thorities to generate sufficient funds to finance capital programs from current revenues. These problems will inevitably affect both state and local government as the municipalities seek greater distributions of state highway user taxes as well as additional sources of local funds.

Analysis of highway debt at all jurisdictional levels has shown a remarkable variability among the states with respect to bonding practices. Several states (primarily western) have followed a pay-as-you-go philosophy and have avoided highway indebtedness completely, or nearly so. The philosophy has been adopted at the state level in a few states but not by the local government agencies. Many states (primarily eastern) appear to have transcended the acceleration principle of bond financing, that is, incurring debt only during short periods of relatively great construction needs and retiring debt as construction needs are reduced. These states tend to utilize bond funds on a regular basis and as a result must use a relatively high proportion of current revenues to retire debt. It must be noted in this discussion that although philosophical differences may account for some of the variation in state bonding practices, it is certainly easier to remain with a pay-as-you-go policy in a rural, low population state than in an urbanized, high population state. It is recognized in many cases that the immediate and long-term benefits of reduced traffic congestion and improved safety derived from a new highway facility will outweigh the costs of incurring new debt to build the facility.

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Development and Application of New Highway Cost-Allocation Procedures

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ABSTRACT

Previous attempts at resolving the highway cost-allocation problem of determining equitable changes for each vehicle class that shares transportation facilities such as highways and bridges can be reduced to two approaches: proportional allocation methods that determine costs in proportion to one or more measures of highway usage, and incremental methods that allocate costs on the basis of highway design differences necessary to accommodate heavier vehicle classes. Developed in this paper are two new highway cost-allocation methodologies that actually extend the basic concepts of the incremental and proportional allocation procedures. The new methods are referred to as the "modified incremental approach" and the "generalized method". Both methods fulfill the following conditions: (a) highway costs are completely financed by users (completeness condition); (b) vehicle classes reduce their cost responsibilities by sharing the facilities with other vehicle classes (rationality principle); and (c) vehicle classes are charged at least enough to cover their corresponding marginal costs (marginality principle). An example using Texas Pavement data illustrates the application of the proposed methods.

The issue of highway financing has received a great deal of attention from state legislators in recent years because a significant portion of U.S. highway pavements is deteriorating to unacceptable levels of user serviceability. To combat this problem, a highway cost-allocation procedure must be implemented that includes the cost of keeping a highway (or other transportation) facility operational during a specific planning horizon. A primary objective of this procedure would be to determine the fraction of the total cost to be charged to each vehicle class served by that facility.

The results of recent cost-allocation studies are summarized in this paper. Two alternative cost-allocation methods are developed in particular: modified incremental and optimization. The optimization method will be referred to as a generalized procedure as it is based on an extension of the concepts used in the incremental (1-3) and proportional allocation (2,4,5) methods.

Proportional allocation methods determine cost responsibilities based on the extent to which each vehicle class uses a highway facility. This is determined by such measures as gross vehicle weight, vehicle miles travelled, and equivalent single axle loads (ESALs). These methods, however, may yield results that conflict with the perception of fairness by individual vehicle classes--this hinders the acceptability of the results by all the users of the facility and questions the overall applicability of the proportional methods.

Incremental allocation methods identify cost responsibilities on the basis of the cost differences associated with the sequential introduction of vehicle classes into the traffic stream. Different results are obtained when vehicle classes are introduced in different sequences, however. This inconsistency constitutes a serious flaw in any cost-allocation method in terms of equitability.

The two procedures discussed in this paper exhibit properties that make them superior to those previously used in the context of highway facility planning. In particular, they fulfill three fundamental requirements:

1. Completeness: the provision of highway facilities must be entirely financed by the various vehicle classes that utilize them;
2. Rationality: the common facility is the most economically attractive alternative for all vehicle classes to meet their transportation needs; that is, any other alternative to satisfy this need, such as using an exclusive facility, would be more expensive for any vehicle class; and
3. Marginality: the allocated costs associated with any vehicle class must be sufficient to at least cover its corresponding marginal costs.

