haul fare levels plus low price elasticity of demand. In intrastate markets, low fares have coincided with high price elasticity.

SUMMARY AND CONCLUSIONS

This analysis has considered smaller air service points whose profitability to a carrier might be marginal or nearly marginal even with allocated intermarket revenues. It has been implicitly assumed that such markets would support only one carrier. (Macon is in fact served by two federally certificated carriers, Delta and Eastern, which between them fly several daily flights.) For larger points—small or medium hubs—the principle of intermarket relations remains the same but the profits accruing from traffic to beyond areas lead carriers to compete for these revenues. It is thus conceivable that a medium hub providing a great deal of feed traffic might receive extensive service even though many of the segments served from that hub do not directly generate enough revenue to cover fully allocated accounting costs.

The clear result of current pricing strategy in the competition for feeder traffic is the existence of joint fares and common-point fares. The reason for these pricing practices is, of course, to encourage feeder traffic from short-haul markets to long-haul markets.

As a result of the analysis we have concluded that

1. Determining whether or not economic cross subsidization exists between or among one or a group of markets and one or another group of markets is more an issue of revenue allocation between and among the respective markets than it is an issue of allocation costs;
2. The economic threshold where cross subsidization begins in a particular market is as much related to the definition of the product as it is to the definition or allocation of accounting costs;
3. The domestic airline business is somewhat unique in that profits from hub-to-hub service in large-volume markets are partly a function of service from the origins and destinations to smaller hubs in beyond areas (the telecommunications industry is conceptually similar);
4. Current joint fares and common fares, both of which reduce the costs of on-line connecting and interline connecting passengers traveling from smaller points over large hub-to-hub service, provide ample evidence of the value in larger markets of the passenger revenue that is a function of service to smaller points; and
5. On-line and interline connecting passengers clearly are highly valued under the current conditions of limited competition and intensive regulation; the value of these passengers will undoubtdely increase conditions of greater competition and less economic regulation (as a result, because an even more intensive effort will be made to control the flow of connecting passengers at major hubs, extensive abandonment of smaller hubs will not occur).

ACKNOWLEDGMENT

The views expressed in this paper are ours and do not necessarily represent the official views of the U.S. Department of Transportation.

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Allocating Highway Program Costs to Washington State Highway Users

Dennis Neuzil, Transportation Development Associates, Inc., Seattle

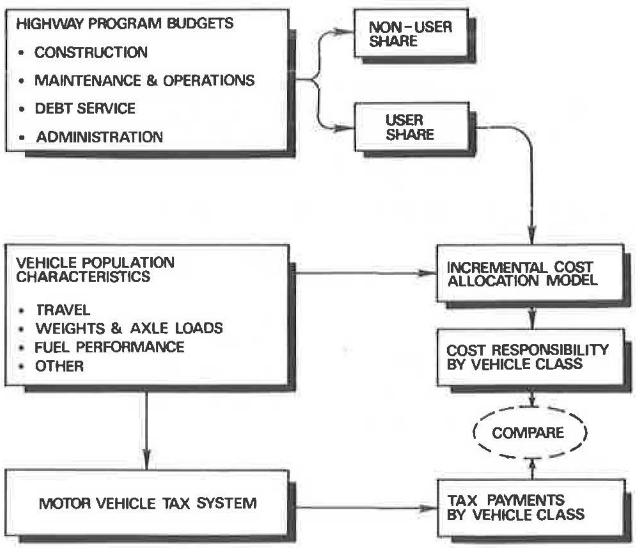
This paper analyzes a Washington State highway cost-allocation study that determined road-user cost responsibilities for support of the state-aided highway program at both the state and local levels. The study used an incremental cost-allocation model for over 350 individual highway user subclasses correlated with vehicle type, use class, power type, and registered gross vehicle weight. Cost responsibilities for alternative funding programs were compared with user tax payments to assess equity performance. There is considerable variance among vehicle classes in the degree to which tax payments meet cost responsibility. The automobile consistently fails to meet its cost responsibility, trucks generally attain measures of equity comparable to that of the automobile, and intercity buses generate the lowest level of tax payment relative to cost responsibility. Equity performance among trucks varies with engine power type and use class; commercial-class and gasoline-powered trucks generally attain the highest equity levels. Cost responsibility for heavier vehicle subclasses varies significantly with changes in budget composition. The proportion of the budget devoted to construction—and in particular to pavement—is a prime factor. The sensitivity of the results to allocation model variations and input data is also addressed.

In the state of Washington, as throughout the nation, mounting highway construction and maintenance costs, heavier trucks, and the impact on revenue flow stemming from energy shortages and rising fuel costs have gen-

erated numerous proposals for raising existing highway user taxes and instituting new taxation devices. Equity for the various classes of highway users is one of the first considerations in assessing proposed tax changes, and appraising the equity of the existing user tax structure is a logical first step in this process. The most technically challenging task is determining, for each class of road user, its fair share of the cost of the highway program in comparison with its user tax payment.

Among the charges to the transportation tax study undertaken in Washington State was the execution of a highway cost-allocation study. The share of the state's highway development program attributable to each highway user type (or class of vehicle) was to be compared to its user tax contribution. Such a study had been conducted in Washington in the mid-1960s (1), but, in view of significant changes since that time in vehicle user characteristics and in the composition and funding process of the highway program, an update study was considered essential (2, 3, 4). Figure 1 shows the essential steps of the highway cost-allocation study.

