Public investment in the transportation infrastructure has traditionally been along modal lines with little effort to develop a multimodal approach. Consequently, it is difficult to determine if public transportation dollars have been invested in the most cost-effective manner. Previous research has indicated that more often than not, planning and investment is economically inefficient and generates fewer social benefits than a multimodal approach. A system cost analysis is a prerequisite to any multimodal investment analysis. A component of the system cost analysis is summarized—a through-cost comparison of truck freight on the Pennsylvania I-80 corridor. The system cost analysis includes truck operating costs with a discussion of truck user taxes and their relationship to infrastructure, accident, and other related and environmental costs. The discussion concerning the relationship between infrastructure costs and truck user taxes and fees is important in identifying the system costs that are supported by truck operators and the actual costs incurred by the system. The truck-supported system costs, using a life cycle cost approach, amounts to $1.07 per mile or 8.1 cents per ton-mile on the Pennsylvania I-80 corridor. The costs incurred by the system, excluding sales tax, average exhaust emissions, amounts to $1.30 per mile or 9.8 cents per ton-mile. Annual truck emissions on the I-80 corridor are estimated for hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter. These can be used for comparison with other modal strategies.

The public sector, unquestionably, plays a vital role in the development of transportation infrastructure. Since 1950, with respect to freight, surface transportation has been the largest recipient of public dollars. The transportation system is evolving into a complex multi-modal network, which was encouraged by regulatory changes and has fostered the growth of transportation companies. The new multi-modal environment requires a more thorough examination of public transportation investment, particularly in light of federal and state budgetary constraints. Fundamental questions about the cost effectiveness of public investment in surface transportation, for example, are appropriate. Is it the best use of public resources to finance highway infrastructure for hauling interstate freight? Currently, policy makers have insufficient information to address this basic question. Information on multimodal investment strategies is essential if the U.S. is to maintain a competitive and growing economic posture.

Consolidated Rail Corporation (CONRAIL) contracted Texas Research and Development Foundation (TRDF) in late 1990 to conduct a system cost truck freight analysis specifically for the South 311 mi I-80 corridor through Pennsylvania. An examination of truck freight interstate transit costs is likely to provide important information for policy directives on multimodal transportation investment. The preliminary findings of the I-80 corridor study are summarized.

The key objectives of the study were to determine the full-system costs for truck operations, and from these costs, identify truck system costs on a per mile and ton-mile basis. System costs include infrastructure or facility costs, vehicle operating costs, and externalities including property and physical damage from accidents, user delay costs, and environmental costs. Additionally, system costs can be categorized as incurred or supported. Incurred system costs are the true system costs defined above. Supported system costs are the costs currently paid by vehicle operators. The previous definition of system costs is modified to exclude externalities, because they are not paid for directly by operators, and to replace actual facility costs with user taxes and fees that are actually paid by operators. Quite simply, supported system costs are what owners or operators pay for operating their vehicle. Examination of system costs is necessary for evaluating modal options and strategies.

Several inputs are combined to identify the total system costs of truck operations over the I-80 corridor. First, incurred facility costs comprising initial construction, rehabilitation, and maintenance are identified. Then, the various user taxes and fees paid by truck operators to determine the relationship of incurred facility costs and supported facility costs. Next, the full range of operating costs paid by truck operators together with externalities not currently met from freight revenue are determined.

FACILITY COSTS

Initial Construction

Initial construction costs include right-of-way (ROW), bridges, and roadway (or pavement costs). Based on a 1970 report by the Keystone Shortway Association, initial construction costs amounted to $424.2 million (1).

Right-of-Way

Based on the initial ROW estimate of $17.9 million, land acquisition costs were approximately $58,000 per mile or about $1,026 per acre for I-80. However, this estimate may be slightly low, because some land may have been donated. There was no convenient way to obtain more precise data within the limits of this study. The average year in which the highway

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was constructed was 1966. Converting ROW to 1989 costs for composite construction yields $236,172 per mile of highway (2). The method of cost allocation for ROW, used in the Pennsylvania highway cost allocation study to allocate ROW costs according to vehicle-miles of travel (VMT) (3), Using traffic data from the Pennsylvania Department of Transportation (PennDOT) data base calculated by individual segment, 34 percent of the I-80 real estate costs are allocated to trucks, yielding $80,913 per mile of highway. In this report, final allocated truck costs are in 1989 dollars for all cost categories.

