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Contents

Private Sector Role in U.S. Toll Road Financing—Issues and Outlook

ROBERT C. SCHAEVITZ

Highway finance in the United States since 1790 has often reflected the relative strengths and attitudes of the public and private sectors at the time of construction. Presently, toll roads are enjoying a renaissance in the United States. Competing economic pressures are creating a variety of approaches to financing toll highways, and several projects are showing signs of privatized approaches to finance and management. These approaches are at once the result of the current attitudes toward project economics and the current mix of economic and fiscal forces at work on infrastructure finance. This paper analyzes apparent trends in the toll road industry through seven case studies to address several related questions: Why has U.S. toll road development increased in recent years? What are the conditions encouraging more private sector participation in toll roads? How can the private sector directly contribute to new toll roads? What role does the federal government toll road pilot program play? What is the outlook for more privatization of toll road projects? A principal conclusion is that direct private sector participation in new toll roads is real, and that such participation will continue. The extent of participation will be governed by the relative presence of growth pressures, the lack of alternative facilities, and the prioritization of projects by regional and state agencies. The federal pilot program may provide assistance to at least two proposed projects; however, it is a transition structure and will not significantly influence private involvement either way. Also, with few exceptions, full privatization of toll roads will be limited. Most private interests will secure their objectives through selective participation in project development, financing, and construction oversight, leaving final ownership and operation in public control.

The methods used to finance U.S. highways for the past 200 yr have consistently reflected the prevailing strengths and weaknesses of the public and private sectors at the time of construction, while also respecting underlying attitudes regarding the correct way to finance that particular type of infrastructure. During that period, approaches to major intercity highway finance have ranged from (a) completely private toll companies with virtually no government oversight to (b) the public agencies and authorities operating the vast majority of American roads today. Issues such as the fiscal resources of governments, the nature of travel demand, competing modes, and the state of governing law have all played a role in yielding particular solutions for particular times.

Presently, highway development in the United States is in a state of flux, whereby severe competing pressures among forces such as government budget deficits, infrastructure investment needs in the trillions of dollars, rapid suburban growth, and a shift in preference to private sector/user fee solutions for capital project finance are yielding a variety of financing approaches for both free highways and toll roads. To be more explicit, toll roads are now enjoying a renaissance in the United States—they are being studied, designed, and constructed at rates not seen since the 1940s and 1950s. Yet, while many of these projects are being implemented in a fashion similar to that used for the post-World War II turnpikes, there are also widely scattered signs of more public-private and privatized approaches—these reflecting, as will be shown, both prevailing economic theory and a mix of economic and fiscal forces at work on infrastructure finance.

This paper will analyze apparent trends in the toll road industry, as well as the characteristics of several current toll road projects to seek answers (or reasonably informed opinions) to some interesting questions: Why has toll road development in the United States increased in recent years? Are private sector roles and responsibilities increasing in toll road development, and how do they relate to the federal government's encouragement of privatization and deregulation? What are some of the conditions conducive to increased private sector roles—particularly in capital finance—and how replicable are they in all projects?

While the facts, issues, and conclusions presented herein are obviously driven in part by U.S. law and fiscal practice, many of the basic principles addressed have potential application elsewhere in the world. Indeed, privatized, toll-revenue-financed transportation facilities can be found in many locations on every continent. Differing legal and economic traditions notwithstanding, therefore, the constraints and opportunities of an expanded private sector role in U.S. toll road development should find considerable relevance elsewhere.

A SHORT HISTORY OF TOLL ROAD DEVELOPMENT IN THE UNITED STATES

Toll roads have been a part of the transportation landscape in the United States since 1792, the year that construction

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of the privately owned Philadelphia-to-Lancaster wagon road began. Public attitudes and public policy toward toll highways, however, have swung around three basic positions:

- Roads should be publicly financed and maintained (free).
- Roads should be toll financed and privately managed.
- Roads should be toll financed and managed by public corporations (authorities).

The first era of toll roads lasted 30 yr, from 1800 to 1830. During this period, the states lacked sufficient wealth to finance roads necessary for expansion from the eastern coastal areas. Drawing on British experiments, over 8,000 mi of roads were successfully completed. Financing through tolls was felt to capture more fairly a return from long-distance interregional users and not to place the whole financing burden on local users. With the coming of the railroads in the mid-1830s, many of these roads could not support themselves, and were abandoned. By and large, state and local governments did not assume responsibility for their maintenance, and so, with the exception of limited segments maintained for local use, they fell into disuse and disappeared.

Important lessons were learned during this period on the delegation of authority and responsibility to private companies engaged in providing necessary public services. In the future, granting of statutory authority to a private concern to own and operate a toll road would require that the collection of tolls be conditioned on the maintenance of minimum operating standards, control of vehicle loads and sizes, and coordination of route locations and access.

During the mid-19th century, some toll road construction continued, primarily to service shorter hauls not appropriate for rail lines or spurs. In this period, there was some experimentation with using a combination of private capital and public (bonded) debt. These early public-private partnerships were the result of the continuing inability of governments to finance the necessary roads and became models for modern revenue bond financing for roads.

Through the remainder of the 19th century, only a very few toll roads were authorized and, as a result of the foregoing failures, many more protections were established for investors and users, including specific provisions for dissolution of the private corporations and transfer to public ownership. This was the era of free highways, where several factors contributed to the (temporary) extinction of the toll road:

- Most trips were medium or short haul.
- States had the wealth and tax base to fund roads from general revenue.
- Tolls were perceived to be excessively inconvenient and costly to collect.

During the period from 1860 to 1900, toll roads were actually bought up by states and local governments and converted to free use. This practice continued through 1940, during which local road management was replaced by state management. Besides the general elimination of toll facilities, this period also saw the creation of the first use/funding classification hierarchy, versions of which are still in use today.

The modern toll road era began with the opening of the Pennsylvania Turnpike in 1940, to be followed in 20 yr by facilities in over 30 states totaling over 4,000 miles (6,400 km). While accounting for only 0.1 percent of all roads, these tollways often connected some of the country's largest population centers, resulting in very high traffic volumes and more than ample revenue collections. The states returned to the practice of constructing toll facilities in specific situations for several related reasons, some of which are still relevant today:

- A large backlog of highway needs was confronting flattening or diminishing revenue yields from fuel and vehicle taxes.
- Debt financing secured with fuel taxes was insufficient and not in line with the "pay as you go" philosophy associated with most state road programs.
- Concern about burden equity shifted attitudes more to direct user fees, particularly where traffic levels could be self-supporting.
- It was felt that greater control could be maintained over the entire design and construction process, leading to more economical standards, techniques, and materials and to an overall faster schedule of implementation.

This modern toll road era was itself overtaken (but not eliminated) by the largest program of free roadway construction ever seen—the federal interstate highway system—begun in earnest with the Federal-Aid Highway Act of 1956. While toll road construction languished after the mid-1960s, it began once more with the planning and construction of projects in the 1980s in Virginia, Florida, and Texas, to name but three states with the most advanced projects.

U.S. TOLL ROAD DEVELOPMENT IN THE 1980s—ORIGINS AND ISSUES

It can be reasonably concluded that road financing in the United States has responded over time to changes in a few key variables, which are still important today and go the major distance in explaining the range of proposed financing and management structures currently observed. These variables are

- Need
  - Level of demand
  - Character of demand (local vs. intercity)
  - Availability of competing modes
- Availability of capital
  - Government (especially state, but also federal and local)
  - Private (secured loans; at-risk investments)

- Cost
  - Capital
  - Operations and maintenance

In times when cost has outstripped the ability of government to finance roads directly, private toll-financed roads have appeared in response to market forces, and then disappeared as cheaper and/or more reliable alternatives have captured traffic (e.g., railroads). At other times, government finances have been more than sufficient to fund networks of free roads to service intercity and local traffic. In addition, the nature of demand has been an important determinant of the type of financing—whether to fund projects carrying predominantly local traffic from general tax revenues or to impose tolls for facilities carrying a large share of intercity traffic.

Concurrent with the resurgence of interest in infrastructure needs of all types, a unique mix of conditions and attitudes have coincided in recent years to produce a new wave of toll road projects in the United States, similar to, but decidedly different from, the projects planned and built in the 1940s, 1950s, and 1960s. These conditions are

- Declining revenue availability for all government programs at all levels in response to pressures to hold taxes down.
- The specific flattening (and possible future reduction) of federal government funding of interstate facilities following a 30-yr period of unprecedented federal involvement in highways of all types. This flattening has the effect of adding responsibility to state and local governments at a time when they also are seeing unprecedented demands for infrastructure maintenance and noninfrastructure programs.
- The increasing acceptance of market-driven, user-fee-financed facilities by the public and the implicit rejection of cross-subsidies inherent in any broadly based, tax-financed program.
- The evolution of rural and urban transportation systems from auto-preferred to auto-only environments, changing urban form and land-use patterns.

This last item, representing a change from conditions existing as recently as the early 1960s, has changed toll road planning in at least two key ways: (a) toll roads are being conceived as reliever routes for other, free facilities, and (b) toll roads, in addition to limited access free highways, are being viewed as essential to unlocking extensive tracts of land for new development.

Accompanying this renewed interest in toll roads is a new cost/demand environment, where escalation in capital costs and O&M costs has outstripped growth in toll rates and revenue per trip. Where it was once possible to establish financial feasibility for a toll road with average daily traffic of only 20,000 vehicle trips, modern facilities can require as many as 100,000 daily vehicle trips and more before meeting debt service coverage and O&M costs. This effect is the combined result of public perceptions of cost not keeping with reality and the presence of many more competitive free highways. This relationship, in addition to limiting more toll roads to urban areas with high traffic volumes, is helping to motivate the search for extended revenue packages, new sources of debt security, and more direct private sector roles and responsibilities.

It can be argued that the development of toll highways in the United States is in many cases mirroring the expanded use of public/private partnerships or privatization in other types of infrastructure development. (Note that the definitions of these two terms are similar, if not virtually indistinguishable. Privatization is often viewed as the act of increasing private sector investment, risk, and control; a public/private partnership is the result.) Reasons often given for merging public and private sector roles include the following:

- Restrictions on direct government outlays and debt,
- Access to new capital markets and collateral,
- Shifting of risk to the private sector,
- Cost reductions through tax benefits (really a shift in burden to the federal government) and labor contract flexibility, and
- Acceleration of project schedules.

It is the purpose of this paper to explore the nature of public-private relationships in financing and implementing toll highways. Several projects, described more fully in the following section, are being proposed as public-private ventures or as privately owned toll roads. This new activity in capital finance and project management raises several questions of potential interest to policy makers in the toll road industry:

- What are the conditions and the stated reasons for exploring toll road financing through a more privatized structure? How applicable are these conditions to the full range of toll road projects?
- What are specific ways in which the private sector can directly contribute to toll road financing?
- What role will the federal government toll road pilot program play in moving needed projects along? Is it likely to become a permanent federal highway program element, and if so, what effect is it likely to have on private sector initiatives?
- What can one speculate on the long-term outlook for greater private sector involvement in toll road financing, development, and management?

Each of these questions is addressed following brief descriptions of several current U.S. toll road projects and a partially privatized approach in France.

CURRENT TOLL ROAD DEVELOPMENT ACTIVITY—PRIVATE AND PUBLIC

At this writing, there are at a minimum four toll road facilities under development or study in the United States involving significant private sector participation and/or unusual capital funding structures. (Note that none of these is part of the federal toll road pilot program.) Brief summaries of these and other projects provide numerous insights into the policy questions raised in the preceding section.

E-470 Roadway—Denver, Colorado

The E-470 roadway is a proposed 48-mi half-beltway to serve the eastern half of the Denver metropolitan area. The roadway would link directly with another portion of the regional beltway (C-470) and would provide direct access to Denver's proposed new airport, interchange with the state highway system in six locations, and generally connect rapidly growing residential and commercial areas north, east, and south of Denver.

The roadway is being developed by the E-470 Authority, a consortium of four local governments in concert with principal landowners and developers within the highway corridor who collectively control over 50 percent of the required right-of-way. Initial funding for studies has been provided by the public and private sectors, although interim funding is now available through arbitrage income from tax-exempt bonds held in escrow (a mechanism no longer available under current U.S. tax law).

Toll revenue is intended to be the principal source for repayment of bond proceeds, though supplementary revenue sources are being defined, including development-related taxes and fees within a 3-mi corridor centered on the highway, and various tax mechanisms drawing on the tax base of the three counties involved in the project.

Due to projected shortfalls in toll revenue in the early years of project operation, alternative arrangements for supplementary financing are being investigated, including the commitment of private equity capital, commercial letters and/or lines of credit, government infrastructure loans, and recycling of excess revenue above that needed for debt service on the initial bond issue.

Dulles Toll Road Extension

Studies are now underway for a 17-mi extension of the very successful Dulles Airport corridor toll road, first opened to revenue service in 1983. Development pressures along the existing corridor have led to studies of widening the initial four-lane roadway to six lanes, while development beyond the corridor to the north and west of Dulles Airport has resulted in a serious proposal to privately construct, own, and operate a four-lane extension.

Dulles Airport is located approximately 26 mi west of Washington, D.C. The proposed extension would deviate from the existing toll road 1 or 2 mi from the airport terminal and proceed in a northerly and then westerly direction to the town of Leesburg, Virginia. Developers are now in the process of assembling large parcels in the area traversed by the proposed extension with an eye toward future development. In addition to providing internal circulation, the toll road would also provide access to Dulles Airport, Fairfax County, and Washington, D.C.

The Dulles toll road extension is the object of a state-sponsored environmental impact study (now scheduled for completion sometime in 1988). At the same time, a financial-engineering joint venture has been assembled to design, build, own, and operate the toll road extension, subject to regulatory control by the state corporation commission and the Virginia DOT. Capital financing would be accomplished through privately placed borrowing, while right-of-way and some interchange costs would be provided by interested developers. The state of Virginia could benefit from this approach through the ability to concentrate its resources on pressing needs elsewhere. Legislative authorization for a privately owned toll road in Virginia has been enacted. Construction under a design/build arrangement may begin as early as fall 1988 and be completed within 3 yr.

Orange County, California, Toll Corridors

As a response to continuing development pressures in the southern and eastern areas of Orange County, California, major developers, the Orange County Transportation Commission (OCTC), and a special intergovernmental agency (TCA) are investigating the feasibility of building one or more proposed freeway facilities as toll roads. The three candidate corridors are referred to as the Eastern, Foothills, and San Joaquin; and each offers critical access to developing areas under the control of three or four major developers.

All three corridors have been designated as federal toll road pilot projects under recently enacted U.S. government legislation, allowing for the first time a commingling of federal funds with toll-revenue-supported debt. Legislation to allow toll roads in California (heretofore prohibited) has now passed. At present, fees on new development are being collected and held in escrow pending implementation of one or more of the toll road projects. Preliminary funding studies indicate that these development fees could support up to 45 percent of the capital needs of one toll road. Additional funding may come from federal government sources, private investors, or both.

Bi-County Thruway—Pasco County, Florida

A major developer is promoting the concept of a new 28-mi toll highway linking I-75 with the coastal town of Tarpon Springs, Florida, just north of the major metropolitan area of Tampa/St. Petersburg/Clearwater. The project would greatly improve access to large sections of Pasco County, which is now rural in nature but which is developing rapidly. The facility would also provide an alternative route to the Pinellas County cities of Clearwater and St. Petersburg by avoiding very congested sections of I-275 through Tampa.

This project is in the very earliest stages of conception, but the institutional and financing structures are already clear. Ownership and operation would remain public, most likely through an existing county expressway authority and the Florida DOT. Development and financing, however, would rest largely in private hands, utilizing donated right-of-way and interchange costs; private, at-risk capital; and tolls.

Preliminary feasibility studies for the project will include traffic forecasts, cost estimates, environment issues investigations, and institutional/financing studies. The project is dependent on the completion of at least two other expressway facilities in the region, and its implementation date is therefore uncertain.

Harris County Toll Road Projects

Harris County, Texas, is presently constructing two toll roads using essentially standard means of revenue-backed borrowing. For the two projects in question—the Hardy Toll Road and the West Belt Toll Road—the county has departed from the otherwise standard practice of relying solely on toll revenues by issuing tax-supported bonds to cover early project costs during design and construction. Additional toll-backed revenue bonds have been issued in several series and are being tapped as necessary to cover the completion costs of the two projects. It is intended (but not guaranteed) that toll revenues will cover the debt service on both series of bonds.

The two Harris County toll road projects are being sponsored by the Harris County Toll Road Authority. The projects are not responsibilities of either the state of Texas, the city of Houston, or Harris County itself. Aside from the normal purchasers of rated, tax-exempt debt (lenders), there is no private sector capital at risk in these projects.

Sawgrass Expressway—Broward County, Florida

The Sawgrass/Deerfield Expressway is a 23-mi project linking I-75 with Florida's turnpike in Broward County, Florida, north and west of the city of Fort Lauderdale. At this writing, most of the project is open to traffic; however, the connection with I-75 at the south end is still awaiting completion. The project is to function essentially as a bypass around Fort Lauderdale, providing significantly improved access to developing areas west of the city.

The project was financed through the issuance of toll revenue bonds backed by 80 percent of the revenue from a county fuel tax and ultimately secured by the full faith and credit of the state of Florida. Further, the Florida DOT committed to complete the project using state resources in the event that project costs ultimately exceeded available bond proceeds. The Florida DOT will operate and maintain the Sawgrass Expressway, receiving funds from tolls in excess of those required for debt service to cover its costs. The Broward County Expressway Authority will maintain ownership of the facility.

Private Concession Motorway System—France

The concept for a private venture to finance, construct, and operate a national system of limited-access highways in France was developed in 1970. Under that concept, the French government gave broad power and discretion to several private consortia of banks, engineers, and contractors to create and manage different portions of the system, subject to certain financial, design, and service requirements. While a majority of the consortia has in fact failed as private, at-risk ventures (with direct control returned to the government), at least one venture continues in private hands.

The motivation for the privatized approach to the system was the ability of the French national government to gain access to private capital and design/construction management without directly committing tax revenue. Also motivating this approach was the goal of centralizing control of the development of the system to coordinate more effectively design and construction of individual elements.

The key elements of the public-private agreements are the following:

- A concession is granted by the government for a period of time, after which control is returned to the government. The government has the right to repurchase control after 20 yr.
- The consortium is responsible for all financing, design and construction, and operations. In return, it has all rights to revenue from tolls and leases of adjoining service areas.
- Capital for the system is provided through 25 percent equity from the consortium and 75 percent government-guaranteed borrowing. The government agrees to loan funds to cover revenue shortfalls.
- The government retains ownership. The private consortium is granted the power of eminent domain.
- The government retains control over alignment, interchanges, permissible loadings, design speeds, etc. The consortium is required to coordinate designs with local authorities.
- The consortium is allowed to modify implementation timetables to account for deviations in traffic levels.
- Finally, the consortium is responsible for the maintenance of safe operations.

This approach represents a highly privatized concept for capital project financing and implementation. It benefits somewhat from the relationships between the national and local governments in France, but elements of it are clearly applicable to the United States.

ANALYSIS AND CONCLUSIONS

Conditions Encouraging Direct Private Involvement in Toll Road Financing

It has been shown that the recent increase in toll road projects in the United States has resulted from the coincidence of growth pressures, cost increases, government tax and funding limitations, and a political shift toward user-fee financing. Many of these characteristics also help explain current interest in public-private partnerships for infrastructure and full privatization of project delivery and services.

It should be noted that any user-fee-financed project, whether public or private, involves the private sector as lender/investors. One key definition of public-private or privatized projects involves the degree of risk and the degree of control granted to private, for-profit entities. As a condition for assuming greater risk, the private sector will require greater control. Risk is present in all three project elements: (a) project cost, (b) project schedule, and (c) future traffic and toll revenue. All of these, then, can yield at least one basis for encouraging a greater private sector role.

More direct private sector involvement in toll financing will almost always occur when one or both of the following conditions are present:

- Landowner/developer interest in improved access
- Limitation or nonavailability of state and local government credit support.

As a result of changes in the development process and cost-revenue relationships in the past 30 yr, the first four examples described in the preceding section all reveal the potential for new financing structures precisely because (a) they are driven in large part by developer interests and needs, and (b) they lack the credit backing of states and (in some cases) local governments. The two examples of traditional toll road financing (Harris County and Broward County) incorporate tax revenue bonds in one case and the full faith and credit backing of a state in the other.

In addition to landowner/developer interest and the apparent lack of adequate credit support from state and local governments, the following conditions will be present, in varying combinations, as motivations for increased private sector roles in toll road financing and/or management:

- Inadequate total traffic and toll revenue in early years of operation,
- High degree of local access travel,
- Perceived need for fast-track implementation (intense development pressure coupled with inadequate access capacity),
- High degree of local consensus,
- Very limited number of controlling landowners, and
- Willingness of state to delegate or share planning control.

In all four examples discussed, local travel and access constitute the major if not majority share of travel on the proposed facilities. Projects that are viewed as fundamentally intercity connectors or congestion relievers—such as the Harris County projects or most of the pilot program projects—are generally better candidates for full public support.

As evidenced by projects such as E-470, Dulles Airport Extension, and Pasco County, an unusually high degree of local political consensus is required, as well as assemblage of adjacent land ownership by a very limited number of parties. Associated with these two conditions is the willingness of the state to work closely with local government or to cede the majority of control to local government.

A combination of (a) lack of government credit and support and (b) forecasts of inadequate traffic and revenue for the early years of a project will greatly increase the risk to passive lenders/investors. This situation, while typically leading to a failure of project feasibility and subsequent project abandonment, may instead lead to an intensified search for new classes of lenders/investors willing to undertake higher risks in return for greater financial gain.

A final, but often critical, motivation for an increased private sector role is the presence of short development timetables and/or development restrictions based on access capacity. In short, development interests perceive that a privatized approach can deliver the project sooner. This perception is definitely a factor in the Denver, Dulles, and Pasco proposals.

In the end, the progression from these conditions to public-private or privatized toll road financing must largely depend on the specific "chemistry" of the public and private sector leaders involved in a project. Examples abound where the public sector has responded rapidly to "win-win" proposals from private interests, while maintaining full control and normal risk levels throughout.

Private Sector Roles in Capital Financing

Common Approaches

The private sector has become involved in financing new transportation infrastructure in recent years through a variety of mechanisms. The most frequently used mechanisms have been the following:

- Dedication or discounted sale of land for right-of-way, and
- Voluntary participation in special taxing districts.

Both of these mechanisms are applicable to toll road projects and are present in each of the four private projects described. It should be noted that special taxing districts can be broadly defined to include any of the following:

- Developer impact fees.
- Special assessment districts—one-time assessments on holders of real property perceived to be specially benefited by construction of a public improvement. (Can be financed using tax-exempt bonds.)
- Special service or improvement districts—voluntary action by property owners to create a district to fund and/or operate a specific project or service.

All of these districts, whether imposed by government or voluntarily created, represent legally authorized actions of municipal subdivisions in states where they are permitted, and should be viewed as special taxes or fees applied to specific groups and areas. Property owners participating in these districts cannot be construed as having any capital at risk; thus, these mechanisms are among the most conservative and limited examples of private sector involvement in infrastructure finance.

Direct Contributions

More unusual, but growing in acceptance, is the situation in which an individual developer or small group of developers will contract directly with an implementing entity to finance the construction of a specific interchange or segment of highway. This approach appears to be most viable where the facility to be financed is an enhancement of a larger project.

Private Partnership

It is considered difficult to finance an entire $100+ million facility through contractual agreements with participating property owners. However, there is at least one example of a non-toll-highway project financed entirely through voluntary contributions by a group of six property owners. The Sun Valley Parkway, located northwest of Phoenix, Arizona, is being financed with tax-exempt debt, with repayment pledged from annual assessments on the six property owners, all agreed to voluntarily.

Subordinated Loans

The concept of pledging real property as collateral for otherwise unsecured loans is a true innovation which may see greater use in projects perceived as essential by developer interests. It may be most applicable in situations where the entire cost of a toll road project cannot be borne through toll-backed debt financing. In that situation, a second, subordinated loan may be negotiated with lenders/investors who are willing to assume higher risk and a delay in repayment in exchange for greater rates of return. Further incentives might come from key benefiting property owners sharing a percentage of net proceeds from land sales or income from developed property—providing, in effect, an equity kicker to those lending in a subordinated position.

Private Ownership/Operation

A total approach to private sector involvement is the concept of private ownership and control of a toll facility, with capitalization provided at risk, secured only by tolls and possible collateral arrangements with property owners. This approach shifts early operating risk to the private sector, but requires the standby assumption of risk by the public sector in the event of financial difficulty or insolvency by the owner/operator. The Dulles Toll Road Extension is planned as a private project controlled in this manner. The Cofiroute concession approach in France also represents one possible model for a more fully privatized toll road program in the United States.

Role of the Federal Government Toll Road Pilot Program

The recently reauthorized U.S. surface transportation program (HR 2) contains provisions allowing, for the first time, the use of federal highway funds in conjunction with toll-financed projects. It is indeed a pilot program, in that federal contributions are limited to 35 percent of the total cost of the project, and they may be applied to only eight projects in eight designated states. Since the program does not add funds to the federal allocation any state would normally receive, it is most beneficial to a state where the candidate toll road project is already given a high priority, and therefore provides for the release of at least some nontoll local revenues for other projects—provided that toll coverage is at least 45 percent of cost. In a situation where the pilot project is not currently programmed, use of federal funds for that project requires diversion of those funds from other projects.

While predicting the future of U.S. federal government participation in toll roads must be pure speculation at this time, the high level of interest in the pilot program to date suggests that the program will be extended and enlarged during or before reauthorization of the highway program in 1991. To the extent that tolls are a new revenue source for state governments, their presence may free other scarce tax revenues for projects not eligible for federal matching funds or for maintenance.

The likely effect of increased federal participation in toll roads on public-private partnerships and privatized projects is exceedingly difficult to forecast. On the incentive side, the availability of federal funds may enhance the feasibility of projects not viable with toll revenue alone, and thereby increase the number of project opportunities for private sector involvement. By the nature of the reviews and approvals accompanying the use of federal funds, however, the focus of project management and control will necessarily shift more to the state level. This change, along with the significant amount of additional time required to complete environmental and design reviews, will dilute the effectiveness of private financing and control in achieving the key goals of fast-track implementation and internally managed cost control. As a result of these conflicting influences, it is possible to foresee the evolution of two separate streams of projects—one with state-federal management and one with local-private management.

Future Private Sector Involvement in Toll Road Financing

A review of the factors influencing toll road development in the United States suggests a mixed outlook for private sector participation in the future. A toll road, by the very nature of its financing structure, can and should be viewed as a business, for which the benefits of the private sector—efficiency and innovation—should be tapped. Alternatively, a toll road is also a public service, with complex, interactive effects on multiple private entities and public resources, often involving numerous political jurisdictions governed under varying and sometimes conflicting values and goals. While the public will indeed benefit from maximizing the efficiency and effectiveness of a given project, the public will also rely on guarantees of service (e.g., access to land) in the face of threats to a project's viability.

After consideration of these complementary and conflicting toll road attributes, one can broadly conclude that public-private partnerships are likely to remain a force in U.S. toll road development in selected situations, as large, statewide roadway capital programs will not always be responsive to small area transportation needs and desires. These partnerships, including the potential for fully privatized operations, will work most effectively in developing areas where traditional state roles of regional and interregional service are less applicable. Further, economic and budgetary pressures on all levels of government will complement local development forces and desires for local control to shift management and financial responsibility to the private sector. Toll roads will, in many cases, represent the only path for early relief of inadequate access and roadway capacity; private control of those projects may, in many cases, represent the best way of ensuring timely project implementation through assumption of additional financing risk in exchange for management control.

The likelihood of a significant private sector presence notwithstanding, there appears to be more limited potential for a large number of truly private highways, such as the Dulles Toll Road or the Cofiroute system in France. Given the number and diversity of parties affected by a toll road project, there may be limited benefit to all parties (as a whole) from taking the final step of total private ownership and control, even though this structure may operate as equitably as a special purpose authority or nonprofit corporation. The issue of public-private partnership really applies to the process requirements of implementation and operations management. Given that the private sector can apply capital and risk in ways not permitted the public sector, and that it can typically bypass many of the process requirements of the public sector in managing implementation and operations, the private sector will, in most cases, be able to channel the majority of benefits to a project without the ultimate step of independent ownership and control.

In summary, therefore, those planning new toll roads in the coming years should be alert to the potential benefits of private sector participation in project finance, implementation management, and operations management. Economic, fiscal, and political conditions within the foreseeable future should continue to support public-private approaches which, if structured properly, will benefit all project participants.

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Local Government Participation in Federal Aid Highway Programs: FAUS Experience and Future Prospects

RONALD EASH AND ANDREW PLUMMER

This paper deals with local government participation in the existing Federal Aid Urban System (FAUS) highway program. The role of local elected officials in programming FAUS projects provides some guidance for a future highway program directed toward urban area highway needs. A description of the FAUS program in northeastern Illinois illustrates how local FAUS programs are generally administered in a major urban area. Data on FAUS programs in other large and small, growing and mature regions were gathered through a questionnaire distributed to selected Metropolitan Planning Organizations (MPOs). Responses provided by MPO staff and the authors' experience with the northeastern Illinois FAUS program are the basis for an evaluation of the FAUS program. The evaluation includes a discussion of local FAUS program strengths and weaknesses and some recommendations for future federal legislation.

There is general agreement that the next major legislation for federal transportation funding will significantly change the organization, administration, and funding levels of federal aid highway programs. The next Surface Transportation Assistance Act will undoubtedly be far different from the act of 1987 (*1*), which made few changes on highway programs and continued program authorizations at near existing levels until 1991. Future legislation will have to consider that the largest single highway program, interstate construction, is expected to end by 1993.

Local government officials are speculating about postinterstate federal aid highway programs and anticipating effects on their highway improvement programs. Urbanized area governments are particularly anxious due to growing traffic congestion on suburban and urban arterial streets. Recent attempts to eliminate or change the funding levels of the FAUS program have further added to local government uncertainty about future highway funding levels.

It seems reasonable to expect a postinterstate federal aid highway program directed toward urbanized area highway needs. Determining the funding levels for an urban area highway program and the procedures for developing eligible projects and moving them to contract are perhaps the biggest challenges facing the drafters of the next federal transportation legislation. One question this legislation will have to resolve is the role of local elected officials in a future urban area federal aid highway program.

This paper relates the experience of local officials with the programming of projects for the FAUS program. A brief description of the programming of FAUS projects in northeastern Illinois illustrates how the FAUS program generally functions in a major urban area. The program was evaluated through a questionnaire distributed to selected Metropolitan Planning Organizations (MPOs), which were asked to describe the FAUS program in their regions and to evaluate local FAUS project programming. Some implications for new urban area highway legislation are developed from the MPO responses and from the authors' experience with the northeastern Illinois FAUS program.

FEDERAL AID URBAN SYSTEM PROGRAM

The FAUS program is the newest of the four federal aid highway system programs; interstate, primary, and secondary are the previous three federal aid system programs. The FAUS program was established by the 1970 Highway Act (*2*), but became a major highway program only after passage of the 1973 Highway Act (*3*), which significantly increased the mileage in the FAU system and the level of federal funding. FAUS routes and programmed projects for federal cost sharing are selected with input from local elected officials in an urbanized area. Though the states are required to sign off on FAUS routes and improvements, the FAUS program, due to the number of local governments in urban areas, has more local government involvement than do the other federal aid highway system programs.