Figure 1. Study process.



HIGHWAY PROGRAM EXPENDITURES

Allocable Costs

Highway program costs assigned to the state's highway users include only those expenditures supported by the state motor-vehicle fund. Expenditures by the state motor-vehicle fund for county and city road programs were included, but federal-aid and non-user-funded road and street support were excluded. Conversely, only state highway user taxes were included in the analysis of tax payment equity.

In Washington the user-nonuser proportions of total highway expenditures have remained relatively constant in recent years. The state-administered highway program is wholly funded by user tax funds. In contrast, only one-third of the city and county program derives overall from user taxes. The balance of the local program is funded from traditional local revenue sources; property tax revenue is the principal source.

Arguments have been made for apportioning part of the cost of the highway program to nonusers—the general public—because of the indirect public benefits of an adequate street and highway system. Various methods have been advanced for determining the user-nonuser split, but considerable disagreement exists as to their validity and relative merits. The approach described here is considered a reasonable and conservative approach to the problem.

Expenditure Elements

In Table 1, allocable expenditures for the "desirable" 4-year program budget on which the cost-responsibility re-

Table 1. 1978 to 1981 desirable program budget for highway user funds.

	Expenditure by Governmental Level ($000s)			
Agency Type and Activity	State	County and City	Total	Percentage of Total
Highway				
Construction				
Pavement and shoulders	146 530	258 070	404 600	30.8
Bridges	58 980	20 090	79 070	6.0
Grading and drainage	75 600	31 960	107 560	8.2
Other	94 730	69 050	163 780	12.5
Subtotal	375 840	379 170	755 010	57.5
Maintenance				
Pavement and shoulders	13 430	–	13 430	1.0
Other	205 900	–	205 900	15.7
Subtotal	219 330	–	219 330	16.7
Administration	90 770	–	90 770	6.9
Total	685 940	379 170	1 065 110	81.1
Nonhighway				
Puget Sound ferry system	57 450	–	57 450	4.4
State patrol				
Weigh-station operations	10 150	–	10 150	0.8
Other	129 850	–	129 850	9.9
Subtotal	140 000	–	140 000	10.7
Department of Motor Vehicles	40 000	–	40 000	3.0
Other state agencies	10 000	–	10 000	0.8
Total	247 450		247 450	18.9
Total expenditures	933 390	379 170	1 312 560	100
Annual average	233 347	94 793	328 140	

sults in this paper are based are broken down by agency, activity, and governmental level. Note that construction represents only 58 percent of the total $328 million average annual expenditure. Construction and maintenance expenditures were allocated to road users according to their use of the five functional classes of state highways and county and city arterials.

Program Budget Levels

Since mid-1974 the Washington cost-allocation study has treated eight program budgets, or funding levels, ranging from $260 million to $560 million on an annual basis. The budgets varied from the lower dollar levels of sharply scaled-back programs associated with revenue projections made soon after the energy crisis, through precrisis program levels, to the maximum level associated with the traditional needs program. Budget composition also varied in relation to distribution among highway functional classes and construction-nonconstruction sectors, as well as in assumptions concerning inflation. The budgets analyzed were 2, 4, and 6-year budgets covering the 1976 to 1981 fiscal period.

TAX PAYMENTS

Projected tax payments were produced by the computerized vehicle revenue model of the Washington State Department of Highways. A single forecast of motor-vehicle-fund tax payments, based on the energy crisis revenue forecast, was used for comparison with cost responsibilities for the treated program budgets. Of the $230 million aggregate revenue, 71 percent derives from taxes on motor fuel and the balance from motor-vehicle fees and miscellaneous revenues. Fuel tax accounts for 81 percent of the total annual user tax payment for automobiles; for trucks, fuel tax typically accounts for only about 60 percent of the total payment and most of the balance is generated by fees on gross vehicle weight. Motor-vehicle fees for trucks vary according to use class—commercial, farm, log, and miscellaneous—and power type—gasoline, diesel, and propane.

CHARACTERISTICS OF THE VEHICLE POPULATION

Comprehensive data on characteristics of the vehicle population are a basic input to the cost-allocation process. For purposes of cost allocation (and analysis of tax payments), the vehicle population consists of over 350 individual subclasses based on vehicle type (visual class), registered gross vehicle weight (GVW), use class, and engine power type. Table 2 gives a profile of the projected 1978 vehicle population by 15 basic vehicle types. A relatively small number of tax-exempt (public) vehicles are omitted from the basic cost allocation. Out-of-state trucks and buses licensed to travel in the state of Washington are converted to equivalent in-state vehicles based on the amount of their annual travel on Washington highways.

The percentage distribution of the 15 basic vehicle types and their share of total travel in the state is noteworthy, particularly for later comparisons of aggregate cost responsibility and tax payment by vehicle type. The dominance in numbers and in total travel of light vehicles—automobiles, motorcycles, and two-axle, four-tire, single-unit trucks (pickup and light panel)—is evident: Collectively they account for 96 percent of the vehicle population and 91 percent of total travel.

Trucks are licensed and taxed according to use class and power type. Ninety-two percent of the truck population falls in the commercial class, 6 percent are farm class, and the log and miscellaneous classes each compose less than 1 percent of the total truck population. Log trucks, however, make up one-third of the state's most populous heavy truck class: the five-axle tractor-semitrailer. Ninety-seven percent of the truck population is gasoline-powered but 84 percent of truck-trailers (the last three vehicle types in Table 2) are diesel-powered.