The completeness requirement ensures that only funds provided by highway users are considered for financing the common highway facility. (This condition conforms to the directives established in Section 506 of the Surface Transportation Assistance Act of 1978.) The rationality requirement is a well-established concept in the economics literature (6) that deals with a fundamental characteristic of economic behavior. Therefore, any procedure that violates this condition would be strongly objected to as it would be uneconomical for a vehicle class to contribute toward a common facility when there are more economical alternatives available. The marginality requirement is another widely accepted economic principle (7). Assuming that the completeness requirement is met, the violation of this principle implies the existence of cross-subsidization among the vehicle classes involved. The rationality and marginality requirements established an essential element of fairness or equity in the cost-allocation procedure.

In conclusion, having an equitable cost-allocation methodology (that satisfies the rationality and marginality principles) to analyze the aspects related to highway financing enhances the acceptability of the results among the various vehicle classes that ultimately must cover the total cost of the facility. This important issue is briefly discussed in the following sections on the proportional and incremental methodologies.

BACKGROUND

Current solution procedures for the highway cost-allocation problem yield results that are not totally acceptable from an economic point of view because they deviate from the ideal concept of charging each user class based on the cost it causes. Although a noncontroversial solution methodology to the problem may not exist, cost must be allocated in some rational way. Traditionally, it has been an accepted practice to define cost responsibilities on the basis of some criterion that represents the use of the facility by the various vehicle classes.

The most widely used highway cost-allocation method is the incremental approach, which was adopted for use in the earlier cost-allocation studies conducted in the United States. This approach was adequate while new construction was the principal element of highway cost. However, now that a larger portion of the budget must be assigned to the maintenance and rehabilitation of existing facilities, the incremental approach has been reviewed and questioned, and some important problems, which will be discussed later, have been discovered.

The incremental method has been used in a number of cost-allocation studies such as the first Federal Highway Cost Allocation Study (1), and studies conducted in several states including Kentucky, Montana, North Dakota, Rhode Island, Virginia, and Washington (2,3,8-11).

According to the incremental method, the cost of a highway facility designed for the lightest vehicle class is initially calculated; then, vehicle classes are added in order of increasing axle weight, and corresponding highway design or rehabilitation costs are calculated for the resulting traffic streams and a specified design period. The cost difference in each step between one design and the next is allocated to the vehicle class incorporated in that step. Some minor variations of the basic incremental method have also been considered (4).

Although it meets the aforementioned completeness, rationality, and marginality requirements, there is one important problem with the incremental method: it is inconsistent. The method produces different results when vehicle classes are introduced in different orders. This is due to the presence of overlapping facility requirements demanded by the various vehicle classes. Figure 1 shows this inconsistency. The shaded areas in parts a-c represent costs allocated to vehicle classes 1, 2, and 3 when they are sequentially introduced. However, the shaded areas in parts d-f represent the same costs when class 3 is included first, followed by classes 1 and 2.

Another accepted approach to the problem under consideration is to allocate costs in proportion to a numerical criterion which, in the context of transportation systems, represents a measure of use or damage caused by the vehicle classes using a common highway facility. This method is known as the

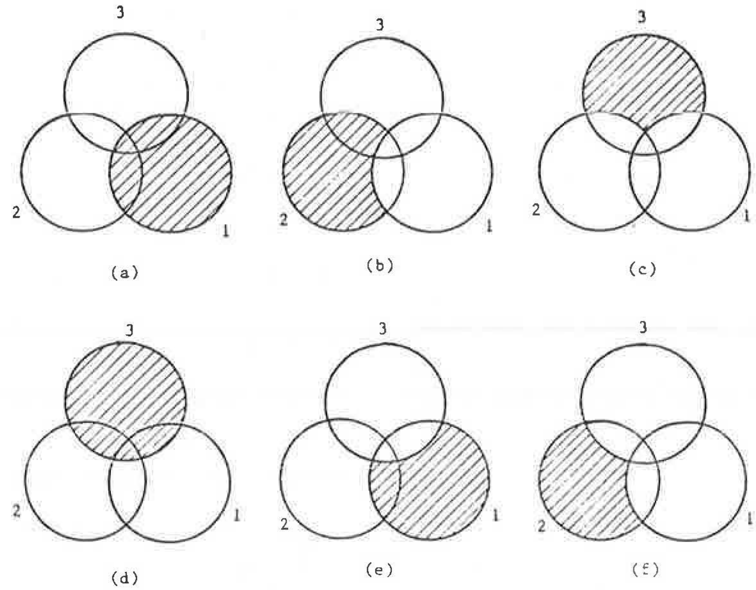

FIGURE 1 Basic approach of the incremental method.

proportional method or the consumption approach (4,5). The appeal of this method lies in its simplicity and that, when the appropriate basis is selected, the fairness of its results is less controversial.

