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# HIGHWAY RESEARCH RECORD

## Number 100

# Engineering Economy

## 6 Reports

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| SUBJECT CLASSIFICATION |
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| 15 Transportation Economics |
| 55 Traffic Measurements |
| 82 Urban Community Values |

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# Foreword

The six papers presented in this Highway Research Record deal with various aspects of economic decision-making for highways. They should be of interest to persons responsible for such decisions, whether they are engaged in planning, location, design, or operations.

The first paper (an abridgment by Brenan and Rothrock) presents a general framework for economic analysis as developed in the "Route and Project Planning Manual" of the West Virginia State Road Commission. Another report, by MacDorman, uses an interesting case study to illustrate the sensitivity of economic decisions to changes in certain common variables. The paper by Lee and Grant deals with the treatment of prospective inflation, an issue that arises in many economy studies for today's highways.

The papers by both Johnson and Bevis deal with the development of mathematical models related to highway user costs. Their papers are interesting not only because of their reference to the generation of data useful in highway economy studies, but because they also contain material of special interest to persons engaged in traffic and operations.

The final paper by Blythe, Dearinger, and Puckett (also an abridgment) deals with the weighing of trucks in motion. This paper obviously is of specific value to persons responsible for securing data on truck weights, but it has general interest as well.

# Contents

# Principles of Highway Engineering Economic Analysis*

MALCOLM F. BRENAN and CLAUDE A. ROTHROCK
Respectively, Director and Highway Engineer, Advanced Planning Division, West Virginia State Road Commission, Charleston

ABRIDGMENT

•THE FOUR principal methods used in highway economic analysis are defined and the relative advantages of each are described.

1. Benefit-Cost Ratio—This method was originally developed for use in evaluating river basin projects as required by the Congress and adopted for highway projects by the AASHO Committee on Planning and Design Policies. It has been presented in a publication commonly called the "Red Book."
2. Present Worth—The values of all costs and benefits are reduced to a present worth for comparison purposes.
3. Annual Costs—Values of all costs, both of construction and users costs, are calculated as an average annual cost, thus giving a direct comparison of alternate schemes.
4. Rate of Return—This method considers the interest rate at which the expected income (net benefits) will amortize the proposed investment.

The paper discusses the determination of quantifiable costs as:

1. Highway costs, consisting of operating, maintenance, and construction costs (capital costs);
2. User costs, consisting of operating costs of motor vehicles, including the evaluation of the users time;
3. Accident costs, an evaluation of monetary worth of an expectation of reduction of accidents by use of a proposed improved facility; and
4. Comfort and convenience, an evaluation of the users' probable preference for the new facility, even if the expected operating costs thereon may be greater than those on the old facility.

The paper discusses the consideration to be given to intangibles, secondary benefits, and social consequences not reducible to money terms.

The principle interest formulas usable in problems of engineering economic analysis are given and described, and definitions of the principal terms used in the discussion are included.

*This paper is based on a manual of the same title issued as a supplement to the "Route and Project Planning Manual," prepared for use by the Advanced Planning Division of the West Virginia State Road Commission, Charleston.

Paper sponsored by Committee on Highway Engineering Economy.

# Case Study in Sensitivity of Highway Economy Factors

LITTLETON C. MacDORMAN, Washington Metropolitan Area Transportation Study

Several plans have been considered as possible solutions to the increasing Shirley Highway traffic crossing the Potomac River, including a reversible express lane bridge, widening of two existing structures, and a new bridge on a removed location. The study reflects the advantages of building additional capacity for the peak hour, as well as maintaining the null condition for off-peak by considering the daily traffic under three operating conditions.

Considerable emphasis has been placed on an analysis testing the sensitivity of "vestcharge" rates, the value of time and traffic growth. The benefit-cost analysis is presented graphically, in addition to rate-of-return solutions illustrating the sensitivity of varying combinations of factors. Optimal decision maps are shown, with consideration given to varying rates of traffic growth providing depth to the cost picture that will aid in forming a reasonably sound engineering decision.

•THE RAPID growth of the area around the Nation's Capital has caused increased desire for better understanding of transportation needs. Those in responsible positions are continually being called upon to make decisions concerning large capital expenditures for major transportation projects. This is particularly true regarding river crossings. The investment, impact and future implication of a new bridge has always been a source of controversy. Such a bridge or bridges are presently being contemplated to relieve expected increases in traffic generated along the Shirley Highway corridor.

The Shirley Highway is not new to the student of highway engineering. The name is synonymous with studies in speed, capacity and fuel consumption. This classic roadway has now reached its life expectancy in terms of capacity. The Virginia Department of Highways has adopted a three-two-three reversible lane redesign of the Shirley Highway and has included the freeway in the Interstate system as I-95. However, there have been several suggestions concerning roadway configurations crossing the Potomac River. The study area in Figure 1 shows the relationship of the river crossing to the presently proposed Interstate Highway System in the Washington metropolitan area.