Bridges

The I-80 corridor includes 486 bridges totaling slightly over 16 mi costing $65.7 million (1970 dollars) to construct. Bridge construction costs are 15 percent of total construction costs but account for only 3 percent of the highway length. The average year the bridges were constructed was 1966. Converting the $65.7 million to 1989 dollars yields $913,352 per mile of highway (2). The method used for cost allocation of structures and pavements, based on the Pennsylvania highway cost allocation study is 30 percent VMT and 70 percent equivalent single axle load (ESAL). Average rural Interstate truck loading of 98 percent (2) yields a 79 percent cost allocation for trucks or $720,452 per mile of highway.

Roadway

The construction, reconstruction, and traffic history were studied to determine the life cycle pavement costs for I-80. The year in which segments of the highway were constructed and the year in which an asphalt or concrete overlay or total reconstruction took place were derived from pavement inventory historical records provided by PennDOT. Based on this data, the average life of the pavements before restoration or reconstruction was nearly 22 years. The entire length of the highway was initially built with 10 in. of reinforced portland cement concrete pavement.

PennDOT does not keep records of accumulated traffic or accumulated ESAL. The Roadway Management System (RMS) data base maintains the current traffic counts by section and calculates current ESAL based on a prior estimate of ESAL per vehicle for the entire statewide network. PennDOT is concerned about underestimating the amount of current ESAL carried on their pavements. Data from the weigh-in-motion (WIM) site on I-80 was used to determine the average ESAL per vehicle for each vehicle class. The historic growth rate of ESAL for the nation’s rural Interstates as reported by FHWA and the average historic ESAL growth rate of I-80 in several sections of Western Illinois were averaged to arrive at an annual growth curve used for this study (4).

The total cost of the roadway was $340.6 million (1970 dollars) or $1,096,000 per mile (7). Using the composite cost indices to adjust for inflation, yields $4,493,838 per mile in 1989 dollars. Application of the 30-70 rule (30 percent allocated by VMT and 70 percent allocated by ESALs) results in 1989 truck costs of $3,544,739 per mile allocated for trucks.

Rehabilitation Costs

A study of the pavement construction and reconstruction history showed that it is possible to combine contiguous segments of the pavement into 25 similar sections with similar construction and rehabilitation histories. These section lengths vary from 2 to 36 mi. The average age of the initial concrete surface and the time of first overlay was determined for each section. Calculations were then made for each section to determine both the accumulated ESAL for the original concrete surface untiloverlay and the total accumulated ESAL since that section was placed in service. The average service life of the initial 10-in. concrete pavement is 22.4 years and the sections accumulated an average of 18.7 million ESAL. Most all the surviving original sections are currently scheduled either for restoration or reconstruction.

Since 1979, PennDOT has maintained a project management system for tracking all rehabilitation, restoration and reconstruction projects. This data was used and converted to 1989 dollars on the basis of FHWA correction values for maintenance costs (2). For the entire I-80 corridor, total rehabilitation costs from 1978 to 1990 are estimated to be $688 million in 1989 dollars.

The $2,219,355 cost per mile is allocated using the 30-70 rule (30 percent by VMT and 70 percent by ESAL) resulting in $1,750,627 per mile allocated to trucks. Using 300 mil tons average over the average 25-year life of the I-80 system yields approximately 0.59 cents per ton-mile. The rehabilitation costs as a whole are underestimated as a system, since some miles of I-80 are in need of reconstruction or restoration and the monetary resources are not available.

Maintenance Costs

Snow Removal

Data were extracted from the maintenance management system for the last 3 years for each of the 15 counties through which I-80 passes. The average reported costs of snow removal for all rural Interstate highways in Pennsylvania was $12,000 per mile annually in 1989 dollars or $300,000 over the 25-year life of the highway, according to information in the maintenance management tracking system. However, this figure may be low because current policy doesn’t require snow plow operators to identify the specific route for the maintenance management system. Using axle VMT as the allocation basis results in truck life cycle snow removal costs of $161,790 per mile of highway or 53 percent of total snow removal costs.