A major issue with the proportional allocation method, however, is that it may yield cost allocations that conflict with the interests of the individual vehicle classes. This problem arises because the strategic alternatives (coalitions) available to the vehicle classes for meeting their transportation needs are ignored in this method. Such strategic alternatives include sharing a common facility with all vehicle classes, sharing a facility with some of the other vehicle classes, and having an exclusive facility. In other words, under the proportional allocation method, it is possible for a particular vehicle class to pay more for sharing a common facility than for having an exclusive one.

In a pioneering and enlightening article, Young et al. (12) analyze several cost allocation methods used in water resources management. Among the methods discussed, those that stem from the theory of cooperative games (6,13) are of particular interest. These methods provide the means for approaching the cost allocation problem by accounting for all the possible strategic alternatives available to each vehicle class in providing needed highway facilities. These various strategic possibilities actually establish constraints that define a set of feasible solutions that satisfy the completeness, rationality, and marginality requirements. The cost allocations resulting from these methods are more likely to be accepted because they are formulated on the basis of fundamental economic principles.

THE MODIFIED INCREMENTAL APPROACH

A modified version of the incremental approach is proposed as a suitable methodology for allocating construction, reconstruction, or rehabilitation costs. The proposed modification to the incremental approach attempts to overcome the consistency problem previously mentioned; however, an indirect result of this modification is that the computational complexity of the new procedure is increased.

In the modified incremental approach, cost estimates are prepared for every vehicle class, as well as for every combination of two or more vehicle classes. As an illustration, if a highway is designed to accommodate vehicle classes 1, 2, and 3, the final cost allocation for each class is determined only after considering hypothetical designs for the following vehicle class combinations and computing the corresponding design costs: (a) class 1, (b) class 2, (c) class 3, (d) classes 1 and 2, (e) classes 1 and 3, (f) classes 2 and 3, and (g) classes 1, 2, and 3.

Using the cost estimates obtained for these class combinations and a few fundamental operations, the total cost (corresponding to the combination including classes 1, 2, and 3) is partitioned into as many cost components as vehicle combinations; moreover, each cost component can be considered as the estimate of the cost effect of a vehicle class combination. To simplify the description of the method, the following notation is used:

C_1 = cost of a highway designed for vehicle class 1 alone,
C_2 = cost of a highway designed for vehicle class 2 alone,
C_3 = cost of a highway designed for vehicle class 3 alone,
$C_{1,2}$ = cost of a highway designed for vehicle classes 1 and 2,
$C_{1,3}$ = cost of a highway designed for vehicle classes 1 and 3,
$C_{2,3}$ = cost of a highway designed for vehicle classes 2 and 3,
$C_{1,2,3}$ = total cost of a highway designed (for vehicle classes 1, 2, and 3).

The shaded areas in Figure 2 illustrate the notation described above. In this figure, each individual vehicle class is represented by a circle. When two or more vehicle classes are simultaneously considered, the corresponding circles exhibit a certain degree of overlapping. This overlapping represents the portion of the total cost that is due to a combined effect of two or more vehicle classes.

As can be shown in Figure 2, the portion of the total cost that can be attributed only to individual

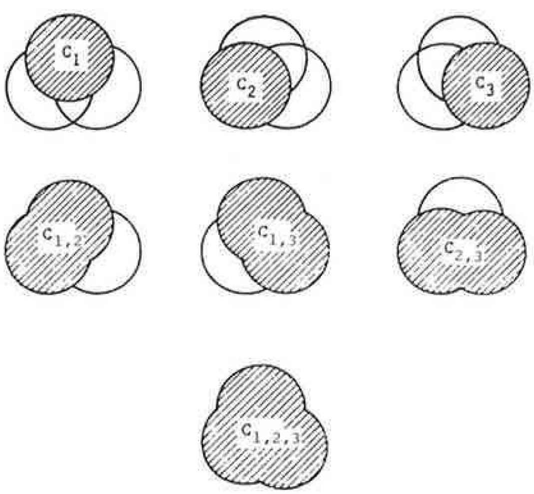

FIGURE 2 Input cost estimates.