With its urban area focus and the involvement of local elected officials, the FAUS program was intended to accomplish three objectives (*4*):

- Obtain federal highway funds for highway needs not eligible for other federal funding participation,

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Chicago Area Transportation Study, 300 West Adams Street, Chicago, Ill. 60606.

- Provide for a more equitable allocation of federal aid highway funds between urban and rural areas,
- Base priorities for a portion of federal aid highway funding on highway needs of local governments.

ORGANIZATION OF THE FAUS PROGRAM IN NORTHEASTERN ILLINOIS

In northeastern Illinois, local FAUS program input is obtained through 11 suburban councils of mayors organizations, plus the city of Chicago. Mayors and their representatives are consulted through these 11 working councils, which are based on geographic and jurisdictional boundaries. A map of the council areas is shown in Figure 1.

The FAUS program in northeastern Illinois is administered through the region's MPO, the Chicago Area Transportation Study (CATS), which also prepares the region's Transportation Improvement Program (TIP) (*5*). The major FAUS program responsibilities of CATS are to keep track of FAUS expenditures by each council and to advise the councils of the balances remaining in their FAUS accounts. The agency also assists in the paperwork required to get projects into the region's TIP and prepares reports containing summary statistics on the program's operation, types of FAUS projects programmed, and estimates of project and regional impacts.

Each council receives planning funds for a subregional planner who coordinates activities among council members. The subregional planner represents his council in meetings with CATS, the Illinois Department of Transportation (DOT), federal transportation agencies, and other regional transportation providers. Some council staff also perform small technical studies for their councils.

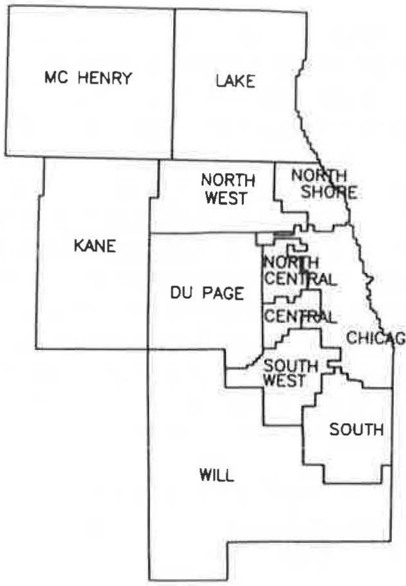

FIGURE 1 Map of council areas.

There is no real competition between councils for FAUS funds. The 11 suburban councils and Chicago share FAUS funds based on population. Reallocation of suburban FAUS funds does take place, however, whenever a council is unable to program enough projects to use up its FAUS funds. The shifting of FAUS funds between suburban councils is supervised by an executive committee elected from council members and staffed by CATS.

SURVEY OF METROPOLITAN PLANNING ORGANIZATIONS

A questionnaire was mailed to MPOs around the country. These agencies were asked to describe the selection and programming of FAUS projects in their region. Some of the questions were open ended to allow further explanation of local procedures followed in the FAUS program. At the conclusion of the questionnaire, respondents were asked to critique their local FAUS programming process and to suggest changes in federal requirements. Any available documentation on their FAUS programs was also requested.

As outlined in the federal transportation planning regulations, the role of the MPO in a region's FAUS project programming is limited. The MPO has joint responsibility with providers of transportation services to prepare the TIP, which must include all FAUS-funded projects. A more direct relationship between MPOs and FAUS programs is the required endorsement by the MPO of the TIP's annual element, the section of the TIP that identifies projects to be funded in the next fiscal year. Within the existing legislation, this is evidence that local elected officials have been involved in selecting FAUS projects.

But most MPOs participate to a much greater extent in the programming of FAUS projects than the role outlined by the federal requirements for transportation planning. The MPOs are the principal recipients of federal funds for transportation planning. They are usually well-established planning agencies, and often the only agency with the resources to administer the local FAUS program. Organizations of elected officials that select FAUS projects are frequently affiliated with an MPO or are part of an MPO's organization, such as the MPO's policy-making board.

The MPO is a common denominator in the FAUS program from one region to another. Staff of MPOs are usually directly involved in the FAUS program, or at least knowledgeable about local procedures, and are a logical group to survey for an evaluation of the FAUS program across regions.

Selection of MPOs

Questionnaires were sent to 32 MPOs, all members of the National Association of Regional Councils' (NARC) MPO

TABLE 1 METROPOLITAN PLANNING ORGANIZATIONS THAT RETURNED QUESTIONNAIRES

Metropolitan Planning Organization	MPO Provided FAUS Program Documentation
Middle Rio Grande COG: Albuquerque, New Mexico	Yes
North Central Texas COG: Arlington (Dallas-Ft. Worth), Texas	
Atlanta Regional Council: Atlanta, Georgia	Yes
Mid-Ohio Regional Planning Commission: Columbus, Ohio	
Denver Regional COG: Denver, Colorado	Yes
Southeast Michigan COG: Detroit, Michigan	Yes
Capital Region COG: Hartford, Connecticut	
Mid-America Regional Council: Kansas City, Missouri	
METROPLAN: Little Rock, Arkansas	Yes
Southern California Association of Governments: Los Angeles, California	Yes
Wilmington Metropolitan Area Planning Coordinating Council: Newark (Wilmington), Delaware	
Regional Planning Commission for Jefferson, Orleans, St. Bernard, and St. Tammany Parishes: New Orleans, Louisiana	
Southwestern Pennsylvania Regional Planning Commission: Pittsburgh, Pennsylvania	
Bi-State Metropolitan Planning Commission: Rock Island, Illinois	Yes
Sacramento Area Council of Governments: Sacramento, California	
East-West Gateway Coordinating Council: St. Louis, Missouri	
San Diego Association of Governments: San Diego, California	Yes
Pima Association of Governments: Tucson, Arizona	Yes

Transportation Advisory Committee. The 18 MPOs that returned completed questionnaires are listed in Table 1. Nine of these 18 MPOs also returned additional material describing FAUS project selection and programming for their regions. This documentation made it possible later to check answers on the questionnaire.

The responding MPOs represented regions in a range of different sizes. The regions fall naturally into four population groups (Table 2), based on their 1985 metropolitan area populations (*6*).

The 18 MPOs also are distributed geographically among growing urban areas in the west, south, and southwest, and mature areas in the east and midwest. Population growth rates from 1980 to 1985 were used to sort regions into high growth areas (growth rates greater than 10 percent) and mature areas (growth rates roughly between plus and minus 5 percent) (Table 3).

Questionnaire

The questionnaire was addressed to the MPO representative on the NARC MPO committee, who usually completed the questionnaire. With two exceptions, the respondent had been employed by the MPO for more than 5 yr.

The questionnaire's format was generally multiple choice or short answer. Space was provided for an explanation of local circumstances not matching and of the possible answers when the multiple choice format was used. This format was selected to make the questionnaire

TABLE 2 METROPOLITAN PLANNING ORGANIZATIONS—REGIONAL POPULATION

Population Group	Metropolitan Area	1985 Population
I	Rock Island	377,200
	Albuquerque	464,300
	Little Rock	498,500
	Wilmington	544,000
	Tucson	585,900
II	Hartford	1,035,000
	Sacramento	1,258,500
	Columbus	1,287,600
	New Orleans	1,324,400
	Kansas City	1,493,900
III	Denver	1,827,100
	San Diego	2,132,700
	Pittsburgh	2,337,400
	St. Louis	2,412,400
	Atlanta	2,471,700
IV	Dallas-Ft. Worth	3,511,600
	Detroit	4,581,200
	Los Angeles	12,738,200

less tedious to fill out and to focus responses. Unfortunately, the resulting questionnaire was lengthy because it was necessary to describe the alternative choices for many of the questions in detail.

The questionnaire included five subject areas: a profile of the MPO, origination of FAUS projects, characteristics of FAUS funding, development of FAUS project priorities, and local FAUS program evaluation. Within each of these sections, questions were asked in the form of an outline. Instructions, such as "select one of the following," were provided as needed. A copy of the questionnaire is included in the project report.

The questionnaire was tested by distributing it in advance to several members of the NARC MPO committee. Their comments were incorporated into a revised questionnaire with some additional instructions and slight rewording of several questions. After the completed questionnaires were received, the answers to multiple choice and yes/no questions were entered into a microcomputer file to simplify data manipulation.

INVOLVEMENT OF LOCAL ELECTED OFFICIALS IN DEVELOPING FAUS PROJECTS

The MPO staff person was asked to describe the relationship between the organizations of elected officials consulted for programming FAUS projects and the MPO. Of five possible organizations identified on the questionnaire, only three were selected: (a) a direct relationship between the MPO and elected officials, whereby the organization of elected officials is also the MPO policy board; (b) an autonomous organization of elected officials with the MPO as a liaison between elected officials and transportation providers; and (c) assembly and endorsement by the MPO of the FAUS component of the TIP from lists of projects developed by an autonomous organization of elected officials. Table 4 presents these responses by size of region.

In smaller urban areas, the number of elected officials is so small that they can all be contacted through one regional organization of local elected officials. Such organizations normally number 10–20 members and tend to be organized as part of the MPO (Table 4).

For large metropolitan areas, a single working organization of elected officials for FAUS project development and endorsement is impractical due to the number of local governments. FAUS projects in the TIP are endorsed by the MPO policy board representing all local officials. Policy board membership is determined through elections or systematic rotation of membership. FAUS projects are either developed by smaller groups of elected officials, by state and regional service providers, or jointly by elected officials and providers.

Questionnaire responses indicated that local officials have an active role in FAUS project development. In only one instance did a returned questionnaire say that the principal role of local officials was to endorse projects originated by state or regional transportation providers. All others answered that local officials were either primarily responsible for FAUS project development or shared this responsibility with providers.

Local elected officials in most regions have a dual role in the FAUS programming process. They originate FAUS projects and also endorse the list of FAUS projects in the TIP, which includes projects they have put forth as well as projects reflecting priorities of state and regional transportation providers. This dual role was brought out by the fact that several questionnaires had multiple answers for the role of local officials in the process. Positive responses were given for endorsement of project lists by local elected officials and also for one of the choices indicating some responsibility on the part of local officials for initiating FAUS projects.

TABLE 3 METROPOLITAN PLANNING ORGANIZATIONS—GROWING AND MATURE REGIONS

Type Region	Metropolitan Area	Percent Change 1980 to 1985 Population
Mature	Detroit	-3.6
	Pittsburgh	-3.5
	Rock Island	-2.0
	St. Louis	1.5
	Hartford	2.1
	Columbus	3.5
	Wilmington	4.0
	Kansas City	4.2
	Little Rock	5.1
	New Orleans	5.4
Growing	Tucson	10.2
	Albuquerque	10.5
	Los Angeles	10.8
	Denver	12.9
	Sacramento	14.4
	San Diego	14.5
	Atlanta	15.6
	Dallas-Ft. Worth	19.8

LOCAL FAUS MATCHING FUNDS

The local match for federal FAUS funds is provided by municipalities, counties, and states. The local matching source generally refers to the unit of government that controls the disbursement of funds, not the unit of government that collects the funds. In Illinois, a portion of state-collected gas taxes is distributed to municipalities for their use.

The bar graph in Figure 2 shows local matching fund sources for the different MPO population groups. Larger metropolitan areas depend more on state and county sources for their local FAUS match share than do smaller regions, where the local match is more likely to be municipal funds.

Figure 3 is a second bar graph showing the source of local FAUS matching funds for mature and growing regions. Municipalities in growing metropolitan areas tend to provide a larger share of the local match than do municipalities in mature regions.

FAUS PROJECT PRIORITIES

To program FAUS projects, there must be some procedure to select projects for the Transportation Improvement Program and some means within the TIP to advance projects from the multiple year element to the annual element. In most metropolitan areas, FAUS funds are allocated to subareas or project categories before priorities are determined. Fifteen MPOs reported that FAUS funds are first distributed to local governments within the region. In larger urban areas, the most frequent allocation was to counties. Other regions distributed FAUS funds to municipalities over a certain population and to urban/urbanized areas.

TABLE 4 RELATIONSHIP BETWEEN METROPOLITAN PLANNING ORGANIZATIONS AND LOCAL ELECTED OFFICIALS

	Number of Positive Answers		
MPO Population Group	Directly Related	Autonomous-MPO Liaison	Autonomous-MPO Minor Role
Group I (smallest)	4	2	0
Group II	4	0	1
Group III	4	1	1
Group IV (largest)	0	2	1
Total(a)	12	5	3

a. Two MPOs responded with two answers.

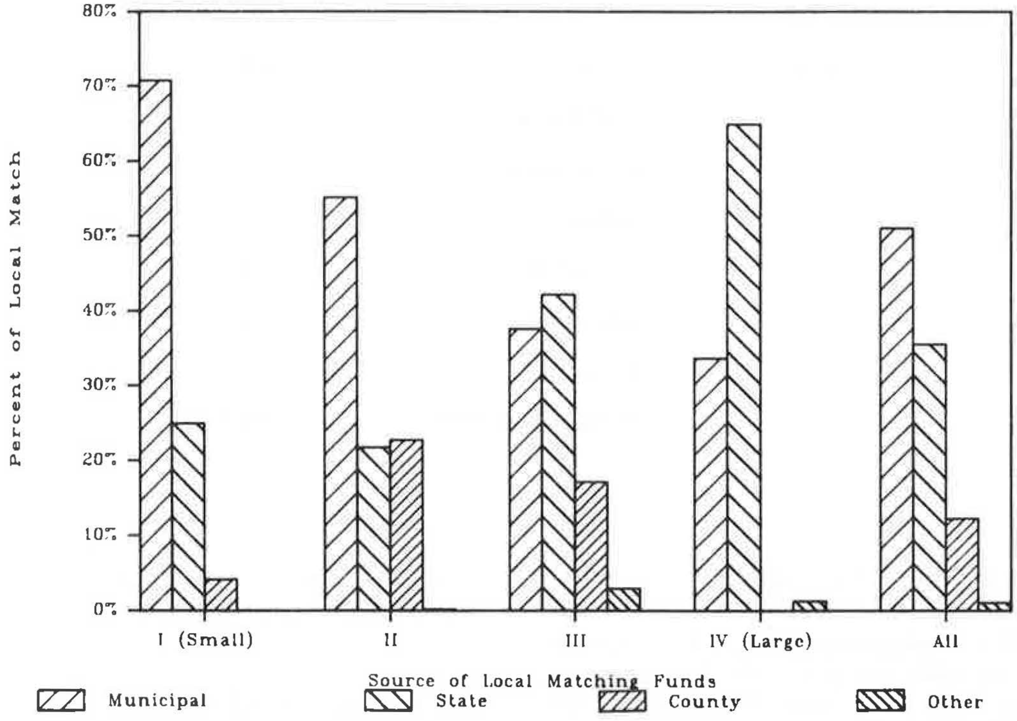

FIGURE 2 Sources of local matching FAUS funds by size of region.

Population is used to allocate funds in nearly all instances. The legislation itself prescribes a population-based allocation of FAUS funds between the central city and suburbs. Distributing FAUS funds in this manner spreads funds around a region in a politically acceptable manner and reduces the importance of project priorities.

Several other means of allocating FAUS funds were described on the questionnaires. Six MPOs said that FAUS funds were distributed to different categories of projects. Several regions set aside a percentage of their FAUS funds for transit. In one metropolitan area, FAUS funds are divided among different functional classes of highways. In all cases, however, the allocation is the result of a negotiated policy agreement rather than an objective measure of need.

The questionnaire asked how projects are compared to set priorities. The bar chart in Figure 4 lists the number of positive responses for five different levels of project

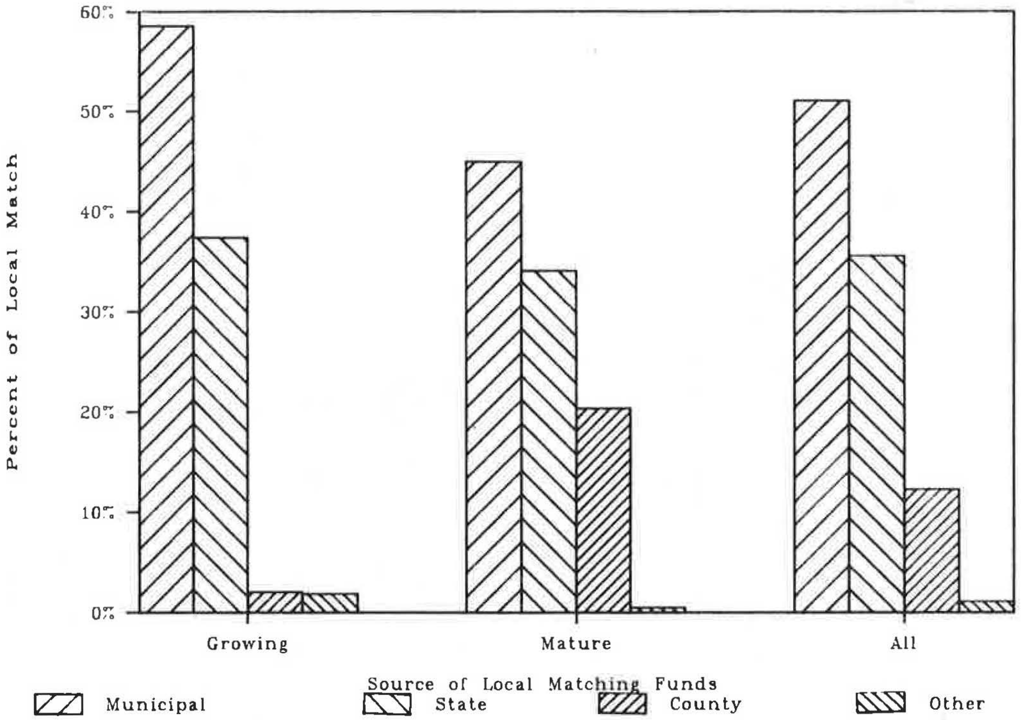

FIGURE 3 Sources of local matching FAUS funds for growing and mature regions.

evaluation and prioritizing: (a) purely subjective project priorities, (b) priorities for general FAUS project categories, (c) priorities based on technical studies without explicit ranking of projects, (d) formal ranking of projects, and (e) other methods for prioritizing FAUS projects.

No one form of FAUS project evaluation and prioritizing is dominant. Most agencies marked more than one choice, and it seems safe to say that FAUS project priorities are commonly based on some combination of technical evaluation and other considerations. Two agencies commented that project readiness for contract letting is a major consideration.

EVALUATION OF LOCAL FAUS PROGRAMS

MPOs were asked to indicate problems in programming FAUS projects from a list of expected problems. None of the MPOs indicated that it was difficult to develop suitable projects for FAUS funding, and several contended that they had a backlog of available projects. Six respondents reported a shortage of local matching funds in their regions. Eight MPO staff members noted disputes among local officials or between local and state officials over project priorities. Satisfying federal program requirements was cited as a problem by five MPOs.

Following is a summary of other identified problems in processing FAUS projects through local programs:

- Local governments are responsible for advancing FAUS projects through a local program, but some have trouble following the procedures required to move FAUS projects to contract letting.
- Design standards required by federal participation are excessive and unnecessarily increase project costs.
- The staff in FHWA regional offices are inflexible in interpreting program procedures; for example, insisting on an exact federal-to-local funding split of 75:25 even when local governments are willing to increase their share to expedite projects. (This comment was made prior to the 1987 act.)
- It is difficult to reach a fair and politically acceptable allocation of FAUS funds in the region.
- There is uncertainty in annual federal funding due to federal program obligations and possible sanctions on federal funds due to a region's failure to meet air quality standards.

Strengths of Local FAUS Programs

One characteristic of local FAUS programs was repeatedly noted as a major program strength. Thirteen respondents said that coordination between local governments, the MPO, public transportation providers, and the state was a major program strength. There is a very positive local opinion that the FAUS programming process produces a coordinated regional program through the joint efforts of participants. One questionnaire contained the comment that the FAUS program "is the only example of regional capital improvement programming in our area."

The technical process itself, the evaluation of projects and development of priorities, was identified as a strength

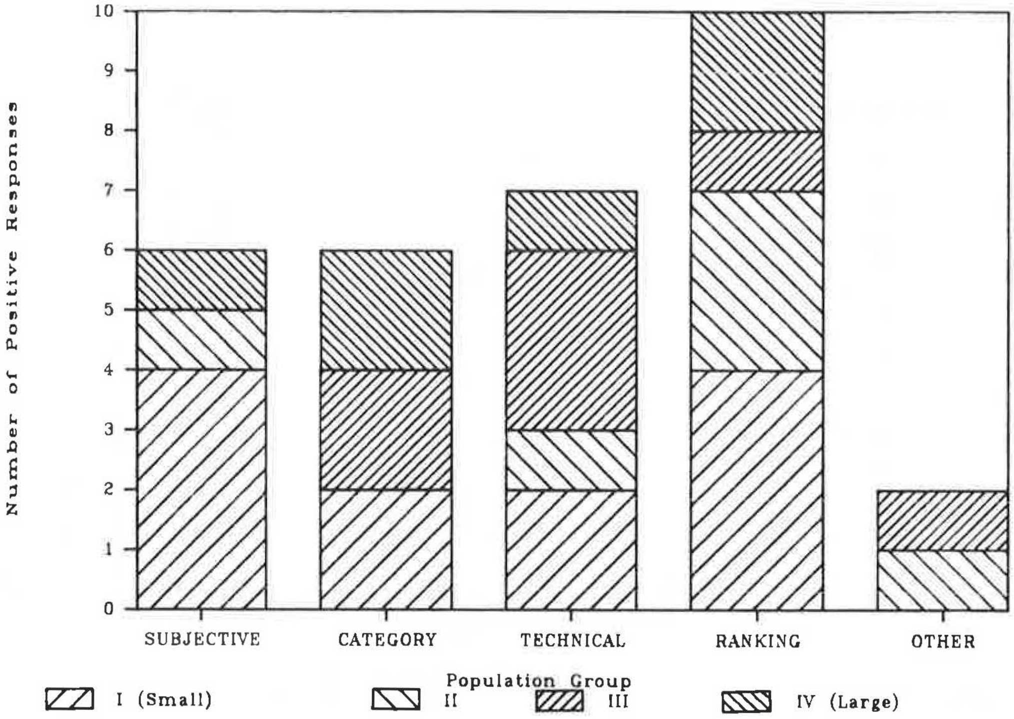

FIGURE 4 Type of FAUS project evaluation.

on four questionnaires. Another MPO felt that the allocation formula used in its region to distribute funds between major highway and local street improvements was an advantage. Two respondents concurred with the national objectives for the program in identifying local program strengths. In these two instances, local government ability to obtain federal funds and the use of FAUS funds to rebuild badly deteriorated urban facilities that could not otherwise be funded were identified as program strengths.

Weaknesses in Local FAUS Programs

The absence of the program strengths noted above was often felt to be a local program weakness. For example, a weak technical process for evaluating and prioritizing projects was reported as a weakness by two MPOs. Not surprisingly, six MPOs said that there was too little federal money. Several MPOs argued that the mileage in their region's FAUS highway system is not balanced with funding levels. There are so many FAUS route miles with deficiencies that current FAUS spending produces negligible impacts when measured on a regional system-wide basis. One MPO stated that limited FAUS funds restricted their use for nonhighway improvements, such as small transit projects and ridesharing programs.

Several regions said that problems meeting program requirements delayed contract letting. In some regions, delays in meeting program requirements have caused unobligated balances to accumulate in FAUS accounts. These unspent funds make it difficult to argue that the FAUS program is needed to meet immediate highway needs or that it is efficient in meeting program objectives. Past inflation in highway construction costs also greatly reduced the purchasing power of these unspent FAUS dollars.

Three MPOs said a poor working relationship between local governments and the state transportation/highway department prevented their region from meeting program requirements. Project design revisions were also cited by one MPO as a reason for delays in processing FAUS projects.

Local Recommendations

The overwhelming suggestion for improving the program was to increase flexibility in the FAUS program requirements and their administration by FHWA regional offices. Three MPOs felt that block grants for local transportation improvements would improve the situation. Other suggestions made by MPOs to increase program flexibility include the following:

- Reduce the federal project approval role.
- Eliminate the requirement that FAUS funds be spent only on designated FAUS routes.
- Reduce program paperwork.
- Eliminate the required formula allocation between central city and suburbs.
- Permit more local discretion on the part of regional FHWA offices in project design and processing.

- Allow an implementing agency to set local match above minimum level, when desired.

IMPLICATIONS FOR FUTURE LEGISLATION

In the following sections, some comments on the questionnaire answers and their implications for future urban highway programs are drawn from the authors' experience with the northeastern Illinois FAUS program.

Program Flexibility

Most local officials favor increased program flexibility, but there is little agreement on how to bring this about. Ultimate flexibility would be provided by local transportation block grants, but local government officials in northeastern Illinois have reservations about the block grant concept. Many feel it was proposed as a means to reduce funds to urban areas; others are concerned about state administration of a block grant program. Another unknown is whether transit projects would receive more or less funding through a block grant program.

Several steps toward increased FAUS program flexibility were included in the 1987 legislation. A new program provision allows local governments to set the local match above the 25 percent figure in the legislation. The five-state demonstration block grant program for FAUS and secondary highways will answer many of the questions raised about this approach.

Program Administrative Requirements

Many of questionnaire responses regarding administrative requirements had a familiar ring to them. However, FAUS program requirements have become less burdensome in northeastern Illinois as the local FAUS program has matured. Most importantly, the federal project approval time has been substantially reduced in this region over the past several years.

Two developments have contributed to this reduction in approval time. First, most communities now hire a consultant to manage the implementation of the project, including the approval process. In the early local history of the program, FAUS projects would get lost in the changing priorities of a community. Municipal staff would find themselves working on other projects and later discover that no progress had been made toward approval of their FAUS projects. A second factor was the initiation of meetings between communities and the FHWA by the local Illinois Department of Transportation office. The meetings have resulted in fewer delays, more flexibility in project design, and a greater willingness on the part of communities to use FAUS funds.

Ability of Local Governments to Participate

In critiquinq local government participation in the FAUS program, it should be remembered that the FAUS program is modeled after the earlier highway system programs that emphasize state participation. By structuring the FAUS program along the lines of earlier federal aid highway system programs, the expectation is that local governments will perform some of the functions that states carry out in federal aid highway programs.

The survey shows that some local governments cannot, nor are they inclined to, perform as states do in the other highway programs. State highway and transportation departments have been partners in major federal aid highway system programs for several decades and have a well-established bureaucracy in place to meet program requirements. State staff have good working relationships with FHWA regional personnel and have accumulated specialized knowledge of the federal aid highway programs as they have evolved.

Specific FAUS Program Problems

Two specific FAUS program problems cited on the questionnaire have generally not been an issue in northeastern Illinois: designation of FAUS routes and central city-suburb allocation of FAUS funds. Designation of FAUS routes is a nonissue in northeastern Illinois for an unfortunate reason. Inappropriate additions to the region's FAUS network over the past several years have produced a regional FAU system that includes too much local street mileage without regional significance. When FAUS projects are approved on local streets, the improvements required by federal standards are excessive, given their traffic. The use of FAUS funds for local street improvements is concentrated in those communities least able to finance capital improvements. and it amounts to a very small portion of the total regional FAUS program.

The current allocation between the suburbs and the city of Chicago is 57:43. The city historically has carried a $10–20-million unobligated balance, while the suburban area has maintained a far smaller $1–3-million balance over the last 5 yr. Yet, there is little sentiment to eliminate the city-suburb allocation of funds based on population. This arrangement keeps volatile city-suburb issues from intruding on the FAUS program, and neither side is sure from year to year of its political ability to influence the allocation in its favor.

Sharing of Program Responsibilities

If local governments participate in a future federal highway program, they must also share in its maintenance. At the very least, local governments should document how local elected officials are involved in the selection of projects and provide some minimal measures of the effectiveness of improvements built under the program.

The questionnaire asked each MPO to return documentation on its local TIP or FAUS program with the completed questionnaire. Half the responding MPOs returned some material, indicating that many regions have little or no documentation on the operation of their FAUS program.

Process documentation is useful for a variety of reasons. It can be used to brief newly elected local officials on how the program operates or to promote the FAUS program among local governments to increase their participation. This documentation is a first step toward introducing changes in local program administration. It also provides evidence of local officials' participation if the local program's legality is challenged.

Few regions appear to have measures of the impacts of FAUS projects other than their cost and the federal funds brought into the region. This lack of documentation on program impacts makes it all but impossible to demonstrate the benefits from FAUS projects or to compare the FAUS program with other federal aid highway programs. Project documentation does not have to be a detailed analysis of the benefits of each improvement, but need only include available data assembled during design and submission of the project for federal aid approval organized in an accessible format.

Project Priorities

The survey indicated that no single form of evaluation and priority setting dominates local FAUS programs. The northeastern Illinois experience is that technical evaluation of FAUS projects has become prevalent as more eligible projects are developed. This region has gone from one council performing a technical project evaluation to virtually all councils using some formal project analysis in the last 3 yr.

This situation is due to having more projects ready for approval than available funds. Formal project evaluation has forced harsh decisions to delay ready projects until more worthy projects are funded. In most project evaluation schemes, smaller less-costly projects tend to rank higher, spreading FAUS dollars among more projects and communities. Marginal projects are less likely to be proposed, and the 5-yr program in the TIP is more realistic, making it easier to move projects to the annual element of the TIP.

CONTINUING LOCAL GOVERNMENT PARTICIPATION

The arguments for participation by local officials in a forthcoming federal aid urban highway program are stronger today than they were when the FAUS legislation was first enacted. Although the degree and effectiveness of local officials' involvement in the FAUS program varies from region to region, the FAUS program has achieved a reasonable level of success in meeting its objective of local participation in the regional programming of federal aid highway improvements. Original concerns that the FAUS program would not function due to the parochial interests of local officials have proved by and large to be groundless.

Increasing traffic congestion in urbanized areas is a national issue threatening the economic vitality of both growing and mature urban areas. Local officials' understanding of local highway needs, combined with their ability to influence land development, seems a necessary input into any federally supported urban highway program directed toward alleviating urban congestion.

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Cost-Effectiveness Methodology for Two-Way Left-Turn Lanes on Urban Four-Lane Roadways

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Two-way left-turn lane (TWLTL) medians are commonly used to solve the safety and operational problems on four-lane undivided roadways caused by conflicts between through and left-turn traffic. Although the potential safety and operational effects of TWLTL medians are well recognized, there are no generally accepted guidelines that define the circumstances under which the costs of TWLTL medians are justified by the benefits they provide. The objectives of the research on which this paper was based were (a) to evaluate the safety and operational effects of TWLTL medians on urban four-lane roadways, (b) to develop a methodology for evaluating the cost-effectiveness of TWLTL medians, and (c) to use this methodology to develop guidelines for their cost-effective use. The cost-effectiveness methodology that was developed is presented in this paper. The formulation of the cost-effectiveness methodology was based on a benefit-cost analysis approach. The benefits were the accident and operational cost savings provided by TWLTL medians. The costs were those of installing and maintaining the medians. A TWLTL evaluation form was designed to facilitate the implementation of the methodology. In addition, a sample problem illustrating the application of the methodology is presented.