Routine Maintenance

The average annual routine maintenance costs (excluding snow removal) for rural Interstate highways in Pennsylvania is reported as $17,600 per mile in 1989 dollars. The average annual routine maintenance costs for I-80 for the last 3 years averaged $10,300 per mile in real dollars. Reported routine maintenance costs for I-80 by county varied from as low as zero to a high of $54,000 per mile. Because of the high variability in annual maintenance costs among counties, it was decided to
use the average maintenance costs established by PennDOT of $17,600 per highway-mile, or $440,000 over the 25-year life of the highway, for rural Interstate pavements, as the basis for this study. Using the 30-70 rule (30 percent by VMT and 70 percent by ESALs) for allocation of truck costs yields a life cycle value of $347,072 per mile of highway or 79 percent of total routine maintenance.

**Truck Weight Enforcement**

PennDOT has a law enforcement division for inspecting, issuing citations for fines, and confiscating the trucks of operators who violate the weight limit and back hauling laws. PennDOT's estimate of the department's costs associated only with enforcement of the truck weight laws on I-80 is $393,000 for 1990. Estimating the same amount for 25 years and dividing by 300 million tons over this period results in 0.01 cents per ton-mile, or 84 cents for a five-axle semi-trailer round trip on I-80.

**Summary of Facility Costs**

Table 1 presents a summary of the average facility costs for trucks. These facility costs are, in principal, recovered in Pennsylvania through user fees and taxes. The facility costs are not recovered within any single year but over the entire life of the facility. The basis of distribution for this analysis is commercial tonnage of freight. Therefore, the life cycle cost of the facility is divided by the total life cycle average of 297,000,000 tons of freight. This converts to a freight cost per ton-mile of approximately 2.2 cents. This equates to 30 cents per mile of travel for a 5-axle semi-trailer based on an average cargo weight of 13.5 tons.

The 25 individual sections of I-80 had fairly large variations in the cost per mile of travel for a five-axle semi-trailer ranging from a low of 18 cents per mile to a high of 51 cents per mile, with an average of 30 cents. The large variations in costs are due to three variables: tonnage on each section, overlayment or reconstruction of the section, and the year in which it was constructed.

**USER TAXES AND FEES**

One of the basic premises of highway transportation is that vehicle owners and operators pay for the use of highways in direct proportion to the cost of constructing and perpetuating the highway system. User financial support for the highway system is functionally classified according to a three-tiered tax structure. The first consists of fees and charges unrelated to the mileage driven by an operator. It is often considered to be the basic "entry fee" to the road network. The second consists of fees and charges related to miles driven on the highway system. Typically, the second-tier tax is a fuel tax. A third-tier tax introduces weight and distance into the user charge computation. A third-tier tax highlights the difference in road damage attributable to vehicle weight (or more accurately, axle-loadings). Pennsylvania user fees and taxes can be categorized as first- and second-tier taxes. Currently, there are no third-tier taxes in Pennsylvania.

In addition to the functional three-tier classification, user charges are categorized by federal, state, and local jurisdiction. Highway user fees account for most of the financial resources spent on the state highway system, including the federally supported system. Local government funding sources for highways and roads are generally not related to use. Traditional local funding sources include property taxes, general funds, bond proceeds, and the like. This study focuses on the Interstate highway system and therefore excludes local government nonhighway user taxes.

**Allocation of State and Federal User Taxes and Fees**

Allocation of user taxes and fees involves a three-step process: (a) identification of federal and state sources, (b) allocation of taxes and fees to the I-80 corridor, and (c) determination

<table>
<thead>
<tr>
<th>TABLE 1 Life Cycle Facility Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period 1966-1980 (all $ figures are 1989 costs)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>All Vehicles</td>
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<tr>
<td>Initial Construction</td>
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<tr>
<td>Right-of-Way</td>
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<td>Bridges</td>
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<td>Maintenance</td>
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<td>Snow Removal</td>
</tr>
<tr>
<td>Routine</td>
</tr>
<tr>
<td>Weight Enforcement</td>
</tr>
</tbody>
</table>

* Based on 297 million tons of freight hauled on I-80.
of truck-contributed taxes and fees. The results of this process are discussed in the next two sections. (All taxes and fees are for 1989.)