classes is given by Equations 1, 2, and 3, respectively:

$$P_1 = C_{1,2,3} - C_{2,3} \quad (1)$$

$$P_2 = C_{1,2,3} - C_{1,3} \quad (2)$$

$$P_3 = C_{1,2,3} - C_{1,2} \quad (3)$$

The portions of the total cost attributed to the interaction of any two vehicle classes, (1 and 2, 1 and 3, and 2 and 3) can be calculated similarly by using Equations 1-3 and the initial cost estimates C_1, C_2, C_3, and $C_{1,2,3}$ as follows:

$$P_{1,2} = C_{1,2,3} - C_3 - P_1 - P_2 \quad (4)$$

$$P_{1,3} = C_{1,2,3} - C_2 - P_1 - P_3 \quad (5)$$

$$P_{2,3} = C_{1,2,3} - C_1 - P_2 - P_3 \quad (6)$$

The results from Equations 4-6 are used to obtain $P_{1,2,3}$, the total portion of the cost attributed to the interaction of all vehicle classes, as follows:

$$P_{1,2,3} = C_{1,2,3} - P_1 - P_2 - P_3 - P_{1,2} - P_{1,3} - P_{2,3} \quad (7)$$

Figure 3 depicts the partitioning of the total cost $C_{1,2,3}$ into the portions defined in Equations 1-7. As shown in this figure, the allocated cost for vehicle class 1, for example, is equal to P_1 plus appropriate fractions of the portions $P_{1,2}$, $P_{1,3}$, and $P_{1,2,3}$. These fractions can be defined in terms of relative facility usage, as measured in vehicle

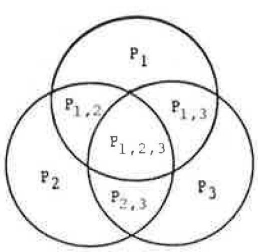

FIGURE 3 Partitioning of the total cost.

miles of travel (VMT). If V_1, V_2, and V_3 represent the amount of VMT associated with classes 1, 2, and 3, respectively, the final allocated cost R_1, is given by Equation 8:

$$R_1 = P_1 + [P_{1,2}V_1/(V_1 + V_2)] + [P_{1,3}V_1/(V_1 + V_3)] + [P_{1,2,3}V_1/(V_1 + V_2 + V_3)] \quad (8)$$

Similar results can be obtained for the cost allocations corresponding to classes 2 and 3.

$$R_2 = P_2 + [P_{1,2}V_2/(V_1 + V_2)] + [P_{2,3}V_2/(V_2 + V_3)] + [P_{1,2,3}V_2/(V_1 + V_2 + V_3)] \quad (9)$$

$$R_3 = P_3 + [P_{1,3}V_3/(V_1 + V_3)] + [P_{2,3}V_3/(V_2 + V_3)] + [P_{1,2,3}V_3/(V_1 + V_2 + V_3)] \quad (10)$$

Figure 4 represents the final cost allocations given in Equations 8-10. In Figure 4a, it can be concluded that the modified incremental method meets the completeness condition because the sum of the areas representing R_1, R_2, and R_3 is equal to the area representing the total cost $C_{1,2,3}$ of Figure 2. The shaded area shown in Figure 4b represents the marginal cost of vehicle class 1. As can be seen by comparing Figure 4b with Figure 3, this marginal cost is exactly equal to P_1. By comparing Figures 4a and 4b it is also clear that $P_1 \leq R_1$; therefore, the cost allocated to vehicle class 1 is at least equal to its marginal cost. This shows that the marginality requirement is satisfied. Similarly, the fact that $R_1 \leq C_1$ indicates that the cost allocation corresponding to class 1 in a joint design is less than it would be in a design intended only for class 1. This also shows that the rationality requirement is satisfied.

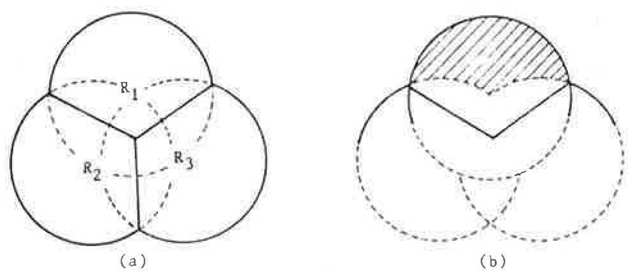

FIGURE 4 Cost allocation using the modified incremental approach.