Data on vehicle operating weight and axle load are important determinants of cost responsibility. Truckload data were obtained from the 1974 and 1975 annual highway load surveys, each of which surveyed nearly 2700 trucks. The observed frequency distributions of axle loads and operating weights were input directly to the cost-allocation model; empty, part-load, and fully loaded vehicle operations were thus accounted for. Individual load profiles were used for each vehicle type classified by GVW. Because of survey limitations, truck use class was not differentiated except in the case of the heavy, log-hauling, semitrailer truck. While 32 660 kg (72 000 lb) is the regular maximum GVW, some heavy three-axle trucks and many large five-axle combination trucks are licensed to operate routinely at heavier weights under overweight permits.

METHODOLOGY

Concept of Incremental Cost

The incremental cost method used in this study is today generally considered to be the most conceptually valid method for highway cost allocation. It requires, however, an extensive data base and a rigorous analytical framework, which combine to create a somewhat formidable and time-consuming exercise.

The central thesis of this method of highway cost allocation is that each vehicle type or class of highway user shall bear the cost it occasions in the construction, maintenance, and operation of the highway system. The cost of the structural and geometric highway elements necessary to bear the load of a given vehicle and to accommodate it in the traffic stream is properly assignable to that vehicle and all other vehicles having the same requirements and is assigned on the basis of relative use.

Consider a simplified example for pavement construction requirements and associated construction cost in which uniform vehicle populations consisting of light, medium, and heavy vehicles are assumed. A minimal pavement thickness, the first increment of pavement thickness, would be adequate to carry the light loads imposed by the light vehicle class. The cost responsibility of light vehicles should therefore be restricted to a share of the cost of this first increment of thickness. Because medium and heavy vehicles also require this first thickness increment, they must also bear a share of its cost. The cost of the first increment is distributed to each of the three vehicle classes based on their proportion of total axle kilometers of travel by all vehicles. A second increment of pavement thickness is required to accommodate vehicles of medium weight; the cost of this increment is shared with the heavy vehicle class, which also requires a pavement increment thicker than the first increment required by light vehicles. The heaviest vehicle class bears the entire cost of the third or final increment of thickness, a cost that would not occur if this vehicle class were not present in the traffic stream. Total pavement cost responsibility for the heavy vehicle class is determined by adding its use-proportioned share of the first two increments to the third increment for which it is solely responsible. The incremental cost system is thus the result of a repeated redesign process that accommodates successively heavier classes of vehicles

up to the vehicle class of maximum weight (axle load).

Some nonconstruction highway program costs also have an incremental nature. For example, the cost of truck weigh-station operation is properly assignable to those truck classes (essentially all dual-tired trucks) that are monitored by this operation.

Procedure

The incremental cost procedure requires examination of all major program costs to determine the portion of those cost elements, such as pavement and bridge construction, that are dictated by specific motor-vehicle characteristics such as axle load, gross operating weight, axle pattern, and vehicle geometry. Parameters must be determined for distributing these cost increments among the responsible vehicles. Axle kilometers and vehicle kilometers of travel and vehicle type and vehicle registrations, which are the typical cost-allocation parameters, were used in this study. Program costs that are basically nonincremental in nature, e.g., traffic signing, roadside maintenance, motor vehicle administration, and highway policing, are allocated equally to all vehicle classes per kilometer of travel or per registered vehicle, as appropriate.

Each vehicle type is assigned a share of the costs of individual highway systems based on its travel on those systems and its operating weight and axle-load profile, which are taken from the highway load survey. Non-system-specific costs (e.g., the vehicle licensing program) are assigned by travel rate or on a flat per-vehicle basis by cost item. Determinants of cost-allocation increments for various program costs are given in Table 3.

The incremental cost model used in this study is a synthesis of the methodology developed by the Washington State Highway Commission for the 1967 cost-allocation study (1) and methods of the U.S. Bureau of Public Roads and the Federal Highway Administration (5, 6) that were developed in the early 1960s and reflect the results of the comprehensive AASHO Road Test of highway pavements and bridges. Several modifications and refinements developed by the study consultants were incorporated, and pavement cost increments were updated by the Washington State Department of Highways for use in the most recent budget runs.

The first cost increment for each program cost, which is shared equally (e.g., per kilometer or per axle kilometer of travel) by all vehicles regardless of vehicle size or weight, can be referred to as the nonweight increment or nonweight cost. Weight cost refers to all succeeding increments because these are shared only by vehicles heavier than the lightest vehicle classes (automobiles, motorcycles, and pickups). When these weight and nonweight proportions were applied to the program cost elements, it was found that, depending on program budget, nonweight costs make up 80 to 85 percent of total program costs. Heavy vehicles alone were thus assigned the 15 to 20 percent weight portion of total program cost, as well as a share of the nonweight portion. However, the relatively small number of such vehicles, combined with their typical high travel rates, results in very high cost responsibilities for heavier vehicles as compared to most light vehicles.

RESULTS

Table 4 gives the average annual cost responsibility and tax payment per vehicle for each of the 15 basic vehicle types for the program budget given in Table 1. These are average values that afford a good overview of comparative cost responsibility and equity performance. However, detailed results for each vehicle type subclassified by GVW, power type, and use class reveal a

Table 2. Selected characteristics of 1978 vehicle population.

