where

$C_1 = -[(1 + \nu)\alpha_c + \alpha_s]$,

$C_2 = -(1 + \nu)\alpha_c w I_s E_s E_c a^2$,

$A = (1/E_s A_s) + (d_1^2/I_s E_s) + [2(1 - \nu^2)/waE_c]$,

$B = (d_1/E_s I_s) - [1.5(1 - \nu^2)/a^2 wE_c]$,

$K = 2wd_1 a^3 E_c - 3(1 - \nu^2) aI_s E_s$, and

$R = 2wa^3 E_c + 3(1 - \nu^2) I_s E_s$.

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Multi-Increment Cost-Allocation Methodology for Bridges

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ABSTRACT

In this paper is presented an overview of a bridge cost-allocation procedure that uses data from bridges built in the state of Indiana between 1980 and 1983. The framework of the present analysis was based on the incremental concept with modification at various steps in the allocation process such that a larger number of cost increments were obtained. A technique is discussed for obtaining a large number of cost increments in order to render the economies-of-scale problem associated with the incremental methodology insignificant. The quantitative correlation between study vehicle classification and AASHTO vehicles was based on the relative effect of both axle loading and axle spacing of each vehicle on continuous-span bridges. The cost responsibility of each vehicle class was determined first on the basis of its structural and geometric requirements and then on the relative frequency with which it uses the bridges. A discussion of the approach employed in the distribution of the bridge construction, bridge replacement, and bridge rehabilitation cost is presented.

There are several methods of allocating bridge costs in the literature. However, the most commonly used and widely accepted methodology for structural cost-allocation analysis is classical incremental analysis (1-6). Although the concept of classical incremental analysis for bridge cost allocation is well documented, the approach for developing the various bridge cost functions in the allocation process varies among studies. The bridge cost-allocation process discussed in this paper is also based on the classical incremental framework but with modification at various steps. Presented herein is a multi-increment cost-allocation process based on data from bridges built in Indiana between 1980 and 1983.

VEHICULAR CLASSIFICATION AND DESIGN LOADING

Vehicles that use the Indiana highway system were categorized into 14 basic classifications (Table 1). Each class was further divided into various weight groups. For the purpose of incremental analysis, with the exception of the live loads, all loads and forces were handled in the same manner as the original bridge. The live loads that represented the weight of the moving traffic were modified to reflect a range of different types of vehicles. According to AASHTO bridge specifications (7), traffic-related loadings can be represented by standard trucks or by equivalent lane loads. The trucks specified are designated with an H prefix followed by a number indicating the total weight of the trucks in tons for the two-axle trucks or with an HS prefix followed by a number indicating the weight of the tractor in tons for the tractor-trailer combinations. The AASHTO bridge specification provides only five classes of design loading, namely, HS 20, HS 15, H 20, H 15, and H 10. Other loadings required for the present analysis can be obtained by proportionally changing the weights of the designated trucks (7). The modified AASHTO live loadings and the corresponding lane loadings used in the present study are shown in Figure 1. The cost functions of each bridge element were

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TABLE 1 Adopted Vehicle Classification *(9)*

Class	Description
1	Small passenger automobiles
2	Standard and compact passenger automobiles and panel and pickup trucks
3	Buses
4	Two-axle trucks (2 S and 2 D)
5	Automobiles with one-axle trailers
6	Three-axle single-unit trucks
7	2 S1 tractor-trailers
8	Automobiles with two-axle trailers
9	Four-axle single-unit trucks
10	3 S1 tractor-trailers
11	2 S2 tractor-trailers
12	3 S2 tractor-trailers
13	Other five-axle vehicles
14	Six or more axles

then computed on the basis of the previously mentioned set of design loadings.

CORRELATION BETWEEN AASHTO VEHICLES AND STUDY VEHICLES

It is to be noted that the design trucks are different from the trucks seen operating on the highways. They are trucks with configurations that would simulate the most severe live loads on a structure. Therefore the correlation between the design vehicles and the study vehicle classes should be viewed as a critical task in any structural cost-allocation study. Without a proper procedure for matching the design vehicles with the study vehicle classes, any attempt to improve computational precision would be limited because the accuracy of the cost functions in terms of design vehicles would not be maintained when converted into the study vehicle classes. Many studies (1-4,6) used gross vehicle weight to establish the relationship between AASHTO vehicles and study vehicles. The use of gross vehicle weight neglects axle load distribution and axle spacing.

Maryland (8,5) used a more rational method in establishing this correlation because it incorporated both axle loading and axle spacing in its analysis. However, the vehicles were analyzed on simply supported single-span bridges of varying span length rather than on continuous-span bridges. The results obtained by using simply supported simple spans would involve approximations when extended to continuous-span bridges.