The modified incremental approach does not have the inconsistency limitation of the standard incremental method because all possible vehicle class combinations are considered in it and the vehicle classes are not required to be included in any sequence. The development presented in this section can be used for any number of vehicle classes.

THE GENERALIZED METHOD

This procedure is based on concepts from the theory of cooperative games (6,13). A linear programming model that includes a set of meaningful economic constraints is formulated and solved to determine the appropriate cost allocation among the vehicle classes that share a transportation facility. Although the procedure developed in this section is valid for any number of vehicle classes, it will be demonstrated by using three classes. The notation given in the previous section will be used here, also.

The generalized method expresses the completeness, rationality, and marginality principles in terms of a mathematical model. The completeness requirement, which establishes that the vehicle classes must entirely finance a highway facility, is stated below:

$$R_1 + R_2 + R_3 = C_{1,2,3} \quad (11)$$

The rationality principle, which imposes the condition that the common facility must be the best alternative for each individual vehicle and for all subgroups of vehicle classes 1 and 2, 1 and 3, and 2 and 3, is represented as follows:

$$R_1 \leq C_1 \quad (12)$$

$$R_2 \leq C_2 \quad (13)$$

$$R_3 \leq C_3 \quad (14)$$

$$R_1 + R_2 \leq C_{1,2} \quad (15)$$

$$R_1 + R_3 \leq C_{1,3} \quad (16)$$

$$R_2 + R_3 \leq C_{2,3} \quad (17)$$

The marginality principle establishes that the cost allocations for vehicle classes 1-3 and the sum of allocations for subgroups 1 and 2, 1 and 3, and 2 and 3, must at least equal the corresponding marginal costs; this requirement is expressed by:

$$R_1 \geq C_{1,2,3} - C_{2,3} \quad (18)$$

$$R_2 \geq C_{1,2,3} - C_{1,3} \quad (19)$$

$$R_3 \geq C_{1,2,3} - C_{1,2} \quad (20)$$

$$R_1 + R_2 \geq C_{1,2,3} - C_3 \quad (21)$$

$$R_1 + R_3 \geq C_{1,2,3} - C_2 \quad (22)$$

$$R_2 + R_3 \geq C_{1,2,3} - C_1 \quad (23)$$

As indicated by Young et al. (12), if Constraint 11 holds, then Constraints 12-17 are equivalent to Constraints 18-23. This means that Constraints 18-23 are redundant and need not be considered in the analysis.

Constraints 11-17 define the set of feasible solutions for the cost allocation problem. This set is called the "core" (13) of the problem and is represented in Figure 5a. In this Figure the core is the shaded segment on the plane representing Constraint 11. The boundaries or sides of the core are indicated by Constraints 12-17.

The core may contain several solutions of which only one must be selected. One way to accomplish this is to systematically reduce the set of feasible solutions until it contains exactly one solution. The core reduction procedure is illustrated in Figure 5b. The core is reduced by "moving" its sides (constraints) in the directions of the corresponding arrows while keeping them parallel to the original positions. Mathematically, the size of the core is reduced if an amount t is subtracted from each right-hand side of Constraints 12-17. Because only one point is desired, the amount t should be as large as possible without violating any of the constraints. In conclusion, the core reduction procedure can be formulated in terms of the following linear programming model:

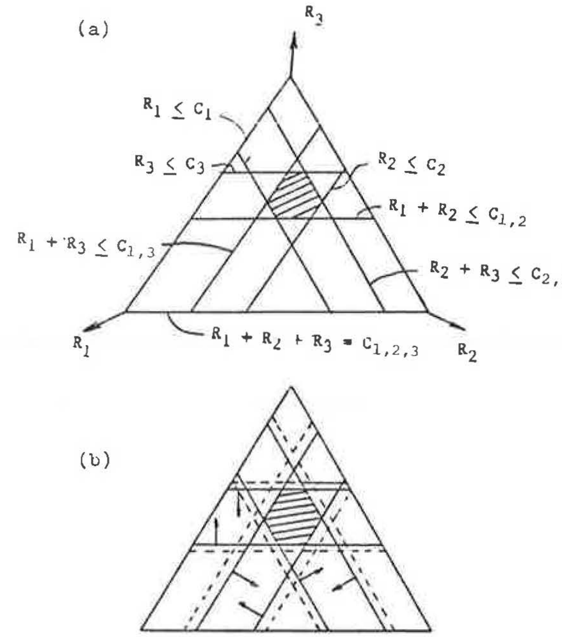

FIGURE 5 The core in the generalized method.