State User Taxes and Fees

A major source of fees by Pennsylvania highway users are registration fees paid to the Motor License Fund. Registration fees, including vehicles in the International Registration Plan (IRP), are allocated to the I-80 corridor on the basis of daily vehicle-miles of travel (DVMT). Registration fees, statewide, for commercial registration class 7-25 trucks were $39,907,059; $982,471 for registration class 7-25 farm trucks; and $19,617,000 for trucks registered in IRP. Other state first-tier taxes, which include title fees, operator licenses, vehicle code fees, inspection stickers, special hauling permits, and other fees, are allocated on the basis of DVMT. In addition, treasury interest accumulated on the funds are also allocated by DVMT. The distribution of these other state fees and registration fees are presented in Table 2 for 1-80 truck operations.

Fuel taxes are the principal source of state revenues for the Motor License Fund, Pennsylvania’s transportation fund. The liquid-fuel tax, or gasoline tax, is assessed at 12 cents per gallon on motor vehicles. The diesel-use tax, or diesel tax, is also 12 cents per gallon for motor vehicles. The oil company franchise tax is calculated at 6 percent of the average wholesale price of petroleum products from a 90 cents per gallon minimum to a $1.25 per gallon maximum. This rate is absorbed in the retail price of motor vehicle fuels. The motor carrier road tax is a tax on motor carriers with gross vehicle weights of more than 17,000 pounds. The rate consists of a 12 cents per gallon excise tax, plus the oil franchise tax rate, plus an additional 6 cents per gallon. Credit is allowed for purchases of fuel in Pennsylvania up to the combined excise and oil franchise tax rate. State fuel taxes attributable to truck operations on the I-80 corridor are presented in Table 2. A total of $28 million was collected in 1990.

Federal User Fees and Taxes

Federal user taxes and fees collected from each of the 50 states are allocated to the states on a formula basis that does not necessarily equate to the federal taxes and fees actually collected in that state. Historically, Pennsylvania has received back 114 percent of its payment into the federal fund. However, in fiscal year 1989, the state received only 86 percent. For the purposes of this analysis no distinction is made between payments into the fund and apportionments from the fund, since this is beyond the scope of this study.

Federal fuel taxes consist of a 9 cents per gallon tax on gasoline and a 15 cents per gallon tax on diesel and are the major sources of federal revenues to the Federal Highway Trust Fund. The same procedure for allocating state fuel taxes is used for federal fuel taxes. The distribution of these taxes to the I-80 corridor are presented in Table 2. A total of $18 million was attributed to the I-80 corridor in 1990.

The distribution of the 12 percent federal sales tax on trucks and trailers are allocated to the I-80 corridor on the basis of daily vehicle miles of travel (DVMT). Trucks under 33,000 lbs and trailers under 26,000 pounds are exempt from the federal sales tax. Included in Table 2 is $7.5 million of the federal sales tax attributable to vehicles operating on the I-80 corridor.

The federal tire tax is a variable tax based on the weight of the tire. Tires weighing under 40 pounds are exempt. The tire tax is calculated as follows: 15 cents per pound for tires weighing 40 to 70 pounds, $4.50 plus 30 cents per pound for weight from 70 lb to 90 lb, and $10.50 plus 50 cents per pound for weight over 90 lb. The tire tax is distributed statewide on the basis of annual tire consumption and allocated to the I-80 corridor on the basis of DVMT. Included in Table 2 is $1.4 million of the federal tire tax attributable to trucks operating on I-80.