Because most bridges have continuous spans, the quantitative correlations between study vehicles and AASHTO design vehicles were based on continuous-span

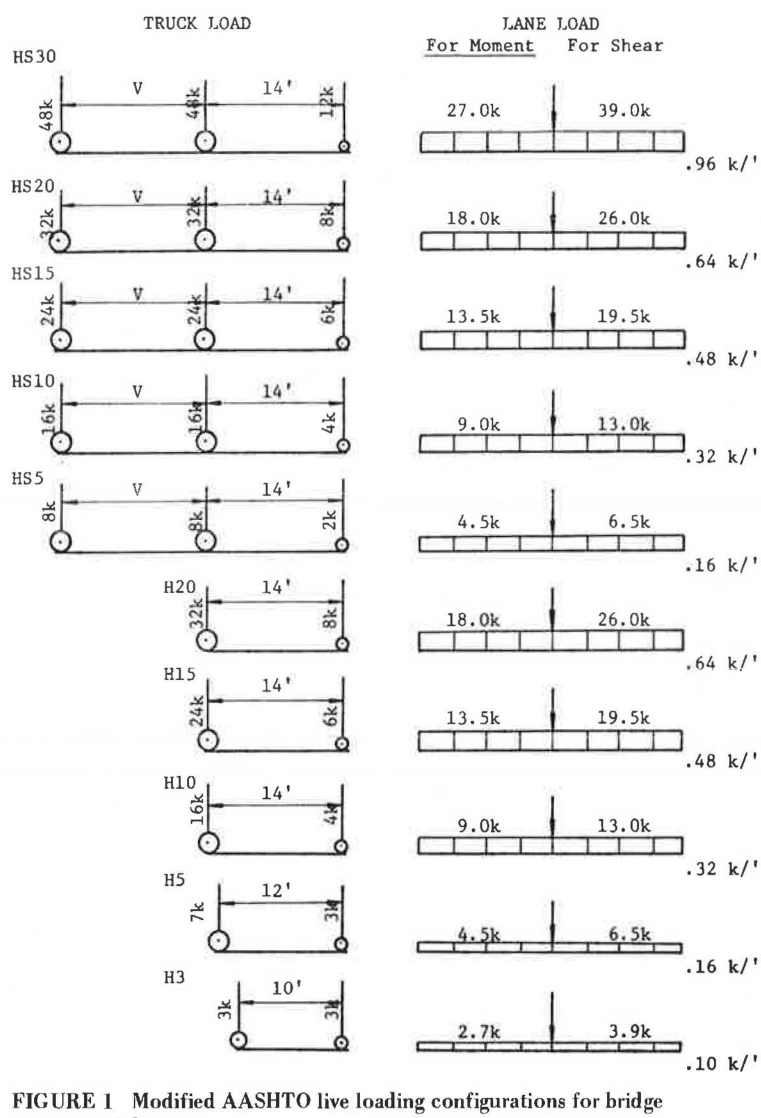

FIGURE 1 Modified AASHTO live loading configurations for bridge incremental designs.

bridges of varying span lengths. Figure 2 shows a flow chart of such an analysis. This approach required knowledge of the axle loads and the axle spacings of each vehicle weight group. It is to be noted that each vehicle within each subweight group may have different axle loading and axle spacing because vehicles were grouped according to their highway use and damage criteria. Therefore, an average value for both the axle loading and the axle spacing of all vehicles in each weight group was used.

Table 2 gives the equivalent AASHTO designation of each study vehicle weight group. Table 3 gives the correspondence of each vehicle weight group with the equivalent AASHTO designation in the correlation matrix.

The correlation between the H and HS trucks was obtained by equating the maximum moments produced on the critical points of bridges. A linear regression analysis was then performed on the results. The regression equation found was HS = 0.68 H with r^2 = 0.89.