$$\text{maximize } t \quad (24)$$

subject to:

$$R_1 \leq C_1 - t \quad (25)$$

$$R_2 \leq C_2 - t \quad (26)$$

$$R_3 \leq C_3 - t \quad (27)$$

$$R_1 + R_2 \leq C_{1,2} - t \quad (28)$$

$$R_1 + R_3 \leq C_{1,3} - t \quad (29)$$

$$R_2 + R_3 \leq C_{2,3} - t \quad (30)$$

$$R_1 + R_2 + R_3 = C_{1,2,3} \quad (31)$$

$$R_1, R_2, R_3, t \geq 0 \quad (32)$$

ENVIRONMENTAL FACTORS

An attractive feature of the generalized method is that it lends itself to a meaningful analysis of environmental costs. Environmental costs are those caused by factors other than traffic loads and, therefore, cannot be directly attributed to the individual vehicle classes.

The procedure described in this section can be easily extended to more than three vehicle classes. For convenience in this presentation, it is assumed that only three classes are involved. The total number of vehicle combinations in this case is eight. Each of these eight combinations can be represented in terms of a sequence of plus and minus signs, as indicated in Table 1. In this table, a negative sign indicates that a vehicle is not included in a combination, and a positive sign indicates that it is included. As an illustration, combination 2 corresponds to a design for class 1 only with cost C_1, while combination 4 corresponds to a design for classes 1 and 2, with cost $C_{1,2}$. In particular,

TABLE 1 Vehicle Combinations

Combination No.	Vehicle Class 1	2	3	Cost[a]
1	–	–	–	C_0
2	+	–	–	C_1
3	–	+	–	C_2
4	+	+	–	$C_{1,2}$
5	–	–	+	C_3
6	+	–	+	$C_{1,3}$
7	–	+	+	$C_{2,3}$
8	+	+	+	$C_{1,2,3}$

[a] "Cost" refers to the cost of a highway designed for a particular vehicle class or classes (i.e., C_0 = highway cost for 0 vehicle classes; C_1 = highway cost for vehicle class 1; and $C_{1,2,3}$ = highway cost for vehicle classes 1, 2, and 3).

combination 8 corresponds to a design for vehicle classes 1, 2, and 3; this is the design whose cost $C_{1,2,3}$ is to be allocated to the three vehicle classes. Combination 1 corresponds to a scenario with no vehicle classes. Because the cost C_0 associated with this scenario is not traffic-load-related, it is assumed that it estimates the cost effect due to environmental factors.

It is always possible to express C_0 as a fraction of the total cost; that is,

$$C_0 = eC_{1,2,3} \quad (33)$$

where e is an unknown number between 0 and 1. The methodology described in this section can be used to find a maximum value for e for given C_1, C_2, ..., $C_{1,2,3}$.

The proposed method is based on the concept of effects associated with a two-level factorial experiment (14). This concept is illustrated here using Table 1. As can be seen in this table, four combinations include vehicle class 1 and four combinations do not include it. The average cost associated with the combinations not including class 1 is given by

$$E_1^- = (C_0 + C_2 + C_3 + C_{2,3})/4 \quad (34)$$

Similarly, the average cost associated with the vehicle combinations including class 1 is equal to

$$E_1^+ = (C_1 + C_{1,2} + C_{1,3} + C_{1,2,3})/4 \quad (35)$$

The statistical effect of class 1 is defined as $E_1^+ - E_1^-$ because this difference measures the average increase in cost due to vehicle class 1. Letting E_1 equal $E_1^+ - E_1^-$, and using Equations 34 and 35, E_1 can be written as

$$E_1 = [(C_1 - C_2 + C_{1,2} - C_3 + C_{1,3} - C_{2,3} + C_{1,2,3})/4] - eC_{1,2,3}/4 \quad (36)$$

By setting $A_1 = [(C_1 - C_2 + C_{1,2} - C_3 + C_{1,3} - C_{2,3} + C_{1,2,3})/4]$ and $B = C_{1,2,3}/4$, it is possible to rewrite Equation 36 as

$$E_1 = A_1 - Be \quad (37)$$

The relationship given in Equation 37 is linear and indicates that the effect due to vehicle class 1 decreases as the impact of the environmental factors is increased. This behavior is shown in Figure 6a.