As the name implies, the federal heavy-use tax is a fee assessed on heavy vehicles. The fee is $100 plus $22 per 1,000 lbs for vehicles weighing 55,000 to 75,000 lbs. Vehicles heavier

<table>
<thead>
<tr>
<th>Group</th>
<th>Fleet</th>
<th>Units</th>
<th>All Taxes &amp; Fees</th>
<th>Fee Per Ton-Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-80</td>
<td>59,311</td>
<td>1,473,894</td>
<td>10,152,742</td>
<td>1.27</td>
</tr>
</tbody>
</table>

S.U. - Single unit truck
Comb. - Tractor and semi-trailer combination
Multi-trailer - Tractor, semi-trailer, and trailer combination
than 75,000 pounds are charged $550. Farm trucks traveling less than 7,500 mi per year are exempt, as are all commercial trucks with annual VMT of less than 5,000. Federal heavy-use tax calculations are based on I-80 operating weights and allocated on the basis of DVMT. Included in Table 2 is $3.7 million of the federal heavy use tax attributable to trucks using the I-80 corridor.

Summary of User Taxes and Fees Allocation

Total state and federal user taxes and fees attributable to trucks on the I-80 corridor are presented in Table 2. The five axle tractor semi-trailer combination pays 80.3 percent of the truck taxes on the corridor. This compares with 72 percent of the I-80 five-axle DVMT and 87 percent of the total I-80 ton-miles. The five-axle combination pays 12.6 cents per mile or 0.9 cents per ton-mile in user taxes and charges to operate on the corridor. The 0.9 and 0.8 cent per ton-mile for the five-axle combination and five-axle multi-trailer, respectively, are significantly less than other less efficient trucks with smaller average payloads.

VEHICLE OPERATING COSTS

Overview

Vehicle operating costs form a major basis of the prices truckers charge to move commodities across the national Interstate system. Vehicle operating costs are split into two major groups; fixed costs, which are independent of vehicle utilization, and variable costs which vary directly with utilization. Fixed costs are significant and includes items such as depreciation, interest, driver salaries, and general trucking overheads. Fixed costs must be covered by the truck operation if long-term service to customers is to be offered.

Variable costs relate to distance traveled, and include fuel, oil, tire-wear, and vehicle repair and maintenance costs. Considerable knowledge has developed over the last 30 years on the relationship between variable costs and highway design characteristics. However, much of this information is not easily transferable over time. Since vehicle technology (for example, engine and transmission design) changes over time, so do consumption rates, which alters the basic relationships between vehicle costs and highway characteristics. However, work on truck cost model calibration has increased in recent years and is reflected here.

Most highway economic evaluation models are structured to allow highway planners to choose between alternative design strategies. To achieve this they use economic resource prices (net of taxes and social transfers) and not the various financial inputs required for a comparative rate study. However, some of these inputs, like user taxes and fees, have already been calculated in the previous section. Therefore, traditional highway design vehicle operating cost models can be used with a slight modification to reflect overhead costs.

After a comprehensive literature review, two approaches were adopted for the I-80 study. First, a traditional base set of vehicle operating costs using well-known relationships, initially developed by Zaniewski for highway design work, was predicted (5). These were first prepared in 1982 and have subsequently been updated as a part of an NCHRP project (6). These methods predict both fixed and variable costs and allow a basic operating cost per mile of travel to be determined, excluding profitability and social transfers such as state taxes. As a consistency check, a second approach examined truck costs predicted from a model developed for the Association of American Railroads (AAR) to examine policy tradeoffs between various commodities and modes, particularly truck and rail.

Vehicle Operating Cost Predictions

First examined was a set of vehicle operating costs requiring the geometric characteristics of I-80 as input. The methodology for the calculation of the vehicle operating costs is relatively simple. Each of the vehicle operating cost components (as described below) are calculated for 1,000 mi of travel using the NCHRP equations, which are then multiplied by 1989 unit prices in order to obtain the operating cost per 1,000 mi for each component. The sum of these component costs is the total vehicle operating cost.

Zaniewski's relationships were used to predict four truck types with the following gross vehicle weights: single unit two-axle, 12,000 lbs; single unit three-axle, 35,000 lbs; four-axle semi-trailers, 40,000 lbs; and five-axle semi-trailers, 62,500 lbs. The five-axle semi-trailer (or 18 wheeler) is a critical vehicle in these calculations, accounting for nearly 87 percent of the ton-miles on I-80.