The two-way left-turn lane (TWLTL) is commonly used to solve the safety and operational problems that result from conflicts between through traffic and midblock left-turn movements on four-lane undivided roadways. Left turns from a four-lane undivided roadway are made from through traffic lanes, causing through vehicles in these lanes to change lanes or be delayed. But on a roadway with a TWLTL, the deceleration and storage of left-turn vehicles are removed from the through lanes. Thus, conflicts between through and left-turn traffic are eliminated, and through vehicles can pass left-turn vehicles without changing lanes and without delay.

Although the potential safety and operational effects of the TWLTL are recognized by highway engineers, there are no generally accepted guidelines that define the circumstances under which the costs of providing TWLTL medians are justified. Numerous before and after studies of the safety effectiveness of the TWLTL have been conducted. However, empirical data pertinent to the assessment of the operational effectiveness of the TWLTL are lacking. Therefore, previous attempts to develop guidelines for the use of the TWLTL have focused on the safety benefits and have not adequately accounted for the operational effectiveness of the TWLTL.

The overall objective of the research on which this paper was based was to develop guidelines for the use of TWLTL medians on urban four-lane roadways that account for the operational as well as the safety effects of these medians. Specific objectives of the research were (a) to evaluate the safety and operational effectiveness of TWLTL medians on urban four-lane roadways, (b) to develop a methodology for evaluating the cost-effectiveness of the TWLTL, and (c) to apply this methodology to develop guidelines for the cost-effective use of TWLTL medians on urban four-lane roadways. The methodology and guidelines were developed to enable the identification of sections of urban four-lane undivided roadway on which the costs of providing TWLTL medians are justified.

Formulation of the cost-effectiveness methodology was based on a benefit-cost evaluation. The benefits were the accident and operational cost savings provided by TWLTL medians; the costs were those of installing and maintaining TWLTL medians. According to the methodology, if the benefits of a TWLTL exceed its costs, the TWLTL is cost-effective. Otherwise, it is not cost-effective.

The cost-effectiveness methodology is described in this paper. The step-by-step procedure and calculation form that were designed to facilitate the implementation of the methodology are presented. In addition, an example illustrating the application of the methodology is provided. The guidelines developed and other findings of the research are presented elsewhere (*1*).

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ACCIDENT COST SAVINGS

Two procedures are used in the cost-effectiveness methodology to compute the accident cost saving provided by TWLTL medians: one method applies to proposed four-lane roadways that do not have accident histories; and the other, to existing four-lane undivided roadways that have accident histories. A description of both procedures follows.

Proposed Roadways

An analysis of accidents on urban four-lane sections of the state highway system in Nebraska was conducted to determine the safety effects of TWLTL medians (*1*). As a result of this analysis, it was concluded that the accident reductions (Table 1) and the accident severity (Table 2) for four-lane undivided roadways should be used in the cost-effectiveness methodology. The accident reductions (Table 1) represent the number of accidents per mile that would not occur if an urban four-lane roadway with a TWLTL median were built instead of a four-lane undivided roadway. If the TWLTL were not included, these accidents would be expected to occur on the four-lane undivided roadway.

The average cost of these accidents is computed by applying the unit accident severity costs to the accident severity for four-lane undivided roadways shown in Table 2 as follows:

$$AC = 0.0001F + 0.265PI + 0.734PDO \tag{1}$$

where

AC = average cost of an accident on an urban four-lane undivided roadway (\$/accident);
F = average cost of a fatal accident (\$/accident);

TABLE 1 ANNUAL REDUCTION IN ACCIDENTS PER MILE

	Driveways Per Mile		
ADT	≤45	50	≥55
≤ 8,000	0	0	0
10,000	25	5	0
12,000	50	30	5
≥14,000	75	55	30

TABLE 2 ACCIDENT SEVERITY ON FOUR-LANE UNDIVIDED ROADWAYS

Level of Severity	Percentage of All Accidents
Fatal	0.1
Nonfatal Injury	26.5
Property Damage Only	73.4
	100.0

PI = average cost of a nonfatal injury accident (\$/accident); and
PDO = average cost of a property-damage-only accident (\$/accident).

The 1986 unit accident costs used by the Nebraska Department of Roads are \$220,000 per fatal accident; \$9,300 per nonfatal injury accident; and \$1,190 per property-damage-only accident. Substituting these costs in equation 1, the average cost of an accident on a four-lane undivided roadway is \$3,560.

Therefore, the annual accident cost savings provided by the installation of a TWLTL on an urban section of proposed four-lane undivided roadway are

$$ACS = \$3{,}560\ RL \qquad (2)$$

where

ACS = annual accident cost savings provided by a TWLTL on proposed urban four-lane roadway (\$/year);
R = annual accident reduction from Table 1 (accidents/mile/year); and
L = length of the roadway section (miles).

Thus, equation 2 is used in the cost-effectiveness methodology to compute the accident cost savings provided by TWLTL medians on proposed urban four-lane roadways.

Existing Roadways

As a result of the accident analysis conducted in this research (*1*), it was concluded that an accident reduction factor of 30 percent should be used to compute the safety benefits of adding TWLTL medians to existing urban four-lane undivided roadways. Therefore, the annual accident cost savings provided by the installation of a TWLTL on an existing four-lane undivided roadway are

$$ACS = 0.30\,(F \cdot N_F + PI \cdot N_{PI} + PDO \cdot N_{PDO}) \qquad (3)$$

where

ACS = annual accident cost savings provided by a TWLTL on existing urban four-lane undivided roadway (\$/yr.);

TABLE 3 REGRESSION EQUATIONS FOR PREDICTING REDUCTIONS IN STOPS AND DELAY

Traffic Volume[a] (vph)	Reduction	Equation[b]	R^2
<800	stops	$\ell n\ S = 0.00579\ V_t + 0.0117\ V_\ell - 0.00678D$	0.975
	delay	$\ell n\ D = 0.00845\ V_t + 0.0330\ V_\ell - 0.00561D - 0.0000308P$	0.978
≥800	stops	$\ell n\ S = 0.00610\ V_t + 0.0282\ V_d$	0.996
	delay	$\ell n\ D = 0.00898\ V_t + 0.0652\ V_d$	0.996

[a] Traffic volume in each direction.

[b] S = reduction in stops (number per hour per 1,000 ft.)
D = reduction in delay (seconds per hour per 1,000 ft.)
V_t = average traffic volume per direction (vph)
V_ℓ = sum of left-turn volumes in both directions (vph)
V_d = average left-turn volume per driveway (vph per driveway)
D = driveway density (driveways per mile)
$P = V_t \cdot V_\ell$

F = average cost of a fatal accident (\$/accident);
N_F = average number of fatal accidents per year;
PI = average cost of a nonfatal injury accident (\$/accident);
N_{PI} = average number of nonfatal injury accidents per year;
PDO = average cost of a property-damage-only accident (\$/accident); and
N_{PDO} = average number of property-damage-only accidents per year.

For the 1986 unit accident costs used by the Nebraska Department of Roads, equation 3 becomes the following:

$$ACS = 66{,}000\ N_F + 2{,}790 N_{PI} + 357 N_{PDO} \tag{4}$$

TABLE 4 STOPPING COSTS (*2*)

	Traffic Volume[a]	
Vehicle Type	≤650 vph[b]	>650 vph[c]
Passenger Car	21.00	17.75
Single Unit Truck	48.47	43.88
3-S2 Combination Truck	163.99	151.47

Note: Values are dollars per 1,000 stops.
[a] Traffic volume in each direction.
[b] Speed = 40 mph.
[c] Speed = 35 mph.

TABLE 5 UPDATING MULTIPLIERS FOR STOPPING COSTS (*2*)

Vehicle Type	Updating Formula
Passenger Car	$M = 0.0022\ CPI_F + 0.0001\ CPI_O + 0.0033\ CPI_T + 0.0001\ CPI_M + 0.0017\ CPI_D$
Single Unit Truck	$M = 0.0018\ WPI_F + 0.0031\ WPI_T + 0.0002\ CPI_M + 0.0008\ WPI_D$
3-S2 Combination Truck	$M = 0.0008\ WPI_{FD} + 0.0047\ WPI_T + 0.0001\ CPI_M + 0.0003\ WPI_D$

where:

CPI_F - Consumer Price Index - Private Transportation, Gasoline Regular and Premium
CPI_O - Consumer Price Index - Private Transportation, Motor Oil, Premium
CPI_T - Consumer Price Index - Private Transportation, Tires
CPI_M - Consumer Price Index - Private Transportation, Auto Repairs and Maintenance
CPI_D - Consumer Price Index - Private Transportation, Automobiles, New
WPI_F - Wholesale Price Index - Regular Gasoline to Commercial Users (Code No. 05710203.05)
WPI_{FD} - Wholesale Price Index - Diesel Fuel to Commercial Users (Code No. 05730301.06)
WPI_T - Wholesale Price Index - Truck Tires (Code No. 07120105.07)
WPI_D - Wholesale Price Index - Motor Truck (Code No. 141106)

OPERATIONAL COST SAVINGS

Operational cost savings provided by TWLTL medians are the savings in road-user stopping and travel time costs that result from the reductions in stops and delay provided by TWLTL medians. A computer simulation study (*1*) was conducted to determine these reductions. The regression equations (Table 3), which were determined in the computer simulation study, are used in the cost-effectiveness methodology to predict the reductions in stops and delay provided by TWLTL medians. The calculation of the operational cost savings using these predicted reductions, described below, is based on economic analysis procedures published by AASHTO (*2*).

TABLE 6 VALUES OF TIME (*2*)

Vehicle Type	$/vehicle-hour
Passenger Car	0.35^a
Single Unit Truck	7.00
3-S2 Combination Truck	8.00

[a] For low time savings, average trips, and 1.56 adults per vehicle.

Stopping Costs Savings

The savings in stopping costs are computed from the reductions in stops provided by TWLTL medians. The hourly stopping costs savings are computed as follows:

$$SCS = 0.00528\ \Delta S \cdot L \sum_{i=1}^{3} P_i S_i M_i \qquad (5)$$

where

SCS = stopping costs savings provided by a TWLTL on an urban four-lane roadway ($/hour);

TWO-WAY LEFT-TURN LANE EVALUATION FORM[a]

Project .... Analyst .... Date ....

Location: On .... From .... To ....

Length .... miles Number of Driveways[b] .... Driveways Per Mile ....

ADT .... vpd Truck Percentages: Single Unit .... % 3-S2 Combinations ....%

Step 1. Calculate Daily Reductions in Stops and Delay.

①[c] Directional Volume Range (vph)	② No. of Hours Per Day in Range	③ Average Directional Volume in Range (vph)	④[d] Average Left-Turn Volume in Range (vph)	⑤ Reduction in Stops from Table A1 (stops/hr)	⑥ Reduction in Delay from Table A2 (sec/hr)	⑦ Stops Reduction (stops) ⑤ X ②	⑧ Delay Reduction (seconds) ⑥ X ②
0-100		▨	▨	▨	▨	▨	▨
101-200							
201-300							
301-400							
401-500							
501-600							
601-700							
					Subtotal A		▨
701-800							
801-900							
901-1,000							
1,000-1,100							
Total	24				Subtotal B		▨
						Total	

[a] Applicable to four-lane roadways only.

[b] Total number of driveways on both sides of roadway.

[c] Directional volume equals total volume divided by two.

[d] Total left-turn volume in both directions per 1,000 ft. of section length.

FIGURE 1 Two-way left-turn-lane evaluation form.

S = reduction in stops from Table 3 (number/hr/1,000 ft);

L = length of roadway section (miles);

P_i = proportion of vehicle type i in the traffic stream (%/100%);

S_i = stopping cost for vehicle type i from Table 4 ($/1,000 stops); and

M_i = updating multiplier for vehicle type i from Table 5.

The stopping costs in Table 4 are those published by AASHTO (*2*) for the year 1975. Three vehicle types are included: passenger cars, single-unit trucks, and 3–S2 combination trucks. The speeds used to determine the stopping costs shown for each level of traffic volume are the same speeds used in the computer simulation study (*1*) and were intended to approximate the speed-volume relationships on urban arterial roadways (*3*). A speed of 40 mph was used for traffic volumes of 650 vph or less; a speed of 35 mph was used for traffic volumes greater than 650 vph.

The updating multipliers in Table 5 enable the 1975 stopping costs in Table 4 to be updated to the current year. These multipliers are computed according to the AASHTO (*2*) procedures based on changes in consumer and wholesale price indices (*4*).

Step 2. Calculate Cost Per Stop.

① Vehicle Type^a	② Proportion of Traffic	③ Stopping Cost^b ($/stop)	④ Updating Multiplier from Table A3	⑤ Cost Per Stop ($/stop) ② X ③ X ④
(a.) Directional Volume ≤700 vph				
PC		0.02100		
SU		0.04847		
3-S2		0.16399		
			Total A	
(b.) Directional Volume >700 vph				
PC		0.01775		
SU		0.04388		
3-S2		0.15147		
			Total B	

^{a}PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
^{b}Source: Reference 30.

Step 3. Calculate Hourly Time Cost.

① Vehicle Type^a	② Proportion of Traffic	③ 1975 Value of Time^b ($/veh-hr)	④ Current Year CPI^c	⑤ 1975 CPI^c	⑥ Hourly Time Cost ($/hour) ② X ③ X ④ / ⑤
PC		0.35		156.1	
SU		7.00		156.1	
3-S2		8.00		156.1	
				Total	

^{a}PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
^{b}Source: Reference 30.
^{c}Consumer Price Index.

FIGURE 1 ***continued***

Travel Time Costs Savings

The savings in travel time costs are computed from the reductions in delay provided by TWLTL medians. The hourly travel time costs savings are computed as follows:

$$TCS = 0.00147\,\Delta D\,L\,\frac{CPI}{156.1}\sum_{i=1}^{3} P_i T_i \qquad (6)$$

where

TCS = travel time costs savings provided by a TWLTL on an urban four-lane roadway (\$/hour);
ΔD = reduction in delay from Table 3 (sec/hr/1,000 ft);
L = length of roadway section (mi);
CPI = consumer price index;
P_i = proportion of vehicle type i in the traffic stream (%/100%);
T_i = value of time for vehicle type i from Table 6.

The values of time in Table 6 are those established by AASHTO (*2*) for the year 1975. However, the results of equation 6 are updated to the current year by the ratio ($CPI/156.1$), which is the current consumer price index divided by the 1975 consumer price index.

The value of time shown in Table 6 for passenger cars was computed from the information given by AASHTO (*2*) for low time savings on average trips (i.e., \$0.21 per person/hr and 1.56 persons per vehicle). These categories were used because (a) all delay reductions found in the computer simulation study were in the low time savings range (0–5 min per vehicle), and (b) the effects of TWLTL medians apply to all trip types (*1*).

Annual Operational Cost Savings

The annual operational cost savings provided by TWLTL medians are computed by summing the hourly stopping and travel time costs savings from equations 5 and 6 as follows:

$$OCS = 365 \sum_{i=1}^{24} (SCS_i + TCS_i) \qquad (7)$$

where

OCS = annual operational cost savings provided by a TWLTL on an urban four-lane roadway (\$/yr);

Step 4. Calculate Annual Operational Cost Savings.

(a) Stops:

$$\underset{\substack{\text{Subtotal A,}\\ \text{Col. 7, Step 1}}}{\underline{\qquad\qquad}} \times \underset{\substack{\text{Total A}\\ \text{Col. 5, Step 2}}}{\underline{\qquad\qquad}} + \underset{\substack{\text{Subtotal B,}\\ \text{Col. 7, Step 1}}}{\underline{\qquad\qquad}} \times \underset{\substack{\text{Total B}\\ \text{Col. 5, Step 2}}}{\underline{\qquad\qquad}} = \underset{\substack{\text{Daily Stopping}\\ \text{Costs Savings}\\ \text{(\$/day)}}}{\underline{\qquad\qquad}}$$

(b) Delay:

$$\underset{\substack{\text{Total}\\ \text{Col. 8, Step 1}}}{\underline{\qquad\qquad}} \times \underset{\substack{\text{Total}\\ \text{Col. 6, Step 3}}}{\underline{\qquad\qquad}} \div \underset{\text{(sec/hour)}}{\underline{3{,}600}} = \underset{\substack{\text{Daily Delay}\\ \text{Costs Savings}\\ \text{(\$/day)}}}{\underline{\qquad\qquad}}$$

(c) Total:

$$\left[\underset{\text{(a)}}{\underline{\qquad\qquad}} + \underset{\text{(b)}}{\underline{\qquad\qquad}}\right] \times \underset{\text{(days/year)}}{\underline{365}} = \underset{\substack{\text{Annual Operational}\\ \text{Cost Savings}\\ \text{(\$/year)}}}{\underline{\qquad\qquad}}$$

FIGURE 1 ***continued***

SCS_i = stopping costs savings from equation 5 for the ith hr of an average day ($/hr); and

TCS_i = travel time costs savings from equation 6 for the ith hr of an average day ($/hr).

In equation 7, stopping and travel time costs savings are computed for each of the 24 hr in an average day. However, these savings are not computed for any hours with traffic volumes outside the traffic volume range (100–1,100 vph in each direction) of the regression equations in Table 3. The stopping and travel time costs savings are assumed to be zero for hours with volumes less than 100 vph in each direction. The cost-effectiveness methodology is not applicable to roadways with hourly directional volumes above 1,100 vph.

TWLTL COST

The TWLTL cost used in the cost-effectiveness methodology is the additional cost of right-of-way, construction, and maintenance required by providing a TWLTL on an urban four-lane roadway. The annual cost of the TWLTL is computed as follows:

$$C = (FC - SV) \cdot CRF_{i,n} + \frac{SV \cdot i}{100} + M \qquad (8)$$

where

C = annual cost of providing a TWLTL on an urban four-lane roadway ($/year);

FC = initial cost of the TWLTL, which includes additional right-of-way and construction costs ($);

SV = salvage value of the TWLTL ($);

$CRF_{i,n}$ = capital recovery factor for interest rate i and project life of n years; and

M = annual cost of maintaining the TWLTL ($/year).

Step 5. Calculate Annual Accident Cost Savings.

(a) Existing Four-Lane Undivided Roadway With Accident History:

①	②	③	④
Accident Severity	**Number of Accidents**	**Unit Accident Cost Savings[a] ($/accident)**	**Accident Cost Savings ($) 2 X 3**
Fatal		$66,000	
Nonfatal Injury		2,790	
Property-Damage-Only		357	
		Total	

....	÷	....	=	....
Total Col. 4		No. of Years of Accident History		Annual Accident Cost Savings ($/year)

(b) Proposed Four-Lane Roadway Without Accident History:

				$3,560		
....	X	....	X	....	=	....
Annual Accident Reduction from Table A4 (accidents/year)		Length of Section (miles)		Average Accident Cost[b] ($/accident)		Annual Accident Cost Savings ($/year)

[a] Based on 30% reduction in accidents and 1986 unit accident costs used by Nebraska Department of Roads ($220,000 per fatal accident; $9,300 per nonfatal injury accident; and $1,190 per property-damage-only accident).

[b] Based on 1986 unit accident costs used by Nebraska Department of Roads and accident severity of four-lane undivided roadways (0.1% fatal; 26.5% nonfatal injury; and 73.4% property-damage-only accidents).

FIGURE 1 *continued*

The user of the cost-effectiveness methodology must determine the initial cost, salvage value, capital recovery factor, and maintenance cost to be used in equation 8.

PROCEDURE

In the cost-effectiveness methodology, the sum of the annual accident and operational cost savings provided by the TWLTL is compared to the annual cost of the TWLTL. If the annual cost savings are greater than the annual cost, the TWLTL is cost-effective; if the savings are less than the annual cost, the TWLTL is not cost-effective. When the annual cost savings and the annual cost are equal, the results indicate indifference relative to the cost-effectiveness of the TWLTL.

The cost-effectiveness methodology is organized into an eight-step procedure. A TWLTL evaluation form that contains the step-by-step approach was designed to facilitate the implementation of the procedure. The evaluation form and the tables used in conjunction with it are presented in Figure 1. The following is an explanation of each step in the evaluation procedure shown in Figure 1.

Step 1: Calculate Daily Reductions in Stops and Delay

The daily reductions in stops and delay that are provided by the TWLTL are calculated by summing the reductions

Step 6. Calculate Total Annual Cost Savings.

.... + ... = ...

Annual Operational Cost Savings from Step 4 ($/year) + Annual Accident Cost Savings from Step 5 ($/year) = Total Annual Cost Savings ($/year)

Step 7. Calculate Annual TWLTL Cost.

First Cost: $........ Project Life .... yrs.

Salvage Value: $........ Interest Rate .... %

[........ First Cost ($) − .... Salvage Value ($)] X .... Capital Recovery Factor

\+ .... Salvage Value ($) X .... Interest Rate (%) ÷ 100% ....

\+ .... Annual Maintenance Cost ($/year) = ... Annual TWLTL Cost ($/year)

Step 8. Compare Savings to Cost.

B: .... Total Annual Cost Savings from Step 6 ($) vs. C: .... Annual TWLTL Cost from Step 7 ($)

Conclusion:

B > C, TWLTL cost-effective. ....

B < C, TWLTL not cost-effective. ....

B = C, Indifference. ....

FIGURE 1 *continued*

during each hour of an average day during which the mean directional volume (i.e., total volume divided by two) is greater than 100 vph. Although these reductions could be computed for each hour individually, acceptable results can be obtained by grouping the hours of the day into 100-vph directional volume ranges and then computing the reductions for the hours in each range using the average of the hourly directional volumes in the range. The reductions in stops and delay are assumed to be zero during the hours when the mean directional volume is less than 100 vph. Two subtotals are computed for reductions in stops because a 40-mph speed is assumed in computing stopping costs for hours with mean directional volumes of 700 vph or less, and a 35-mph speed is assumed for hours with mean directional volumes above 700 vph. The methodology is not applicable to roadways with mean directional volumes greater than 1,100 vph.

Step 2: Calculate Cost Per Stop

The cost per stop is calculated as the weighted average of the stopping costs of the passenger cars, single-unit trucks, and 3–S2 combination trucks in the traffic stream. The unit stopping costs are 1975 stopping costs published by AASHTO (*2*). The updating multipliers enable the 1975 stopping costs to be updated to the current year in accordance with the AASHTO (*2*) procedures.

Step 3: Calculate Hourly Time Cost

The hourly time cost is calculated as the weighted average of the hourly time costs of the passenger cars, single-unit trucks, and 3–S2 combination trucks in the traffic stream. The unit values of time are 1975 values published by AASHTO (*2*) updated to the current year by means of the consumer price index in accordance with the AASHTO (*2*) procedures.

Step 4: Calculate Annual Operational Cost Savings

The annual operational cost savings are calculated by applying the unit costs computed in steps 2 and 3 to the daily reductions in stops and delay computed in step 1.

Table A1. Equations for predicting reductions in stops.

Traffic Volume[a] (vph)	Equation[b]
<800	$\Delta S = 5.28\, L \cdot e^{(5.79\, V_t + 11.7\, V_1 - 6.78D)/1{,}000}$
≥ 800	$\Delta S = 5.28\, L \cdot e^{(6.10\, V_t + 28.2\, V_d)/1{,}000}$

[a] Average traffic volume per direction (total traffic volume/2).

[b] ΔS = reduction in stops (stops/hour).
L = length of roadway section (miles).
V_t = average traffic volume per direction (vph).
V_1 = total left-turn volume in both directions per 1,000 ft. of section (vph).
V_d = average left-turn volume per driveway (vph per driveway).
D = driveway density (driveways per mile).

Table A2. Equations for predicting reduction in delay.

Traffic Volume[a] (vph)	Equation[b]
<800	$\Delta D = 5.28\, L \cdot e^{(8.45\, V_t + 33.0\, V_1 - 5.61\, D - 0.0308P)/1{,}000}$
≥ 800	$\Delta D = 5.28\, L \cdot e^{(8.98\, V_t + 65.2\, V_d)/1{,}000}$

[a] Average traffic volume per direction (total traffic volume/2).

[b] ΔD = reduction in delay (seconds per hour).
L = length of roadway section (miles).
V_t = average traffic volume per direction (vph).
V_1 = total left-turn volume in both directions per 1,000 ft. of section length (vph).
V_d = average left-turn volume per driveway (vph per driveway).
D = driveway density (driveways per mile).
$P = V_t \cdot V_1$

FIGURE 1 *continued*

Step 5: Calculate Annual Accident Cost Savings

One of two procedures is used to calculate the annual accident cost savings. If the TWLTL is being added to an existing four-lane roadway with an accident history, the annual accident cost savings is computed on the basis of a 30-percent reduction in the average number of fatal and nonfatal injury and property-damage-only accidents per year during the accident history. If the TWLTL is being added to a proposed four-lane roadway without an accident history, the annual accident cost savings is computed on the basis of a predicted reduction in accidents per year. The unit accident costs are 1986 costs used by the Nebraska Department of Roads.

Step 6: Calculate Total Annual Cost Savings

The total annual cost savings are the sum of the annual operational cost savings computed in step 4 and the annual accident cost savings computed in step 5.

Step 7: Calculate Annual TWLTL Cost

The annual cost of TWLTL is the sum of the capital recovery cost of the TWLTL and the annual cost of maintaining the TWLTL.

Step 8: Compare Savings to Cost

The final step in the procedure is to determine whether or not the TWLTL being evaluated is cost-effective. This determination is based on a comparison of the TWLTL median's benefits, which are the total annual cost savings computed in step 6, to its annual cost, which is computed in step 7. If its benefits are greater than its cost, the TWLTL is cost-effective. If its benefits are less than its cost, the TWLTL is not cost-effective. If its benefits are equal to its cost, the results of the evaluation are indifferent relative to the cost-effectiveness of the TWLTL.

SAMPLE PROBLEM

A sample problem, which illustrates the application of the cost-effectiveness methodology, follows. This sample illus-

Table A3. Updating multipliers for stopping costs.[a]

Vehicle Type	Updating Formula	1986 Multiplier
Passenger Car	$M = 0.0022\ CPI_F + 0.0001\ CPI_O + 0.0033\ CPI_T + 0.0001\ CPI_M + 0.0017\ CPI_D$	1.643
Single Unit Truck	$M = 0.0018\ WPI_F + 0.0031\ WPI_T + 0.0002\ CPI_M + 0.0008\ WPI_D$	1.796
3-S2 Combination Truck	$M = 0.0008\ WPI_{FD} + 0.0047\ WPI_T + 0.0001\ CPI_M + 0.0003\ WPI_D$	1.562

where:

CPI_F – Consumer Price Index – Private Transportation, Gasoline Regular and Premium

CPI_O – Consumer Price Index – Private Transportation, Motor Oil, Premium

CPI_T – Consumer Price Index – Private Transportation, Tires

CPI_M – Consumer Price Index – Private Transportation, Auto Repairs and Maintenance

CPI_D – Consumer Price Index – Private Transportation, Automobiles, New

WPI_F – Wholesale Price Index – Regular Gasoline to Commercial Users (Code No. 05710203.05)

WPI_{FD} – Wholesale Price Index – Diesel Fuel to Commercial Users (Code No. 05730301.06)

WPI_T – Wholesale Price Index – Truck Tires (Code No. 07120105.07)

WPI_D – Wholesale Price Index – Motor Truck (Code No. 141106)

[a] Source: Reference 30.

Table A4. Annual reduction in accidents per mile.

	Driveways Per Mile		
ADT	≤45	50	≥55
≤ 8,000	0	0	0
10,000	25	5	0
12,000	50	30	5
≥14,000	75	55	30

FIGURE 1 ***continued***

trates the use of the methodology to evaluate the addition of a TWLTL to an existing four-lane undivided roadway.

Traffic congestion, caused by conflicts between left-turn and through traffic, is being experienced during several hours each day on a 1,000-ft section of an urban four-lane undivided street that serves commercial development. The ADT on the street is 18,000 vpd with 18 percent single unit and 10 percent combination trucks. Within the 1,000-ft section, there are five driveways. Throughout much of the day, the left-turn volume into these driveways is about 10 percent of the traffic volume on the section. During the past 3 yr, there have been 14 accidents on the section: 6 nonfatal injury and 8 property-damage-only accidents.

Addition of a TWLTL is being considered to improve the safety and efficiency of traffic operations on the street. Therefore, the cost-effectiveness of installing and maintaining a TWLTL on this section is to be determined.

The completed Two-Way Left-Turn Lane Evaluation Form for this problem is presented in Figure 2. The evaluation was conducted using 1986 cost data. A brief explanation of each step of the evaluation follows.

Step 1: Calculate Daily Reductions in Stops and Delay

The hourly distribution of directional volumes shown in column 2 (Figure 2) was determined from traffic counts conducted at the site. During 4 hr of the day, directional volumes are not greater than 100 vph. Therefore, according to the cost-effectiveness methodology developed in this research, the reductions in stops and delay are assumed to be zero during these 4 hr. The average values of directional

TWO-WAY LEFT-TURN LANE EVALUATION FORM[a]

Project *Example I* Analyst *R. A. Jones* Date *8/1/86*
Location: On *Hwy. A* From *First St.* To *Fourth St.*
Length *0.19* miles Number of Driveways[b] *5* Driveways Per Mile *26*
ADT *18,000* vpd Truck Percentages: Single Unit *18* % 3-S2 Combinations *10* %

Step 1. Calculate Daily Reductions in Stops and Delay.

①[c]	②	③	④[d]	⑤	⑥	⑦	⑧
Directional Volume Range (vph)	**No. of Hours Per Day in Range**	**Average Directional Volume in Range (vph)**	**Average Left-Turn Volume in Range (vph)**	**Reduction in Stops from Table A1 (stops/hr)**	**Reduction in Delay from Table A2 (sec/hr)**	**Stops Reduction (stops) ⑤ X ②**	**Delay Reduction (seconds) ⑥ X ②**
0-100	4						
101-200	2	119	24	2.2	4.8	4	10
201-300	3	256	50	6.7	26.5	20	80
301-400	1	387	76	19.2	113.2	19	113
401-500	1	472	92	38.0	255.8	38	256
501-600	2	555	108	74.0	525.8	148	1,052
601-700	3	621	122	127.7	895.4	383	2,686
					Subtotal A	612	
701-800	6	733	144	197.7	4,737.6	1,186	28,426
801-900	2	819	160	365.6	12,634.9	731	25,270
901-1,000							
1,000-1,100							
Total	24				Subtotal B	1,917	
						Total	57,893

[a] Applicable to four-lane roadways only.

[b] Total number of driveways on both sides of roadway.

[c] Directional volume equals total volume divided by two.

[d] Total left-turn volume in both directions per 1,000 ft. of section length.

FIGURE 2 Example of completed two-way left-turn-lane evaluation forms.

volume and left-turn volume, shown in columns 3 and 4 (Figure 2), were computed from the traffic count data.

Step 2: Calculate Cost per Stop

The cost per stop was computed for the traffic composition of 72 percent passenger cars, 18 percent single-unit trucks, and 10 percent combination trucks. This cost was updated using the 1986 multipliers given in Table A3 of Figure 1. One cost per stop was computed for the 12 hr during which the directional volume was 700 vph or less. Another cost per stop was computed for the 8 hr during which the directional volume was above 700 vph.

Step 3: Calculate Hourly Time Cost

The hourly time cost was computed for the traffic composition of 72 percent passenger cars, 18 percent single-unit trucks, and 10 percent combination trucks. It was updated using the 1986 consumer price index of 362.3.

Step 4: Calculate Annual Operational Cost Savings

Utilizing the results of the previous steps, an operational cost savings of nearly $240/day was computed. Based on

Step 2. Calculate Cost Per Stop.