The number of alternate solutions proposed for crossing the Potomac River have been reduced to four possibilities:

Alternative 1, Do-nothing or null condition. The two-lane reversible express roadway in Virginia is terminated in the Hayes St. area before the interchange of the Shirley Highway and US 1. There are no changes considered to take place on either the northbound Rochambeau Bridge or the southbound George Mason Bridge. The approach roadways in the District of Columbia are also to remain as they presently exist (Fig. 2).

Alternative 2, Reversible express lane bridge. The two-lane reversible express roadway is extended in a northerly direction across the Potomac River on a separate structure, one lane split to 14th St. and one lane to the Washington Channel Bridge (Fig. 3). This is the same scheme presented in a consultant's report (5) to the Virginia Department of Highways.

Paper sponsored by Committee on Highway Engineering Economy.

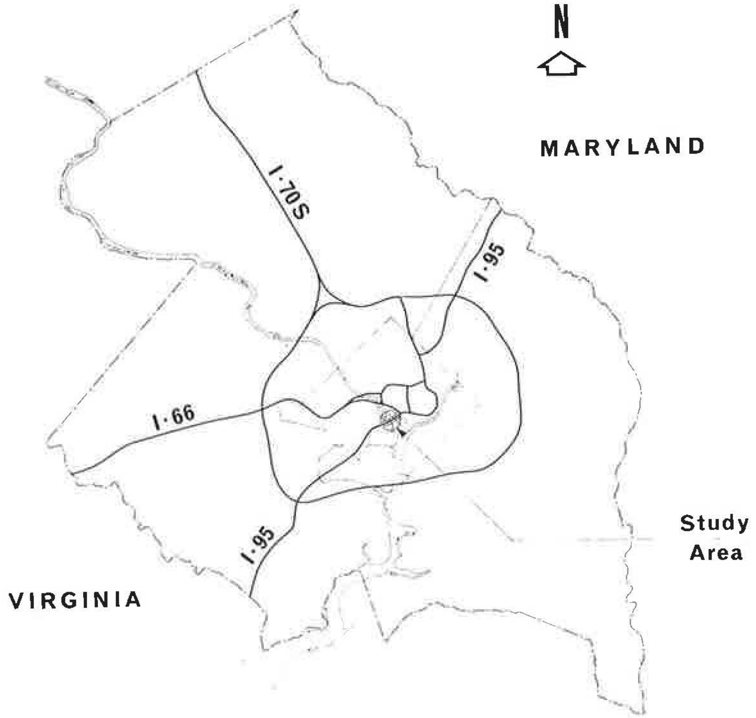


Figure 1. Study area in relation to proposed Interstate system for Washington metropolitan region.

