project coordinator to ensure that development and implementation comply with ISTEA's minimum requirements.

Appoint Technical Committees

ISTEA mandates that each management system be developed and implemented in cooperation with MPOs in urban areas and with affected agencies receiving assistance under the Federal Transit Act. To meet this charge and ensure appropriate integration and consistency among systems, NYSDOT decided that each technical committee should include representatives from each of the following:

- Planning division;
- Information management division;
- Strategic planning and management systems;
- Professional staff from one of the state's MPOs;
- Professional staff from a non-MPO area of the state;
- Department central office staff involved as users of the system (in each case, the staff person should be one appropriate to speak for his or her program area in discussing issues and making decisions);
- Regional staff—two representatives, one from downstate and one from upstate;
- FHWA division office; and
- Principal customers and interested parties for each management system as identified by the individual management system concept plans and federal regulation. Examples include the regional and local transportation authorities and FTA for the PTMS, and county highway superintendents for the BMS and PMS.

Prepare a Concept Plan

Preparing a concept plan is perhaps the most important step in the successful development and implementation of a management system. The document serves as the overall charter for the system, and as such it is reviewed and scrutinized by executive management. The plans should be written clearly and concisely but, at the same time, must be comprehensive enough to provide a road map to future system development. Each plan should identify ISTEA goals and objectives, critical issues, system development and integration considerations, overall schedule, and major project milestones. Specifically, the concept plan should include the following components (*3*):

- Appropriate legislation and regulations governing system development;
- System-specific goals and objectives that relate to and support the agency's overall ISTEA management system goals and objectives. This should be a vision statement that describes the "as-is" condition (i.e., how the functional areas affected by the management system currently do business) and the "desired" condition (i.e., how the functional areas will do business under ISTEA) as well as highlighting significant business or process changes that must be accomplished to comply with ISTEA requirements;
- Summary of key system-specific issues that must be addressed for system development to succeed;
- A system framework, that is, a detailed model or schematic (e.g., flowchart) of the overall system should be provided showing system components and principal points of functional and technical integration with other ISTEA or agency systems. The framework also should specify to what extent existing agency programs, processes, and procedures satisfy ISTEA requirements;
- Identification of the data bases and information necessary to develop the system;
- Detailed project work plan that identifies project tasks, milestones and schedule, deliverables, and task responsibilities; and

• An estimated annual budget, including automation needs (hardware, software, additional programming expertise), staffing needs, and incremental required data collection costs.

Carefully Define Management System Scope

Management systems are often thought of as data-intensive computer systems designed to answer difficult questions at the touch of a keyboard. This is far from the case. Although the automated data base is an important component of a management system, it is only a supporting component. A management system must also address the administrative side of the organization—its relevance to business policies, plans, and processes. Failure to recognize administrative considerations during system scoping will impede success as surely as technical inadequacies. Furthermore, the processes selected must be within the organization's resources and compatible with existing policies and procedures. Systems require resources, principally people and money. System developers must be sure that the scope and relevance of the management system can and will be borne by the agency. Otherwise, the scope must be changed until the planned processes and commitments match (*4*).

Another important consideration in scoping management systems is early identification and definition of outputs of their automated elements. Data are valuable corporate commodities. They are extremely expensive to collect and maintain. Thus, data should be collected only if they are to be used in decision making. Systems developers must avoid the tendency to collect all possible information "just in case we might need it someday." Inputs should be defined by output requirements. Understanding this is the key to successfully scoping the automated component of the management system.

Recognize Existing Processes and Technical Tools

Successful deployment of a management system requires that it be tailored to an agency's organizational structure, at least during initial stages of implementation. Even introducing the management system concept may create major stress because this causes a change in the way an organization does business. Such change should be slow enough to allow all functional groups involved to buy into the new processes and procedures. Because deadlines for implementation are rapidly approaching, there is no time to introduce radically new system constructs. Thus, system developers are considering the department's existing decision-making culture and shaping the architecture of the management system accordingly, thereby increasing the chance that the system will be embraced by users and immediately integrated into the decision-making process.

Furthermore, existing technical tools, data bases, and procedures should form the basis for management system design whenever possible. It is much easier and more economically feasible to build on technologies and administrative procedures already germane to an organization than to start from scratch. Efficiency in data collection is explicitly recognized in the federal regulation recommending use of four currently available data sources—the Traffic Monitoring System, the Highway Performance Monitoring System, FTA's Section 15 reporting requirements, and the National Bridge Inventory.