① Vehicle Type[a]	② Proportion of Traffic	③ Stopping Cost[b] ($/stop)	④ Updating Multiplier from Table A3	⑤ Cost Per Stop ($/stop) ② X ③ X ④
(a.) Directional Volume ≤ 700 vph				
PC	0.72	0.02100	1.643	0.0248
SU	0.18	0.04847	1.796	0.0157
3-S2	0.10	0.16399	1.562	0.0256
			Total A	0.0589
(b.) Directional Volume > 700 vph				
PC	0.72	0.01775	1.643	0.0210
SU	0.18	0.04388	1.796	0.0142
3-S2	0.10	0.15147	1.562	0.0237
			Total B	0.0589

[a] PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b] Source: Reference 30.

Step 3. Calculate Hourly Time Cost.

① Vehicle Type[a]	② Proportion of Traffic	③ 1975 Value of Time[b] ($/veh-hr)	④ Current Year CPI[c]	⑤ 1975 CPI[c]	⑥ Hourly Time Cost ($/hour) ② X ③ X ④ / ⑤
PC	0.72	0.35	362.3	156.1	0.585
SU	0.18	7.00	362.3	156.1	2.924
3-S2	0.10	8.00	362.3	156.1	1.857
				Total	5.366

[a] PC - passenger car; SU - single unit truck; 3-S2 - 3-S2 combination truck.
[b] Source: Reference 30.
[c] Consumer Price Index.

FIGURE 2 *continued*

365 days/yr, this amounts to an annual operational cost savings of $87,500/yr.

Step 5: Calculate Annual Accident Cost Savings

The street in this problem is an existing four-lane undivided roadway with an accident history. Therefore, computation of the annual accident cost savings of $6,532 was based on a 30-percent reduction in accidents.

Step 6: Calculate Total Annual Cost Savings

The sum of the annual operational and accident cost savings is $94,000. More than 90 percent of this total is operational cost savings.

Step 7: Calculate Annual TWLTL Cost

The estimated first cost of the TWLTL is $200,000. In accordance with the policy of the agency for which the analyst works, a zero salvage value and a 6-percent interest rate were used. Because substantial traffic impacts are expected to result from future development planned along other sections of the street, a project life of only 5 yr was used. The estimated annual maintenance cost of $1,000/yr includes pavement repair, pavement markings, and snow removal that would be required by the TWLTL.

Step 8: Compare Savings to Cost

The total annual cost savings are greater than the annual cost of the TWLTL. Therefore, the TWLTL is cost-effective. In fact, it is cost-effective solely on the basis of the

Step 4. Calculate Annual Operational Cost Savings.

(a) Stops:

$$\underset{\substack{\text{Subtotal A,}\\ \text{Col. 7, Step 1}}}{612} \times \underset{\substack{\text{Total A}\\ \text{Col. 5, Step 2}}}{0.0661} + \underset{\substack{\text{Subtotal B,}\\ \text{Col. 7, Step 1}}}{1{,}917} \times \underset{\substack{\text{Total B}\\ \text{Col. 5, Step 2}}}{0.0589} = \underset{\substack{\text{Daily Stopping}\\ \text{Costs Savings}\\ \text{(\$/day)}}}{153.36}$$

(b) Delay:

$$\underset{\substack{\text{Total}\\ \text{Col. 8, Step 1}}}{57{,}893} \times \underset{\substack{\text{Total}\\ \text{Col. 6, Step 3}}}{5.366} \div \underset{\text{(sec/hour)}}{3{,}600} = \underset{\substack{\text{Daily Delay}\\ \text{Costs Savings}\\ \text{(\$/day)}}}{86.29}$$

(c) Total:

$$\left[\underset{\text{(a)}}{153.36} + \underset{\text{(b)}}{86.29}\right] \times \underset{\text{(days/year)}}{365} = \underset{\substack{\text{Annual Operational}\\ \text{Cost Savings}\\ \text{(\$/year)}}}{87{,}500}$$

FIGURE 2 *continued*

Step 5. Calculate Annual Accident Cost Savings.

(a) Existing Four-Lane Undivided Roadway With Accident History:

①	②	③	④
Accident Severity	**Number of Accidents**	**Unit Accident Cost Savings[a] ($/accident)**	**Accident Cost Savings ($) ② X ③**
Fatal	0	$66,000	0
Nonfatal Injury	6	2,790	16,740
Property-Damage-Only	8	357	2,856
		Total	19,596

19,596 Total Col. 4 ÷ *3* No. of Years of Accident History = *6,532* Annual Accident Cost Savings ($/year)

(b) Proposed Four-Lane Roadway Without Accident History:

.... Annual Accident Reduction from Table A4 (accidents/year) X .... Length of Section (miles) X $3,560 Average Accident Cost[b] ($/accident) = ... Annual Accident Cost Savings ($/year)

---

[a] Based on 30% reduction in accidents and 1986 unit accident costs used by Nebraska Department of Roads ($220,000 per fatal accident; $9,300 per nonfatal injury accident; and $1,190 per property-damage-only accident).

[b] Based on 1986 unit accident costs used by Nebraska Department of Roads and accident severity of four-lane undivided roadways (0.1% fatal; 26.5% nonfatal injury; and 73.4% property-damage-only accidents).

FIGURE 2 ***continued***

operational cost savings. However, it is not cost-effective solely on the basis of the accident cost savings.

CONCLUSION

The methodology presented in this paper provides a practical, quantitative procedure for evaluating the cost-effectiveness of TWLTL medians on urban four-lane roadways. However, factors other than cost-effectiveness must also be considered before making the final decision to install a TWLTL. Even though it may be evaluated as cost-effective, a TWLTL may not be appropriate in a particular case because of other factors such as inadequate sight distance, high pedestrian volume, classification as a major arterial street, short block lengths, inappropriate driveway configuration, and availability of adequate, indirect left-turn access. The results obtained by using the cost-effectiveness methodology must be considered in light of these other factors.

ACKNOWLEDGMENTS

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Step 6. Calculate Total Annual Cost Savings.

87,500 + *6,532* = *94,000*

Annual Operational Cost Savings from Step 4 ($/year) + Annual Accident Cost Savings from Step 5 ($/year) = Total Annual Cost Savings ($/year)

Step 7. Calculate Annual TWLTL Cost.

First Cost: $ *200,000* Project Life *5* yrs.

Salvage Value: $ *0* Interest Rate *6* %

[*200,000* First Cost ($) − *0* Salvage Value ($)] X *0.23740* Capital Recovery Factor

\+ *0* Salvage Value ($) X *6* Interest Rate (%) ÷ 100%

\+ *1,000* Annual Maintenance Cost ($/year) = *48,500* Annual TWLTL Cost ($/year)

Step 8. Compare Savings to Cost.

B: *94,000* Total Annual Cost Savings from Step 6 ($) vs. C: *48,500* Annual TWLTL Cost from Step 7 ($)

Conclusion:

B > C, TWLTL cost effective. ✓

B < C, TWLTL not cost effective.

B = C, Indifference.

FIGURE 2 ***continued***

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Transport Demands of Scotland's High-Technology Industries

KENNETH J. BUTTON

The nature of U.K. industry has changed considerably over the past two decades. Traditional industries have declined with the advent of high-technology products. Equally, production techniques of the established sector have also been subjected to major change. This paper looks at the role transport now plays in the new industrial situation and the different pressures that high-technology manufacturing industry is placing on transport suppliers. The paper takes, as a case study, the transport needs of the high-technology enclave known as Silicon Glen in central Scotland and examines how a sample of high-technology firms use different transport modes and how transport fits both into their production process and into the way the local labor market functions.

The importance of suitable transport infrastructure in attracting industry to specific locations has long been recognized although the exact nature of the link has been the subject of some dispute. In the United Kingdom, the initial strategic planning of the trunk road system, for example, was to a large extent justified in terms of stimulating economic development and balanced growth (*1*). More recently, though, the link between transport and industrial location has been perceived to be weaker; the Armitage Inquiry (*2*), for instance, places transport costs toward the bottom of the list of influences affecting the location of factories or industrial distribution systems. An oft-cited reason for this view is that the financial costs of transport for modern, footloose firms constitute only a small part of total production costs. In truth, however, it seems more likely that the importance of transport lies somewhere between these extremes.

The changing nature of western economies, with the onset of postindustrialization combined with major shifts away from the traditional industries in the manufacturing sector, means that a better understanding of linkages between modern industry and transport would help future infrastructure planning.

In the specific context of high-technology industry, the role of transport in influencing location has, in the past, proved difficult to isolate. The work that has been done is primarily American. Rosenfeld et al. (*3*), for example, found that in the southern states, while pockets of growth have occurred in rural counties, "new technology industries grew [between 1977 and 1982] predominantly in counties with interstate corridors." In contrast, Glasmeier et al. (*4*), although finding that airport proximity was a significant attribute for an area seeking to attract high-technology firms, also found that the quality of the local freeway network was not. To add to this rather confused picture, while Hummon et al. (*5*) found that 60 percent of high-technology firms in Pennsylvania stated that Philadelphia International Airport was an important variable in their decision making (4 percent said it had no effect); Allen and Robertson (*6*) found that proximity to a commercial airport rated only 16th in order of importance in influencing location choices of high-technology firms and 17th when questions of expansion arose. The most extreme position has perhaps been taken by the U.S. Congress Joint Economic Committee (*7*), "The traditional locational factors of access to markets and raw materials [are] not important factors for high-technology plant location decisions."

The evidence available in the United Kingdom is, to date, much less extensive. There is some general indication (*8*) that proximity, which is not explicitly defined or quantified, to international aviation services and to a good road network is helpful in attracting research and development (R&D) firms to science parks. A more thorough study of the M4 Corridor in Berkshire highlighted the importance of access to Heathrow Airport and to the national motorway system in the decision making of electronics companies (*9*). Some relevant details from this latter study are set out in Table 1.

There are a number of reasons why the work in this area is relatively thin and why the studies that have been completed often generate conflicting results.

First, high technology is difficult to define in a way that generates data suitable for quantitative analysis. Those who have studied the sector, be it in terms of labor needs, transport use, or technology diffusion, have used a variety of definitions, usually based on groupings derived from the official Standard Industrial Classifications (SIC) (*10*) for a comparison of some of the groupings of SIC industrial classes used in empirical work. Sometimes the definition is essentially subjective (i.e., the investigator simply takes

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TABLE 1 INFLUENCE OF TRANSPORT AVAILABILITY ON FIRMS LOCATING IN BERKSHIRE (*9*)

Communications	Percentage of Firms		
	Single Firm Firms	Multi-Site Firms	Total Firms
Heathrow Airport	77	72	75
Other Airports	9	11	10
M4 Motorway	73	50	63
Other Motorways & Major Roads	36	44	40
Rail Network	23	22	23

those SIC industries "felt" to be high technology); while on other occasions, more specific criteria are employed (e.g., the percentage of personnel engaged in R&D or officially classified as scientists, engineers, and technicians). While the latter approach is often claimed to be objective, it in fact requires judgment regarding critical cutoff points. The major problem with all approaches that rely on the SIC categorization is that, even at the lowest level of aggregation, each SIC category contains a mix of high- and low-technology firms, making meaningful analysis difficult.

Second, this problem is linked with the need to decide whether one draws the boundaries of high-technology industry simply around the manufacture of high-technology products or whether the domain includes the high-technology service industries and/or those traditional industries, such as automobile manufacturing and textiles, that have introduced robotics into their production process and computers into their design work.

Third, on the other side of the equation, there is the problem of specifying exactly what constitutes the transport input into high-technology production. Traditionally, analyses of industrial location and production costs have focused on the financial transport costs of distributing final outputs to market and of acquiring necessary raw materials and intermediate goods. High-technology production (setting aside the issue of exact definitions for the moment), it is generally agreed, involves high-value products with short technical shelf lives resulting in concomitantly high inventory-holding costs. Consequently, speed and reliability in transportation are frequently more important than the simple financial costs involved. Additionally, many aspects of producing high-technology goods necessitate employing scarce, qualified personnel; and the ability to attract qualified workers may, to some extent, depend on local access to social and recreational facilities. Specification of the transport variable is, therefore, extremely difficult; and certainly use of accountancy data relating to the direct financial outlays of firms can be potentially misleading.

Fourth, and tied to the above because of the high inventory costs involved, high-technology firms tend to employ more up-to-date management procedures than traditional companies and have relatively sophisticated logistics systems (*11*). Consequently, at the micro-level of analysis, involving case study work, one needs to go beyond the simple transport or distribution management function within a company to study the entire production process. Because of the importance of communications in the sector and the development of ideas and concepts, person movements cannot be ignored.

Finally, high-technology goods, like all products, have a product life-cycle (*12*, *13*) with each product going successively through development, growth, maturity, and decline phases before finally becoming obsolete. With high-technology products, the first two phases are particularly important—indeed, are possibly the major characteristics—and these phases have transport implications somewhat different from those of the late phases. It is, thus, necessary when examining transport needs of high-technology industry to be clear about the exact phase under review rather than to average across entire life-cycles.

This study attempts to circumvent some of these problems by adopting a case-study-oriented approach. The empirical work focuses on a small number of firms located in a limited geographical area. Further, it concerns itself with only producers of high-technology goods and does not attempt to extend analysis to either the service sector or to the use of high-technology products in older industries. It relies on unstructured interviews, questionnaires, and observation rather than on statistical analysis of published data sets, the objective being to incorporate qualitative as well as quantitative factors. While this method may appear less rigorous in the sense that generalizations are less easy to make, it does avoid the potential pitfalls that can occur if one examines only hard numbers and relies on data averaged over a large set of often heterogeneous firms frequently involved in different stages of a product's life-cycle. In the U.K. context, this method also helps minimize the added complication that many high-technology plants are foreign owned and fulfill the role of providing back-door access to European markets by U.S. and Japanese companies. This latter feature of the U.K. industry means there is a wider picture to consider—a picture somewhat different from that examined in studies conducted in the United States.

SILICON GLEN

Silicon Glen in central Scotland and the M4 Corridor in the south of England are generally agreed to be the United Kingdom's two main high-technology production centers. There are, in addition, several major science parks (most notably Silicon Fen or the Cambridge Phenomenon in Cambridgeshire) and smaller geographical concentrations of production. The rationale for focusing on the Scottish high-technology sector is that, unlike the M4 Corridor, the transport system of the area is not totally dominated by major national transport terminals (e.g., Heathrow Airport) or by the hubbing of the national motorway system. Nor has the area the overriding natural advantage of being adjacent to one of the world's leading financial centers or to a major market for high-technology products. Silicon Glen, like several other high-technology centers, enjoys good transport facilities; but decisions about locations and production require trading these off against other, less advantageous features of the area. It is also worth noting that the Scottish high-technology industry is important in its own right and represents a major growth sector in the Scottish economy. Table 2 is based on a definition of high-technology industry derived from an industrial grouping comprising the 10 industries with the highest ratio of intramural R&D to value added in the United Kingdom. The importance, in employment terms, of high-technology industry to Scotland in the early 1980s is indicated in Table 2. Employment has subsequently remained fairly stable. The output of these same 10 industrial classes nearly doubled between 1975 and 1983, when manufacturing output as a whole fell; and in 1984 there was a further 25-percent rise (Figure 1).

Just as an exact definition of high technology is elusive, so is the location of Silicon Glen. Some previous studies have defined it broadly to encompass the whole east-west corridor across central Scotland (*10*), while others have taken a much smaller area such as Glenrothes, north of Edinburgh across the Firth of Forth (*14*). Certainly the claims of the region around Edinburgh, encompassing the area to the west and north of the city, to be called Silicon Glen seem to be strong. Table 3 provides a breakdown of the U.K. location quotients for some of the sectors often deemed to be high-technology oriented. If one focuses purely on the Scottish high-technology sector, then the Fife region (together with the very north of Scotland) is the only one with a location quotient for R&D employment in excess of 2.0 (*15*). In addition, Lothian and Fife represent major exporting regions contributing a substantial part of the increase in electronics exports, from $593 million in 1980 to $1,300 million in 1983. For these reasons, the region is important for the future of the national economy.

TABLE 2 EMPLOYMENT IN HIGH-TECHNOLOGY INDUSTRY IN SCOTLAND

	1979	1980	1981	1982
High-Technology Employment in Scotland	45400	47900	47500	46200
Share of High-Technology in Manufacture Employment	7.9	9.0	10.0	10.3

(Source: C.M.J.McKay, A Note on High Technology Manufacturing in Scotland, *Scottish Economic Bulletin*, No. 32, 1985, pp.10-11.)

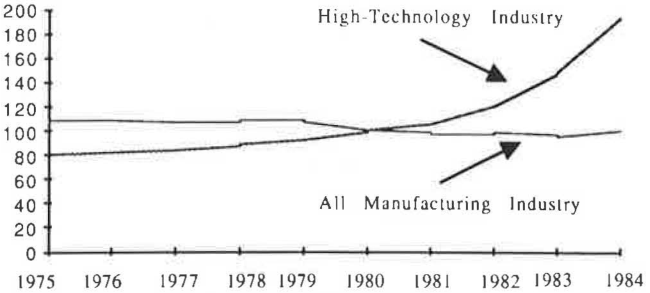

FIGURE 1 Index of production for Scotland (1980 = 100).

The study area has an established transport infrastructure with links to both the main national trunk road network and the intercity rail system. Transport times to major European destinations by road and rail are given in Table 4. There are international air and sea terminals, including container ports at Leith and Grangemouth and airports at Prestwick, Glasgow, and Edinburgh, coupled with a small local airport at Glenrothes. The quality of access also depends on the availability of transport companies operating in the area. Some 30 TIR carriers operate around Edinburgh through 20 roll-on/roll-off points in the United Kingdom, and numerous domestic haulage companies also operate in the highly competitive market place. In addition, a number of international freight handlers, such as LEP Transport Ltd., IPEC, TNT, and MSAS, provide a comprehensive range of services including packaging, customs documentation, and pickup-and-delivery services.

Despite these transport facilities, however, there is still some concern about the access the area enjoys to the national market. Tyler and Kitson (*16*), using an index of transport costs, found less geographical variations between regions than some of the earlier studies did. Nevertheless, the Edinburgh area still showed a transport index of 2.18 for mechanical engineering and of 2.36 for export-oriented activities (the lowest cost locations having the base index of 1.00). The relevance of Tyler and Kitson's study for high-technology industries, however, is uncertain given the industries' particular characteristics and the study's exclusive focus on freight movements.

SAMPLE

The definition of high-technology industry, as emphasized above, is problematic. Indeed, given the heterogeneity of both product and production methods within a single industry, the notion of high-technology industry has been dismissed by some (*17*). There seems to be a general consensus, however, of what is meant by a high-technology firm (although this may well differ between countries depending on the overall state of economic development), and it is this concept that is favored here. The firms subjected to detailed, case study examination were selected following discussions with area economic agencies, local government personnel, consultants who have been actively involved in high-technology industry, and academics at local research centers. The vast majority of the firms sampled were located in the "new towns" of Livingston (to the west of Edinburgh) and Glenrothes (to the north).

In all, some 16 companies were initially involved, although one ceased to produce in the area in late 1986 and has been excluded from the analysis. Lengthy interviews were held at the firms' plants with transport, personnel, marketing, and production management; and the logistics systems in operation were inspected. Details of the size and ownership of the companies are set out in Table 5. The dominance of U.S. and, more recently, Japanese involvement in the area is apparent. The firms were also relatively large; their primary function was the manufacture of high-technology components or the assembly of finished goods, although, in several cases, they also undertook product development and marketing activities.

Table 6 provides a subjective assessment of the mode of competition of the various firms and offers a general guide to the stage in the product life-cycle in which their particular activities fall (*18*). Innovation is important at the earlier stages of the life-cycle; cost, at the maturity and decline phases. The role of transport is likely to differ according to the firm's mode of competition. Most of the sample firms, mainly foreign-controlled plants, are at the latter end of the product life-cycle (i.e., when customer service and low-cost production become important). One would anticipate from the previous studies of links between product life-cycles and transport (*12*, *18*) that these plants would be seeking reliable transport (for customer service) or economy in movement (for cost leadership).

The length of time the firms had been located in Silicon Glen varied, although 60 percent had been established on their premises since 1980. The newness of the firms, coupled with the high level of foreign ownership, is fairly typical of the high-technology industry in the area. Overall, figures from the New Town Development Corporation

TABLE 4 TRANSPORT TIMES TO EUROPE FROM CENTRAL SCOTLAND

Destination	Days Taken	
	Rail	Road
London	1/2	1
Paris	2	2
Brussels	2	2
Frankfurt	3	2
Milan	3	4
Copenhagen	4	3
Berlin	5	3
Rome	4	4
Oslo	5	3
Dublin	1	1

TABLE 3 LOCATION QUOTIENTS FOR COUNTIES FOR INDIVIDUAL HIGH-TECHNOLOGY SECTORS: 1981 DATA (*9*)

Location Quotient	MLH272	MLH363	MLH364	MLH365	MLH366	MLH367	MLH383
8.0+				Mid-Glamorgan Essex			
7.5-8.0					Berkshire		
7.0-7.5					Hertfordshire		
6.5-7.0		**Fife Region**					Avon
5.5-6.0							Isle of Wight
5.0-5.5	Nottinghamshire West Sussex						Somerset
4.5-5.0	Cheshire	Cleveland Nottinghamshire					Hertfordshire Derbyshire Lancashire Clwyd
4.0-4.5		West Midlands				West Sussex **Fife Region**	
3.5-4.0	Hertfordshire	Merseyside	**Fife Region**		Hampshire	Berkshire **Lothian Region**	
3.0-3.5			Essex	Hampshire		Hertfordshire Essex Dorset	
2.5-3.0	Kent		Bedfordshire Mid-Glamorgan		Staffordshire	Surrey	Gloucestershire
2.0-2.5	Merseyside		Wiltshire West Sussex			Kent Hampshire	Dorset Surrey

<u>List Headings</u>: 272 - Pharmaceuticals; 363 - Telegraph & Telephones; 364 - Radio & Electronic; 365 - Broadcast Sound; 366 - Electronic Computers; 367 - Radio, Radar & Electronics; 383 - Aerospace.

TABLE 5 CHARACTERISTICS OF SAMPLE FIRMS

Employees	Number of Firms	Ownership
11-50	3	UK(1); France(1);Japan(1)
51-100	3	USA(2); Japan(1)
101-400	3	UK(1); USA(1); Japan(1)
401-600	3	USA(2); UK(1)
601-1000	2	USA(2)
1001+	1	UK(1)

TABLE 6 MODES OF COMPETITION ENGAGED IN BY SAMPLE FIRMS

Mode of Competition	Number of Firms
Product Innovation	6
Consumer Service	4
Cost Leadership	5

show that in Livingston 41.9 percent of employees work in externally owned, mainly foreign multinational companies; and in Glenrothes, 37 percent.

The companies interviewed were also typical of those in the region in that they were predominantly from the electronics sector. They were, however, chosen so as to encompass the main high-technology activities within this sector, ranging from silicon wafer circuiting to the production of video machines and from the manufacture of computers to the production of technical ceramics. Those interviewed confirmed that their use of transport was much the same as that of similar companies in the area; indeed, several of the personnel had previously been employed by other local companies.

In terms of factor and goods movements, the foreign-owned firms tended to bring inputs from the United States and Japan (with smaller flows from continental Europe), process them in combination with U.K. inputs, and then distribute them to the U.K. market and continental Europe, especially the European Economic Community (*19*). The U.K.-owned firms served mainly the domestic market; defense equipment was a dominant feature of their production. This picture fits closely with an earlier study by the Scottish Development Agency which showed that 80 percent of foreign-owned electronics multinationals in Scotland were selling more than 20 percent of their output overseas compared with only 41 percent of Scottish-owned firms.

SIMPLE ANALYSIS OF TRANSPORT USED

A simple questionnaire approach, asking transport managers about the transport modes used to bring inputs to the plants and those used to distribute the final products to markets, yielded the results seen in Figures 2 and 3. This form of analysis has, in the past, been widely used in the study of transport utilization in the production process. As one can observe, air transport plays a central role and appears to be more important than is generally the case with traditional industries—a reflection of both the physical nature of the materials involved and the international orientation of the firms located in Silicon Glen. The contrast with other industries in the area is clear if reference is made to a recent study of the transport demands of a mixed group of local firms carried out in conjunction with the planning of the Edinburgh City By-Pass (*20*).

The usefulness of such analysis is, however, questionable. It is clear that many of the companies make extensive use of forwarders and have very limited knowledge of the forms of transport actually used, while others tended to respond to the questions excessively in terms of the dominant, usually trunk haul, segment of a trip. For this latter reason, shipping emerges as important to many firms; their transport movements involving roll-on/roll-off ferries are classified as "by sea" rather than "by road." In some instances where, for example, a manager thinks a consignment is going by air (because it has a flight number), it is actually taken by road; Scotland to/from London "flights" are often of this nature.

Responses to questions on the importance of transport considerations in decisions regarding plant location were bland. No factor emerged as central, although given the predominance of overseas involvements, it is unlikely that such decisions would be taken in the United Kingdom anyway. Indeed, discussions with the main planning agencies in the region suggest that, in their experience, the availability of suitable sites is generally a dominant factor influencing the location of footloose firms, although there must be at least a reasonable access to markets. The availability of government grants was also a force attracting firms to the area.

There was a general view, however, that the transport in the area met satisfying criteria in the sense that while Silicon Glen seldom offered a cost-minimizing location it did, in general, at least meet necessary threshold conditions. Many firms perceived attributes of the transport system as exceeding these thresholds. In particular, the customs facilities for international movements were felt to be more expeditious than those at London air terminals, while the pressure of competition ensured high-quality but low-cost public road haulage. The ability to bring inputs from the Far East and the United States through Prestwick and, to a lesser degree, Glasgow airports; to move them by motorway directly to Livingston and Glenrothes; and then to export to European markets through Edinburgh and England's east coast roll-on/roll-off ports was commented upon favorably by most of the firms interviewed.

Given the rather limited use such information has for transport planning and policy development, however, a more extensive series of interviews was conducted with both personnel employed by the high-technology firms and those providing transport services.

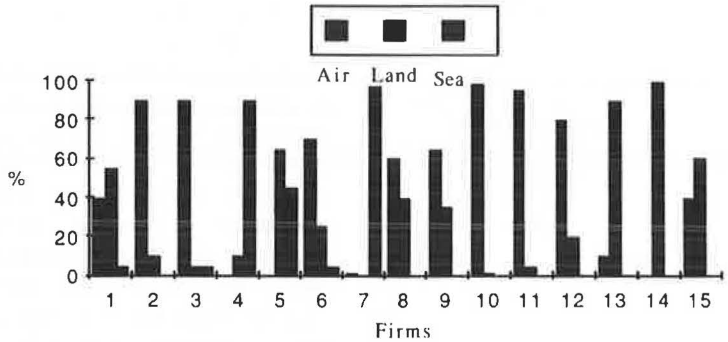

FIGURE 2 Transport employed for inputs to sample firms.

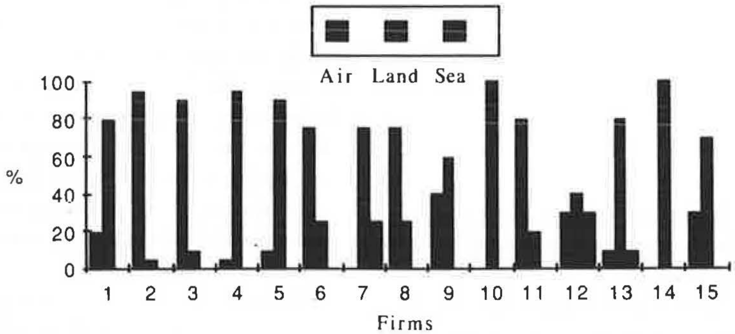

FIGURE 3 Transport employed for outputs of sample firms.

TRANSPORT OF FACTOR INPUTS

Cognizance of the inventory costs involved in handling large stocks of components, raw materials, and final products has led to the development of "just-in-time" production techniques; that is, parts and raw materials arrive at the production plant just as they are needed in the manufacturing process. This technique yields a number of potential benefits:

- Reductions in the amount of cash tied up in idle inventories,
- Stimulation of suppliers and dispatchers to greater efficiency,
- Reduced risk of being left with obsolete stocks, and
- Reduced wastage and improved quality in the production process as workers are forced to solve problems as they occur rather than to draw on inventories and leave difficulties unresolved.

While just-in-time techniques are not unique to the high-technology sector, the nature of its products and the speed of technical progress has encouraged its adoption by many firms. Its employment means that transport needs to be considered as part of an integrated production process with production management closely linked to the logistics side of the business. There must be fine-tuning of the production process coupled with liaison between production management, transport management, and the independent suppliers of transport services.

Of the 15 firms sampled, 10 claimed to be operating just-in-time management techniques and all were certainly aware of the concept although to varying degrees (perhaps not surprisingly, the Japanese and U.S. multinationals seemed to exhibit the most comprehensive analytical grasp of its meaning). Detailed examination of the actual procedures, however, revealed important differences in ways just-in-time operations are practiced and, indeed, suggest that many of the firms not claiming to have adopted the technique, in practical terms, pursue it more rigorously than some that do! Certainly, several of the plants surveyed were responsible for manufacturing at least two different products—usually one associated with high technology, the other not—and the levels of inventory-holding differed markedly between the lines. Management explained this in terms of purchasing attitudes of customers in the traditional sector where there is a tendency to place bulk orders intermittently and thus inventory-holding is pushed the full length of the production chain.

Even where just-in-time techniques are practiced, they are seldom pursued to the fullest extent. Table 7 provides a breakdown of the explanations offered by companies for not embracing a comprehensive just-in-time approach.

Interestingly, while the companies particularly concerned with improving their overall inventory handling consciously seemed to be seeking ways to improve the

TABLE 7 REASONS FOR NOT FULLY ADOPTING JUST-IN-TIME PRACTICES

Concerns	Firms*
Fear of damage to goods/inputs in transit	6
Possible delays for customers	2
Inappropriately designed factory	4
Poor quality of components affected continuous production	1
Lack of complete coordination between the transport function and the production	1
The particular needs of one-off,specialized products	2
The demands of some customers buying 'ex-works' leading to scheduling problems	1
Possible customs delays	2
Experimental and small size of plant	1
Economies of scale in bulk buying or carriage of inputs	2

*Several firms had more than one reason for not full adopting just-in-time procedures.

reliability of their transport usage and to reduce damage to consignments, only one had any substantial own-account fleet. This finding contrasts markedly with an earlier, more general study of the U.K. scientific and industrial instruments and systems industry; this study found that more than 70 percent of firms possessed their own transport facilities (*21*). The explanation may lie in the frequent need for specialized vehicles. In some cases, Silicon Glen firms had firmly tied themselves to a particular forwarder or hauler, one firm giving long-term contracts to allow special-purpose vehicles to be purchased to meet specific loading requirements, while another had a joint enterprise to develop a computerized inventory control and accounting system. More generally, the abundant supply of transport services meant that the high-technology companies regularly used a number of different transport firms and haulers to reap the price and service benefits generated in a competitive market place. Even where own account operations were still practiced, they were relatively long standing and were coming up for review.