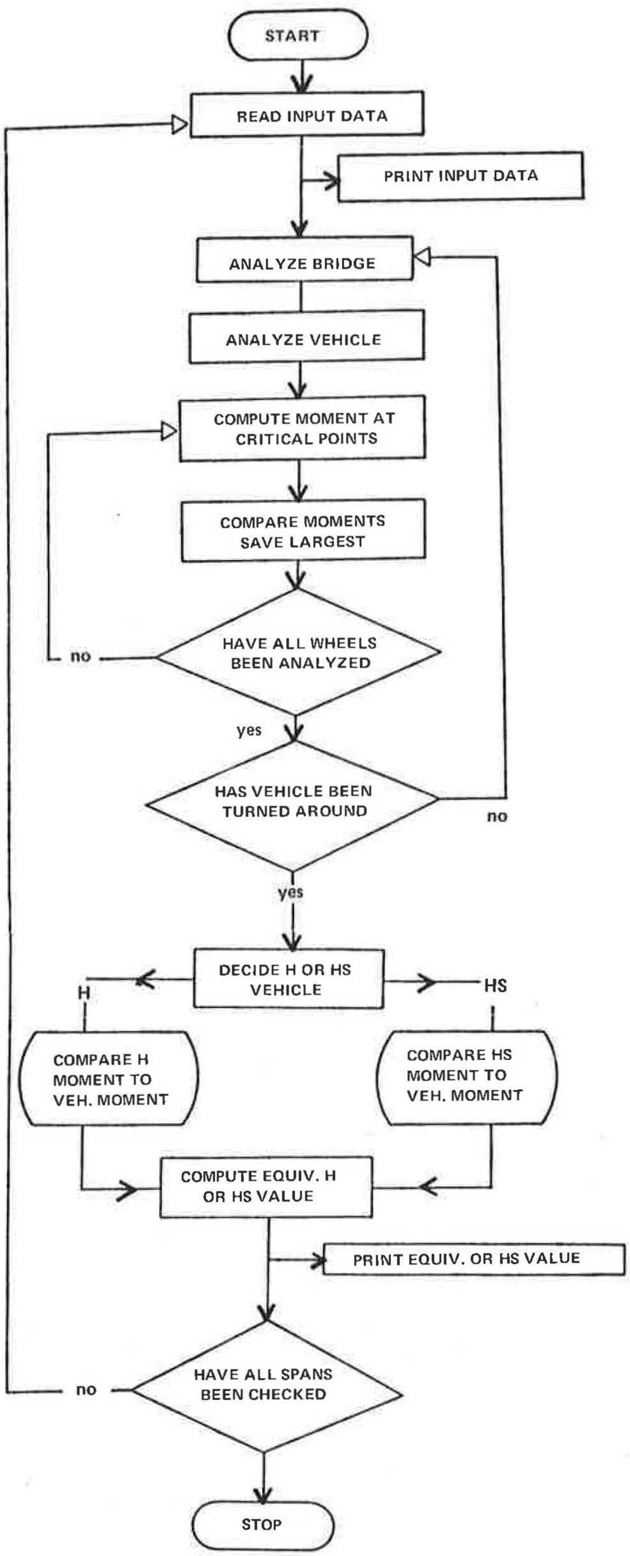

FIGURE 2 Flow diagram for AASHTO loadings and study vehicle classes correlation analysis.

BRIDGE TYPES

The most recent bridge projects were used in the analysis because they represent modern construction trends and techniques. Bridges in Indiana built within the base period (1980 through 1983) were categorized as follows:

1. Reinforced concrete slab,
2. Prestressed concrete I-beam,
3. Prestressed concrete box-beam,
4. Steel beam, and
5. Steel girder.

Bridges within each category usually have rather similar properties and characteristics. Hence, a representative bridge was selected from each of the five categories. Incremental analyses were performed on each representative bridge using the selected set of design loadings described earlier.

HIGHWAY CLASSIFICATION

In general, the characteristics of a highway are reflected by the bridges constructed on that highway. Bridges on principal arterials have higher design standards than do those on county roads. The following highway classification was used (9):

1. Interstate urban,
2. Interstate rural,
3. State primary,
4. State secondary,
5. County road, and
6. City street.

BRIDGE COST COMPONENTS

Bridge costs were divided into the following components:

1. Superstructure
2. Substructure
   a. Abutment and pier
   b. Piling
   c. Excavation and backfill
3. Railing
4. Drainage system
5. Miscellaneous items

Incremental cost analyses, based on the geometric and structural requirements of the design vehicles, were performed separately on each of the cost components.

COST FUNCTIONS

The design drawings, plans, and bid information were obtained from the Indiana Department of Highways. All of the selected bridges were designed for HS 20 loading. By replacing the HS 20 loading with other