Truck operating costs derived from the Zaniewski relationships were found to be inconsistent for negative grades (5). Accordingly, tangent (zero-grade) sections and positive 3 percent grades were averaged to produce an appropriate figure for rolling terrain. The initial results from the basic equations did not report all items, like interest charges and driver salaries. Consequently, revisions were necessary, including removal of user fees and taxes, more accurately estimated in this study for the I-80 corridor. The selected components predict a total cost-per-mile of 58 cents for a two-axle single unit, 79 cents for three-axle single units, 90 cents for four-axle semi-trailers, 93 cents for five-axle semi-trailer units, and $1.13 for five-axle multi-trailer units.

The results from the highway design models were next compared with predictions from the AAR intermodal policy truck cost model. The truck cost model is interactive, allowing the user to select commodity type, shipment size, and length of haul. Model output includes total cost for the selective movement in dollars, dollars per ton, cents per mile, and cents per ton-mile.

A base case was developed using a detailed range of inputs reflecting the differences between company and owner-driver vehicle. Owner-drivers are unable to get the price discounts on new vehicles offered to companies, and also prefer more options, which raises the purchase price ($60,010 for company versus $81,415 for the owner-driver) and, therefore, the cost per ton-mile estimates. There are other significant input differences between company and owner-driver vehicles. As an example, the five-axle semi-trailer driver wages are higher for company than owner-driver operations, $33,583 versus $30,066 per year; fuel consumption is slightly better (5.8 versus 5.4
mpg) for reasons not explained in the model; and tractor maintenance is 2 cents per mile higher for owner-drivers, which again is somewhat unexpected.

The results show that company costs for five-axle single 48-ft trailer units are 96 cents per mile, compared with $1.03 for owner-drivers. These translate into $14.67 and $15.70 per ton, or 4.70 and 5.03 cents per ton-mile, for company and owner-driver operations, respectively. The highway design model predictions for five-axle trucks and those from the AAR models are similar, 93 cents per mile from the highway design models and 96 cents per mile from the AAR models.

For the purposes of this research, the highway design vehicle operating cost predictions are reported in the systems cost matrix.

**EXTERNALITIES**

**Economic Cost of Truck Accidents**

In evaluating the economic costs of truck-related accidents, at least five major cost components need to be addressed: (a) accident damage of all types, (b) time delay costs to other users, (c) fuel and operating costs, (d) clean-up costs associated with accidents; and (e) emergency and police costs attributed to trucking operations.

**Accident Costs**

Accident costs consist of all property damage and injury-related costs such as lost income, medical expenses, and pain and suffering. The PennDOT accident data base for I-80 is used with annual averages determined from time series data during a 5-year period. There was an average of 488 serious truck accidents per year on I-80 during the period 1985–1989, classified into five categories ranging from property damage only to fatalities. PennDOT costs for each category were used to determine a total 5-year truck cost impact of $139 million. This averages to $27.7 million per year for the entire I-80 route or $89,208 per mile per year.

Examining all reported I-80 accidents during the 5-year period yields a value of $157,000 per mile per year, partly because of the large number of costly fatalities (109) and major injuries (235). Results from other urban studies show that the average annual cost per mile for urban truck accidents was $182,000 compared to this study's estimate of $89,208 for rural interstate travel. This shows the magnitude of rural and urban accident impacts, and demonstrates that the I-80 data appear consistent with national figures.

**Delay Costs**

Delay costs are defined as the monetary value of occupant time lost as a consequence of delay imposed by truck-related incidents. Only delay created during the accident period or incident is attributable to vehicle-related incidents. Thus, delay at normal peak period congestion must be removed from delay calculations. In this study, an adjusted medium value of $4.25 per hour was employed for automobile occupant time, which approximates to the U.S. current minimum wage.

This value was multiplied by 1.3 for every vehicle to compensate for average vehicle occupancy. Similar, a value of $25.00 per truck-hour with no occupancy adjustment factor was used, which approximates the national average for driver salary and overhead. An average delay of 13 min per vehicle, per truck accident, was applied to estimates of the affected traffic volume per vehicle category (7). The 488 average annual truck accidents on I-80 result in a total delay costs of approximately $1.5 million, which when divided by the route miles gives an annual figure of $4,853 of delay costs per mile of highway attributable to truck accidents.