Despite the problems in fully adopting just-in-time practices, the general movement was clearly in the direction of extending this type of operational approach. The longer-term impacts on the transport system are already emerging. Warehousing, in the traditional sense, is little used by the companies sampled or by the freight forwarders interviewed; major transport terminals themselves are used by the high-technology firms as consolidation points. Where warehousing is practiced, it is in highly automated facilities, again usually adjacent to major transport interchanges. From a public policy perspective the traditional warehousing facilities in the inner city areas or at ports are inappropriate for the needs of the industry.

Many of the firms were particularly concerned about the customs difficulties sometimes encountered. The problems stemmed more from uncertainty about the length of time a consignment would take to clear customs than from the actual process itself. The largest firms with substantial and regular flows of both imports and exports had arrangements for bonded areas at their factories with clearance done there. The medium and smaller concerns found customs clearance the greatest impediment to their operations.

Again, from the public policy perspective, there was concern that many of the factories available were ill equipped to deal with rapid loading and efficient intrafactory handling. While there are clear implications for publicly financed advanced factory design, the complaint was voiced by one plant manager with respect to a company-designed and built factory.

Modal interchange points also posed difficulties for many of the firms concerned with reliability and safety in their transport operations. Nearly half of the companies interviewed spoke of forwarders explaining delays or damage as being due to problems of interchange facilities. Road/air interchange posed particular problems because it is here that the damage to the more highly valued products tends to be greatest. Many companies had developed specialized packaging or had modified existing packaging in general use in plants in other countries to meet this particular problem. In a slightly different context, one major multinational user of road transport had been forced to develop more protective containers for its components because of damage incurred in transit from U.K. ports despite the adequacy of standard packaging for movements across continental Europe.

EXPRESS PARCEL SERVICES

High-technology products, especially those manufactured by the electronics industry, are frequently small items that require rapid delivery. The need for transport systems to meet this demand extends into the R&D activities of companies and the shipment of documents, spare parts, and samples. In the United States, express parcel services have grown to fill this niche in the market (e.g., the industry grew by some 38 percent between 1984 and 1985), and there is now a prospering 24-hr delivery service. The use of express parcel services is also growing in Europe although with something of a lag attached to it. A recent survey of 61 U.K. firms revealed that some 24 different operators were providing express parcel delivery, although Datapost, TNT Overnite, and Securicor Parcels in aggregate held more than 50 percent of the market (*22*).

With one exception, all the firms interviewed in Silicon Glen had used express parcel services in the preceding 3 mo. Some used the same carriers on a regular basis (Table 8), although many companies seemed to have no preferred

TABLE 8 EXPRESS PARCEL SERVICES USED BY SAMPLE FIRMS

Service	Firms
Pandair	1
TNT	5
DHL	3
Red Star	5
Elan	3
No Regular Carrier	5

carrier, and even those that did frequently employed other carriers on an almost casual basis. In several cases, the express parcel services were perceived as backups for regular road haulage operations or air transport. Several large high-technology companies predicted that express parcel services, now extensively employed for transfers of documentation, were likely to be rapidly superseded by electronic transfers of documentation. Further, two of the largest multinationals in Silicon Glen preferred courier services to express parcel service for transporting their sensitive documentation, believing courier service to be not only more secure, but also more cost effective, reliable, and flexible.

PERSONNEL TRANSPORTATION

High-technology industry is often thought to involve considerable numbers of highly qualified individuals. Certainly high levels of technical expertise are required at the R&D stage—the first stage—of the product life-cycle of most high-technology products. In the case of Silicon Glen, however, much of the activity is at later stages in the cycle (most Japanese and U.S. firms maintain their primary R&D units in the home country). The argument that superior international transport is required to keep the region's research personnel at the cutting edge of their fields is, therefore, less valid than would be the case if one were looking at a science park. The area's industry is, however, heavily engaged in the marketing as well as the manufacture of high-technology products. For example, at the time of the survey (summer 1986) five of the companies visited had personnel in Finland, a country striving to develop its own high-technology base. Equally, the multinational nature of many of the firms means there is substantial intracompany travel, particularly between Silicon Glen and the plants and offices in rest of the United Kingdom and in other EEC countries.

The importance of Edinburgh Airport as a gateway to the main international terminals of Heathrow (which, through the Shuttle Service, accounts for about 60 percent of the airport's traffic) and Amsterdam was confirmed by all 15 companies although Glasgow Airport, because of its motorway link to Livingston, also attracted business travel. The Scottish air link to the United States from Prestwick (via Shannon) was felt to be of limited use because the service was restricted and few personnel had final destinations at eastern U.S. gateways. (Prestwick was, however, seen as a useful freight terminal for U.S. traffic.) The range of European flights available from Edinburgh and Glasgow was considered very important by marketing personnel although all felt that high European air fares under the current regulated regime were a disadvantage when contrasted with the much more liberal system in the United States.

Small, special-purpose commuter-style airports located very close to the high-technology centers, such as Glenrothes, were not seen as part of the main transport system. This view stems primarily from the ease of road access at larger, regional facilities, such as Edinburgh and Glasgow airports, and tends to confirm the importance of accessibility, rather than proximity, highlighted in a recent study of Pennsylvania's high-technology industry (*23*). In the particular conditions of the United Kingdom, the low overall volume of air travel also means that smaller airports, close to more substantive alternatives, simply cannot generate enough traffic to offer viable services. In other areas of the United Kingdom where there are pockets of high-technology activity, e.g., in the South West, there are successful small local airports but they are distant from regional facilities.

Local transport is also important for the continued success of a high-technology center. "Burnout" in some of the U.S. centers is feared by some as those with the vital technical skills leave them in search of better living environments. Polls in high-technology centers such as Atlanta, Houston, and the Bay Area have shown that traffic congestion heads the list of perceived regional problems (*24*).

Congestion is relative. Traffic congestion in the Edinburgh region would seem mild to someone used to London or New York traffic, but it is nevertheless perceived as severe by some living and working in the area. One firm in Livingston, for instance, which has a large number of professional employees, expressed serious concern about 5-min delays at a roundabout during the evening peak travel period. Thus, while congestion may be minimal measured against traffic problems in larger cities, at the eastern end of Silicon Glen it is still noticeable. Also, the need to cross the Firth of Forth Bridge (and pay a toll) to travel between Glenrothes and Edinburgh, while not a major time or financial burden, was perceived as a disadvantage to firms in the area.

The observed split in modes of travel to work in the Livingston and Glenrothes areas is not out of line with that reported in U.S. high-technology areas; the car mode dominates, and public transport use is lower than in most comparable U.K. towns. Three of the firms surveyed had, for internal reasons, just looked at the travel-to-and-from-work patterns of their employees. The professional employees, as anticipated, used private motor cars with a limited amount of carpooling. To accommodate these drivers, all the recently constructed factories in the New Towns have extremely generous car parking provision—a point insisted on by the development agencies.

Assembly workers and other blue collar employees, who constitute most of the labor force at the high-technology firms in Silicon Glen, also traveled predominantly by car, although with a high incidence of carpooling. The companies that conducted the inquiries initially believed that the poor quality of local public transport was the reason so many workers commuted by car. In fact, the companies' objective had been to see if some alternative could be arranged. Indeed, public transport in the areas provides poor service for most high-technology firms. Many of those working in Livingston reverse commute from Edinburgh against a public bus service geared for radial movements into the city. Within Livingston, the Buchanan style of town planning has sited the high-technology plants on estates located at the far corners of the town, whereas the local public transport links housing estates to shopping and recreational areas. There is effectively no public transport for late-shift workers, and several of the larger firms regularly operate a full, three-shift system. The studies by the three firms, however, found little support for a private bus service, especially at night; and there was in all cases a feeling that existing carpooling arrangements worked well. Nevertheless, one of the companies does offer subsidized taxi service at night; the reported usage was small.

CONCLUDING COMMENTS

The work reported here lacks technical rigor in the sense that there is no in-depth, quantitative analysis, but rather an attempt to explore the less easily measured factors influencing the demands high-technology industry places on the transport system. Conclusions must, therefore, be rather tentative, but the case study reported in the body of the paper has provided a number of pointers that may help in the long-term formulation of transport policy.

This study of Silicon Glen in central Scotland has confirmed that good transport by itself is insufficient to attract high-technology industry to an area. Equally, it has shown that adequate transport, of the appropriate type, is necessary to stimulate high-technology production. Not only is adequate transport an important direct input into the production process, but it also plays a vital secondary role in assisting in marketing and in the efficient operation of the local labor market. The generality of these findings must be set in the particular setting of the type of firm found in Silicon Glen. It is unlikely, for instance, that they extend to the science-park type of high-technology concentrations where physical output is much smaller and R&D-related employment much greater. Equally Silicon Glen is dominated by large multinational companies with interests somewhat different from those of most U.K.-owned high-technology companies. The evolving internationalization of production, which is being stimulated by the growth of trade barriers, is likely to see this particular type of geographical concentration of multinational firms grow in number.

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Distributional Changes in Consumer Transportation Expenditures: 1972–1985

STEVEN M. ROCK

From 1972 to 1985, there were two periods of substantial increases in energy prices and one period of price decreases. Along with other macroeconomic events and policies, the combined impact has altered the distribution of income and transportation expenditures. Using U. S. Department of Labor statistics, the expenditures by families of different incomes on new and used vehicles and gasoline and total transportation spending can be examined. It was determined that wealthier families continued to purchase new cars; poor families drove less energy efficient autos. Transportation recently consumed more than 50 percent of a poor family's cash income. The greatest beneficiaries of lower energy prices would be the poor.

During 1972–73, the average urban American family spent just over 14 percent of its pretax income on transportation, including new and used vehicles, finance charges, gasoline, insurance, repairs, licenses, and fares on other travel modes. The price of a barrel of oil was $3; inflation was running at just over 3 percent; the unemployment rate was about 5 percent. Energy supply shocks and other macroeconomic events intervened to substantially change all of these indicators. By 1981–82, spending on transportation exceeded 17 percent of income; oil prices peaked near $33 per barrel; inflation surged to 13 percent; unemployment exceeded 10 percent. Subsequently oil prices, inflation, and unemployment fell.

While the impact of these events can be measured on average, this method obscures the fact that different families have been affected to different degrees. It is possible to calculate how households at various income levels have reacted. It is the purpose of this paper to document and comment on these changes.

In the last 15 yr, there have been three energy crises. In reaction to the Yom Kippur War, members of the Organization of Petroleum Exporting Countries (OPEC) embargoed oil to the United States in October 1973. As a result, the price of oil quadrupled by early 1974. Consumers confronted gas lines and higher prices. The second crisis began with the fall of the Shah of Iran in early 1979. A cutoff of Iranian crude, reinforced by panic stockpiling, led to a further doubling of oil prices.

Energy conservation gained increasing importance. In early 1986, a third energy crisis (from the viewpoint of most OPEC members and energy-producing states in the United States) contributed to a decline in oil prices under $15 per barrel.

Besides energy shocks, other macroeconomic events and governmental policies affected transportation expenditures. In 1972–73, the economy was distorted by price controls. As these were relaxed, inflation, in conjunction with the first energy crisis and a simultaneous food price supply shock (first in the grain, then in the beef markets), shot up. As monetary and fiscal policy were tightened in reaction, a recession ensued and unemployment rose. Just before the second energy crisis, another food price shock (in the meat market) contributed to an acceleration of price increases. Combating the resulting inflation through tightened monetary policy increased unemployment. The economy hit bottom at the end of 1982; subsequently, economic indicators improved. Inflation and unemployment fell; energy prices steeply declined and then rebounded somewhat.

Over the entire period, spending on gasoline, new and used vehicles, and other transportation expenditures have changed in ways that can be documented using the Bureau of Labor Statistics' (BLS) *Consumer Expenditure Survey* (CES) (*1–4*). This survey obtains comprehensive documentation of spending on different categories of goods and services by different household groupings. The CES was undertaken in 1972–73, then updated and made annual in 1980. By comparing consumer expenditures in 1972–73 with those in 1980–85, it can be determined how the macroeconomic events of that time period altered transportation spending. By focusing on the 1982–85 data, it is possible, with some educated guesswork, to explore the impact of the 1986 oil price decline.

The CES reports expenditures by consumer units (households) aggregated in various ways. Of interest for this analysis is a breakdown by income. Households will be ranked by population quintiles (20-percent intervals): quintile 1 will comprise the poorest 20 percent of all families; quintile 5, the richest 20 percent. Income, defined as money income before taxes (a definition that is somewhat broader than that of the Internal Revenue Service), includes unemployment compensation, public assistance, food stamps, and social security payments.

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The post-1980 data are not strictly comparable to the original 1972–73 figures due to certain changes in collection procedures. The most important alterations include limitation of the sample to urban areas only (until 1985), utilization of a smaller sample, and the treatment of students living away from home as separate consumer units for the latter data periods. The BLS has revised some of the original 1972–73 data to make them comparable to the 1980–81 data with students excluded. Since the 1982–85 data include student consumer units, an adjustment of the BLS numbers is necessary so all years are reasonably consistent. Comparing the 1980–81 data without students to those years' data with students provides an adjustment factor applicable to each income quintile and each expenditure component that can be carried forth and used to adjust the 1982–85 data.

OBSERVATIONS

Data for income before taxes, total transportation, new vehicle, used vehicle, and gasoline expenditures for 1972–73 and 1980–85 for the average family in each of the five income quintiles are displayed in Table 1. Much of the increase is due to inflation; prices increased by almost 150 percent in this time period. Nominal income rose in each year reported for all families except those in quintile 1, where there was a decline over the 1982–84 period. Real income fell for all quintiles, but more so at lower income levels.

Total transportation expenditures (including vehicle purchases, finance charges, gasoline, maintenance, insurance, licenses, and spending on other modes) increased substantially from 1972–73 through 1980 and again after

TABLE 1 AVERAGE HOUSEHOLD INCOME AND TRANSPORTATION EXPENDITURES, 1972-73, 1980-85

	Quintile:				
Year	1	2	3	4	5
			Income		
1972-3	$2448	6336	10553	15335	27260
1980	3468	9576	16379	24269	42938
1981	3968	10591	17771	26381	46635
1982	4449	10923	18181	27937	50960
1983	4329	10936	18646	28952	53914
1984	3831	11153	19602	30608	58878
1985	3850	11136	19704	31243	60989
Total change	+57%	+76%	+87%	+104%	+124%
			Transportation Expenditures		
1972-3	524	1087	1733	2266	3149
1980	1325	2409	3329	4417	6134
1981	1301	2263	3488	4597	5969
1982	1201	2151	3327	4460	6558
1983	1379	2473	3632	4833	7323
1984	2046	2829	4039	5352	8272
1985	1952	2916	4301	5690	8460
Total change	+273%	+168%	+148%	+151%	+169%
			New Vehicle Expenditures		
1972-3	100	234	408	509	894
1980	233	345	536	916	1394
1981	197	275	522	898	1254
1982	72	276	450	862	1614
1983	103	385	720	1112	2280
1984	423	610	854	1193	2592
1985	307	569	966	1531	2686
Total change	+207%	+143%	+137%	+201%	+200%

TABLE 1 AVERAGE HOUSEHOLD INCOME AND TRANSPORTATION EXPENDITURES, 1972–73, 1980–85

	Used Vehicles Expenditures				
1972-3	93	177	311	372	411
1980	175	450	486	632	845
1981	200	362	628	809	731
1982	257	325	637	722	976
1983	325	496	691	782	934
1984	386	546	817	1137	1182
1985	403	573	929	1018	1248
Total change	+333%	+224%	+119%	+174%	+204%
	Gasoline				
1972-3	121	262	413	533	678
1980	498	877	1240	1576	1911
1981	458	878	1251	1519	1879
1982	431	777	107[illegible]	1387	1692
1983	475	787	1069	1323	1696
1984	567	775	1025	1322	1667
1985	568	800	1020	1317	1580
Total change	+369%	+205%	+147%	-147%	+133%

Note: Values are dollars unless otherwise noted.

Source: Bureau of Labor Statistics (1-4) and author's adjustments.

1982. This increase in percentage terms was at least as great as that of overall prices and much greater than that of income, across all quintiles. As a result, such expenditures now account for a higher percentage of income for all families. The impact has been especially significant on quintile 1 families; transportation expenditures in 1984 and 1985 amounted to more than 50 percent of income (versus just over 20 percent in 1972–73).

Looking at the individual components of transportation, the uneven impact of the recession of 1980–82 is evident in spending on new vehicles. Quintile 1 families cut back substantially; quintile 5 households were barely affected. The economic expansion that began in 1983 coincided with a rebound in new car purchases, particularly in the lowest quintile. This seems somewhat paradoxical in light of the decline in nominal income for this group over the time period. One may wish to question the accuracy of the data on new vehicle expenditures for quintile 1 given the substantial fluctuations.

The second energy crisis and the recession of 1980–82 are also reflected in used car expenditures. Those expenditures held up rather well during this time period, suggesting that many households purchased used cars instead of new cars. Finally, gasoline spending has in general declined since 1980, although more so for the middle and upper income groups.

It is interesting to observe how vehicle expenditure dollars were divided between new and used vehicles for each quintile. As displayed in Table 2, the distributional impacts of the events of the 1972–84 period are evident. The recession of 1980–82 caused quintile 1 families to substitute used for new car purchases. On the other hand, quintile 5 household expenditure patterns held constant during this period. Wealthier families were able to continue buying newer and more energy efficient vehicles; lower income families were forced to purchase "gas guzzlers."

New-versus-used-vehicle expenditure patterns may partially explain the share of gasoline expenditures accounted for by each quintile in each time period (Table 3). Even though gasoline prices have declined since 1981, the share of such expenditures accounted for by quintile 1 and 2 families has continued to increase. However, gasoline expenditures and percentages could also have been affected by the number of vehicles owned by each group. This information is presented in Table 4. Vehicles per household rose most noticeably for quintile 1 families; for other quintiles, the increase was less.

Computing gasoline expenditures per vehicle (Table 3 data divided by Table 4 data) suggests roughly equal figures across quintiles. At first glance, it would appear that auto ownership alone could explain difference in gasoline expenditures. However, data from the 1983–1984 Nationwide Personal Transportation Study (5) indicate that mileage driven per vehicle is related to income. The highest income group reported ($40,000 and over) had mileage per vehicle that was 45 percent above that of the lowest income group (under $10,000) for 1983. These data confirm the suspicion that lower income groups owned less energy efficient vehicles at that time, since they spent almost as much on gasoline on a per vehicle basis.

IMPLICATIONS BEYOND 1985

With the price of energy falling substantially at the end of 1985 and the first half of 1986, when consumer expenditures on gasoline are reported for this period, the decline that began in 1981 should continue. With the short-run price elasticity of demand in the range of −0.2 to −0.4 (*6*), a 40-percent decrease in gasoline prices would lead to an 8–16-percent increase in quantity purchased; thus, total gasoline expenditures will decline. If the lower prices had lasted longer, they would have proven particularly beneficial to the poor, who are relying on less energy efficient vehicles. This benefit would have been reinforced over time as the gas guzzlers are scrapped from the car fleet and more efficient autos trickle down to lower income families. A strong new car sales trend, particularly in higher-price vehicles, should continue to be observed in the upper quintiles.

QUALIFICATIONS

Certain concerns need to be raised about the CES data. As with any survey, sampling inaccuracies are possible. However, comparisons with alternative data sources suggest the overall numbers are reasonable. For example, the CES aggregate figures on vehicles and gasoline expenditures

TABLE 2 NEW CAR EXPENDITURES AS A PERCENTAGE OF TOTAL VEHICLE EXPENDITURES

			Quintile:		
Year	1	2	3	4	5
1972-3	51.8%	56.9	56.7	61.3	68.5
1980	57.1	43.4	52.4	59.2	62.3
1981	49.6	43.2	45.4	52.6	63.2
1982	21.9	45.9	41.4	54.4	62.3
1983	24.1	43.7	51.0	58.7	70.9
1984	52.3	52.8	51.1	51.2	68.7
1985	43.2	49.8	51.0	60.1	68.3

TABLE 3 PERCENTAGE OF GASOLINE EXPENDITURES BY EACH QUINTILE

			Quintile:		
Year	1	2	3	4	5
1972-3	6.0	13.1	20.6	26.66	33.8
1980	8.2	14.4	20.3	25.8	31.3
1981	7.7	14.7	20.9	25.4	31.4
1982	8.0	14.5	20.0	25.9	31.6
1983	8.9	14.7	20.0	24.7	31.7
1984	10.6	14.5	19.1	24.7	31.1
1985	10.8	15.1	19.3	24.9	29.9

Note: Each row sums to 100 percent.

TABLE 4 VEHICLES PER HOUSEHOLD, 1972–73, 1980–81, 1985

	Quintile:				
Year	1	2	3	4	5
1972-73	0.6	1.2	1.8	2.4	2.9
1980-81	0.8	1.4	2.0	2.5	2.9
1985	1.1	1.5	2.0	2.5	3.0

were within 2–5 percent and 5–11 percent, respectively, of the personal consumption expenditures in the National Income and Product Accounts prepared by the U.S. Department of Commerce over the 1980–83 period. Beginning in 1980, the CES relied on a smaller sample, possibly leading to more volatility in results. The smallest sample size for any quintile for any year was 672 families. The 1985 sample included rural families; the previous data reported were for urban areas only. Finally, the dollar expenditure numbers are averages for each quintile. For example, if a cell contains 750 households, 10 percent of which spend $5,000 each on a used car (the other 90 percent not purchasing this item), the average family will be reported as spending $500 on used vehicles.

CONCLUSIONS

The major observations are summarized as follows:

- Over the 1972–85 period, expenditures on transportation increased more than income for all quintiles.
- Due to the second energy crisis and the resulting recession of 1980–82, lower income families substituted the purchases of used cars for new cars.
- Gasoline expenditures have in general been declining since 1981 for all quintiles except the first. Quintile 1 expenditures have not declined because used cars have lower fuel efficiency and because the number of vehicles per quintile 1 household has increased.
- Lower energy prices would benefit the poor more than they would benefit higher income groups.

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Measuring Economic Stimulation from Capital Investment in Transportation

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This paper reports on an interactive computer model developed to calculate the economic impacts of capital investment in transportation facilities. The Transport Impact Model (TRIM) works within the framework of input-output analysis and is based on the 43-commodity input-output table for the province of Ontario in Canada. For a given capital project, described in terms of several categories of input costs, TRIM computes values for labor income, gross domestic product, employment, gross sales, tax revenue, imports from other provinces and abroad, and primary energy consumed. Some of the preceding categories are further disaggregated. For each impact indicator, TRIM shows the initial effect and the indirect and induced effects of a capital expenditure. While the version of TRIM described herein applies to the Ontario economy, it can be adapted for use in any economic unit for which input-output data exist.

In addition to providing new services and maintaining service quality, capital expenditures by transportation agencies have secondary effects on the economy: they affect income, employment, and production inside and outside the jurisdiction involved; they generate tax revenues of various sorts; and they use energy resources. Such secondary effects are of interest to those who decide how much to spend on transportation capital projects and how to allocate the funds across projects. For any particular project it is useful to know what the impacts are and how they change in response to adjustments in the content or scale of the project. Comparisons of economic impacts across projects in different parts of the transport sector are also useful in deciding which projects to fund. The purpose of this research effort has been to construct an analytical tool that will provide transportation decision makers with a comprehensive set of indicators of the economic impacts of spending programs.

The result of the project is the Transport Impact Model (TRIM), a self-contained microcomputer program based on a prototype model developed by Econometric Research Ltd. of Burlington, Ontario. With TRIM, analysts can calculate impact indicators for a variety of capital projects in minutes. In the present version, designed for use in the Ontario provincial transportation system, one can view the impacts on the Ontario economy of 35 predefined typical projects, either individually or in combinations; one can adjust the assumptions made about the content or scale of these typical projects; and one can run one's own specially defined projects through the program.

The next section of this paper briefly describes the logic of TRIM and sets out the variables that are calculated as indicators of the effects of capital expenditures. A full description of TRIM is provided by Allen et al. (*1*). Other sections explain how the data that define a simulated project were constructed and entered into the model and describe some illustrative simulations with the present version of TRIM. The concluding remarks indicate how the model will be further developed.

ECONOMIC IMPACTS

Input-output analysis provides a framework within which industrial linkages, as well as the feedbacks between consumers and the producing sector of the economy, can be simulated. Miller and Blair have written a useful textbook on the subject (*2*). The economy is modeled as a set of linear equations, the parameters of which are estimated by a central statistical agency and organized into an input-output table. The input-output table is an extension of the familiar national product accounting system to the level of individual industries and commodity groups. TRIM operates within this framework.

A variety of economic impacts may be of interest to decision makers. TRIM calculates the set shown in Table 1. For each of these variables, an economic impact is defined as the sum total of changes in all sectors of the relevant economy associated with a given capital project or program expenditure. In the output of TRIM, these changes are broken down into initial, indirect, and induced effects. Consider each of these effects in turn.

The initial effect measures the change in the impact variables closely associated with the original expenditure

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TABLE 1 ONTARIO IMPACT INDICATORS CALCULATED BY TRIM

- Labor Income
- Gross Domestic Product (at market prices)
- Employment
- Gross Sales
- Tax Revenue (by level of government & type of tax):
  - Personal Income Tax
  - Indirect Business Tax
  - Customs Duties
  - Corporate Profits Tax
  - Property & Business Tax
  - Total Tax Revenue (Federal & Provincial)
- Imports from other provinces
- Imports from abroad
- Primary Energy Consumed:
  - Coal
  - Crude Oil
  - Natural Gas
  - Electricity
  - Other
  - Total Primary Energy

itself. For instance, in the case of gross sales, the initial effect of a transport project is the value of expenditures on equipment and materials required to construct the facility; otherwise put, it is the project expenditure itself less the payments to labor working directly on the project and the profit generated directly by the project. In the case of gross domestic product (GDP) (at market prices), the initial effect is equal to the value of materials, equipment, and labor used in the project itself plus profit and indirect taxes paid. Alternatively, the initial GDP effect is equal to the original expenditure, i.e., the sum of the input values entered into TRIM in the first place. The initial employment impact variable measures the number of person-years of work used directly in project construction.

Second, the output of one industry cannot be expanded without drawing on the output of other industries. The changes associated with these latter products are called the indirect impacts of the project. Indirect impacts are those associated with the production of intermediate goods and services that enter into the initial inputs. Note that there are many rounds of indirect effects. For example, one initial input into highway construction is mineral aggregate. To deliver the amount required, the quarry operator uses equipment that consumes fuel. The delivery of the extra fuel is part of the indirect effect; it is part of a first round of intermediate goods expenditures following the initial expenditure. But to deliver the extra fuel, a petroleum wholesaler also has to use extra fuel. This is a second round indirect effect. The extra demand for fuel by the gravel supplier and the petroleum supplier together creates an extra need for fuel at the refinery, creating a third round, and so on. This process continues until the extra increments of production in subsequent rounds become negligible.

Finally, as income expands due to the initial and indirect effects, households increase their purchases of goods and services, thereby giving rise to still further changes in production and corresponding changes in all of the other impact variables. These effects, which work through changes in household consumption, are referred to as induced effects.

It is important to interpret the numbers calculated by an impact model such as TRIM accurately and with some caution. TRIM provides consistent useful estimates of the specific variables identified within it. These estimates should not, however, be mechanistically interpreted as the net benefits of the project expenditure involved, although they are related to such benefits. For a variety of reasons (e.g., a lack of idle productive resources or the presence of pollution and other types of spillover effects), the net effect of a given capital expenditure can be evaluated comprehensively only in its own context. (A standard textbook on cost-benefit analysis will provide a discussion of this problem.)

INPUT DATA

The use of TRIM to estimate the impacts of a given spending project involves two steps. First, an account of the goods and services to be used in the project is prepared. These are the dollar values of labor, equipment, and materials (excluding the cost of land) that go into constructing the facility involved. Up to 20 categories of project inputs are involved. Then this "recipe" is used as input data for TRIM, which calculates the values of the impact variables shown in Table 1 for the project under consideration.

While the user of TRIM can prepare input cost data for any transportation project, it was regarded as useful to provide a series of typical capital projects within the program database. These sample data sets are referred to as standard unit projects (SUPs). To construct them, members of the research team obtained information from engineers and estimators involved in actual design and construction of transportation facilities. For a given SUP, a list of the tasks required to build or service the transport facility was prepared. For instance, in the case of a municipal arterial road, this list included excavation of the existing road base; grading and shaping the subbase; filling with granular "A"; granular backfilling for soft spot excavation; adjusting manholes, catchbasins, and valve chambers; constructing curb drains; relocating utilities; and so on until the full recipe for the unit-section of road was well defined.

With the help of engineers and estimators, the cost for performing each of these tasks was obtained and then broken down into the categories of inputs defined by the Ontario input-output table. Examples of these categories are wage payments, equipment, fuel, nonmetallic mineral products (e.g., gravel), primary metal products, electrical products, and so on. The result was a cost data matrix for each standard unit project, with the tasks defining rows and the input categories defining the columns. A sample is shown in Table 2, which reproduces the data matrix for standard unit project 6, a 100-m length of two-lane municipal roadway.

This process was followed for 25 of the 35 SUPs shown in Table 3. (The data for SUPs 18–27 were adapted from an earlier project on highway impacts carried out by the Ontario Ministry of Transportation and Communications.) When the TRIM program is run on a microcomputer, the user chooses at the outset whether to calculate impact indicators for one of these SUPs or whether to construct a unique simulated project. If an existing SUP is chosen, the user has the option of viewing and adjusting the table of input costs, in which case a list of cost categories like the one shown across the top of Table 2 will appear on the screen. The column total for each cost category is the number entered into the TRIM input cost list.

TRIM OUTPUT

This section illustrates the use of TRIM for the analysis of projects and programs. As already noted, such analysis focuses on the economic impacts of a capital expenditure

TABLE 2 INPUT DATA, STANDARD UNIT PROJECT 6, TWO-LANE LOCAL MUNICIPAL ROAD

		ADMINISTRATION		LABOUR		EQUIPMENT			
	TOTAL	OVERHEAD	PROFIT	WAGES	BENEFITS	FUEL	REPAIRS	INSURANCE	DEPREC.
Tasks									
EARTH EXCAVATION	6020	482	120	2252	337	368	283	57	2122
GRANULAR 'A' (450 MM)	9450	756	189	987	147	123	95	19	709
HOT MIX HL-8 (80 MM)	7650	612	153	865	129	99	77	15	574
HOT MIX HL-3 (40 MM)	4080	326	82	461	69	53	41	8	306
CONCRETE CURB AND GUTTER	5250	420	105	1233	184	82	63	13	473
HOT MIX HL-3 FINE IN DRIVEWAYS	990	79	20	241	36	21	16	3	119
CACL2	460	37	9	40	6	3	2	0	17
ADJUST EXISTING MANHOLES	1335	107	27	441	66	0	0	0	0
WATER FOR COMPACTION	250	20	5	98	15	15	11	2	84
RELOCATION OF UTILITIES, MISC.	3549	710	177	772	115	115	89	18	665
ENGINEERING DESIGN	3123	874	219	1766	264	0	0	0	0
ENGINEERING CONSTRUCTION MANAGEMENT	2732	765	191	1545	231	0	0	0	0
COLUMN TOTAL	44889	5188	1297	10702	1599	879	676	135	5069

	NON-MET. MINERALS	NON-MET. MINERAL PRODUCTS	PETROLEUM & COAL PRODUCTS	TAX	PRIMARY METAL PRODUCTS	CHEMICALS CHEMICAL PRODUCTS	ELECTRICAL & COMM PRODUCTS	PLASTIC FABRICAT PRODUCTS	TRANS
EARTH EXCAVATION	0	0	0	0	0	0	0	0	0
GRANULAR 'A' (450 MM)	4284	0	0	0	0	0	0	0	2142
HOT MIX HL-8 (80 MM)	1595	0	2392	342	0	0	0	0	797
HOT MIX HL-3 (40 MM)	765	0	1371	215	0	0	0	0	382
CONCRETE CURB AND GUTTER	0	2008	0	167	0	0	0	0	502
HOT MIX HL-3 FINE IN DRIVEWAYS	106	0	297	0	0	0	0	0	53
CACL2	0	0	0	0	0	345	0	0	0
ADJUST EXISTING MANHOLES	0	93	0	0	601	0	0	0	0
WATER FOR COMPACTION	0	0	0	0	0	0	0	0	0
RELOCATION OF UTILITIES, MISC.	0	133	0	11	71	0	532	106	33
ENGINEERING DESIGN	0	0	0	0	0	0	0	0	0
ENGINEERING CONSTRUCTION MANAGEMENT	0	0	0	0	0	0	0	0	0
COLUMN TOTAL	6749	2235	4060	736	672	345	532	106	3910

NOTE: Values are hundreds of meters.