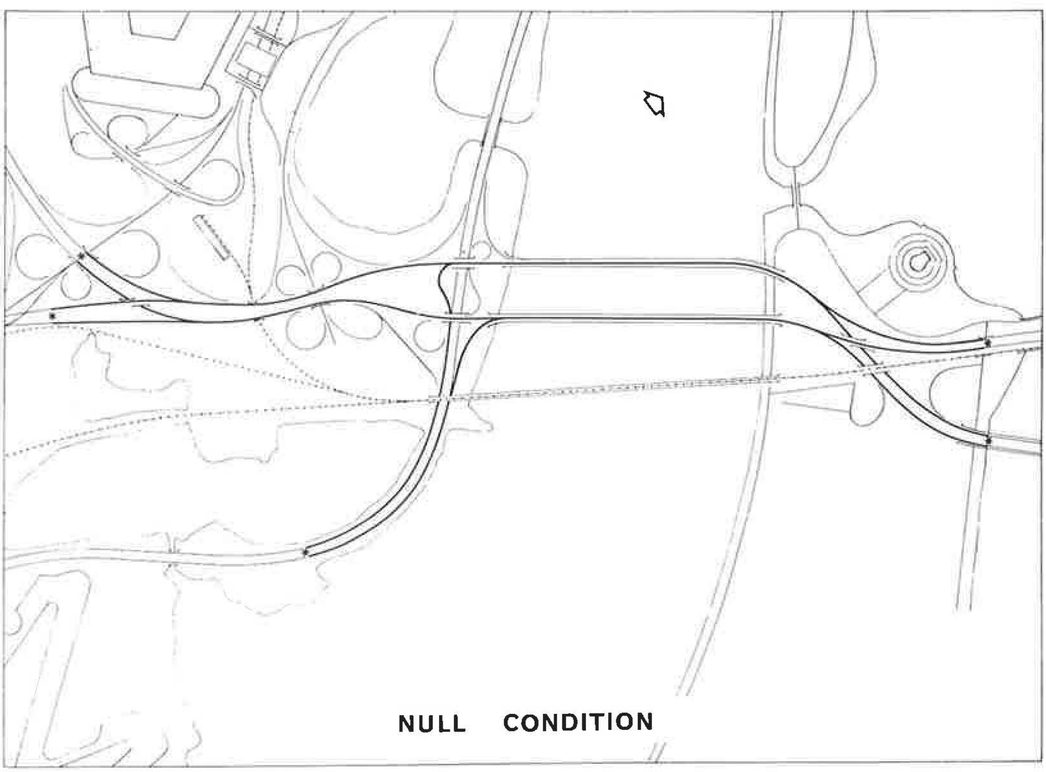


Figure 2. Alternative 1.

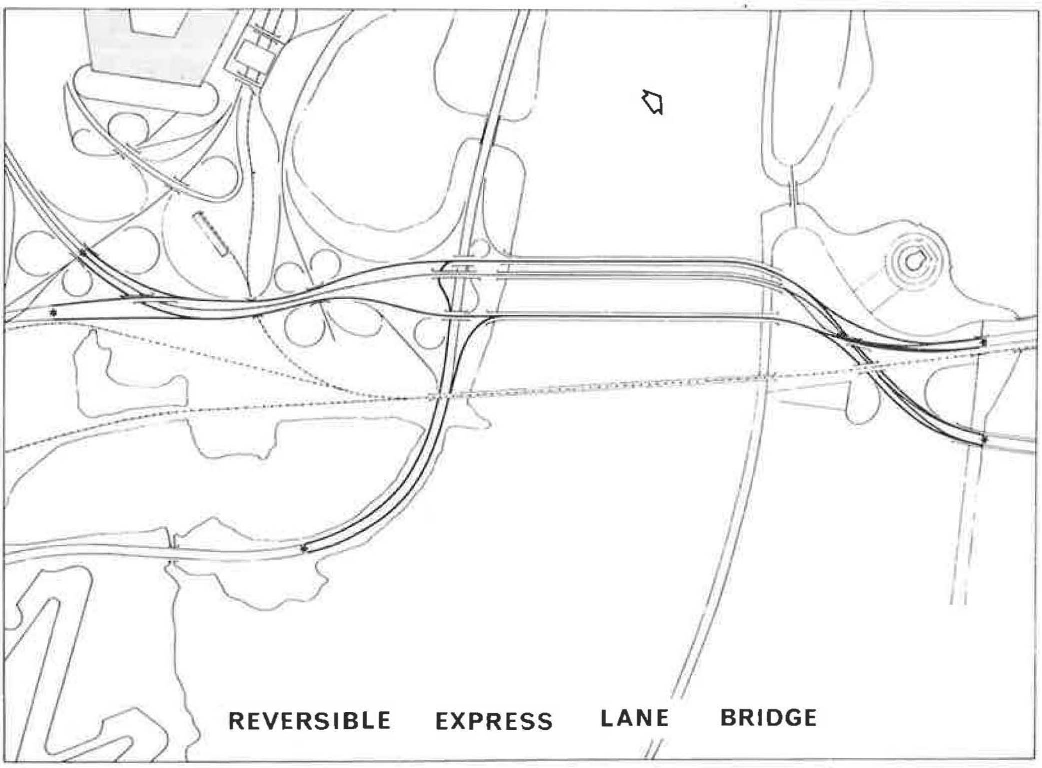


Figure 3. Alternative 2.