Vehicle Type	Vehicles		Annual Travel in State	
	Number	Percent	Percentage of Total	Kilometers per Vehicle
Automobile	2 072 548	70.88	76.63	15 800
Taxi	1 244	0.04	0.47	160 500
Public bus (intercity type)				
2-axle	734	0.03	0.19	113 900
3-axle	50	—	0.02	134 100
Private bus	4 501	0.15	0.13	12 500
Motorcycle	152 592	5.22	2.47	6 900
Single-unit truck				
2-axle, 4-tire	578 107	19.77	11.72	8 700
2-axle, 6-tire	87 274	2.98	3.84	18 800
3-axle	7 590	0.26	1.07	60 200
Tractor-semitrailer				
3-axle	2 564	0.09	0.24	39 600
4-axle	2 338	0.08	0.21	39 300
5-axle	10 499	0.36	2.04	82 900
Truck-trailer				
4-axle	144	0.01	0.04	111 700
5-axle	1 951	0.07	0.53	115 600
Tractor train	1 722	0.06	0.40	99 100
Total	2 923 858	100	100	

Note: 1 km = 0.62 mile.

Table 3. Incremental cost allocation for various program costs.

Expenditure	Increment Determinant	Number of Increments	Cost in First Increment (%)	Allocation Parameter
Construction				
Pavement and shoulders	Observed axle load	9 to 11[a]	32 to 52[a]	Axle kilometers
Bridges	Observed gross operating weight	17	86	Vehicle kilometers
Grading and drainage	Observed gross operating weight	2	91	Vehicle kilometers
Other	Nonincremental	1	100	Vehicle kilometers
Maintenance				
Pavement and shoulders	Observed axle load	9 to 11[a]	32 to 52[a]	Axle kilometers
Other	Nonincremental	1	100	Vehicle kilometers
Department of Highways, other	Nonincremental	1	100	Vehicle kilometers
Debt service	Incremental[b]			
State ferry system	Vehicle type	2	95	Vehicle registrations
State patrol				
Weigh-station operations	Trucks with dual tires	1	100	Vehicle kilometers
Other	Nonincremental	1	100	Vehicle kilometers
Department of Motor Vehicles				
Fuel tax administration	Power type	—	—	Vehicle kilometers
Other	Nonincremental	1	100	Vehicle registrations
Other state agencies	Nonincremental	1	100	Vehicle kilometers

[a] Varies with highway class. [b] The majority of debt service is for highway construction and is allocated accordingly.

fairly wide range of values about the averages presented here; those results are discussed later in this paper.

Light vehicles are seen to have annual cost responsibilities ranging from $31 for motorcycles to $94 for automobiles. An exception is the taxi: Its high cost responsibility stems from a high annual travel rate, nearly 10 times that of the private automobile. Medium-weight trucks show cost responsibilities of $400 to $1200, and cost responsibilities for heavy five-axle trucks range from $2800 to $4500, or 30 to 50 times that of the automobile. Public buses of the intercity type, with their relatively high average axle loads and high annual travel rates, have cost responsibilities comparable to the heaviest trucks; the annual cost responsibility of the large three-axle public bus is $4800, more than that of any other vehicle type. These annual cost responsibilities translate to unit travel cost responsibilities ranging from about 0.6 cents/km (1 cent/mile) for light vehicles, 1.2 to 2.5 cents/km (2 to 4 cents/mile) for medium-weight vehicles, and 2.5 to 3.7 cents/km (4 to 6 cents/mile) for the heaviest vehicles.

Table 4. Annual per-vehicle cost responsibility and tax payment by vehicle type.

Vehicle Type	Annual Cost Responsibility per Vehicle ($)	Annual Tax Payment per Vehicle ($)	Cost Less Tax ($)	Tax/Cost Ratio ($)
Automobile	94	64	30	0.68
Taxi	531	909	378	1.71
Public bus (intercity type)				
2-axle	2200	706	1494	0.32
3-axle	4798	1283	3515	0.27
Private bus	85	81	4	0.95
Motorcycle	31	18	13	0.58
Single-unit truck				
2-axle, 4-tire	69	63	6	0.91
2-axle, 6-tire	344	212	132	0.62
3-axle	901	846	55	0.94
Tractor-semitrailer				
3-axle	1172	695	478	0.59
4-axle	1095	875	221	0.80
5-axle	2805	1862	943	0.66
Truck-trailer				
4-axle	3016	1725	1291	0.57
5-axle	4467	2083	2381	0.47
Tractor train	2927	1898	1029	0.65

Table 4 also shows annual user tax payments for the basic vehicle types. Ratios of heavy-vehicle tax payments to automobile tax payments are somewhat less than cost-responsibility ratios; tax-payment ratios for the heaviest vehicles range from 20 to 30 times those of the automobile.