TABLE 3 STANDARD UNIT PROJECTS IN TRIM

Program Type	SUP No.	Nature of Project
Municipal Roads	1	6-lane Collector/Arterial road
	2	5-lane Collector/Arterial road
	3	4-lane Collector/Arterial road
	4	2-lane Collector/Arterial road
	5	2-lane Rural Road
	6.	2-lane Local Road
Airports	7	Major runway upgrade, 3500 ft
	8	Major runway upgrade, 5000 ft
	9	Major runway upgrade, 2000 ft
	10	Navigation aid upgrade, 3500 ft
	11	Navigation aid upgrade, 5000 ft
	12	Navigation aid upgrade, 2000 ft
	13	Minor runway upgrade, 3500 ft
	14	Minor runway upgrade, 5000 ft
	15	Minor runway upgrade, 2000 ft
	16	Airport access road, 200 m
	17	Airport access road, 500 m
Provincial Highways	18	New construction, unpaved, 2 lanes
	19	New construction, paved, 4 lanes
	20	Reconstruction, paved, 2 lanes
	21	Recon., paved (with rock), 2 lanes
	22	Resurfacing, 2 lanes
	23	Resurf. recycled hot mix 2 lanes
	24	Post-tensioned concrete structure
	25	Bridge deck, latex/concrete overlay
	26	Br. deck repairs, latex patch/asphalt
	27	Major widening (no structures)
Provincial Transit	28	Suburban parking lot
	29	Ride-Share parking lot
Municipal Bridges:		
	30	3-span Rehabilitation
	31	Single span, land
	32	Single span, water
	33	Medium span, land
	34	Medium span, water
Municipal Transit	35	Municipal transportation centre

on the total economy. It takes account of interindustry demands and feedbacks and of the effects on consumer spending. The version of TRIM described here is based on the Ontario input-output table for 1979 (the most recent provincial table available until the 1984 table is ready for use in 1988–89). Standard-unit-project data reflect prices at the beginning of 1987; appropriate adjustments have been made to convert impact values to 1987 prices.

Our illustration is based on SUP 3, a 100-m section of four-lane collector/arterial road. Input data for the project were developed from a reconstruction job in the city of Hamilton during 1985, with adjustments to eliminate atypical aspects of that particular project. The hypothetical project assumes reconstruction of an existing road that has deteriorated to such a level that resurfacing or other such remedial work will not provide a satisfactory riding surface and/or sufficient roadway life. Traffic is maintained on the roadway during all construction activities. Each lane is 3.5 m wide, with standard concrete curb and gutter, a 1.5-m boulevard and a 1.5-m concrete sidewalk on each side of the road. It is assumed that some roadway widening is required to provide standard lane widths. As a result, new catchbasins are required; storm sewers are assumed not to require replacement. The roadbed is excavated, subgrade is prepared, and subbase is provided to a depth of 600 mm with granular "A," covered with 120 mm of HM5 binder asphalt, and a surface course of 40 mm of HM3 surface asphalt. Intersections with local roads are provided for, and an allowance equal to 15 percent of total construction costs is provided to cover the cost of utility relocations necessitated by roadway widening. Finally, it is assumed that only minor grade changes are required.

The TRIM printout for SUP 3 is shown in Table 4. An initial expenditure of $137,647 generates a total increment to Ontario income (GDP) of $192,360 when the indirect and induced effects are included. The ratio of the total effect to the initial effect—the multiplier—for GDP is 1.82. The employment multiplier is significantly higher than the GDP multiplier in this case; 1.1 initial direct jobs expand into 4.7 jobs when the total impact of the project expenditures are tallied. This finding suggests that an expenditure on municipal roads uses inputs from sectors of the economy that tend to be labor intensive, making it an efficient area of expenditure for job creation. (The latter

TABLE 4 TRIM OUTPUT, STANDARD UNIT PROJECT 3, FOUR-LANE COLLECTOR/ARTERIAL ROAD

Provincial Impact

(Canadian Dollars)

	Initial	Indirect & Induced	Total
Gross Domestic Product	137647	54713	192360
Gross Sales	93409	180287	273696
Labour Income	38026	74595	112622
Employment (Person-Years)	1.1	3.6	4.7

Taxes	Federal	Provincial	Local	Total
Personal Tax	13270	6245	0	19515
Indirect Business Tax	4921	7913	0	12834
Tariffs	2894	0	0	2894
Corporate Profit Tax	3982	1961	0	5944
Property & Business Tax	0	0	6850	6850
Total Taxes	25068	16119	6850	48037

Imports	
Imports from Other Provinces	33567
Imports from Outside Canada	32475
Total Imports	66041

Energy	
Physical Units	
Coal	0.0 Kilotonnes
Crude Oil	0.2 Megalitres
Natural Gas	0.0 Gigalitres
Electricity	0.1 Gigawatt-Hours
Energy Units	
Coal	0.8 Terajoules
Crude Oil	6.5 Terajoules
Natural Gas	1.5 Terajoules
Electricity	0.4 Terajoules
Liq. Pet. Gases & Nuc. Steam	0.1 Terajoules
Total Energy	9.2 Terajoules

hypothesis can, of course, be checked by comparing this employment multiplier with those for other SUPs.)

The income and gross output (sales) generated by municipal road construction give rise to tax recoveries, indicating that the net cost to the provincial government of a municipal road project is significantly less than the initial cost. In this case, a total of $16,119 is recovered by the provincial government from sales, income, and corporate taxes. The federal government collects a larger amount, about $25,000, while local governments recover $6,850. Total tax recoveries add up to $48,037, about 35 percent of the original cost of the project.

Economic impacts associated with this project are not restricted to Ontario; other provinces experience an increase in demand for their products to the tune of $33,567. A slightly smaller amount of increased demand, $32,475, flows outside Canada. Total imports associated with this project amount to $66,401. In other words, about 23 percent of the total sales generated by expenditure on 100 m of four-lane municipal road involve goods produced outside Ontario.

Finally, Table 4 shows the amounts of primary energy consumption associated with the initial, indirect, and induced effects of the project. The use of crude oil accounts for the largest portion of energy use, amounting to 71 percent of the total energy units—in addition to the petroleum-based fuels used in construction and in the manufacture and delivery of intermediate goods, asphalt, and related materials used on the road itself. In general, transportation projects depend heavily on oil-based energy, although a comparison across SUPs shows that the "oil intensity" of energy use varies across different types of projects.

The above illustration shows the results of the simulation of a standard unit project with no adjustment to the input data. The TRIM user considering a road project that varies from the above description could adjust the input data accordingly. In addition to running any of the 35

SUPs individually, the program easily handles combinations of projects. With one run, the user might analyze a more complex expenditure program, e.g., expanding an airport, improving an access road, constructing a parking lot, or building a new stretch of highway to the airport. It is also a simple matter to convert the calculations from projects defined in physical units to projects defined in dollar amounts. Thus the model can be used for the simulation of budgetary changes.

The usefulness of the TRIM database is obviously influenced by whether standard unit projects can be rescaled. Although the SUP data are most accurate for the project sizes originally costed, projects can be rescaled to multiples of the standard unit within a set of judgmental constraints. When variations in the scale of projects are being analyzed, the user of TRIM must decide whether to rescale the SUP data mechanistically or to construct a new set of input data. For scale changes of large magnitude relative to the defined SUP, a new data set is advisable.

CONCLUDING COMMENTS

This paper has provided a brief overview of a system of indicators of economic stimulation and energy use associated with capital investment in various transportation modes in the province of Ontario. Based on input-output accounting, TRIM calculates the impacts of a transportation project on labor income, gross domestic product, employment, gross sales, tax revenue, imports from other provinces and abroad, and primary energy consumed. For each impact indicator, TRIM measures the initial effect and the indirect and induced effects of a capital expenditure.

In addition to providing estimates that are directly useful to decision makers, TRIM can be viewed as an aid to analysis and communication that, for various reasons, will enhance the planning process within transportation agencies. For instance, in an agency using such a model, staff involved in different activities will be led to communicate reports and opinions on project planning in a common framework and to focus on a common set of variables that are mutually understood. Furthermore, it is likely to help agency staff to develop consistent techniques of cost analysis. Users of TRIM who become familiar with the standard-unit-project database will learn how to analyze project costs in a way that allows their secondary impacts to be calculated.

While TRIM is a working model as it stands, in its present form it should be viewed as a starting point. There is scope for further development, both in terms of the model itself and in terms of how it can be used in a transportation agency. The Ontario Ministry of Transportation is now deciding the specific ways it would like to extend, customize, and maintain the model.

A number of observations are relevant:

- To remain useful, an economic impact model should be updated regularly. As already noted, there is a considerable lag in the publication of input-output data by Statistics Canada. When the 1984 version of the Ontario input-output table becomes available, it will be desirable to update TRIM to account for structural changes in the Ontario economy between 1979 and 1984.
- The input data and the parameters of the model also depend on the prices of goods and services. As inflation occurs, and as the prices of goods and services important in the construction of transportation facilities change relative to each other and to other goods prices, the existing model will produce outdated calculations. Price data in the model should be updated regularly.
- TRIM can be converted to calculate economic impacts for any other jurisdiction for which input-output data exist.
- An input-output-based computer program involves literally hundreds of decisions regarding the source and use of data and the method of calculation (*1*, Appendix A). In the initial development of such a complex model, it is inevitable that some aspects of its structure will involve arbitrary assumptions and/or assumptions necessarily made for pragmatic reasons. After some experience in using it, the model can be customized to meet an agency's specific needs.
- An interesting possibility for a fundamental extension of the model is the integration of cost analysis into it. In the present version, the cost of each input component of a capital project is prepared ahead of time and entered into TRIM. Instead, one could develop a module to generate a task/input cost matrix. Input data would then be developed more conveniently and standardized further. The impacts of variations in design could be more easily simulated within such a framework.
- While the set of 35 projects represented in the TRIM database provides extensive coverage of various transportation facilities, there is scope for expanding the number and variety of standard unit projects in the database. Cost data, for example, are currently being gathered for a set of rapid transit SUPs based on the Toronto subway system. For those users who wish to depend on the standard unit projects, an expanded database would be desirable.

Note that TRIM calculates only the secondary impacts of capital expenditures. Obviously a transportation agency is also interested in the development of indicators of the primary effects of transportation investment initiatives. (Estimates of the primary impacts of a project would capture the value of the actual transportation services produced as a result of capital spending. Secondary impacts are all other effects.) Various primary indicators are in use, e.g., value of travel time saved, reduction in accidents per time period, etc. If such indicators were to be standardized within an internally consistent framework, applicable across the various transportation modes, it would be useful to integrate them into a model that provides secondary impact indicators. Preliminary work on such a strategy is already under way.

ACKNOWLEDGMENTS

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Schedule Delay and Departure Time Decisions with Heterogeneous Commuters

RICHARD ARNOTT, ANDRE DE PALMA, AND ROBIN LINDSEY

The dynamics of morning rush-hour traffic congestion have been studied extensively in recent years. In most theoretical work, however, commuters are assumed to have identical travel cost functions and to face the same arrival-time constraints at work. In this paper, we allow commuters to differ in their travel time costs, their starting time at work, and the costs incurred from early and late arrival. Early in the rush hour, the departure rate exceeds road capacity, causing a queue to develop. Commuters order themselves systematically in the departure sequence to minimize their individual travel costs. The order in which different groups depart is not necessarily efficient. A time-varying congestion toll can be constructed to eliminate queueing and induce the optimal order of departure. Travel-cost savings from such congestion tolls and from road capacity investments are computed. Estimated benefits are generally biased if computed using average travel-cost parameters and average work start times rather than actual distributions. Savings tend to be overestimated if commuters differ primarily in travel costs, but can be underestimated for capacity investments when commuters differ primarily in starting times at work.

The trade-off between time spent commuting in the morning rush hour and the cost of arriving early or late at work has been studied extensively in recent years. With few exceptions, however, the theoretical work has been highly aggregative. Commuters are usually assumed to incur the same costs from travel and to face the same arrival-time constraints at work. For at least two reasons, the analysis needs to be generalized to allow for differences in commuters.

First, empirical studies by Ott et al. (*1*), Small (*2*), and Moore et al. (*3*) have found that different socioeconomic and age groups differ in their commuting behavior. White-collar workers as a group display greater variability in arrival time at work, and are more likely to arrive at the end of the rush hour than is the general population. Workers with children tend to arrive earlier and exhibit less variability in arrival time. Older workers and carpoolers also tend to arrive earlier, while the results for individuals with long commutes are mixed.

Systematic differences between groups in commuting behavior can be attributed to differences in employer policies toward work hours, to family scheduling constraints, and to differences in the real or perceived cost of travel time. Professional and self-employed workers, for example, with high values of time but relatively flexible work hours, tend to travel on the tails of the rush hour to avoid the worst congestion. Carpoolers may depart earlier than single drivers to ensure that members with the earliest starting times arrive on schedule.

To explain the distribution of rush-hour travel times and to predict the response of traffic to changes in the system, it is necessary to account for differences in the commuting population.

A second reason for disaggregation is to provide a framework that will allow more accurate cost-benefit analysis of congestion tolls, road investments, and other transport policies. Most studies have employed single values for the cost of travel time, the desired arrival time at work, and the costs of arrival either earlier or later than desired. But since commuters of different types tend to order themselves systematically in the departure sequence, calculations based on single representative values will generally be biased. A tolling scheme, for example, may pass a cost-benefit testing using an aggregate model, but fail it after disaggregation, or vice versa.

Despite the apparent need to treat heterogeneity of the commuting population, only two authors have done so in the theoretical literature. Henderson (*4*, ch. 8) considers two groups of commuters, with identical costs of travel and waiting time, but different values of noncommuting time. On the assumption that no one arrives late for work, Henderson shows that the group with the lower value of time departs first. Travel time for this group is lower, but waiting time is higher than for the other group. In a later work, Henderson (*5*) again considers two groups of commuters, this time differing in schedule delay costs and with equal unit costs for early and late arrival. The group with higher costs travels at the peak of the rush hour, the other group on the tails.

Recently, Newell (*6*) provided a detailed analysis of the pattern of morning rush-hour departures when traffic flow is constrained by a bottleneck of constant capacity. Commuters are assumed to differ in their costs of travel time, their work start times, and their schedule delay costs (costs

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of early and late arrival). In this paper, developed independently of Newell's, the bottleneck framework is also adopted, and the focus is on differences between commuters in travel time and schedule delay parameters. The paper differs from Newell's in three respects.

First, Newell treats continuous distributions of commuters differing in both work start time and commuting costs, whereas we assume discrete distributions differing either in work start time or in commuting costs, but not both simultaneously. Our approach is thus less general than Newell's, but allows us to derive explicitly the equilibrium distribution of departure times. Second, we derive the socially optimal departure sequence of commuter groups and indicate how it differs from that in user equilibrium. And third, we calculate the benefits from optimal time-varying congestion tolls and road capacity investments. We also determine the direction of bias when benefits are computed using average population parameters rather than their actual distributions.

The queueing model on which our analysis is based was introduced by Vickrey (*7*) and extended by Hendrickson and Kocur (*8*), Fargier (*9*), and Arnott et al. (*10*). In the next section we review the main results of the model for identical commuters. In later sections, commuters are allowed to differ in their costs of travel time and schedule delay, differences in the relative costs of early and late arrival are considered, the assumption of homogeneous cost parameters is restored and focus is on differences in starting times at work, and conclusions are drawn.

REVIEW OF THE MODEL WITH IDENTICAL COMMUTERS

The precise assumptions and notation employed here follow our earlier model (*10*). N identical commuters travel each morning from home in the suburbs to work downtown. There is a single road along which each individual commutes in his own car. Travel is uncongested except at a single bottleneck (a bridge, tunnel, intersection, etc.) which at most s cars can traverse per unit of time. If the arrival rate at the bottleneck exceeds s, a queue develops. Travel time is

$$T(t) = T^f + T^v(t) \tag{1}$$

where T^f is travel time in the absence of a queue, $T^v(t)$ is waiting time at the bottleneck, and t is departure time from home. Without loss of generality, we set $T^f = 0$, so that an individual reaches the queue at the bottleneck as soon as he leaves home, and arrives at work upon exiting the bottleneck. The length of the queue, $D(t)$, is

$$D(t) = \int_{\hat{t}}^{t} r(\tau)\, d\tau - s(t - \hat{t}) \tag{2}$$

where $\hat{t}$ denotes the time at which the queue was last zero and $r(t)$ the departure rate. Waiting time at the bottleneck is

$$T^v(t) = D(t)/s \tag{3}$$

Individuals are assumed to have a common starting time at work t^*. Their travel cost is given by the linear function

$$C(t) = \alpha T^v(t) + \beta(\text{time early}) + \gamma(\text{time late}) \tag{4}$$

where for individuals who arrive early (before t^*), time late = 0, and for those who arrive late (after t^*), time early = 0. The parameter α measures the (vehicle operating and opportunity of time) costs of time spent in transit. β measures the cost of arriving an extra minute early at work and γ the cost of arriving an extra minute late. (These costs may be nonlinear, or exhibit discontinuities; we follow common practice in assuming linearity.) To assure that the equilibrium departure rate is finite we assume $\alpha > \beta$. For convenience, we define $\eta \equiv \gamma/\beta$ to be the relative unit cost of late arrival to early arrival.

Finally, t_n is defined to be the departure time for arrival at t^*, determined implicitly by the condition

$$t_n + T^v(t_n) = t^* \tag{5}$$

Henceforth, we take "depart early" to mean arrive early and "depart late" to mean arrive late.

User Equilibrium

In choosing when to leave home, individuals face a tradeoff between travel time and schedule delay. Individuals are assumed to have full information about the departure time distribution. Equilibrium obtains when no one can reduce costs by altering departure time. With identical individuals this means that costs are constant over the rush hour.

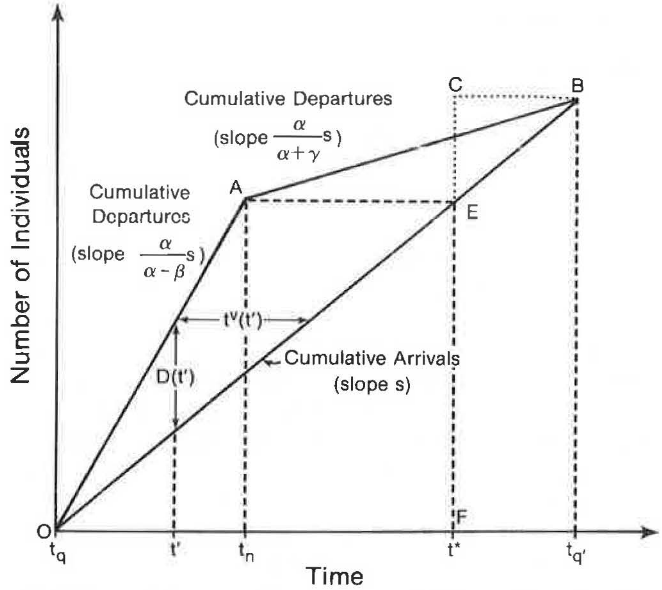
The equilibrium is depicted in Figure 1. Queue length is measured by the vertical distance between the cumulative departures and cumulative arrivals schedules. Travel time is measured by the horizontal distance. From the beginning of the rush hour at t_q until t_n, the queue builds up at a constant rate. Once past t_n the queue dissipates, again at a constant rate, reaching zero at the end of the rush hour at $t_{q'}$.

Over the interval $[t_q, t_n]$, the equal cost condition implies from equation 4 that

$$C(t) = \alpha T^v(t) + \beta[t^* - t - T^v(t)] \tag{6}$$

is constant. Differentiating equation 6 and using equations 2 and 3, the departure rate for individuals departing early is found to be

$$r(t) = r_E^e = s + \frac{\beta s}{\alpha - \beta} = \frac{\alpha s}{\alpha - \beta} \qquad t \in [t_q, t_n] \tag{7}$$



Total Travel Time = Area OABO
Total Time Early = Area OEFO
Total Time Late = Area BECB

FIGURE 1 Cumulative arrivals and departures, queue length, total travel time, total time early, and total time late in user equilibrium.

where the superscript e denotes user equilibrium and the subscript E early arrivals. By similar reasoning, the late departure rate is

$$r(t) = r_L^e = s - \frac{\gamma s}{\alpha + \gamma} = \frac{\alpha s}{\alpha + \gamma} \qquad t \in [t_n, t_{q'}] \tag{8}$$

where the subscript L denotes late arrivals. Equating the costs of the first and the late individuals to depart,

$$\beta(t^* - t_q) = \gamma(t_{q'} - t^*) \tag{9}$$

Since the bottleneck operates at capacity throughout the rush hour,

$$t_{q'} = t_q + N/s \tag{10}$$

Combining equations 9 and 10, one obtains the following:

$$t_q = t^* - \frac{\eta}{1+\eta}\frac{N}{s} \qquad t_q' = t^* + \frac{1}{1+\eta}\frac{N}{s} \qquad \text{(11a, 11b)}$$

Finally, using equations 5 and 7 and defining $\delta \equiv \beta\gamma/(\beta + \gamma)$ one obtains

$$t_n = t^* - \frac{\delta}{\alpha}\frac{N}{s} \tag{12}$$

Aggregate travel time and schedule delay are identified in Figure 1. Aggregate travel time costs (TTC), schedule delay costs (SDC), and travel costs (TC) are

$$TTC^e = SDC^e = \frac{\delta}{2}\frac{N^2}{s} \tag{13}$$

$$TC^e = TTC^e + SDC^e = \delta\frac{N^2}{s} \tag{14}$$

It is noteworthy that neither the timing of departures nor aggregate costs depend on the unit cost of travel time, α.

The Social Optimum

The social optimum is determined by minimizing the sum of travel time and schedule delay costs. To eliminate queueing while minimizing schedule delay costs, the departure rate is maintained at s throughout the rush hour. The time of first departure is chosen so that the first and last commuters incur equal costs, since otherwise costs could be reduced by moving an individual from the beginning of the rush hour to the end, or vice versa. Since this condition is also true of user equilibrium, the timing of the rush hour and the arrival distribution are the same as in equilibrium.

Denoting variables corresponding to the social optimum with a superscript o, aggregate costs are given by

$$TTC^o = 0 \tag{15}$$

$$SDC^o = TC^o = \frac{\delta}{2}\frac{N^2}{s} \tag{16}$$

Total costs are half their value in user equilibrium.

INDIVIDUALS WITH DIFFERENT α AND β, BUT THE SAME γ/β

Characterization of User Equilibrium and Social Optimum

In this section, we allow the unit costs of travel time and schedule delay to differ across commuters. We assume that commuters have the same relative cost of late arrival and desired arrival time, $\eta = \gamma/\beta$.

Let there be G groups of commuters indexed in order of decreasing relative cost of travel time, α/β, so that

$$\alpha_1/\beta_1 \geq \alpha_2/\beta_2 \geq \ldots \geq \alpha_G/\beta_G \tag{17}$$

Let N_i be the number of individuals in group i and N the number in all groups.

User Equilibrium

The equilibrium departure rate is described by the following theorem.

Theorem 1. In user equilibrium, a fraction $\eta/(1 + \eta)$ of each group departs early, with the remainder departing late. Group 1 is the first to depart early, then group 2 and so on to group G. Members of group G who do not depart early are the first to depart late, followed by the remainder of group $G - 1$ and so on until everyone has departed.

Theorem 1 is proved in Arnott et al. (*11*). (Proofs and derivations of the major results in this paper are contained in the earlier paper, which is available upon request.) Since the fraction of commuters in the homogeneous case who depart early is also $\eta/(1 + \eta)$, the rush hour begins and ends at the same time as with identical commuters. Individuals with the highest cost of travel time relative to schedule delay travel furthest out on the tails of the rush hour, as in Henderson's (*5*) model.

An example of equilibrium with four groups is shown in Figure 2. Group 1, with the lowest relative cost of travel time, travels at the beginning and end of the rush hour. Group 2 travels on adjacent time intervals, and so on. Group j follows group i in the departure sequence at time t_{ij}. Individuals arrive on time (at t^*) along the locus Ot^* with slope $-s$. To the left of Ot^*, individuals arrive early; to the right, they arrive late. The equilibrium travel costs incurred by each group are shown by the equal-cost contours labeled $C_1 \ldots C_4$. To the left of Ot^*, the slope of C_i is $\beta_i s/(\alpha_i - \beta_i)$; to the right, it is $-\gamma_i s/(\alpha_i + \gamma_i)$. The upper envelope of the equilibrium cost curves describes what can be called the travel equilibrium frontier (TEF). Commuters in each group select departure times that minimize their costs on the TEF. Group 2, for example, departs between t_{12} and t_{23} and again between t_{32} and t_{21}.

The Social Optimum

As is the case with identical individuals, the social optimum involves no queueing. To minimize schedule delay costs, the group with the largest value of α travels closest to t^*, with a fraction $\eta/(1 + \eta)$ departing early and the rest late. The group with the second highest value of α departs on adjacent time intervals with the same proportions early and late, and so on for the remaining groups.

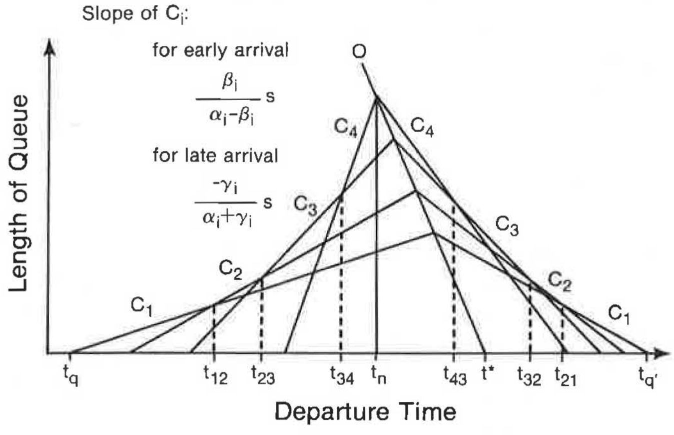


FIGURE 2 Equilibrium with four groups of commuters with different α and β and the same γ/β.

The rush hour thus begins and ends at the same time as with identical individuals, and the same time as in user equilibrium. However, the order in which groups depart differs from equilibrium unless the ranking of groups according to α is the reverse of the ranking according to α/β, that is, $\beta_1 < \beta_2 < \ldots < \beta_G$. This is true if $\alpha_1 = \alpha_2 = \ldots \alpha_G$, but is not true in general. Thus, schedule delay costs are not necessarily minimized in equilibrium.

The social optimum can be brought about with a time-varying toll. A toll with four groups is drawn in Figure 3, where it is assumed that $\beta_2 < \beta_1 < \beta_3 < \beta_4$, so that groups 1 and 2 are reversed in the departure sequence relative to equilibrium. The equal-cost contour of group i rises with slope β_i for departures before t^* and falls with slope $-\gamma_i$ for departures after t^*. In equilibrium, group i departs early while the toll is increasing at rate β_i and late while the toll is decreasing at rate γ_i. The toll changes at a rate that just offsets any incentive to queue. Since commuters in a given group prefer their existing departure times to departure at any other times, the toll induces commuters to self-select into the socially efficient departure time intervals.

Cost-Benefit Analysis and Aggregation Bias

Since further calculation in the general case is tedious we shall focus, with little sacrifice of insight, on two groups. Suppose there are N_1 members of group 1 and N_2 of group 2, with $N = N_1 + N_2$ and $\alpha_2/\beta_2 < \alpha_1/\beta_1$. Let $f_2 \equiv N_2/N$ denote the fraction of commuters who are in group 2, and define $\alpha_r \equiv \alpha_2/\alpha_1$, $\beta_r \equiv \beta_2/\beta_1$, and $\delta_i \equiv \beta_i\gamma_i/(\beta_i + \gamma_i)$. To fix ideas it may be helpful to think of white-collar workers comprising group 1 and blue-collar workers group 2.

Total costs in equilibrium are as follows:

$$SDC^e = \frac{\delta_1}{2} \frac{N^2}{s} [1 + (\beta_r - 1)f_2^2] \tag{18}$$

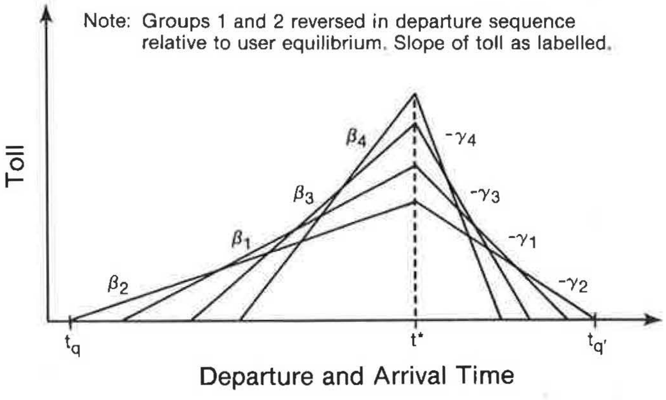


FIGURE 3 Optimal time-varying toll for groups of commuters with different α and β and the same γ/β.

$$TTC^e = \frac{\delta_1}{2} \frac{N^2}{s} [1 - 2(1 - \alpha_r)f_2 + (1 + \beta_r - 2\alpha_r)f_2^2] \tag{19}$$

$$TC^e = \delta_1 \frac{N^2}{s} [1 + (\alpha_r - 1)f_2 + (\beta_r - \alpha_r)f_2^2] \tag{20}$$

Note that total travel time costs depend on the relative unit costs of travel time for the two groups, β_r, whereas with homogeneous commuters TTC^e is independent of unit travel time costs, β.

In the social optimum there is no queueing. If $\beta_r > 1$, group 2 travels in the middle of the rush hour, just as in equilibrium, and with the same arrival time distribution. If $\beta_r < 1$, the optimal order of departure is reversed, and group 2 travels on the tails. Total costs in the social optimum are

$$SDC^o = TC^o = \begin{cases} \frac{\delta_1}{2} \frac{N^2}{s} [1 + (\beta_r - 1)f_2^2] \quad \text{if } \beta_r \geq 1 & (21a) \\ \frac{\delta_1}{2} \frac{N^2}{s} [1 - 2(1 - \beta_r)f_2 + (1 - \beta_r)f_2^2] \quad \text{if } \beta_r \leq 1 & (21b) \end{cases}$$

Expression 21a for $\beta_r \geq 1$ is identical to equation 18, while expression 21b for $\beta_r \leq 1$ obtains by interchanging subscripts in 21a.