A similar procedure is followed to find the relationships for vehicle classes 2 and 3. Figure 6b shows three hypothetical linear relationships for the three vehicle classes under consideration. Since E_1, E_2, and E_3 must be positive, the range for e is

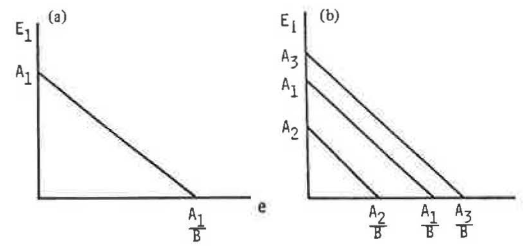

FIGURE 6 Effects of the vehicle classes on cost as functions of e.

between zero and the minimal A_i/B value. In the case of the illustration given in Figure 6b, this value is A_2/B. In general, $0 \leq e \leq e'$ where

$$e' = \min[(A_1/B), (A_2/B), (A_3/B)] \quad (38)$$

In summation, the cost effect due to the environmental factors can, at most, be a fraction e' of the total cost. Values of e exceeding e' are not valid because they would yield a negative value for the effect associated with at least one vehicle class.

APPLICATION

An application of the modified incremental approach and the generalized method using a small sample from Texas pavement data is presented in this section. Although realistic, these data are by no means comprehensive and are used here only for illustrative purposes. Results from these methods are compared to those from existing procedures.

It is intended to allocate the estimated rehabilitation costs incurred in an 18-year analysis period among four vehicle classes for a highway system consisting of two kinds of pavements. Table 2 describes the vehicle classes considered in this example, accumulated ESALs throughout the analysis period for each vehicle class, and percentages of VMTs corresponding to each vehicle class. Table 3 displays highway classification, pavement type, and pavement mileage for each of the two kinds of pavement.

TABLE 2 Vehicle Class Data

Vehicle Class	Truck Type	ESALs (millions)	VMT (%)
1	2D	3.590	96.43
2	3A	0.647	1.18
3	3-S2	15.317	2.06
4	2-S1-S2	5.172	0.33

TABLE 3 Illustrative Pavement System

Pavement	Highway Classification	Pavement Type	Mileage (lane miles)
1	Interstate	Flexible overlaid	57
2	U.S.	Hot mix	135

A modification of the RENU program (15) was performed to obtain rehabilitation costs for the variation vehicle combinations. Using these figures and ESAL data, rehabilitation costs were estimated for all vehicle combinations. Table 4 gives the rehabilitation cost estimates associated with each vehicle class combination. Figure 7a shows the behavior of

TABLE 4 Rehabilitation Cost Estimates

Combination	Cost ($ millions)
1	1.06
2	0.76
1,2	1.11
3	1.87
1,3	2.04
2,3	1.90
1,2,3	2.06
4	1.18
1,4	1.46
2,4	1.24
1,2,4	1.51
3,4	2.105
1,3,4	2.22
2,3,4	2.13
1,2,3,4	2.24

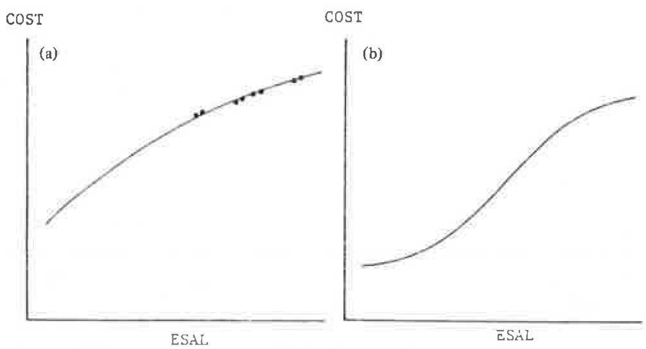

FIGURE 7 Rehabilitation cost as a function of ESALs.

these costs as a function of the number of ESALs applied during the analysis period.

Table 5 displays allocated rehabilitation costs for five cost allocation methods. The first column (INCR1) corresponds to the standard incremental method as described previously. The second column (INCR2) gives results from a variation of the standard incremental method where a cost increment is assigned not only to the vehicle class introduced at a given step but also to heavier vehicle classes, and is further divided among them on the basis of vehicle miles travelled (VMT). The column labeled "PROPR" shows costs allocated using a proportional method where the total cost is divided into nonload-related cost (33 percent) and load-related cost (67 percent). Nonload-related costs are allocated on the basis of VMTs whereas load-related costs are assigned in proportion to ESALs. The last two columns (MIA and GM) correspond to the application of the modified incremental approach and the generalized method, respectively.