Cost Responsibilities Versus Tax Payments

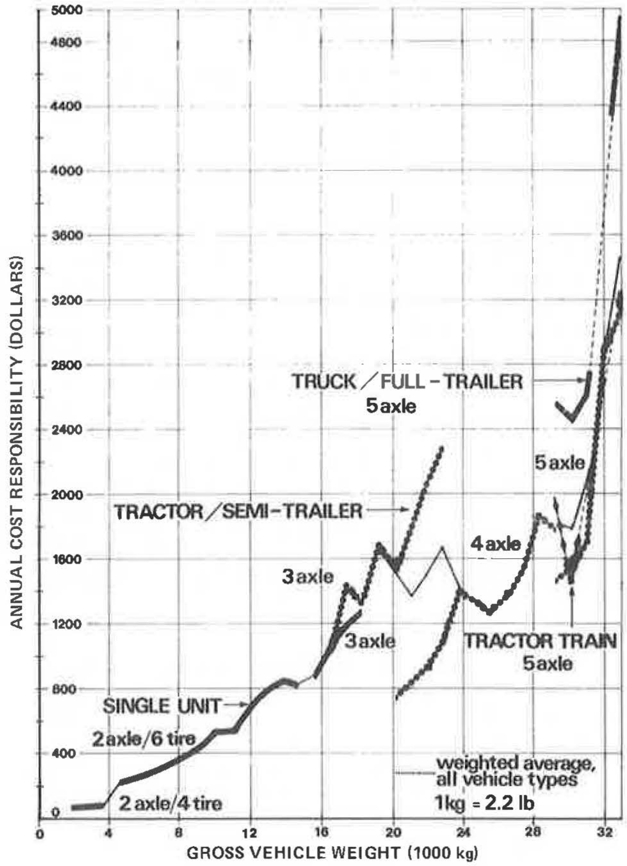
Evaluating the equity of the tax structure for motor-vehicle users requires a comparison of user tax payments to cost responsibilities. The difference between tax payment and cost responsibility, and particularly the ratio of tax payment to cost responsibility, are of concern here. The tax/cost ratio provides the single best measure for equity comparisons among various users. The dollar difference scales the potential financial impact on the individual user if the tax system were to be altered to eliminate or reduce inequities (Table 4). The $64 annual automobile tax payment falls $30 short of its annual cost responsibility, which is $94. Medium truck classes have tax-payment shortfalls of $100 to $500, and tax payments for heavy trucks fall $1000 to $2400 short of their assigned costs. Heavy intercity buses fail to meet cost responsibilities by as much as $3500/year. Only the taxi shows a tax overpayment—nearly $400 in excess of its annual cost responsibility. The prevalence of tax-payment shortfalls partly results from the fact that the subject program budget ($328 million) exceeds total revenue ($230 million) by $98 million/year. Tax/cost ratios given in Table 4 show that the automobile tax payment covers only 68 percent of the automobile cost responsibility for this program budget but tax payments for trucks range from 50 percent to over 90 percent of their cost responsibilities.

In Table 5, cost responsibilities and tax payments are aggregated by vehicle class and the difference between them is given. The percentage distributions of cost and tax payment relative to total program cost and total tax revenue respectively are also given. Thus, Table 4 gives a tax payment per automobile that is $30 less than cost responsibility, and Table 5 translates this to a $61 million shortfall by vehicle class (roughly 2 million automobiles times a shortfall of $30/vehicle). Per-vehicle tax shortfalls for heavy truck classes amount to an aggre-

Table 5. Aggregate annual cost responsibility and tax payment by vehicle class.

Vehicle Class	Annual Cost Responsibility		Annual Tax Payment		Cost Less Tax ($000s)
	Amount ($000s)	Percentage of Total Program Cost	Amount ($000s)	Percentage of Total Tax Payment	
Automobile	193 828	59.07	132 643	57.68	61 185
Taxi	661	0.20	1 131	0.49	470
Public bus (intercity type)					
2-axle	964	0.29	309	0.13	655
3-axle	1 655	0.50	443	0.19	1 212
Private bus	383	0.11	365	0.16	18
Motorcycle	4 784	1.46	2 747	1.19	2 037
Single-unit truck					
2-axle, 4-tire	39 787	12.12	36 430	15.84	3 357
2-axle, 6-tire	30 029	9.15	18 503	8.05	11 526
3-axle	6 837	2.08	6 418	2.79	419
Tractor-semitrailer					
3-axle	3 006	0.92	1 782	0.77	1 224
4-axle	2 560	0.78	2 046	0.89	514
5-axle	29 459	8.98	19 554	8.50	9 905
Truck-trailer					
4-axle	434	0.13	248	0.11	186
5-axle	8 715	2.65	4 064	1.77	4 651
Tractor train	5 040	1.54	3 269	1.42	1 771
Total	328 142	100	229 952	100	98 190

Figure 2. Annual cost responsibility versus registered gross vehicle weight for commercial diesel-powered trucks.



gate shortfall of $2 million to $10 million, depending on class, in spite of the small population of these trucks.

Table 5 underscores the fact that even fairly substantial tax-payment increases among selected vehicle types will not bring tax revenues into balance with the projected program budget unless the more populous vehicle classes are involved. Four of the 15 basic vehicle types—the automobile; the two-axle, four-tire truck; the two-axle, six-tire truck; and the five-axle tractor-semitrailer—in the aggregate account for 90 percent of both program cost responsibility and revenue and 94 percent of the vehicle population (Table 2).

The findings in Table 5 and the vehicle population characteristics given in Table 2 provide insight into relationships among vehicle population and use, cost responsibility, and tax revenue. Although the automobile represents over 71 percent of the total vehicle population and 71 percent of total statewide travel, it is assigned only 59 percent of total program cost and generates only 58 percent of total user tax revenue. In contrast, the popular five-axle tractor-semitrailer collectively accounts for only 0.4 percent of the vehicle population and 2 percent of systemwide travel but 9 percent of program cost and 8.5 percent of total user tax revenue.