To measure the bias introduced by treating commuters as identical, we use for the aggregate specification population-weighted average values of α and β:

$$\hat{\alpha} = (N_1\alpha_1 + N_2\alpha_2)/N = \alpha_1[1 + (\alpha_r - 1)f_2] \tag{22}$$

$$\hat{\beta} = (N_1\beta_1 + N_2\beta_2)/N = \beta_1[1 + (\beta_r - 1)f_2] \tag{23}$$

(Although this is not the only way that aggregate parameters might be determined, it is probably the most natural.) Using equations 13 and 14, the aggregate model yields the following values:

$$S\hat{D}C^e = T\hat{T}C^e = S\hat{D}C^o = T\hat{C}^o = \frac{\delta_1}{2} \frac{N^2}{s} [1 - (1 - \beta_r)f_2] \tag{24}$$

$$T\hat{C}^e = \delta_1 \frac{N^2}{s} [1 - (1 - \beta_r)f_2] \tag{25}$$

$$TT\hat{C}^o = 0 \tag{26}$$

Tolls

To determine the direction of aggregation bias in estimating the benefits from tolls, there are two cases to consider: $\beta_r \geq 1$ and $\beta_r < 1$. When $\beta_r \geq 1$, the optimal and equilibrium departure sequences coincide, so that toll benefits are simply travel time costs in equilibrium. Aggregation bias is computed by subtracting equation 19 from equation 24:

$$T\hat{T}C^e - TTC^e \overset{s}{=} (1 + \beta_r)/2 - \alpha_r \tag{27}$$

where $\overset{s}{=}$ means identical in sign. Combining equation 27 with the restriction $\alpha_r < \beta_r$ one obtains Figure 4. Aggregation leads to underestimation of toll benefits when $\alpha_r > (1 + \beta_r)/2$, and overestimation otherwise. To see why, note that since group 2 travels at the peak of the rush hour it bears a disproportionate fraction of travel time costs. If $\alpha_2 > \alpha_1$, the unit costs of travel time are underestimated in the aggregate model. This bias may be sufficient to outweigh the fact that total travel time is nevertheless overestimated with the aggregate model.

In the second case with $\alpha_r < 1$, it is clear from Figure 4 that travel-time cost savings from tolls are always overestimated with the aggregate model. However, tolls yield additional benefits by reducing schedule delay costs, so that a priori the direction of bias is unclear.

Road Investment

Much of the literature in urban transportation is concerned with the optimal capacity of the road network. Benefits are usually calculated on the assumption that road users are identical. The question arises whether aggregation creates a bias toward over- or underinvestment in capacity. Now since total costs in both the equilibrium and social optimum are inversely proportional to capacity, the marginal benefit from capacity expansion is proportional to total costs. Aggregation thus leads to overinvestment if calculated total costs exceed actual costs, and vice versa.

Subtracting equation 20 from equation 25, one finds for the user equilibrium that

$$T\hat{C}^e - TC^e \overset{s}{=} \beta_r - \alpha_r \geq 0 \tag{28}$$

Since $\beta_r \geq \alpha_r$ by assumption, total costs are overestimated with the aggregate model. Similarly, by subtracting equation 21 from equation 24 one can show that in the social optimum, total costs are overestimated unless $\beta_r = 1$. Thus, aggregation introduces a bias towards excessive road investment.

Numerical Examples

Some idea of the magnitude of aggregation bias can be obtained from the numerical examples in Table 1. Five sets of values for (β_r, α_r) are listed, corresponding to the five points labeled in Figure 4. Only the relative magnitudes of the table entries are meaningful. For simplicity, it is assumed that $N_1 = N_2$.

From the percentage figure in column 8 of Table 1, one can see that toll benefits are neither consistently overestimated nor underestimated under aggregation. In example 1, $\beta_r < 1$, and it is optimal for group 1 to travel in the middle of the rush hour, rather than group 2 as occurs in user equilibrium. The reduction in schedule delay costs from imposing an optimal toll (columns 4–7) exceeds the overestimate of travel time costs (the percentage figure in column 5). Aggregation thus leads to underestimation of toll benefits. In example 2, $\beta_r < 1$, and there is no reordering of departure times, hence no reduction in schedule delay costs. But this time, travel time costs are underestimated, so that aggregation again leads to underestimation of toll benefits. In the remaining three examples, schedule delay costs are unaffected by tolls, whereas aggregation leads to overestimation of travel time costs. Toll benefits are thus also overestimated.

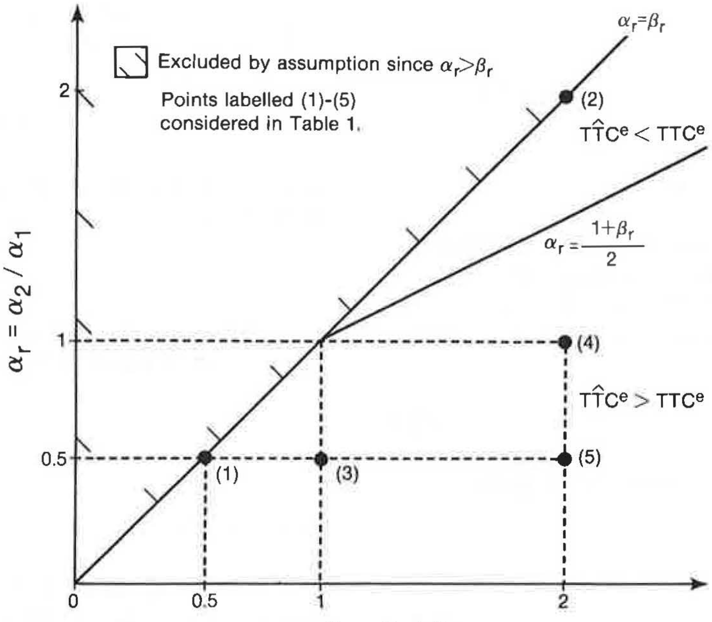


FIGURE 4 Aggregation bias in calculation of travel time costs with two groups of commuters with different α and β and the same γ/β.

TABLE 1 EXACT AND AGGREGATE CALCULATIONS OF SCHEDULE DELAY, TRAVEL TIME, AND TOTAL COSTS IN USER EQUILIBRIUM AND SOCIAL OPTIMUM WITH TWO COMMUTER GROUPS OF EQUAL SIZE DIFFERING IN α AND β, BUT WITH THE SAME γ/β

Example	β_r	α_r	Calculation	SDC^e	TTC^e	TC^e	$TC^o = SDC^o$	$TC^e - TC^o$
	1	2	3	4	5	6	7	8
1	0.5	0.5	Exact	0.4375	0.3125	0.7500	0.3125	0.4375
			Aggreg/Exact	85.7%	120%	100%	120%	85.7%
2	2.0	2.0	Exact	0.6250	0.8750	1.5000	0.6250	0.8750
			Aggreg/Exact	120%	85.7%	100%	120%	85.7%
3	1.0	0.5	Exact	0.5000	0.3750	0.8750	0.5000	0.3750
			Aggreg/Exact	100%	133%	114%	100%	133%
4	2.0	1.0	Exact	0.6250	0.6250	1.2500	0.6250	0.6250
			Aggreg/Exact	120%	120%	120%	120%	120%
5	2.0	0.5	Exact	0.6250	0.5000	1.1250	0.6250	0.5000
			Aggreg/Exact	120%	150%	133%	120%	150%

The aggregation bias in road investment can be determined from the values of total costs in equilibrium and the social optimum, shown respectively in columns 6 and 7. Consistent with the general results discussed above, total costs in the user equilibrium and the social optimum are never underestimated and are usually overestimated. In example 5, equilibrium costs are overestimated by 33 percent. With constant marginal construction costs, this would lead to overconstruction of road capacity by a factor $(1.33)^{1/2}$, or about 15 percent.

INDIVIDUALS DIFFERING WITH RESPECT TO γ/β

User Equilibrium and Social Optimum

In this section we allow the relative cost of late arrival $\eta \equiv \gamma/\beta$ to differ across commuters. For simplicity, α, β and t^* are assumed to be the same for everyone. Let there be G groups of commuters, indexed in order of decreasing η so that

$$\eta_1 > \eta_2 > \ldots \eta_G \tag{29}$$

As before, N_i is the number of commuters in group i, and N the number in all groups.

User Equilibrium

User equilibrium is described by the following theorem.

Theorem 2. In user equilibrium, groups of commuters with the highest η depart late, in strict sequence of decreasing η, with group G the last to depart. Groups with lower η depart early. The order of departure of these groups is indeterminate. At most, one group departs both early and late.

Proof

Let C_G and C_{G-1} be cost curves for groups G and $G - 1$ respectively, as shown in Figure 5. Since $\eta G > \eta G - 1$, C_G has the same slope as C_{G-1} for early departure but is flatter for late departure. In equilibrium, the right-hand branch of C_G must intersect the abscissa to the right of C_{G-1}; otherwise members of group $G - 1$ could reduce their travel costs by switching to departure times chosen by group G. Since C_G cannot lie everywhere above C_{G-1}, the cost curves must intersect. Since cost curves for groups $G - 2$, $G - 3$, etc., are progressively steeper than C_{G-1} for late departure, group G must depart last, group $G - 1$ second last, and so on while individuals are departing late.

For individuals traveling early, the order of departure is indeterminate since all groups have the same cost curves. QED.

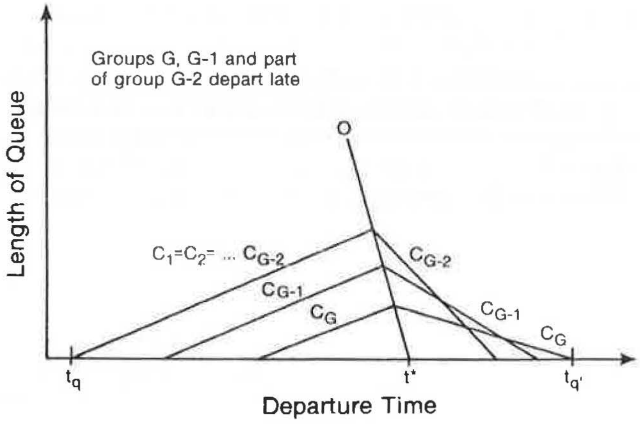


FIGURE 5 Equilibrium with groups of commuters with different γ/β.

According to theorem 2, individuals with the lowest relative cost of late arrival depart last, which is common sense.

The Social Optimum

The social optimum is intuitive. To prevent queueing, the departure rate is held at s throughout the rush hour. To minimize schedule delay costs, groups depart in strict sequence of decreasing η during late departure, just as in equilibrium.

The timing of the rush hour also turns out to be the same as in equilibrium, as was the case with commuters varying in α and β. Similarly, a time-varying toll can be constructed to decentralize the social optimum. Since schedule delay costs are minimized in the user equilibrium, toll benefits equal travel time saved.

Cost-Benefit Analysis and Aggregation Bias

At this point we again simplify by restricting attention to two groups. (The two-group case incorporates the solution for any number of groups when no more than two groups depart late.) Group 1 will largely comprise blue-collar workers, with relatively high penalties for late arrival at work. Group 2 will consist predominantly of white-collar workers. There are two cases to consider:

1. Group 2 is sufficiently small that all members depart late, as well as part of group 1,
2. Group 2 is sufficiently large that none of group 1 departs late.

Case 1

Case 1 applies when

$$f_2 < 1/(1 + \eta_2) \tag{30}$$

Aggregate costs are

$$SDC^e = TTC^e = SDC^o = TC^o = \frac{\delta_1}{2}\frac{N^2}{s}[1 - \mu_1] \tag{31}$$

$$TC^e = \delta_1 \frac{N^2}{s}[1 - \mu_1] \tag{32}$$

where

$$\delta_i \equiv \beta\gamma_i/(\beta + \gamma_i) \tag{33}$$

$$\mu_1 \equiv (1 - \eta_2/\eta_1)f_2\,[2 - (1 + \eta_2)f_2] > 0 \tag{34}$$

As is true of identical commuters, travel time costs and schedule delay costs are equal in equilibrium. Since $d\mu_1/df_2 > 0$ for values of f_2 satisfying equation 30, travel costs decrease monotonically with the proportion of commuters in group 2. Thus, in case 1, increasing the proportion of commuters with flexible work hours (i.e., converting group 1 workers to group 2) reduces total commuting costs.

Case 2

The solution for case 2 is the same as for identical commuters with $\eta = \eta_2$. Thus

$$SDC^e = TTC^e = SDC^o = TC^o = \frac{\delta_2}{2}\frac{N^2}{s} = \frac{\delta_1}{2}\frac{N^2}{s}[1 - \mu_2] \tag{35}$$

$$TC^e = \delta_2 \frac{N^2}{s} = \delta_1 \frac{N^2}{s}[1 - \mu_2] \tag{36}$$

where

$$\mu_2 \equiv \frac{1 - \eta_2/\eta_1}{1 + \eta_2} \tag{37}$$

To measure aggregation bias we again use a population-weighted average value:

$$\hat{\eta} = (N_1\eta_1 + N_2\eta_2)/N = \eta_1[1 + (\eta_2/\eta_1 - 1)f_2] \tag{38}$$

The aggregate specification yields

$$S\hat{D}C^e = T\hat{T}C^e = S\hat{D}C^o = T\hat{C}^o = \frac{\delta_1}{2}\frac{N^2}{s}[1 - \hat{\mu}] \tag{39}$$

$$T\hat{C}^e = \delta_1 \frac{N^2}{s}[1 - \hat{\mu}] \tag{40}$$

where

$$\hat{\mu} \equiv \frac{\delta_1}{2} N \left[1 - \frac{(1 - \eta_2/\eta_1)f_2}{1 + \eta_1 - f_2(\eta_1 - \eta_2)}\right] \tag{41}$$

Tolls

Because schedule delay costs at the social optimum are the same as in equilibrium, toll benefits equal travel time saved. Given equations 31, 35, and 39, the ratio of estimated to actual toll benefits in case 1 is

$$\frac{T\hat{T}C^e}{TTC^e} = \frac{1 - \hat{\mu}}{1 - \mu_i} \tag{42}$$

It is straightforward to show that $\hat{\mu} < \mu_1$ and $\hat{\mu} < \mu_2$, so that toll benefits are overestimated under aggregation.

Road Investment

The marginal benefit from capacity expansion is proportional to total costs. Given equations 32, 36, and 40, the ratio of estimated to actual total costs is

$$\frac{T\hat{C}^e}{TC^e} = \frac{1 - \hat{\mu}}{1 - \mu_i} > 1 \tag{43}$$

Hence, aggregation introduces a bias toward excessive road investment. This accords with the results shown earlier ("Individuals with Different α and β, but the Same γ/β").

INDIVIDUALS WITH DIFFERENT t^*

User Equilibrium and Social Optimum

Suppose now that commuters differ only with respect to t^*. One interpretation is that individuals differ in their starting time at work. An alternative interpretation is that individuals have the same work hours, but work at different distances from the bottleneck. Those with further to travel wish to pass through the bottleneck earlier.

Hendrickson and Kocur (*8*) address this problem under the assumption that the cumulative desired arrival time distribution, $W(t)$, crosses the cumulative arrivals schedule once, as shown in Figure 6. The equilibrium departure time distribution is the same as if all individuals desired to arrive at the crossing time $t^* = W^{-1}[\eta N/(1 + \eta)]$. Travel time costs are the same as with identical desired arrival times, while schedule delay costs are smaller. The arrival time distribution is socially optimal.

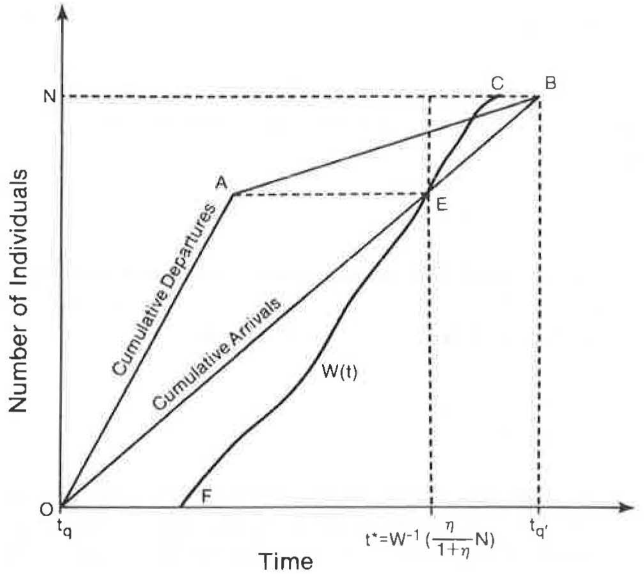
In this section, we extend Hendrickson and Kocur's analysis to discrete groups of commuters, allow for multiple crossings of the desired and actual arrival time distributions, and perform cost-benefit analysis. Groups can be thought of as teams of workers in industry or government departments with the same work hours.

Let N_i be the number of commuters with desired arrival time t_i^*, $i = 1 \ldots G$, with

$$t_1^* < t_2^* < \ldots t_G^* \qquad (44)$$

Let $W(t)$ be the cumulative desired arrival time distribution:

$$W(t) = \sum_i N_i H(t - t_i^*) \qquad (45)$$



Total Travel Time = Area OABO
Total Time Early = Area OEFO
Total Time Late = Area BECB

FIGURE 6 Equilibrium with a distribution of desired arrival times that crosses the cumulative arrivals schedule once.

where $H(x)$ is the Heaviside function: $H(x) = 1$ if $x \geq 0$, 0 otherwise. It is assumed that desired arrival times are sufficiently close that the bottleneck operates at capacity throughout the rush hour, implying

$$t_{q'} - t_q = N/s \qquad (46)$$

User Equilibrium

The user equilibrium is described by the following theorem.

Theorem 3. Suppose that commuters differ only in desired arrival time. Let the cumulative desired arrival time distribution be $W(t)$. Then the equilibrium departure rate is given by

$$r(t) = \begin{cases} r_E^e \\ r_L^e \end{cases} \text{as } s(t - t_q) + D(t) \gtrless W\left[t + \frac{D(t)}{s}\right] \qquad t \in [t_q, t_{q'}] \qquad (47)$$

where $D(t_q) = 0$, $D(t_{q'}) = 0$, and where r_E^e and r_L^e are defined in equations 7 and 8.

The intuition behind the theorem is that if at time t cumulative departures exceed cumulative desired arrivals, then the individual departing at t arrives early. If the individual and those departing just before and after him, who also arrive early, are content with their departure times then the departure rate must be r_E^e, just as with identical commuters. Similarly, when cumulative departures are less than cumulative desired arrivals, the departure rate must be r_L^e.

An example of equilibrium with three groups, in which the cumulative desired arrivals schedule $W(t)$ crosses the cumulative actual arrivals schedule three times, is shown in Figure 7. $t_{n,i}$ denotes the departure time for which an

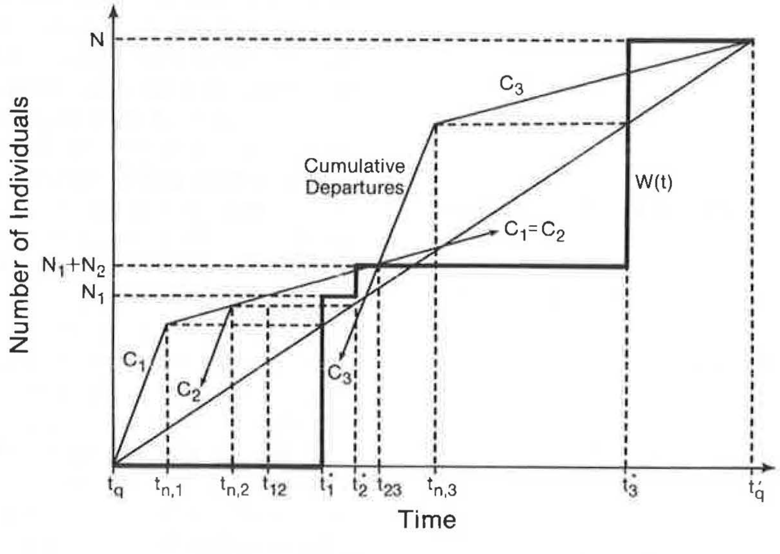


FIGURE 7 Equilibrium with three groups of commuters with different desired arrival times.

individual arrives at t_i^*. From t_q until $t_{n,1}$ cumulative arrivals exceed cumulative desired arrivals and the departure rate is r_E^e. Between $t_{n,1}$ and t_{23}, cumulative arrivals fall short of desired arrivals and the departure rate is r_e^L, and so on. All of group 2 arrives late, while some members of groups 1 and 3 are early and some late. The queue peaks at $t_{n,1}$ and $t_{n,3}$, and reaches a local minimum at t_{23}.

We have assumed that groups depart in strict sequence. If the equilibrium cost curves of two or more groups coincide, however, the order of departure is indeterminate. In Figure 7, for example, the equilibrium cost curves of groups 1 and 2, C_1 and C_2, coincide during the time interval $[t_{n,2}, t_{23}]$. Members of the two groups may depart at any time during this interval.

The Social Optimum

Since groups differ only in t^* it is clear that departure in strict sequence by group is optimal, although not necessarily the unique optimum. Both the timing of the rush hour and the indeterminacy in the order of departure are the same as in the user equilibrium. To see this, note that if two individuals in different groups are both arriving early or both late, they can be interchanged in the departure sequence without affecting total schedule delay costs. This is the same condition under which indeterminacy arises in equilibrium.

Two Groups

We now turn to a more thorough investigation of equilibrium with two groups. There are three cases to consider. In case 1, group 2 is sufficiently small that all members travel late and the timing of the rush hour is the same as if everyone belonged to group 1. Total travel time costs are the same as with identical commuters, but schedule delay costs are smaller.

In case 2, group 1 is sufficiently small that all members travel early and the timing of the rush hour is the same as if everyone belonged to group 2. Again, travel time costs are the same as with identical commuters while schedule delay costs are smaller.

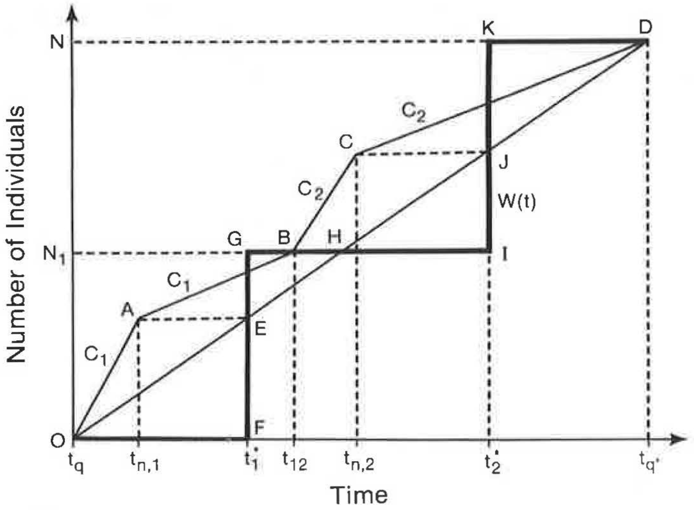
In case 3, shown in Figure 8, the queue has a double peak, with group 1 traveling around the first peak and group 2 around the second. (As earlier it is assumed that t_1^* and t_2^* are sufficiently close that the rush hours for the two groups are connected.) The equilibrium cost curves of the two groups, C_1 and C_2, intersect only at t_{12}, so that all of group 1 departs before group 2. Both travel time costs and schedule delay costs are smaller than with homogeneous commuters.

Cost-Benefit Analysis and Aggregation Bias

From the preceding discussion it is clear that if t^* is assumed to be the same for everyone, then schedule delay costs are overestimated, whether the actual queue is single- or double-peaked. Travel time costs are calculated correctly if the queue is single-peaked, but overestimated if it is double-peaked.

Tolls

Since the timing of the rush hour and order of departure in user equilibrium are socially optimal, toll benefits equal travel time costs in equilibrium. Aggregation introduces



Total Travel Time = Area OABCDO
Total Time Early = Area OEFO + HJIH
Total Time Late = Area EGHE + JKDJ

FIGURE 8 Equilibrium for two groups of commuters with different desired arrival times and a double-peaked queue.

no bias in calculated toll benefits when the queue is single-peaked because travel time costs are the same as with identical commuters. But toll benefits are overestimated when there is a double peak.

Road Investment

The marginal benefit from capacity expansion is found to be

$$|dTC^e/ds| = \delta(N/s)^2 \quad \text{with a single-peaked queue} \quad (48)$$

$$\left|\frac{dTC^e}{ds}\right| = \delta\left(\frac{N}{s}\right)^2 \left\{1 + \frac{[1 - (1 + \eta)f_2]^2}{2\eta}\right\} \quad \text{with a double-peaked queue} \quad (49)$$

Equation 48 for the single peak is the same as with identical commuters because the difference in schedule delay costs with identical and nonidentical commuters is independent of capacity.

When the rush hour is double-peaked, however, the marginal benefits of capacity expansion are greater than with identical commuters unless $f_2 = 1/(1 + \eta)$. The reason is that as capacity is expanded, the queue left by group 1 when group 2 begins to depart becomes smaller, leading to a more than proportionate decrease in overall travel time costs. This outweighs the fact that total travel costs are smaller with identical work start times, except if $f_2 - 1/(1 + \eta)$ when the two factors balance.

CONCLUDING REMARKS

We have analyzed the departure time decisions of morning commuters who differ in one of three respects: (1) travel time and schedule delay costs, (2) relative costs of early and late arrival, (3) desired arrival time. The principal results of the analysis are summarized in Table 2. In equilibrium, groups of commuters order themselves systematically in the departure sequence. Early in the rush hour the departure rate exceeds capacity, causing a queue to develop and increasing travel time costs. The timing of the rush hour is optimal in each of the above groups (1, 2, and 3) (although this is not true in general). Schedule delay costs need not be minimized in case 2, however, because

TABLE 2 SUMMARY OF RESULTS

	Characteristics of User Equilibrium				Aggregation Bias[1] (Two Groups)	
Variable Parameters	Order of Departure	Shape of Queue	Timing of Rush Hour	Schedule Delay Costs	Toll Benefits	Capacity Expansion Benefits
None (Homogeneous commuters)	N/A	Single-peaked	Optimal	Minimized	N/A	N/A
α and β (γ/β fixed)	High α/β groups travel on shoulders	Single-peaked with convex shoulders	Optimal	Generally not minimized	+ or −	+
γ/β (α and β fixed)	Smallest γ/β groups travel last	Single-peaked with convex right-hand shoulder	Optimal	Minimized	+	+
t*	In order of increasing t*, possibly indeterminate over limited periods	Single or multiple peaked	Optimal	Minimized	0 or +	0 or −

Aggregation bias refers to the error when a population of nonidentical commuters is treated as being homogeneous.

+ means the value calculated under aggregation is too large,
− means it is too small, and 0 means no bias

N/A: Not Applicable

the order in which commuters depart in user equilibrium is not necessarily optimal.

Cost-benefit studies of congestion tolls and of investments in road capacity often ignore heterogeneity of the commuting population. To measure the aggregation bias in computing benefits we used population-weighted average parameter values. We showed that aggregation usually leads to overestimation of benefits, although underestimation is possible. The direction and magnitude of bias depend on which parameters vary across commuters, and by how much.

There are several directions in which the analysis could be fruitfully extended.

Empirical Determination of Parameter Distributions

The results of this paper, as well as those of Newell (*6*), indicate that the qualitative characteristics of the departure time distribution are sensitive to the travel time and schedule delay costs of different commuter groups and to the proportion of commuters in each group. Further empirical work in the spirit of Small (*2*, *12*) will be necessary before accurate cost-benefit calculations are possible, although the difficulty of obtaining adequate data may prove an obstacle.

Algorithms

For practical cost-benefit applications it will be necessary to divide the population into several groups and to allow all parameters to vary at once. Networks of roads and performance models more realistic than the idealized bottleneck should also be considered. To solve for user equilibrium in this more complex setup and to investigate the effects of smoothly varying or coarse (step-function) congestion tolls, an algorithmic approach will be necessary because analytical methods are intractable.

Welfare Considerations

Congestion tolls, road investments, and other transport or workplace policies affect the distribution of welfare. Because the cost of travel time varies with income and because socioeconomic groups differ in the flexibility of their work hours, the benefits of congestion relief tend to fall unequally. For example, both theoretical (*13*, *14*) and empirical (*12*, *15*) studies have concluded that the incidence of congestion tolls is probably regressive and that distributional effects can be significant compared to efficiency gains. In an earlier draft of this paper (*11*), we showed, using the bottleneck model with two commuter groups, that congestion tolls and road investments both tend to favor commuters with high values of travel time relative to schedule delay. Since such commuters are likely to be white-collar workers with above-average incomes, this finding is consistent with earlier findings that policies to reduce congestion tend to have regressive welfare effects. Clearly, the analysis needs to be done at a greater level of disaggregation and under more realistic assumptions.

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"After" Benefit-Cost Analysis of the Elko, Nevada, Railroad Relocation

GUILLAUME SHEARIN

This paper presents the "after" part of a before-after benefit-cost case study of the FHWA railroad relocation and grade separation demonstration project in Elko, Nevada. The object of the demonstration project was to reduce the effects on a small western city of two transcontinental railroads passing through the downtown. Construction began about 1979 and finished in 1983. The after benefit-cost study was completed in 1987 as part of an overall before-after report submitted to FHWA, the Nevada Department of Transportation, and the city of Elko. The main result of the benefit-cost study was the quantification and pricing of the primarily social and environmental benefits of the railroad relocation, including flood control as well as reduction of noise, vibration, accidents, and considerable delay and disruption in the downtown. Depending on the discount rate, benefit-cost ratios of 0.61 to 1.12 were calculated. Approximately 80 percent of the benefits went to the community and 20 percent to the railroads.

This paper presents the "after" part of a before-after benefit-cost case study of the FHWA railroad relocation and grade separation demonstration project in Elko, Nevada. The after benefit-cost study was completed in 1987 as part of an overall before-after report submitted to FHWA, the Nevada Department of Transportation, and the city of Elko.

The object of the demonstration project was to reduce the effects on Elko, a small western city (population 11,500 in 1985), of two transcontinental railroads passing through the downtown. Both the Southern Pacific Transportation Company (SP) and Western Pacific Railroad (WP), acquired in 1983 by the Union Pacific Railroad (UP), passed through the middle of the downtown and literally cut the town in two, sometimes for hours at a time. Besides the noise and vibration associated with the railroad tracks, the 18 mainline grade crossings in the downtown had become a significant source of accidents. The railroads that once had been the lifeblood of the town had become a blight and a hazard.

Consideration of the project was begun in the early 1970s with construction beginning about 1979 and finishing in 1983. The main action of the project was to remove the railroad tracks from the downtown and relocate them in an adjacent grade-separated corridor along a realigned section of the Humboldt River. The WP yard was also moved from immediately adjacent to the west side of the downtown to a more remote and spacious location at the eastern end of town. De Leuw, Cather and Company and Chilton Engineering (later Kennedy/Jenks/Chilton) performed the planning, environmental analysis, and design of the project.