TABLE 2 Study Vehicle Classification and Equivalent AASHTO Designation

Vehicle Type[a]	Gross Weight (kips)	Design Axle Load[b] (kips)						Axle Spacing[c] (ft)					Equivalent AASHTO Vehicle
		A	B	C	D	E	F	AB	BC	CD	DE	EF	
1	4.0	2.0	2.0					7.2					H 2.9
2	6.0	3.0	3.0					10.05					H 4.0
3	30.0	12.0	18.0					31.65					H 17.0
4	5-10.0	4.5	5.5					11.0					H 8.9
4	10-15.0	6.5	8.5					13.0					H 9.41
4	15-20.0	7.7	12.3					14.0					H 12.95
4	20-25.0	10.2	14.8					15.0					H 15.29
4	25-30.0	12.0	18.0					17.0					H 17.67
5	9.0	4.0	4.0	1.0				11.5	8.6				HS 3.0
6	10-15.0	5.0	6.0	4.0				14.0	4.0				HS 6.0
6	15-20.0	8.0	6.0	6.0				14.0	4.0				HS 7.0
6	20-25.0	10.0	7.0	8.0				14.0	4.0				HS 8.0
6	25-30.0	12.0	8.0	10.0				14.0	4.0				HS 10.0
6	30-35.0	13.0	10.0	12.0				14.0	4.0				HS 11.0
6	35-40.0	15.0	12.0	13.0				14.0	4.0				HS 13.0
7	0-20.0	7.0	8.0	5.0				10.0	16.0				HS 6.0
7	20-25.0	9.0	10.0	6.0				10.0	17.0				HS 7.0
7	25-30.0	9.0	11.0	10.0				10.0	18.0				HS 8.0
7	30-35.0	10.0	13.0	12.0				10.0	21.0				HS 9.0
8	10.00	4.0	4.0	1.0	1.0			11.5	8.60	5.80			HS 3.50
9	0-30.0	6.0	6.0	18.0				4.0	40.0				HS 13.0
9	30-60	16.0	16.0	28.0				4.0	40.0				HS 23.0
10	0-40.0	13.0	9.0	9.0	9.0			17.30	4.0	21.00			HS 10.0
11	20-25.0	7.0	8.0	5.0	5.0			10.0	22.0	4.0			HS 7.0
11	25-30.0	8.0	10.0	6.0	6.0			10.0	22.0	4.0			HS 8.0
11	30-35.0	9.0	11.0	7.0	8.0			10.0	22.0	4.0			HS 9.0
11	35-40.0	10.0	14.0	8.0	8.0			10.0	22.0	4.0			HS 10.0
11	40-45.0	10.0	15.0	10.0	10.0			10.0	22.0	4.0			HS 11.0
11	45-50.0	10.0	16.0	12.0	12.0			10.0	22.0	4.0			HS 12.0
11	50-55.0	11.0	18.0	13.0	13.0			10.0	22.0	4.0			HS 14.0
12	20-25.0	7.0	6.0	6.0	3.0	3.0		10.0	4.0	25.0	4.0		HS 7.0
12	25-30.0	8.0	7.0	7.0	4.0	4.0		10.0	4.0	25.0	4.0		HS 8.0
12	30-35.0	9.0	8.0	8.0	5.0	5.0		10.0	4.0	25.0	4.0		HS 9.0
12	35-40.0	10.0	9.0	9.0	6.0	6.0		10.0	4.0	25.0	4.0		HS 10.0
12	40-45.0	11.0	10.0	10.0	7.0	7.0		10.0	4.0	25.0	4.0		HS 11.0
12	45-50.0	12.0	11.0	11.0	8.0	8.0		10.0	4.0	25.0	4.0		HS 12.0
12	50-55.0	11.0	12.0	12.0	10.0	10.0		10.0	4.0	25.0	4.0		HS 13.0
12	55-60.0	10.0	13.0	13.0	12.0	12.0		10.0	4.0	25.0	4.0		HS 14.0
12	60-65.0	10.0	14.0	14.0	13.0	13.0		10.0	4.0	25.0	4.0		HS 15.0
12	65-70.0	10.0	16.0	16.0	14.0	14.0		10.0	4.0	25.0	4.0		HS 17.0
12	70-75.0	11.0	17.0	17.0	15.0	15.0		10.0	4.0	25.0	4.0		HS 18.0
12	75-80.0	12.0	18.0	18.0	16.0	16.0		10.0	4.0	25.0	4.0		HS 19.0
13	0-40.0	5.0	7.0	12.0	8.0	8.0		9.0	18.0	5.0	11.0		HS 11.0
13	40-70.0	10.0	18.0	16.0	13.0	13.0		9.0	18.0	5.0	11.0		HS 17.0
14	0-40.0	8.0	7.0	7.0	8.0	5.0	5.0	10.0	4.0	21.0	5.0	11.0	HS 11.0
14	40-60.0	9.0	12.0	12.0	13.0	7.0	7.0	10.0	4.0	21.0	5.0	11.0	HS 19.0
14	60-80	9.0	16.0	16.0	17.0	11.0	11.0	10.0	4.0	21.0	5.0	11.0	HS 24.0

[a] Refer to Table 1 for description of vehicle types.
[b] A = first axle, B = second axle, C = third axle, D = fourth axle, E = fifth axle, and F = sixth axle.
[c] AB, BC, CD, DE, and EF = distance in feet between adjacent axles.

AASHTO design loadings, bridges of different structural and geometric characteristics were obtained. For the selected bridges, the original specifications, configurations, and materials that were independent of vehicular loadings were retained where appropriate. In areas in which AASHTO specifications governed, those specifications were used in place of the original specifications.

The three lowest bids submitted by contractors were chosen and their itemized unit costs were averaged. The total cost of each bridge cost component was obtained using these itemized unit costs. For each type of bridge and cost component, a cost function of the form shown in Figure 3 was obtained. Next, by dividing the total cost by the deck area, the unit cost per square foot was obtained. Table 4 gives the unit cost per square foot of superstructure by design loading and by bridge type.

It is to be noted that the distribution of each type of bridge is important. For example, there were 30 slab bridges and 50 prestressed box-beam bridges of various dimensions built within the base period. To account for this, the total deck area of all bridges of each bridge type built within the base period (1980 through 1983) was determined and grouped according to highway class. A summary of total deck area by highway classification and by bridge type is given in Table 5. The cost factors for different AASHTO loadings and by bridge type were then obtained using Equation 1:

$$CF(k) = \left[\sum_{k=1}^{(10)} \sum_{j=1}^{(5)} U(i,k)A(i,j)\right] \Big/ \left[\sum_{j=1}^{(5)} U(i,20)A(i,j)\right] * 100\% \qquad (1)$$

where

i = type of bridge,
j = type of highway class,
k = [set of design loadings],
A(ij) = total deck area for the ith type of bridge and jth highway class, and
U(ik) = unit cost for the ith bridge type and kth loading.