TABLE 5 Comparison of Cost-Allocation Methods

Vehicle Class	Cost by Method ($ millions)				
	INCR1	INCR2	PROPR	MIA	GM
1	0.349	1.075	0.883	0.947	0.410
2	0.759	0.009	0.049	0.033	0.320
3	0.731	1.098	0.979	1.047	1.030
4	0.401	0.058	0.329	0.213	0.480

Note: INCR1 and INCR2 = incremental methods 1 and 2, PROPR = proportional method, MIA = modified incremental approach, and GM = generalized method.

A considerable difference in the results can be observed among the different methods. When there is a small increment in cost as a result of introducing a new vehicle class, the standard incremental method gives an unfair advantage to the newly introduced vehicle class, as can be seen in the first column (INCR1). The difference between the modified incremental approach and the generalized method is explained by the influence of the measure of (nonload-related) highway usage (VMT) on the allocation of common costs in the modified incremental approach. In these examples, the modified incremental approach attributes a significant portion of the total cost to the interaction of all vehicle classes. A large percentage of this interaction cost is absorbed by vehicle class 1 due to the high number of VMTs associated with it. On the other hand, the generalized method is insensitive to VMTs and allocates costs solely on the basis of costs occasioned by the vehicle classes. The maximum percentage of the total cost e' that can be attributed to the environment is equal to 45 percent, as indicated by Equation 38.

EXTENSIONS

The generalized methodology developed in this paper can always be used when the design costs correspond to the relationship shown in Figure 7a; however, if this relationship is changed to that shown in Figure 7b, the core may not exist. The reason for this is that the straight lines that are used to reduce the core, as shown in Figure 5b, will be actually displaced in the opposite directions. As indicated by Young et al. (12), it is necessary in this case to generate a core by introducing a procedure that will force the straight lines to be moved toward the center of the feasible region.

The core generation procedure is mathematically equivalent to changing the objective function (Equation 24) to minimization and changing the sign of t from negative to positive in Constraints 25-31. It should be noted that when the core generation procedure is needed, the marginality and/or rationality principles may not apply to some vehicle combinations.

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Funding Sources for Transit System Operations

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ABSTRACT

This paper contains an analysis of transit system operating fund sources in the United States. Data were compiled from individual operators' reports to the Urban Mass Transportation Administration, U.S. Department of Transportation, as required by Section 15 of the Urban Mass Transportation Act of 1964, as amended. Funding sources are tabulated into five categories: earned income, locally provided support, federal support, state support, and other income. The average shares of a transit operator's income from these five sources are computed by the number of vehicles operated and by geographic region. The statistical correlations between the share of an operator's funding from a particular source and simple system performance measures are computed. Conclusions are drawn on the importance of federal operating support to different categories of transit operators.

The process of funding transit systems in the United States has changed substantially over the past 40 years. Until the end of the 1940s, transit systems were predominantly privately owned companies that depended on farebox revenues. Shortly after World War II, transit ridership started to decline because of increased automobile ownership and the shift of population and employment from central cities to lower density suburban areas. From 1945 to 1955 transit ridership declined by more than 50 percent in the United States (1,p.156). Private transit operators found it increasingly difficult to stay in business, and either curtailed service temporarily or abandoned operations altogether.

The 1950s marked a major conversion of the transit industry from private to public ownership, usually in the form of municipal and regional transit operating authorities. These operating authorities were able to obtain funds to buy needed transit equipment because they normally had the authority to issue bonds backed by the newly purchased equipment or future farebox revenues. Operating expenses were, however, still largely covered by passenger fares.

By the early 1960s, most transit agencies were at the point where additional public subsidies were needed to cover operating expenses as well as new equipment purchases. The Urban Mass Transportation Act of 1964 established federal support for the purchase of new transit vehicles and the construction of facilities. This federal capital assistance freed some local and state funds for operating subsidies. But the need for additional transit operating subsidies led to the National Mass Transportation Assistance Act of 1974, which provided for Section 5 federal operating assistance for transit systems.

Reviewed in this paper is the 1982 funding of