**Vehicle Operating Costs**

Additional vehicle operating costs are created when congestion results from incidents. The primary component of additional vehicle operating costs caused by truck accidents, is increased fuel consumption resulting from delay and speed-cycle changes. The estimated increased operating cost of $947 for 17.4 minutes of delay (7) was adjusted to reflect the I-80 delay estimate of 13.2 min per affected vehicle, resulting in an operational cost of $718 per truck accident. Taking the average number of accidents (488) and dividing by route-miles results in an average of $1,127 per mile of highway.

**Cleanup Costs**

Cleanup costs are defined as the costs to public agencies and private organizations for removing accident debris from the roadway and returning the roadway to serviceable condition. The cleanup costs resulting from truck accidents vary drastically according to the type of accident and the cargo being transported and are difficult to determine. The California Department of Transportation estimated that the 6,700 to 8,000 annual truck accidents on the Los Angeles County Freeway System cost from $500,000 to $2,000,000 for cleanup (7). Employing these data results in an approximate cost of $250 per accident which for I-80 would give a total of $122,000 for the 488 annual truck accidents, or $392 per mile of highway.

**Emergency and Police Costs**

There is no dedicated highway patrol system for I-80, so the analysis is based on alternative sources. Costs attributed to the Pennsylvania Turnpike are comparable to the I-80 corridor, and their data reported a cost of $10,898,000 for 1989 Highway Patrol activities, excluding costs associated with truck-weight enforcement. I-80 costs per mile were estimated from the average 1989 cost of $14,022 per mile for the Pennsylvania Turnpike Highway Patrol.

**Total Truck-Accident-Related Costs**

Total estimated truck-accident costs from the preceding categories amounted to an average cost per mile of highway of $109,602 for I-80. Expanding this annual per mile cost estimate over the 311 mi of I-80 results in a total annual route cost of about $34 million.
The nitrogen oxides emissions limit was reduced to 6.0 g/BHP-hr level. New particulate limits for trucks of 0.25 g/BHP-hr are scheduled to take effect in late 1991, with a revised limit of 0.1 g/BHP-hr for 1994. Because these limits only apply to new units, it will be some time before all vehicles can comply with the cleaner standards. In the meantime, truck engines will show a wide range of emissions performance.

Using the vehicle ton-miles of travel calculated in the traffic section of this study, some broad estimates can be made about I-80 truck emissions for four key diesel truck pollutants: hydrocarbons, carbon monoxide, nitrogen oxides, and particulate matter. These are presented in Table 3, which estimates 29,648 tons of pollutants annually from truck traffic on I-80. Currently, it is difficult to place monetary values on such pollutant levels, particularly as I-80 in Pennsylvania does not pass through a nonattainment area. Air pollution of the type generated by truck traffic has always been treated as an externality, although this view is rapidly changing with the recent federal air quality legislation. Although this study does attempt to value the truck pollution monetarily, it has reported it as a nonmonetary social burden.

### CONCLUSIONS

In this final section, system cost inputs from the previous sections are combined to identify both supported and incurred system truck costs over the I-80 corridor. A limitation of traditional highway cost and revenue analyses (as seen in most highway cost allocation methodologies) is that important costs related to transportation operations are excluded. This limitation has significant ramifications when evaluating and comparing the cost of intermodal freight operations. Failure to consider all economic costs associated with transportation operations can lead to inefficient public and private investment in freight infrastructure.

Table 4 presents a summary of the supported system costs for I-80 on the basis of cost per ton-mile of freight and average truck costs per mile assuming a 13.25 average ton payload. Additionally, five-axle tractor and semi-trailer costs per mile of travel (13.5 ton payload) are shown. The five-axle tractor and semi-trailer is the predominant vehicle operating on the I-80 corridor. Under existing policy, supported system costs include vehicle operating costs and user taxes and fees (the vehicle operating costs for using the highway facilities). On average, trucks paid 8 cents per ton-mile or $1.07 per mile of travel in 1989. The predominant five-axle vehicle paid only slight less, $1.06/mile of travel. These supported system costs are the expenses currently paid by truck operators.