It is important to note that the interest here is in obtaining cost factors by highway type not by bridge type. The cost factors by highway type should account for the distribution of each bridge type. For instance, certain types of bridges may not be found or may be less predominant on particular types of highway. The cost factors by highway type were

TABLE 3 Correlation Matrix of Study Vehicular Classification and Equivalent AASHTO Designation

AASHTO Classification		Gross Vehicle Weight (kips) of Vehicle Type[a]													
HS	H	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	1.5														
2	2.9	*	*												
3	4.4					*									
4	5.9				5-10				*						
5	7.4														
6	8.8				10-15		10-15	0-20							
7	10.3						15-20	20-25				20-25	20-25		
8	11.8				15-20		20-25	25-30				25-30	25-30		
9	13.2							30-35				30-35	30-35		
10	14.7				20-25		25-30				*	35-40	35-40		
11	16.2			*			30-35					40-45	40-45	0-40	0-40
12	17.7				25-30							45-50	45-50		
13	19.1						35-40			0-30			50-55		
14	20.6											50-55	55-60		
15	22.1												60-65		
16	23.5														
17	25.0												65-70	40-70	
18	26.5												70-75		
19	27.9												75-80		40-60
20	29.4														
21	30.9														
22	32.3									30-60					
23	33.8														
24	35.3														60-80
25	36.8														
26	38.2														
27	39.7														
28	41.2														
29	42.6														
30	44.1														

Note: HS = combination trucks, H = single unit trucks, and * = vehicle class without weight subdivision.
[a]Refer to Table 1 for description of vehicles.

obtained by adding the cost factors of each bridge type found on each particular type of highway. For the purpose of illustration, Table 6 gives the bridge cost factors obtained for state secondary highways. A statistical regression analysis was performed on these results and plotted as shown in Figure 4.

BRIDGE COST ALLOCATORS

In the present study, the basic structure is the facility constructed to support the smallest design vehicle. The cost of providing the basic facility should be allocated to all vehicle classes, irre-

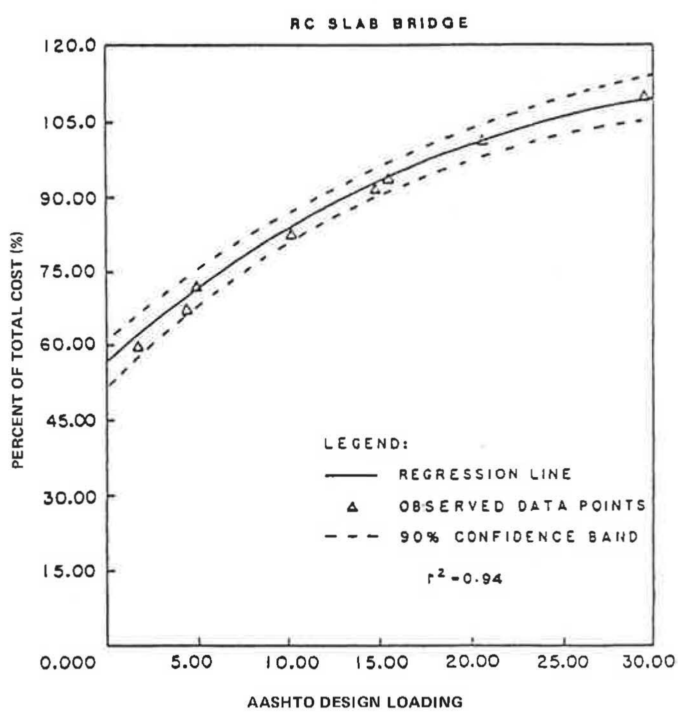

FIGURE 3 Slab bridge superstructure cost function.

TABLE 4 Bridge Superstructure Unit Costs

	Unit Cost ($/ft^2)									
Bridge Type	H 3	H 5	H 10	H 15	H 20	HS 5	HS 10	HS 15	HS 20	HS 30
Slab	12.19	14.27	17.44	18.73	19.92	16.41	18.61	19.90	21.17	23.03
Box-beam	16.03	17.07	18.25	19.45	20.48	17.87	19.30	20.63	22.31	25.02
I-Beam	14.78	15.53	16.63	17.71	18.62	16.19	17.59	18.75	19.94	22.10
Steel beam	15.71	17.36	20.19	22.91	26.31	19.37	23.16	26.48	29.81	32.73
Steel girder	18.07	19.97	23.22	26.34	30.26	22.85	26.64	30.45	34.29	37.64

TABLE 5 Bridge Deck Area (ft^2) Constructed in 1980–1983 by Bridge Type and Highway Classification

	Highway Classification				
Bridge Type	Interstate Urban	Interstate Rural	State Primary	State Secondary	Local Road
Slab	*	*	97,723.60	97,795.40	10,967.50
Box-beam	*	*	18,566.50	4,146.90	*
I-beam	14,464.80	*	188,871.30	126,291.80	2,412.00
Steel beam	17,606.30	29,702.4	133,766.20	72,970.90	*
Steel girder	*	*	171,835.50	91,637.50	*

Note: * = No bridge of this type constructed within the base period.