Effects of Vehicle Subclass Characteristics

The analysis of 15 vehicle classes presented above provides an overall assessment; the following analysis reviews the results for a number of common vehicle subclasses, alternatively holding constant variables such as use class and power type to reveal the effect of these factors on cost responsibility and equity.

Table 6. Annual cost responsibility and tax payment for three truck classes and combinations of vehicle type, power type, and gross vehicle weight.

Truck Class and Type	GVW (kg)	Engine Power Type	Annual Cost Responsibility ($)	Annual Tax Payment ($)	Cost Less Tax ($)	Tax/Cost Ratio (¢)
Commercial						
Single-unit						
2-axle, 6-tire	12 700	Gasoline	660	390	270	0.59
		Diesel	790	410	380	0.52
3-axle	18 145	Gasoline	1050	1070	20	1.02
		Diesel	1250	1030	220	0.82
Combination						
5-axle tractor-semitrailer	32 660	Gasoline	2270	2480	210	1.09
		Diesel	3120	2130	290	0.68
5-axle truck-full trailer	32 660	Gasoline	3630	2570	1060	0.71
		Diesel	4950	2200	2750	0.44
Farm						
Single-unit						
2-axle, 6-tire	12 700	Gasoline	440	240	200	0.55
		Diesel	610	280	300	0.46
3-axle	18 145	Gasoline	630	540	90	0.86
		Diesel	1030	640	390	0.62
Combination						
5-axle tractor-semitrailer	32 660	Gasoline	1070	1140	70	1.07
		Diesel	2190	1250	940	0.57
5-axle truck-full trailer	32 660	Gasoline	–	–		
		Diesel	3480	1310	2170	0.38
Log						
Single-unit						
2-axle, 6-tire	12 700	Gasoline	500	330	170	0.66
		Diesel	570	340	230	0.60
3-axle	18 145	Gasoline	700	710	10	1.01
		Diesel	910	730	180	0.80
Combination						
5-axle tractor-semitrailer	32 660[a]	Gasoline	625	1230	605	1.97
		Diesel	2640	1500	1140	0.57
5-axle truck-full trailer	32 660	Gasoline	–	–	–	
		Diesel	–	–	–	

Note: 1 kg = 2.2 lb.

[a]Nominal GVW for a log vehicle is 30 845 kg, but allowable operating weight with overload tolerance is 33 930 kg.

Table 7. Annual cost responsibility of selected vehicle types for various program costs.

Cost	Automobile Amount ($)	Automobile Percentage of Total	Single-Unit, 2-Axle, 12 700-kg Truck Amount ($)	Single-Unit, 2-Axle, 12 700-kg Truck Percentage of Total	Tractor-Semitrailer Truck 3-Axle, 20 865-kg Amount ($)	Tractor-Semitrailer Truck 3-Axle, 20 865-kg Percentage of Total	Tractor-Semitrailer Truck 5-Axle, 32 660-kg Amount ($)	Tractor-Semitrailer Truck 5-Axle, 32 660-kg Percentage of Total
Construction								
Pavement	15.43	16.6	478.52	75.2	1 007.03	75.3	1 806.25	60.1
Grading and drainage	8.98	9.6	29.10	4.6	53.22	4.0	152.44	5.1
Bridges	6.08	6.5	18.75	2.9	43.05	3.2	244.69	8.1
Other	15.03	16.0	24.97	3.9	40.47	3.0	103.12	3.4
Subtotal	45.52	48.7	551.34	86.6	1 143.77	85.5	2 306.50	76.7
Maintenance								
Pavement and shoulders	0.52	0.5	7.63	1.2	20.81	1.5	93.19	3.1
Other	18.69	20.0	24.38	3.8	54.25	4.1	201.88	6.7
Subtotal	19.21	20.5	32.01	5.0	75.06	5.6	295.07	9.8
Total	64.73	69.3	583.36	91.7	1 218.84	91.2	2 601.58	86.6
State ferry system	4.93	5.3	11.18	1.7	11.18	0.8	11.18	0.4
Highway administraion plus state patrol	20.81	22.3	26.71	4.2	71.59	5.4	267.12	8.9
Weigh-station operations	0	0	12.17	1.9	32.61	2.4	121.78	4.0
Department of Motor Vehicles[a]	2.94	3.1	2.94	0.5	2.95	0.2	2.94	0.1
Total costs	93.41	100.0	636.36	100.0	1 337.18	100.0	3 004.60	100.0

Notes: 1 kg = 2.2 lb.
Weighted average values for all power types and use classes.
[a]Excludes cost of fuel tax collection (typically 1 to 4 percent of total cost responsibility).

Vehicle Type and Gross Vehicle Weight

Figure 2 shows the relation for trucks among annual cost responsibility, registered gross vehicle weight, and vehicle type as demonstrated by the commercial-class, diesel-powered truck. For most individual truck types, annual cost responsibilities are seen to approximately double between low and high points of the GVW range. Note that, in instances where several truck types fall within the same GVW interval, sizeable errors would occur if cost allocations were made solely on the basis of GVW without consideration of vehicle type (this is true of the current Washington State GVW fee schedule). Weighted average cost responsibility based solely on GVW is shown in Figure 2 as a light dashed curve. Cost responsibilities vary, in some instances, from $200 to $600 or more above or below the average and reach a peak in the case of the 32 660-kg (72 000-lb), five-axle truck-full trailer, which has a $5000 cost responsibility in contrast to the $3400 weighted average value for all vehicles of 32 660-kg GVW.