Table 5 presents a summary of the incurred system costs. Unlike supported system costs, actual costs to the facilities are used in place of the user taxes and fees paid by truck operators. Additionally, accident externalities are included. (Emissions should be included as a cost, but are reported separately for reasons stated previously.) Not surprisingly, the incurred truck system costs are higher. Actual facility costs are 123 percent higher than the paid truck user taxes and fees. Externalities (i.e., accidents and related costs), amount to 0.5 cents per ton-mile or about 7 cents per mile of highway travel.

Comparing the incurred system costs with the supported system costs results in a truck subsidy of 1.7 cents per ton-mile or 23 cents per mile of truck travel. In total dollar amounts, this results in an annual truck subsidy of about $458,741 over the I-80 corridor in 1989 dollars. (Life cycle facility costs are converted to an annual amount based on a 7 percent annuity for 25 years.)

Absent from these monetary results is the issue of emissions, since there is as yet no agreed methodology for calculating such costs. The average five-axle truck emits about 4 g of pollutants (hydrocarbons, carbon monoxides, nitrogen oxides, and particulates) per mile of travel on I-80. Since this

### TABLE 3 I-80 Truck Emissions

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Emissions</th>
<th>Grams (ton-mi)</th>
<th>Annual (tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrocarbons (HC)</td>
<td>0.292429</td>
<td>0.03</td>
<td>2,128</td>
</tr>
<tr>
<td>Carbon Monoxide (CO)</td>
<td>0.038110</td>
<td>0.03</td>
<td>6,098</td>
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<tr>
<td>Nitrogen Oxides (NOx)</td>
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</tr>
<tr>
<td>Particulate Matter (PM10)</td>
<td>0.358813</td>
<td>0.15</td>
<td>2,611</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td></td>
<td><strong>29,648</strong></td>
</tr>
</tbody>
</table>

* Based on diesel-powered trucks exceeding 20,000 lbs gross vehicle weight.
  ‡ Based on 6.6 billion annual diesel ton-miles on I-80.

### TABLE 4 Truck-Supported System Costs

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Cost per Ton-Mile of Freight</th>
<th>Cost per Mile of Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Trucks</td>
<td>$1.0100</td>
<td>$1.1325</td>
</tr>
<tr>
<td>5 Axle Combinations</td>
<td>$1.0706</td>
<td>$1.2514</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$0.0806</td>
<td>$1.0680</td>
</tr>
</tbody>
</table>

### TABLE 5 Truck-Incurred System Costs

<table>
<thead>
<tr>
<th>Cost Category</th>
<th>Cost per Ton-Mile of Freight</th>
<th>Cost per Mile of Travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Trucks</td>
<td>$0.2223</td>
<td>$0.2955</td>
</tr>
<tr>
<td>5 Axle Combinations</td>
<td>$0.7060</td>
<td>$0.9355</td>
</tr>
<tr>
<td>TOTAL</td>
<td>$0.9790</td>
<td>$1.2973</td>
</tr>
</tbody>
</table>
highway does not pass through an Environmental Protection Agency (EPA) nonattainment area, the dispersion problem is unlikely to be a significant issue, with the important exceptions of global warming and acid rain. It remains an unpalatable fact that trucks produce around 30,000 tons of pollutants annually along the I-80 alignment in Pennsylvania, an issue which may be of growing concern to the state in the 1990s.

To summarize, truck traffic on the Pennsylvania section of I-80 is not paying the full costs of sustaining the system for the operation of heavy vehicles. The key underpayment is in funding the facility costs through user taxes and fees, and this deficit is compounded by operating cost externalities imposed on other users and entities. Operating costs per mile for trucks need to be increased by around 22 percent to maintain the truck freight operations over I-80 in Pennsylvania without subsidies. The increase in truck user contributions is necessary to achieve full economic and equitable modal competition.

ACKNOWLEDGMENTS

This report represents the first phase of a research project by TRDF for CONRAIL, Inc. A second phase analyzing the rail system costs was also completed by the above authors. For a more comprehensive report of the entire study, see Truck Versus Rail Freight System Cost Comparison: Conrail and I-80 Pennsylvania Corridors, TRDF, September 30, 1991.

REFERENCES


The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of TRDF or CONRAIL.

Publication of this paper sponsored by Committee on Transportation Economics.