Incorporate Essential Components into the Management Systems

The proposed federal regulation states that each management system requires data to define and monitor the magnitude of problems, identify needs, analyze alternative solutions, and measure the effectiveness of implemented actions. To accomplish these activities, each system should have the following components:

- An inventory identifying problem areas,
- A process to establish performance measures,
- A data-collection element to monitor system performance (e.g., condition),
- Analysis capability to identify needs and analyze alternative corrective strategies,
- A process to implement the strategies selected, and
- Procedures to evaluate effectiveness of the strategies implemented (i.e., a feedback loop).

Developers are advised to build their systems around these essential components. They must determine early in management system development which components are already available or can be completed by in-house staff. For others, it might be necessary to engage consultants or universities funded through the department's research program. If consultants must be hired, considerable lead time must be allotted because of the time requirements for consultant selection. Figure 4 shows the framework of a typical management system.

Build in Staged System Implementation

Building the data bases and developing such complex analysis tools as the GIS may take years and will require significant re-

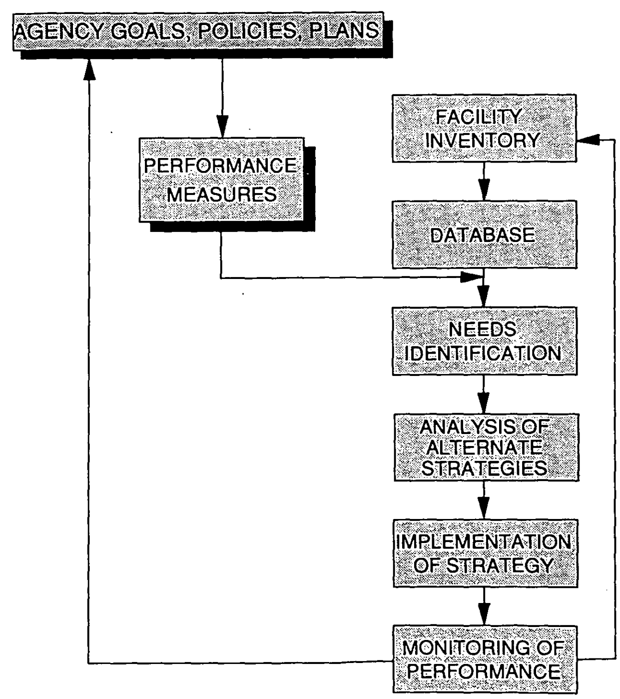


FIGURE 4 Components of a typical management system.

source commitment by executive management. One way to promote this support is by providing executive management with an immediate return on investment. This can be accomplished by staging system implementation so that products become available early in the process. Certainly a major milestone and early goal of all the systems must be meeting the federal deadline for certification.

Staged implementation can take different forms. For example, the NYSDOT pavement management system is being implemented in three stages—crawl, walk, and run. Crawl-stage activities basically involve development of methodologies and technical tools to sharpen existing practice, whereas walk- and run-stage activities focus on further refinements to these tools in a microcomputer and mainframe environment. Such an approach to staged implementation might not be appropriate for all systems, but the important point is that early benefits must be realized from the management systems development effort.

Another advantage of staged implementation is that functional groups involved with the management systems will have time to learn the newly developed processes and be more likely to accept the system once it is fully operational. The sooner a system is institutionalized, the sooner it will serve an integral role in an agency's day-to-day operations.

SUMMARY

Successful development and implementation of ISTEA management systems require support of top management. At NYSDOT, general oversight of the system development effort is provided by an executive steering committee. Two of these managers (the assistant commissioner for management and finance and the director of the planning and program management group) have joint responsibility for direct supervision of system development. The systems and program planning bureau of the planning division acts as project coordinator to oversee day-to-day development activities. Outreach to MPOs and other affected transportation providers is ensured through formal technical committees charged with providing ongoing input to development of each system.

History has shown that timely implementation of a management system requires that it be tailored to the organizational structure and processes of the implementing agency. Thus, system developers are advised to consider existing culture, processes, and technical tools when developing management system architecture. Upfront planning and careful scoping are key considerations in meeting the federal deadlines for system implementation.

ACKNOWLEDGMENTS

The authors acknowledge Michael J. McCarthy and Thomas W. Clash for their leadership and support. Special thanks to Diana M. Brown and A. Donald Emerich for their assistance in preparing the graphics and the manuscript.

REFERENCES

1. Fleet, C. R. Data Needs for Management Systems. In *Transportation Research Circular 407*, TRB, National Research Council, Washington, D.C., April 1993, pp. 23–35.
2. A Work Plan to Implement Geographic Management Systems. NYSDOT Information Management Division, May 1993.
3. Overall ISTEA Concept Plan Guidelines. NYSDOT Information Management Division, March 6, 1993.
4. Geoffroy, D. N. A Management Perspective on Developing and Implementating Safety Management Systems. In *Transportation Research Circular 416*, TRB, National Research Council, Washington, D.C., Oct. 1993, pp. 8–16.

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