Use Class

Variations in cost responsibility and tax payment among truck use classes are given in Table 6 for some of the most common combinations of vehicle type, power type, and GVW. A detailed examination of the results for all truck subclasses indicates that commercial-class trucks generally have the highest cost responsibilities and tax payments, owing to high travel rates, and typically most closely approach equity in terms of the ratio of tax payment to cost responsibility.

Power Type

The general effect of power type on cost responsibility and tax payment can be seen in Table 6. Cost responsibilities for commercial diesel-powered trucks are typically about 20 percent greater than those for gasoline-powered trucks, except in the case of trucks of 32 660-kg (72 000-lb) GVW. At that weight annual diesel travel rates rise more steeply than gasoline travel rates and diesel cost responsibilities are typically 40 percent greater than gasoline cost responsibilities. Cost responsibilities and tax payments for propane-powered trucks, which are not included in the table, are generally comparable to those for gasoline-powered trucks.

Annual tax payments for most commercial gasoline-powered trucks are seen to be about 5 to 15 percent greater than those for the same type and class of diesel-powered truck; the higher percentage for the heaviest trucks represents a difference of over $300. Although the diesel truck typically travels more kilometers per year, it often achieves 50 percent more kilometers per liter than the counterpart gasoline vehicle, which results in a lower annual tax payment. In the categories of cost less tax and tax/cost ratio, gasoline-powered vehicles overall generally come closer to ideal equity than do diesel-powered trucks.

Cost Responsibility for Selected Vehicle Types

To gain a better understanding of the effect on cost responsibility of the composition of the highway program and the incremental cost system, an analysis was made of the contribution of individual program costs such as pavement construction, grading and drainage, and state patrol to the overall cost responsibility for selected vehicles representative of some of the most important vehicle classes. This analysis indicates that overall cost responsibility for heavier vehicles is highly sensitive to the cost composition of the program, particularly in terms of the emphasis on pavement construction and reconstruction.

In Table 7 construction cost accounts for a much higher share of the total cost responsibility for trucks (75 to 85 percent) than for automobiles (49 percent). The relative importance of pavement construction is evident. Although pavement construction constitutes 31 percent of total program cost (Table 1), it accounts for 60 to 75 percent of the total cost responsibility for trucks but only 17 percent for the automobile. Thus, modifying incremental cost factors for pavement construction could substantially affect cost responsibility for heavier vehicles.

Sensitivity Aspects

Sensitivity analyses indicated that variations in treatment

of incremental cost factors and errors or biased sampling in vehicle population characteristics (such as travel rates, the relative amount of travel on the various highway classes, and load characteristics) as well as changes in program budget composition can significantly alter the results of cost allocation. Many of these variations, particularly those dealing with cost increments, have as their principal effect a redistribution of cost responsibility among medium and heavy trucks and buses rather than between trucks and light vehicles.

In one test the percentage of cost for the first increment (that shared by all vehicles) of all construction elements was arbitrarily reduced 50 percent and reassigned to the remaining higher weight increments—those supported solely by trucks and buses. This reduced the annual cost responsibilities for automobiles and pickups by only about $10. In contrast, heavy-truck cost responsibilities were increased by $500 to $1000 depending on truck type.

An examination was made of the sensitivity of cost responsibility to rather small changes in program budget composition. In this analysis budget dollar level was held constant. Construction expenditures for the desirable budget were reduced 2.5 percent for pavement, 1.1 percent for structures, and 0.1 percent for all other construction elements, for a total change of 3.7 percent. Cost responsibilities for light vehicles remained virtually the same. Cost responsibilities for heavy trucks and buses declined by 5 to 15 percent (by $200 to $500/vehicle depending on vehicle type).

Increment Cost Factors for Pavement Construction

Although current truck axle-load data have been used in the allocation of pavement costs in the Washington State study, the initial study phases used increment cost factors for pavement construction (expressed as percent of total pavement cost) developed in the mid-1960s. In the most recent study phase these increment factors were updated to account for shifts in truck population, axle loads, and travel rates.

Two alternative updates for pavement increment factors were developed by the Washington State Department of Highways. The alternative cases differ only in the way in which higher axle loads are suppressed in determining the percentage cost savings (increment factors) that would occur as progressively lower axle loads are eliminated from the pavement design. In case 1 the suppressed axle-load repetitions were proportionally assigned to all lower load (increment) levels. In case 2 the suppressed axle-load repetitions were entirely assigned to the next lower load level. The latter method is referred to as the federal procedure (3) and was used in developing the pavement increment factors for the 1967 study. Both update cases also used a finer gradation of load intervals—910 kg (2000 lb) for single-axle increments rather than 1360 to 2270 kg (3000 to 5000 lb) as in the 1967 study. This yielded 9 to 11 pavement increments, depending on highway class, compared to 6 increments in the 1967 study.

Three cost-allocation model runs for total cost responsibility were performed: the two update cases as well as the 1967 case. In all three runs the same current axle-load profiles and projected travel rates were used in the cost-allocation model. In general, case 2 (the federal method) produced cost responsibilities comparable to those obtained with the 1967 increment factors; case 1 yielded cost responsibilities $200 to $500 more for the heaviest vehicles, although these dollar differences generally represent differences of 10 percent or less in total annual cost responsibility. Automobile cost responsibility was almost identical in all three model runs. The differences among the three cases were even further reduced when they were translated into measures of equity performance by use of the tax/cost ratio. The alternative sets of pavement increment factors did not appear to significantly alter comparative equity among the various vehicle types for the particular factors of program budget and vehicle population that characterize the Washington State situation.