A major purpose of the benefit-cost study was to demonstrate methods of pricing out intangible benefits, such as the reduction of noise and community disruption. This paper presents one way to price some of these benefits. The period of analysis is 30 years, from the base year of 1978 to 2008, to reflect a more typical analysis period for the flood control part of the demonstration project as well as to capture a significant fraction of the design life of the major bridges.

The selected annual discount rate is 4 percent in contrast to 7 percent or 10 percent used in some analyses. The results of discounting at the other percentages are presented, however. This choice reflects the belief that a 4-percent discount rate in a low risk, constant-dollar environment is equivalent to a private sector opportunity cost of 11 percent or greater. Selection of the discount rate is discussed in greater detail later in this paper (see Calculation of Benefit-Cost Ratio). Corresponding to the 4-percent discount rate, all benefits and costs used in the analysis are expressed in constant 1978 dollars.

The first three sections of the benefit-cost analysis correspond to the primary recipients of the benefit: the railroads, the highway users, and the community. Within each section, the basic assumptions of the analysis are presented together with the results of each step. The analysis concludes with a summary of net capital costs and the calculation of a benefit-cost ratio.

RAILROAD BENEFITS

Distance and Curvature

Because railroad operating costs vary by the distance traveled, the curvature of the track, and the tonnages carried, increased operating costs from increased post-project

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travel distance and curvature were calculated reflecting the following conditions:

- An initial analysis year of 1984, corresponding to the first full year of railroad operation in the new corridor.
- Increased distance of 0.35 miles and increased curvature of 79° eastbound and 88° westbound.
- Conservative tonnage projections with railroad tonnage assumed constant through the year 2000, then increasing from approximately 59 million gross tons/yr to 66 million gross tons/yr by 2008.

Based on these parameters, total increases in operating costs in 1984 are estimated to be $34,300/yr in 1978 dollars. From tonnage increases anticipated between 2000 and 2008, the increased costs are expected to rise to $38,700 by 2008. At a 4-percent discount rate, the 1978 present value of this increase in operating cost is $447,200.

Savings in Running Time

The running times between terminals were calculated to reflect speed limits raised from 20 to 35 mph eastbound and 35 to 65 mph westbound and changed mainline railroad operations resulting from relocation of the UP/WP yard. UP still stops when eastbound to refuel, resulting in less time saving than SP. Running time savings ranged from about 6 to 12 min per train, depending on the direction and carrier.

To calculate the value of these time savings, the cost of operating the trains is taken at $33.75/train hr, not including the costs of the crew. Because train crews are paid on a mileage basis, there is no direct cost saving to the railroad for less crew time. However, the time savings do constitute a social benefit to the train crews, valued here at one-half the average transportation wage rate for the Elko area based on unpublished county payroll data and a similar procedure used for the benefit-cost analysis of the Pensacola-Milton railroad bypass (*1*, pp. 4–10, 4–32).

Based on 2,555 trains per year in each direction for each railroad, the estimated savings would approximate $62,200/yr (in 1978 dollars) for 1984 through 2008. Although the freight traffic is assumed to increase about 1.4 percent per year between 2000 and 2008, the savings are not assumed to increase because trains may simply become longer with no increase in crew, here assumed to average 4.25 persons per train. This benefit stream corresponds to a 1978 present value of $798,800 at a 4-percent discount rate.

Freight Car Per Diem Payments

To place a value on the marginal effect of faster rail operations on more efficient service for shippers and railroad system benefits, the concept of freight car per diem payments is used. The 1978 average daily rate paid by each of the nation's railroads for the use of foreign cars on its system was $4.50/day. This value was applied to both foreign- and operator-owned cars to reflect the increase in car availability, reduction in the minimum size of the car fleet, or potential revenue to the owner from foreign carriers. Privately owned or leased cars are excluded from the computations because their compensation is on a mileage rather than a time basis.

The annual per diem savings from the time savings tabulated above are equal to $18,400 in 1978 dollars based on 1984 railroad traffic volumes. This value is estimated to remain constant through 2000 and then increase at 1.4 percent per year, corresponding to the expected growth in freight traffic. The 1978 present value of these avoided costs is $239,700.

Grade Crossings and Automatic Warning Systems

The grade-crossing warning system in Elko very likely would have required improvement by 1980 or 1985 if the demonstration project had not been implemented because 15 crossings were among the most dangerous in the state. The grade crossings averaged about six accidents per year and a fatality every other year, not including the secondary accidents between cars waiting in the queues or racing to the next open crossing. The remaining three crossings probably would have received automatic gates by 2000 because of the growth of traffic in Elko. The 1978 present values of the avoided community capital costs and avoided railroad maintenance costs for a new warning system with automatic gates are $1,071,400 and $1,557,500, respectively, based on initial costs of $64,200 per gate installed and annual maintenance costs of $80,800–$93,700/yr over the study period.

Other Maintenance Cost Reduction

A one-time approximation is taken of the value of avoided track renewals, totaling $2,098,000. The benefit is the cost that would have been expected in about 1988 if the project had not been implemented. Also included in this category are 2 years of benefits from the increased efficiency of the new yard for full-scale Western Pacific/Union Pacific operations from October 1983 through summer 1985. The value of the increased efficiency was estimated by De Leuw, Cather to be $400,000/year. The 1978 present value is $2,037,000.

Accident Cost Reduction

To determine the probable reduction in rail accident cost of the demonstration project, the following topics are considered: the probable project reduction in accident risk or exposure, the anticipated baseline accident frequencies and damages, and the estimated accident cost savings.

Reduction in Accident Risk or Exposure

Because about 45 percent of national rail accidents, including derailments, have been found to be related to track or roadbed conditions (*2*), the replacement of the aging mainline track through Elko with a new roadbed and continuously welded rail reduces the expected frequency of track-related derailments. The elimination of switches along this section of mainline also reduces the potential for derailments because of human factors, the source of about 25 percent of national rail accidents (*2*). To estimate the reduction in derailment exposure, the new mainline is assumed to reduce 55 percent of derailments (all track-related derailments plus a share of those related to human factors) by 95 percent for 10 yr. The human factor saving is assumed to continue after 10 yr. In addition to reducing the frequency of derailments, the demonstration project also eliminates rail accidents in the congested downtown area, thus reducing by 500 the number of persons who would have to be evacuated in the case of fire or the release of hazardous material along the mainlines.

Baseline Accident Frequencies and Damages

Two types of derailments are considered: small scale and large scale. In the small-scale derailment, the damage is confined to within 150 ft of the tracks. Damages usually range from \$10,000 to \$500,000, with an average figure of \$150,000. With aging track, the rate for this type of accident might have approached two per year had the demonstration project not taken place.

In a large-scale derailment, damage can extend up to 0.5 mi on either side of the tracks because of fire, fumes, and explosions. Damages in this case can range from \$1 million to \$20 million plus, with an average figure of \$10 million. The rate for this type of accident was based on the frequency of SP accidents involving damage to cars carrying hazardous material and release of hazardous material (*2*). Allocating the risk on the basis of track miles and considering the effect of two railroads passing through Elko leads to a no-project expected rate of 0.009 large-scale accidents per year in Elko—roughly a 9-percent chance of such an accident in the 10-yr no-project comparison period.

In the case of a large-scale accident or even the threat of explosion or hazardous fumes, a zone extending 0.5 mi to either side of the tracks and including 58 percent of the population of Elko, or 6,700 persons, would be at risk and require evacuation. The social cost of evacuations is estimated to be the value of 48 hr of evacuation time per person, valued at one-half the wage rate corresponding to the 1978 per capita income in Elko (\$3.74/2 = \$1.87/hr). The risk of evacuation is substantially higher than that for a large-scale accident because evacuations tend to be precautionary in nature. Based on the frequency per track mile of cars damaged carrying hazardous materials, the no-project expected rate of evacuations in Elko is estimated to be about 0.067 per year or roughly a 67-percent chance of an evacuation in the 10-year no-project comparison period.

Estimated Accident Cost Savings

Applying the expected accident reduction to the baseline accident rates gives an expected value of savings of \$230,000/yr over 10 yr and \$45,000/yr over the remaining life of the project. Assuming that all of the evacuation cost savings accrue to the community along with 20 percent and 60 percent of the savings in small- and large-scale accidents, respectively, the 1978 present values of the benefits are

Benefit	*Present Value*
Railroad Accident Savings	\$1,128,683
Community Accident Savings	\$823,041

HIGHWAY USER BENEFITS

Delays at Grade Crossings

The highway delay benefits were calculated using a grade crossing delay model developed by De Leuw, Cather and procedures developed by AASHTO and Stanford Research Institute. The grade-crossing delay model is based on measured crossing blockages in Elko. It calculates stopped delay including the effects of queueing, assuming random arrivals over the blockage times with arrival rates based on average daily traffic. Future delay was a function of rail traffic levels described under the heading Railroad Benefits above and of traffic increases based on expected population growth.

There are two components of benefit from the avoided delay at railroad grade crossings in downtown Elko. The first component is the avoided motor vehicle passenger time delay from either being stopped by a closed grade crossing or simply slowing to cross the railroad tracks. The second component is the reduction in vehicle operating costs for the speed-change cycles and idling associated with the railroad grade crossings. These components of cost are described below.

Avoided Motor Vehicle Delay

A total of 28,900 hr of vehicle delay is estimated to have been avoided in 1984 because vehicles were no longer stopped for railroad grade crossings in downtown Elko. It is anticipated that this figure would have exceeded 74,300 hr/yr by 2008. The slowing of vehicles for rough grade crossings is estimated to add 20,400 and 43,100 hr in 1984 and 2008, respectively. Because of a higher population growth rate prior to 1990, these delays and all traffic-related impacts increase faster prior to 1990 than later.

Based on data from the AASHTO *Manual on User Benefit Analysis of Highway and Bus-Transit Improvements* and updated to 1978 dollars with the consumer price index (CPI), a value of time is chosen of $1.06/hr, which reflects rates of about $7.50/hr for large trucks and $0.42/hr for passenger vehicles with an occupancy of 1.56 for average trips (*3*, pp. 19, 70). The latter value is low because the value of passenger vehicle time savings has been found to be sensitive to the amount of time saved, here less than 5 min per trip. The total value of time saved is then about $52,200 in 1984 and $124,500 in 2008.

Avoided Speed-Change and Idling Costs

Using volumes and times from the grade-crossing delay model, vehicle operating costs for the stop-start cycles and idle times were calculated from AASHTO procedures for a 25-mph approach speed (*3*, pp. 19, 70). Savings peaked at the end of the analysis period in 2008 with avoidance of the stop-start of 5,800 vehicles daily with annual operating cost savings of $68,000.

As with vehicle time savings, vehicle operating savings resulted when automobiles avoided the speed-change cycles associated with slowing for the rough crossings even when no train was present. Although the cost per vehicle is minor, the savings to society become substantial when all of the traffic across the crossings is considered. Based on the AASHTO data cited above and SRI nomographs for railroad crossings of average roughness and a 25-mph approach speed (*4*, pp. XI-6, XI-7), the number of vehicles that would have been slowed and the associated cost avoided ranged from 65,000 in 1984 to 138,000 in 2008 with annual cost savings of $150,000 and $319,000, respectively.

Accident Reduction

From city and state records of accidents between trains and automobiles for the 8 yr prior to the study, the following accident rates were calculated (excluding accidents from vehicles waiting in line or rushing to the next crossing):

Accident Type	*Accident Rate (accidents/million vehicles crossing)*
Property Damage Only	0.29
Injury	0.14
Fatal	0.04

Because most of the flashing-light crossing active warning systems would have been replaced with automatic gates if the demonstration project had not been implemented, this rate of exposure would have been reduced considerably. Based on data reported by SRI (*4*, pp. XI-6, XI-7) from NCHRP (*5*) and Voorhees (*6*, ch. XI, p. 7) and conservatively assuming that the reduction applies to all crossings, a factor of 0.35 was applied to these rates to estimate the reduction. This reduction factor compares favorably with a 40-percent factor found by the California Public Utilities Commission (PUC) (*7*).

The costs for motor vehicle property damage and fatalities were derived from the National Highway Transportation Safety Administration (*8*) and Forester (*9*), respectively (the latter as reported in *1*, pp. 4-10, 4-32). The cost of injuries in railroad grade crossing accidents was derived from a weighted distribution of injury types at urban railroad grade crossings by FRA and FHWA (*10*. p. 77). All costs were adjusted to 1978 levels with the CPI.

Accident Type	*Cost*
Property Damage Only	$1,400/acc
Injury	$33,200/acc
Fatal	$401,200/acc

Applying the above corrected rates to the total traffic that would have crossed the railroad tracks at grade, and using these per accident costs suggests a 1978 present value of accident reduction benefit equal to $3,192,400.

COMMUNITY BENEFITS

Reduced Disruption and Pollution

Because primary effects of railroads running through downtown Elko were the disruption of the community and the creation of vibration, noise, air, and visual pollution in an area important to the well-being of Elko, an important benefit to the community was the removal of these effects. It is difficult to quantify and assign a price to this benefit. Because these impacts have some effect on property values, the change in property values that is attributable to the relocation of the railroad is used as a surrogate price for these effects.

In traditional economic analysis, increase in land value as a result of a capital investment is considered a transfer effect. This effect is based on the theory that demand for land in a community is relatively constant and, as a result, increases in value in one location may result in decreases elsewhere. In this case, the increase in land value attributable to the project is assumed to be a surrogate measure for the benefit of reduced pollution and community disruption and for increased efficiency of commercial activity in the central business district.

Additional supporting evidence of this assumption comes from an examination of the demand for land in Elko. Because federal lands surround much of Elko, there has been a shortage of developable land for business, particularly land that is centrally located with respect to the downtown. Businesses in Elko have had the choice of accepting either the disutility of the railroads' environmental impacts downtown or the disadvantage of less central locations. The unexpected growth of Elko in the last 8 yr has accentuated this problem, even to the point of new businesses failing to locate in Elko because there were no available parcels of adequate size with utilities.

The demand for land, as measured by valuation in constant 1978 dollars, went up for all areas of the city. There was no measurable decrease in value from a transfer effect. At the most, some parcels did not increase in value because of the development or release of previously unavailable but more desirable parcels, which allowed supply to temporarily match demand. This is also expected to be the case in the release of yard property (see Release of Railroad Property). The proportional increase in value contributed by the project was only a fraction of the total increase. This effect was because of a latent value potential of property values to increase that was dependent on the project removing the railroad tracks before enabling public and private investment would be worthwhile. Property values in some residential areas also went up because of the project because residential neighborhoods had been adversely affected by the railroad impacts, particularly noise and community disruption, prior to the demonstration project.

The change in property value attributable to the project is thought to be a conservative measure of the reduction in these impacts. For example, the value of reducing interior noise of buildings is also valued by estimating the price for accomplishing the equivalent reduction through noise insulation. Based on unpublished Elko assessment data, this type of home improvement is thought to be similar to structural improvements in that only about 10 percent of the actual money spent on the improvement can be expected to show up in an increase in value of the property.

From an analysis of the change in property values by zone between 1978 and 1984, the total increase in property value attributable to the removal of the railroad is about \$4.1–\$5.3 million, exclusive of the value of released railroad property and some adjacent properties in the vicinity of the old WP yard. The 1978 present value of the midpoint of this range is \$3.68 million. This present value is net of the overlap with the noise reduction value discussed next, and assumes that the benefit is taken in 1984 after the removal of the trains. This tabulation also excludes the increase in value of the old WP yard released for use as a business park, which is presented after the analysis of community benefit.

Noise Reduction

The value of reducing noise by moving the railroad out of the downtown is quantified by assuming that it is worth the cost of reducing interior noise to acceptable levels by sound insulation. The number of homes and businesses exposed to excessive noise was defined by comparing before and after noise measurements and projections. The cost of insulating a home from noise by lowering the interior day-night average noise level (L_{dn}) to an acceptable level of 40 dB(A) is estimated to be \$5,000 per home. This estimate is based on the cost of double glazing windows of \$5–\$10/ft^2 and installing air conditioning where not already present to permit windows to stay closed all year. Comparable estimates were made for businesses, industries, and motels with a total cost or benefit of \$2.2 million, equivalent to a 1978 present value of \$1.81 million. Ten percent of this amount was subtracted from the increase in property value representing reduction of disruption and pollution.

Flood Control

A major benefit of the project was the reduction in damage to property from flooding. Prior to the demonstration project, the channel of the Humboldt River through Elko had a capacity of less than 2,000 ft^3/sec (cfs). Based on a 1975 study by the Army Corps of Engineers (ACOE) for winter conditions, the relocated channel was designed for the 100-yr flood, a flow of 12,500 cfs (*11*). Since the construction of the channel in 1981, damage from flooding has been averted in all but 1 yr. In 3 of the 5 yr of this wet cycle, peak flows have approached or equaled the largest flood of historical record, 7,100 cfs in 1962.

A model of Elko flood damage was constructed from hydraulic calculations of the preconstruction and postconstruction channels with flows that corresponded to the 10-, 50-, and 100-yr floods (*11*). Estimates of the damage averted by the new channel were made for the three flows from 1985 assessed property valuation and the depth of flooding, utilizing curves developed by the Flood Insurance Administration of the Department of Housing and Urban Development. Property values were corrected to 1978 levels using the CPI for the period. From this model, an estimated \$1.6 million in property damage was avoided in the 5 yr through 1986. Future flood damage was also estimated from the model based on the ACOE expected flows corrected by assuming a 60-percent chance of the current wet cycle's continuing for another 5 yr.

The city of Elko also avoided the costs of likely bridge damage and emergency repair by virtue of replacing the two downtown bridges prior to the start of the wet cycle. The expected value of the benefit was estimated to be \$600,000, based on a 75-percent chance of having lost the main Fifth Street Bridge. A capital credit is also taken for project cost of replacing the substandard and deteriorating Ninth Street Bridge because it would have had to be replaced in the immediate future in the no-project case.

Emergency Services

The demonstration project improved emergency vehicle service by eliminating the occasional 3–8-min train delays for police, fire, and ambulance service. Prices for these three factors are estimated to place a value on improved emergency services—reduced insurance costs, improved life-saving service, and avoided city expenditure for facilities.

Reduced Insurance Costs

Based on unpublished data from an Elko insurance agent, the relocation of the railroad tracks was one of four factors in the reduction of Elko's fire risk rating. Because the project improved the city's ability to fight two fires at once, one south of the river and one north, one-fourth of the estimated reduction in insurance cost for property improvements in the whole city is used as a measure of realistic, expected savings in property damage from fire. Assuming that 75 percent of the value of assessed property in Elko in 1978 was for improvements ($51.8 million × .75), a 0.6% insurance rate, and a 15-percent total decrease in premiums, the insurance savings would total about $25,000/yr from 1984 to 2008.

Improved Life-Saving Service

Comments on the effect of delayed emergency service have included stories about a hospital administrator who died of a heart attack at home while an ambulance waited for a train to clear the crossing or about fire engines delayed while responding to a life-threatening fire. In view of an expected 200-percent increase in vehicle delay in the no-project condition and the separation of the south of town from the hospital by the railroad tracks, it is assumed that the improvement in emergency access would save one life every 5 yr. From the $401,200 value of life noted in the Highway User Benefit section of this paper, the expected annual saving would be $80,200/yr.

Avoided City Expenditure for Emergency Facilities

The costs of a new ambulance station south of the river that was avoided because of the project is estimated to be $100,000. This cost is assumed to be a benefit in 1978. The 1978 present value of all of the emergency service benefits is $1,451,000.

Reduced Risk of Hazardous Derailments

From the previous presentation of the expected reduction in derailments under railroad benefits, the 1978 present value of the portion accruing to the community is $823,041.

Reclamation of River Property

The rechannelization of the Humboldt River converted 8.03 acres of private property from river bottom to usable property. The $300,000 increase in the value of the land reflects the social benefit of the land being available for productive use. A conversion date of 1982 gives a 1978 present value of $282,800.

Release of Railroad Property

After the completion in 1978 of the relocation project in Elko, the old Western Pacific yard was to be turned over to the city of Elko with specific restrictions regarding its ultimate use. The restrictions placed on the property by the federal government stated that, as original railroad land grant property, the land could be used only for public purposes unless it could be paid for at assessed market value by the city. An agreement was reached between the city of Elko and FHWA to auction the property for development of an industrial park and to credit the proceeds toward the project. The proceeds will be apportioned to the relocation project and to the various other property owners within the industrial park boundary. The credit to the project, based on the assessed value of about 40 acres of railroad parcels to be sold at public auction in 1987, is $1,129,000 in 1978 dollars, which is equivalent to a 1978 present value of $0.79 million.

In addition to the 40 acres to be sold of the 170 total acres in the planned industrial area, there are about 47 acres of existing railroad leases and 71 acres of land in city or private ownership according to unpublished city of Elko data. Because of the shortage of developable business property in Elko, the release of railroad property for business development is a social and economic benefit to the community that is valued at the net increase in value of the land for parcels previously leased, with transfers assumed to take place by 1990. The value of the 71 acres already in private or public hands also increased at a rate similar to the rate of increase in property values elsewhere in Elko. The average increase realized in 1984 is estimated to be $10,000 per acre in 1978 dollars by the Elko city assessor. In addition, 7.8 acres acquired by the city for a jail site and Silver Street right-of-way has a net value per acre of $20,000. The value of these lands credited as a project benefit is $1.34 million in 1978 dollars, equivalent to a 1978 present value of $981,000.

CALCULATION OF BENEFIT-COST RATIO

Selection of Discount Rate

Research performed by leading benefit-cost and financial investment authorities (*12*, pp. 214–251, 376; *13*, p.10; *14*, pp. 122, 129, 135) leads the author of this paper to suggest that 4 percent is the appropriate discount rate to use for public projects similar to the Elko demonstration project. Suggestions for higher rates have used the opportunity cost of leaving the funds in the private sector as a rationale for discount rates of 7 percent, 10 percent, or even higher. However, when the effects of inflation and uncertainty are subtracted from the interest rates, these higher rates are equivalent to 4 percent or less for a public project similar to the Elko railroad relocation. These effects are discussed in turn below.

Inflation

When a private investor invests money, he does so with the realization that his dollars will be worth less when he gets his money back. Over the 57 yr prior to 1983, the amount of real goods and services that $1 would purchase has declined about 3.2 percent/yr as measured by the CPI. From 1966 through 1982, this rate has averaged 6.9 percent/yr (*13*, p. 10). Hence the return that any prudent investor seeks on his money includes an allowance just to maintain the status quo against inflation. Examination of the minimum rates that the U.S. government must pay to borrow in the form of short-term Treasury bills confirms this expectation by indicating that, on the average, investors demand to keep up with the expected rate of inflation on risk-free investments: between 1926 and 1982, the average rate of return on Treasury bills and the CPI rate of increase have been virtually identical at about 3.2 percent each annually.

For the purposes of selecting a discount rate, it is only necessary to specify whether inflation is included or excluded from the rate. If inflation is included in the discount rate, then the value of project benefits in future years should be escalated by the expected inflation rate. If inflation is not included, benefits should be valued in constant dollars. Because the latter approach is simpler, although equivalent mathematically to the former, the latter is chosen here. The allowance for inflation is excluded in both the discount rate and in the valuation of the project benefits. Consequently, in the long run, the inflation-free discount rate would be expected to be about 3.2 percent below the equivalent private market rate for return on investment.

Uncertainty

Uncertainty has an even greater effect on the comparison of private rates of return with the proper discount rate. The private investor demands a higher return from risky investments than from safe investments. Brealey and Myers explain that the difference between the return on an average stock portfolio and on a Treasury bill is all risk premium, equal to an average of 8.3 percent/yr over the last 56 yr (*14*, pp. 122, 129, 135). If an investment is less risky or more risky than the standard stock portfolio, the risk premium should vary correspondingly.

The issue of uncertainty is extremely important for the selection of the proper discount rate. Mishan, a leading authority on benefit-cost economics, argues that the highest reasonable discount rate under certainty would be equal to the annual certain yield on a dollar of private investment (*12*). Correspondingly, Brealey and Myers explain that they would evaluate a safe private investment at the Treasury bill rate (3.1 percent through 1981), an investment of average risk at 3.1 percent + 8.3 percent = 11.4 percent, and so on (*14*, pp. 122, 129, 135).

To judge the amount of risk involved in the stock market, the standard deviation has been 21.9 percent on an average rate of return of 11.4 percent in the stock market over the last 56 yr (*14*, pp. 122, 129, 135). Assuming that returns on stocks are normally distributed, this standard deviation means that there is a 67 percent chance that the actual rate of return will be included in the range of + 21.9 percent around the average of 11.4 percent, and a 95 percent chance that the actual rate of return will be included in the range of + 43.8 percent around the average of 11.4 percent, and so on.

However, the case for this public investment in Elko is different. Because of the spreading of risk in public investments, a lower discount rate should be used than in the private sector where the effects of the risk have more effect on individual investors through lower rates of return or even losses (*12*, pp. 214–251, 376). In this case, there is so much spreading of risk by the investors that the individual risk is insignificant: $25 million spread over some 100 million employed taxpayers versus $20 million in benefits spread over some 10,000 beneficiaries or $.25 in investment versus $2,000 in benefits per person. Public benefits are lower than costs because 20 percent of the benefits go to the railroad. From this calculation, it is evident that this project also avoids spreading the benefits so widely that they become insignificant, a problem often associated with projects that spread risk. In this case the benefits are comparatively concentrated.

With respect to the risks faced by the beneficiaries, looking at the type of risk is informative. Elko growth is fairly predictable or, at least, is likely to continue, removing the question of whether people would be there to receive the benefits of less delay, fewer accidents, less environmental impact on the city, less flood damage, and so on. There are some uncertainties on the magnitude of the benefits because of uncertainty about actual growth, weather, and so on.

However, a significant amount of that uncertainty has been removed 9 yr into the 30-yr period because many of the major benefits have already been realized or adjusted for changing conditions. For example, benefits are now estimated to be much lower than expected in 1978 because of the lack of utility of the new yard to the Union Pacific, greatly lowered expectations for transcontinental rail traffic, and the elimination of possible gaming benefits in Elko. Furthermore, remaining variations in benefits will be more heavily discounted than those already accounted for, thereby reducing the effect of future benefit uncertainty on the actual benefit-cost ratio.

Because of the spreading of risk by the investors and the after adjustment of the benefits, this project appears to have very low risk compared with the risk faced by investors in the stock market. If an annual risk premium of 0 percent is used, the 4-percent discount rate corresponds to a private sector opportunity cost of about 15 percent/yr when the effects of inflation (3 percent) and average private sector risk (8 percent) are added. Because the stock market returns have averaged around 11 percent/yr, this discount rate seems more than adequate to account for the social opportunity cost of capital. In fact, one could reason backwards from the average 11-percent opportunity cost and conclude that a 4-percent discount rate for this project includes an annual risk premium of up to 4 percent (11 percent − 3 percent inflation − 4 percent or half the 8 percent average risk premium = 4 percent).

Capital Costs and Salvage Value

Capital costs for the project total $45,887,000 in actual dollars. These costs are offset by project credits, such as land transfers and salvage of the previous railroad trackwork, which in actual dollars amount to $2,599,000. In 1978 dollars, the offsetting credits total approximately $1,534,000. Minus an additional $139,000 in nonparticipating costs, net capital costs are $34,494,000. The 1978 present value of this net capital cost is $30,558,500. Because the Ninth Street Bridge would have been replaced in the no-project case (see Flood Control above), an additional credit is taken in 1983 for $600,000 of the cost of the bridge in 1978 dollars. The 1978 present value of the new net capital cost is $30,065,400 before salvage value is considered. These capital costs are summarized in Table 1.

TABLE 1 CAPITAL COSTS

Item	1,000 Actual $	1,000 1978 $	Present Value 1,000 1978 $ Discounted at 4%
Total Cost Before Credits	$45,887	$36,167	
Project Credits	(2,599)	(1,534)	
SUBTOTAL	43,288	34,633	
Non-Partici-pating Costs (in 1978 $)	(139)	(139)	
SUBTOTAL	43,149	34,494	$30,558.5
9th St. Bridge Credit (in 1978 $)	(600)	(600)	(493.1)
CAPITAL COSTS	$43,749	$33,894	$30,065.4

The salvage value is based on 100 percent of the initial cost of the land with adjustments for the increase in value of the land in the new yard because of improvements. The new yard covers about 230 acres of land exclusive of mainline right-of-way, of which about half was purchased

TABLE 2 BENEFIT-COST SUMMARY

	Discount Rate (1,000 1978 $) 4%	7%	10%
RAILROAD BENEFITS			
Distance and Curvature	($447)	($269)	($177)
Savings in Running Time	$799	$483	$319
Freight Car Per Diem Payments	$240	$144	$95
Grade Crossings & Protection	$1,558	$1,137	$873
Other Maintenance Cost Reduction	$2,037	$1,582	$1,240
Railroad Accident Reduction	$1,129	$813	$601
Subtotal	$5,315	$3,890	$2,950
HIGHWAY USER BENEFITS			
Delays at Grade Crossings	$4,293	$2,570	$1,618
Accident Reduction	$3,192	$1,927	$1,224
Subtotal	$7,486	$4,497	$2,842
COMMUNITY BENEFITS			
Reduced Disruption-Pollution	$3,681	$3,194	$2,781
Noise Reduction	$1,808	$1,569	$1,366
Flood Control	$2,717	$2,159	$1,751
Emergency Services	$1,451	$974	$693
Grade Crossings & Protection	$1,071	$1,021	$994
Reduced Risk of Haz. Derailments	$823	$593	$438
Reclamation of River Property	$283	$252	$226
Release of Railroad Property	$981	$788	$641
Subtotal	$12,815	$10,550	$8,891
TOTAL BENEFITS	$25,616	$18,936	$14,684
CAPITAL COSTS	$30,065	$27,647	$25,512
SALVAGE VALUE	$7,259	$3,093	$1,349
NET COSTS	$22,807	$24,554	$24,163
BENEFIT-COST RATIO	1.12	0.77	0.61

for approximately $600 per acre. The 1985 appraised value per acre of the entire yard was $59,000 per acre, giving an added value of $11.1 million in 1985 dollars or $6.8 million in 1978 dollars. The salvage also includes 46 percent of the construction cost of earthwork and major structures based on an approximate service period of 27 yr within the study period and a total estimated life of 50 years. In undiscounted 1978 dollars, the salvage value is $23.5 million. The 1978 present value of the salvage value is $7.3 million, giving a present value of the project net capital cost for benefit-cost purposes of $22.8 million.

Benefit-Cost Ratio

Table 2 summarizes the 1978 present value of the benefits and costs of the demonstration project. Based on total benefits of $25,402,000 and net costs of $22,806,600, a benefit-cost ratio of 1.12 is calculated for the project with a discount rate of 4 percent. Results of higher rates of 7 pecent and 10 percent are also shown, but are not believed relevant in this case.

Two factors have a large effect on the magnitude of this ratio. Inasmuch as no tourist or gaming revenue benefits (estimated previously to amount to more than one-third of the benefits of the project) are counted for the project, this ratio is conservative. An additional factor is the reduced benefit from the $5.5 million investment in WPRR yard facilities, particularly the diesel locomotive and car maintenance shop. Had the acquisition of Western Pacific by Union Pacific and the consequential lack of utility of the new yard been foreseen, the project would show a higher benefit-cost ratio by having avoided about 20 percent of the net investment.

The distribution of benefits is quite significant. The railroads account for only 20 percent of the total benefits; highway users, 30 percent; and the rest of the community, 50 percent. The monetary values calculated here reflect the preponderant social benefit of removing the railroads from the center of town.

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