TABLE 6 Cost Factors for State Secondary Bridge

	Cost by AASHTO Loading Type ($)									
Bridge Type	H 3	H 5	HS 5	H 10	HS 10	H 15	H 20	HS 15	HS 20	HS 30
Prestressed I-beam	1,192,125	1,395,540	1,604,822	1,705,551	1,819,972	1,831,708	1,946,128	1,948,084	2,070,328	2,252,228
Reinforced concrete slab	66,474	70,788	74,105	75,680	80,035	80,657	84,928	85,550	92,517	103,755
Prestressed box-beam	1,866,592	1,961,311	2,044,664	2,100,232	2,221,473	2,236,628	2,351,553	2,367,971	2,505,629	2,791,049
Continuous steel beam	1,146,372	1,266,774	1,449,932	1,473,282	1,671,763	1,690,006	1,919,864	1,932,269	2,175,263	2,388,337
Continuous steel girder	1,655,889	1,830,000	2,093,916	2,127,822	2,413,731	2,441,223	2,772,950	2,790,361	3,142,249	3,449,236
Total	5,927,452	6,524,413	7,267,439	7,482,567	8,206,974	8,280,222	9,075,423	9,124,231	9,985,982	10,984,605
Percentage of total cost	59	65	73	74	82	83	91	91	100	110

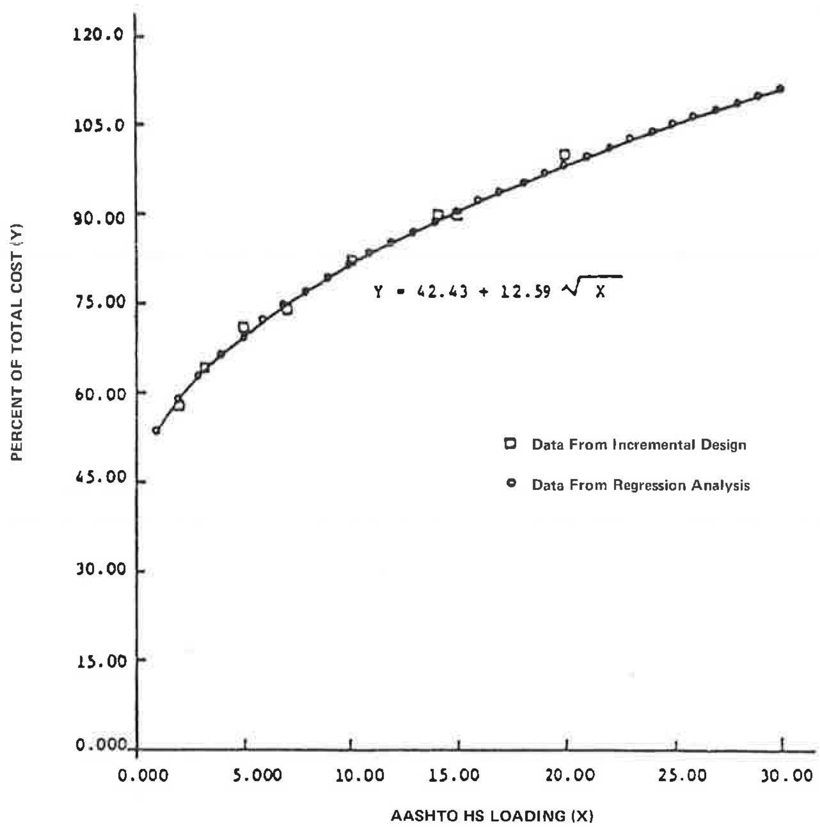

FIGURE 4 Regression equation for state secondary bridges.

TABLE 7 Percentage Distribution of Bridge Rehabilitation Cost by Cost Item and by Highway Class, 1980-1983

	Interstate (rural and urban)	State Primary	State Secondary	Local Road
Superstructure	28.5	29.5	26.2	27.00
Substructure				
Piers and abutments	7	2.6	6.0	5.74
Piling	0.01	0.6	0.13	1.37
Excavation and backfill	9.88	19.6	18.6	18.51
Drainage	0.01	0.10	0.007	0.12
Railing	5.7	3.2	6.50	6.08
Miscellaneous	48.9	44.4	42.50	41.18
Total	100	100	100	100

spective of their size and weight features. The additional cost of providing the additional facility above the basic structure to accommodate heavier vehicles was assigned to the heavier vehicles. Vehicle miles of travel (VMT), which indirectly measures the frequency of the vehicle in a traffic stream, was used as the cost allocator for the basic structural costs and additional facility costs.

TYPES OF BRIDGE PROJECTS

Bridge projects were categorized into bridge construction, bridge replacement, and bridge rehabilitation. Bridges in each category were further divided according to highway type. Next, the itemized unit costs of each project within each project type and highway type were analyzed and grouped according to their cost components described earlier. As an illustration, Table 7 gives the percentage distribution of bridge rehabilitation cost by cost component and by highway class. The cost responsibilities of each vehicle class were then computed according to project type and highway classification for each cost component.