CONCLUSIONS

The findings of the Washington State cost-allocation study are obviously conditioned by the particular characteristics of Washington's vehicle population, the composition and dollar level of the budgets analyzed, the state's user tax structure, and the particular features of the incremental cost treatments of the cost-allocation model. Differences in highway user equity among vehicle types were observed among the alternative budgets analyzed. In general, however, the following results tended to hold true throughout all phases of the study.

1. Non-weight-related expenditures dominate total program cost.
2. The automobile fails to meet its cost responsibility.
3. Most truck classes attain equity levels comparable to those of the automobile.
4. Intercity buses grossly fail to meet cost responsibilities, and taxis heavily overpay user taxes.
5. In addition to registered gross vehicle weight, truck type is a significant variable.
6. Trucks of the commercial use class and gasoline- and propane-powered trucks have the highest overall equity performance.
7. Cost responsibility for heavy vehicles is extremely sensitive to program budget composition, particularly to the percent of the budget earmarked for pavement construction and reconstruction.
8. Alternative updates of pavement increment cost factors had only a minor impact on cost responsibility and equity performance.

It should be emphasized again that these findings are based only on expenditures by the state motor-vehicle fund and on tax payments. Federal and local funding and taxes are not included.

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Improving Ferry Service Across Long Island Sound

Michael R. Cohen, * Sikorsky Aircraft, Stratford, Connecticut

A study of vehicle-carrying ferry service across Long Island Sound is described. The purposes of the study were (a) to consider a wide range of possible services; (b) to explore and evaluate the economic performance, environmental impacts, and economic development impacts of these services; and (c) to combine the various measures of performance into an overall measure of feasibility that could be used as a basis for making recommendations. Five types of vessels were earmarked for study, from small, conventional-displacement vessels to high-speed hovercraft. A range of volumes and several possible crossing sites were chosen. A relatively simple economic model was constructed that used as input cost and performance data for ferry vessels, crossing distances and limitations on harbor speed, site-specific terminal cost estimates, and projections of fare versus the volume of vehicles carried at each site. A computer program written for this model was run for a wide range of vehicle volumes, crossings, and vessel types. Detailed studies were made of environmental impacts and the feasibility of terminal locations for services that performed well economically. The study concludes that high-technology vessels are not economically viable for vehicle-carrying service across the Sound and recommends near-term improvements to existing services that would lead to greatly expanded services over the long term.

Travel between Long Island and New England must currently take either a long, circular route passing over congested highways and bridges in New York City or one of two relatively high-cost ferry routes, one of which operates in the summer only. A bridge study conducted in 1971 (1) was part of an early attempt to improve travel between Long Island and the mainland. The study evaluated several potential bridges at various sites on the Sound. A bridge between Rye and Oyster Bay was proposed but met with strong public opposition and was subsequently abandoned. The proposed bridges east of the Rye-Oyster Bay Bridge were ruled out from the start because their tolls would not be able to cover their costs. The New York and Connecticut Departments of Transportation then decided to consider ways of improving ferry routes and services.

This paper describes the methodology and results of a study of ferry service across Long Island Sound performed by the Tri-State Regional Planning Commission for the New York and Connecticut Departments of Transportation (2). The purpose of the study was to examine a variety of potential ferry routes and determine the costs and benefits of each route. This involved a careful analysis of ferry vessels, terminals, sites, and a range of volumes of vehicles and passengers as well as an evaluation of the impact that such a ferry service would have on the environment and on local development. The results were then combined to formulate a set of recommendations.

SERVICE CHOICES AND IMPACTS

The basic choices that must be made in setting up a ferry service and the major impacts of these choices are summarized in the following table.

Choices	Impacts
Vessels	Economic
Speed	Capital cost
Vehicle capacity	Operating cost
Turnaround time	Fare revenues
Length	Deficits
Draft	Developmental
Operating cost	Employment
Terminal sites	Population
Crossing distance	Environmental
Harbor cruise	Ferry traffic on local roads
Water depths	Terminal construction and operation
Site location	Vehicle emissions
Size of service	Energy use
Annual volume	
Peak-day volume	
Load factor	
Crossing time	
Vessels required	
Vessel hours	
Vessel berths	
Headway	

Each of the basic choices (vessels, terminal sites, and size of service) is critical in determining the economic and environmental consequences of a ferry service.

Vessels

The types of vessels studied were

1. The conventional displacement vessel, which has low capital and operating costs as well as relatively low speeds and high capacities. Four vessel types were studied, including 200-vehicle, 100-vehicle, 100-vehicle used (converted from steam to diesel power), and 50-vehicle "T-boat" (designed to operate with a smaller crew).
2. The amphibious hovercraft, which floats on a cushion of air. This feature gives the vessel high speed and allows it to land directly on shore. Capital and operating costs (especially for fuel) are high as are noise-emission levels.
3. The rigid-sidewall surface effect ship, which floats on a bubble of air trapped between rigid sidewalls that pierce the water. Its costs and speed are less than those of hovercraft but more than those of a conventional-