MULTI-INCREMENT COST-ALLOCATION METHOD

The inherent weakness of the incremental concept is the economies-of-scale problem. However, by increasing the number of loading increments, the unequal cost problem would be proportionately reduced. Unfortunately, it was not economically feasible to use a large number of loading increments. For example, suppose that five types of bridges were selected. For each additional loading, there would be five additional hypothetical bridges that would require a large number of design computations. Therefore, an indirect approach to obtaining a large number of design computations was developed.

Initially, bridges were analyzed with a set of AASHTO design loadings to obtain the necessary cost function in the form shown in Figure 5. It was found that seven AASHTO loadings would be sufficient to cover the entire range of study vehicles and would provide the necessary points to plot the cost function accurately.

The next step was to group all study vehicles that produce the same effect on a bridge together. This was done by grouping all vehicles with similar AASHTO designations together (Table 8). The important point here is that all vehicles in the same group basically require the same size bridge and the next higher group will require a slightly larger bridge.

It should be noted that the accuracy of each point derived from careful analysis is more important than the number of points. Each cost function was of the form $Y = a+B/\sqrt{X}$, where a and b were constant and Y and X represented the cost and design increment, respectively. By substituting different values for X into the equation, the additional cost increments could be determined. The graphic way of obtaining the necessary cost increments was through interpolation, as shown in Figure 6.

The last step of the analysis was the distribution of cost responsibilities to all of the study vehicles. For example, in Figure 6, Cost Increment A

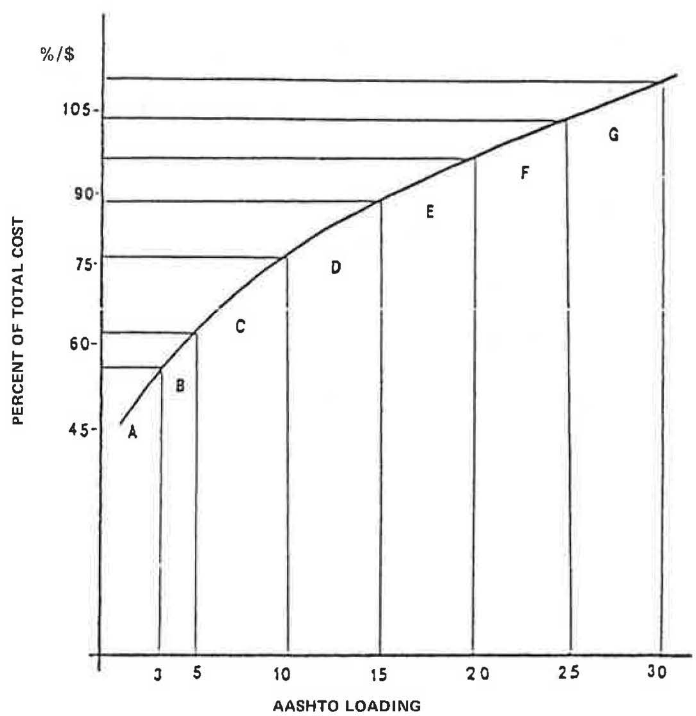

FIGURE 5 Example cost function obtained from the initial set of loading increments.

TABLE 8 Relationship Between AASHTO Design Loadings and Vehicle Class Weight Groups

AASHTO Design Loading	Weight Group
HS 2	[V1:1, V2:1]
HS 3	[V3:1]
HS 4	[V4:1, V8:1]
HS 6	[V4:2, V6:1, V7:1]
HS 8	[V4:3, V6:3, V7:3, V11:2, V12:2]
HS 9	[V7:4, V11:3, V12:3]
HS 10	[V4:4, V6:4, V10:1, V11:4, V12:4]
HS 11	[V3:1, V6:3, V11:5, V12:5, V13:1, V14:1]
HS 12	[V4:5, V11:6, V12:6]
HS 13	[V6:6, V9:1, V12:7]
HS 14	[V11:7, V12:8]
HS 15	[V12:9]
HS 17	[V12:10, V13:2]
HS 18	[V12:11]
HS 19	[V12:12]
HS 20	[V12:13, V14:2]
HS 22	[V9:2]
HS 24	[V14:3]

Note: V = study vehicle designation, number before colon = study vehicle class, and number following colon = position of the study vehicle weight group given in Table 3, HS = AASHTO vehicle designation, and number following HS = AASHTO vehicle index.

was distributed to all vehicles and Cost Increment B was distributed to all vehicles in increments B through R according to their VMT-values. Table 9 gives the data for an example problem, and Table 10 gives the application of the incremental analysis to the example problem. It is to be noted that, for illustrative purposes, only four arbitrary AASHTO loadings were used. This process is repeated for each project type, for each highway type, and for each bridge cost component.

DISCUSSION OF FINDINGS

In Table 11 are given the cost responsibilities of the four generalized vehicle classes determined in the present study. These results are compared with those of the FHWA study (10). It is to be noted that the definition of the four generalized vehicle classes was not the same in the two studies. Consequently, the results could not be precisely compared. However, it could be concluded that passenger vehicles as a group were responsible for more than 68 percent of the total cost. Such a high figure for passenger vehicles was due to their higher frequency of using the facility (VMT), even though structurally they were responsible for a smaller percentage of the total cost.

SUMMARY AND CONCLUSIONS

As noted earlier, an accurate correlation between design vehicles and study vehicles is important in a structural cost-allocation study. The present study obtained such correlation based on the relative effect of both the axle loading and the axle spacing of each vehicle on a series of continuous-span bridges. Continuous-span bridges were used because most bridges are of this nature.

It is proposed here that the cost of new construction, replacement, and rehabilitation of bridges be distributed on the basis of the relative costs associated with providing the necessary services to each class of vehicle. This is accomplished by

TABLE 9 Cost Allocation Problem Data

AASHTO Loading	Cost Increment ($\$ \times 10^5$)	Cost Allocator (VMT x 10^7)
HS 1	55	45
HS 2	10	20
HS 3	15	25
HS 4	20	10
	100	100

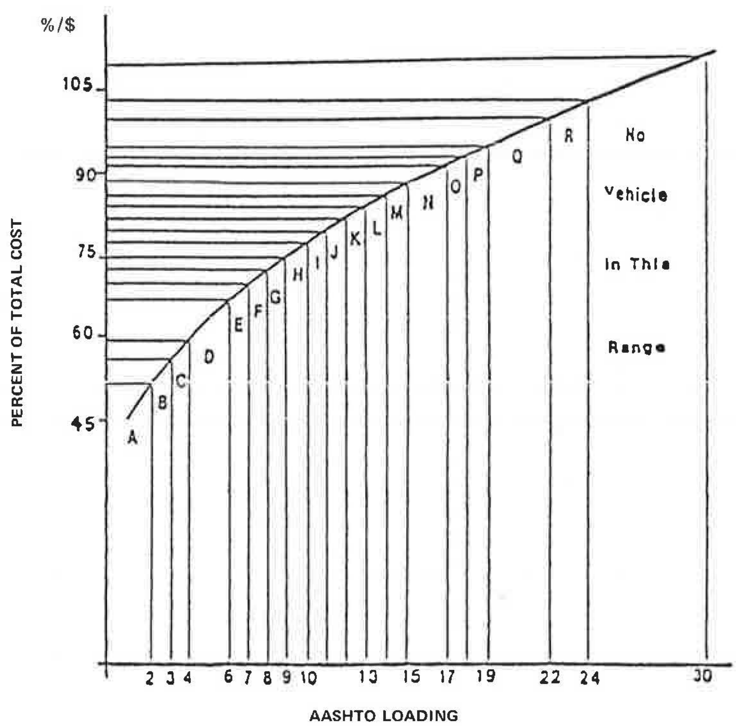

FIGURE 6 Final set of cost increments derived from superimposition of Figure 5 and Table 8.

TABLE 10 Application of Incremental Cost Analysis

	AASHTO Design Vehicle				Total Cost Increment
	HS 1	HS 2	HS 3	HS 4	
First increment	55 · (45/100) = 24.75	55 · (20/100) = 11.0	55 · (25/100) = 13.75	55 · (10/100) = 5.5	55
Second increment		10 · (20/55) = 3.64	10 · (25/55) = 4.54	10 · (10/55) = 1.82	10
Third increment			15 · (25/35) = 10.71	15 · (10/35) = 4.29	15
Fourth increment				20 · (10/10) = 20	20
Cost responsibility	24.75	14.64	29.0	31.61	100

TABLE 11 Comparison of Bridge Cost Responsibility Factors (%) of Indiana Study *(9)* and FHWA Study *(10)*

	FHWA Study (1985)[a]		Indiana Study (1983)	
Vehicle Type	Recommended Approach[b]	Incremental for All Bridge Costs[c]	State Highways	All Highways[d]
Passenger vehicles	65.02	69.12	68.58	73.18
Buses	1.21	0.94	0.28	1.59
Single-unit trucks	7.67	6.69	6.27	8.28
Combination trucks	27.32	24.19	24.87	17.83

[a]Federal Highway Cost-Allocation Study *(10)*, pp. iv-52.
[b]Assigns bridge rehabilitation costs to all vehicles as common costs.
[c]Groups rehabilitation costs with other structure costs.
[d]State highways + county roads + city streets.

grouping the itemized unit costs attributable to each vehicle class according to bridge cost components.

The chief drawback of the incremental cost methodology is the economies-of-scale problem. This problem is particularly pronounced when only a few cost increments are used. Because the number of design analyses required increases with the number of cost increments used, often the tendency is to minimize design analyses and, thereby, cost increments. The proposed multi-increment analysis would reduce the economies-of-scale problem without requiring a large number of design computations.

The cost responsibility of each vehicle class was based first on its structural and geometric requirements and then on the frequency with which it uses the facility. Therefore, from the structural standpoint, passenger automobiles were responsible for only a small portion of the total bridge cost but, because of the high frequency with which they use the facility, they were responsible for a high percentage of total bridge cost.

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