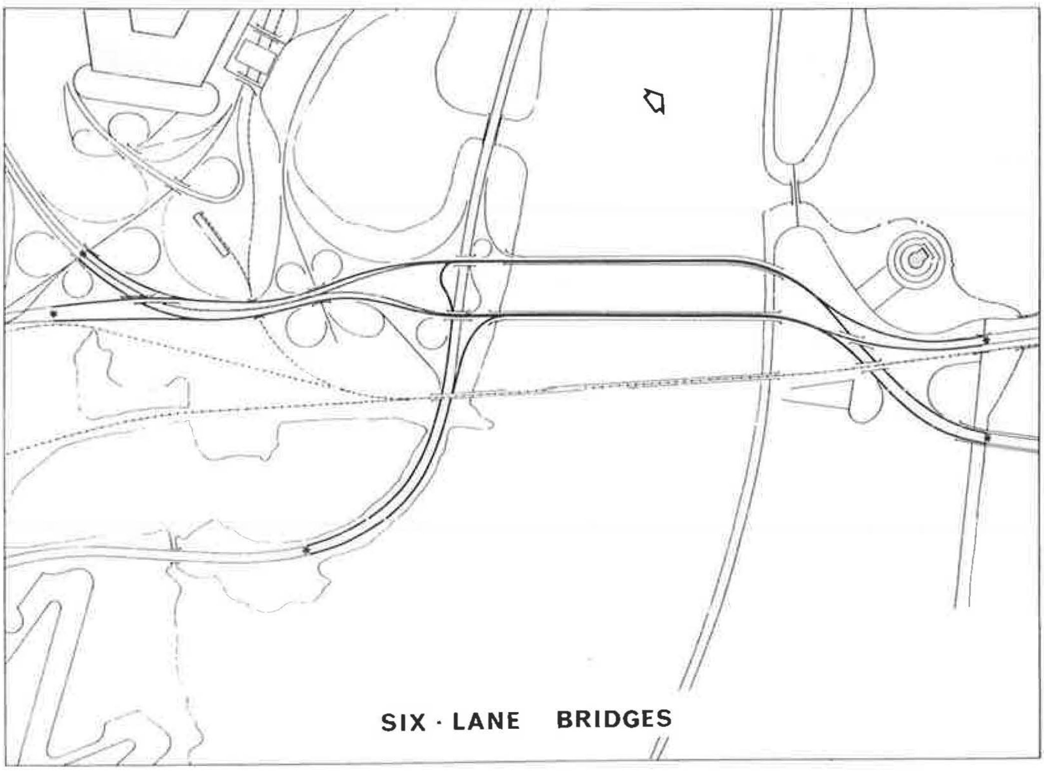


Figure 4. Alternative 3.

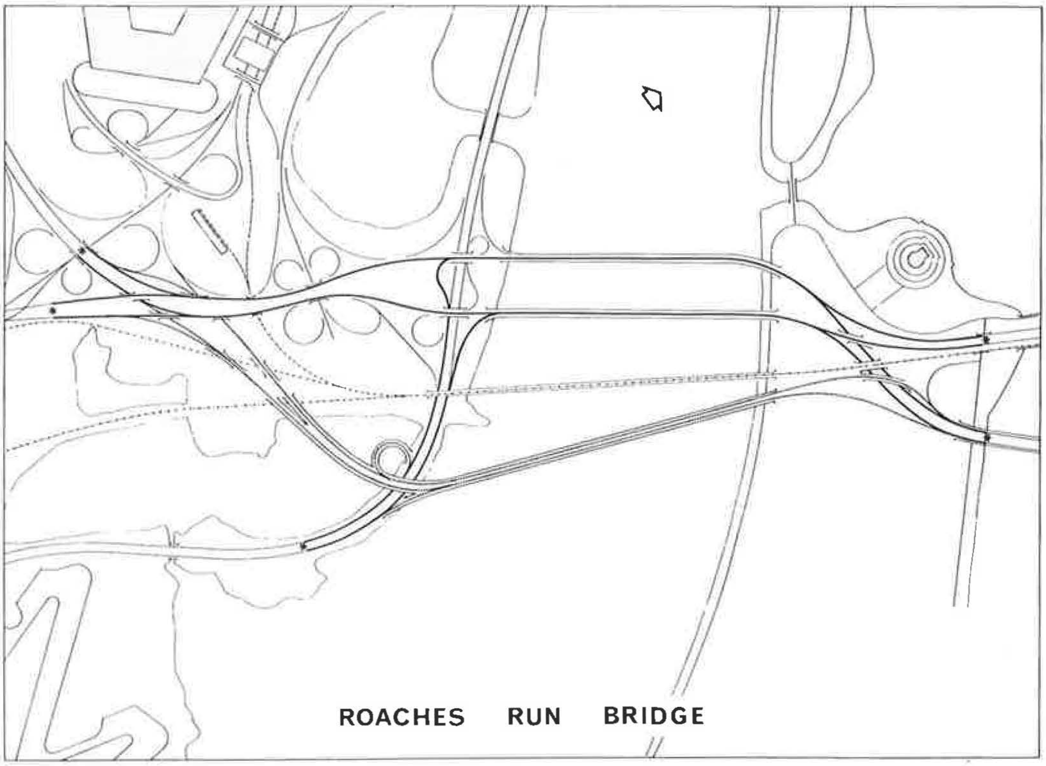


Figure 5. Alternative 4.

Alternative 3, Six-lane bridges. The reversible express lanes are carried in Virginia to the Potomac River where they divide connecting to both the Rochambeau and George Mason Bridges. The present structures and the approaches in the District of Columbia are to be widened from four to six lanes (Fig. 4).

Alternative 4, Roaches Run Bridge. A new four-lane bridge east of the Richmond, Fredricksburg and Potomac Railroad Bridge is connected to the Shirley Highway in the vicinity of the existing interchange with US 1. Connections are made with the Shirley Highway, the George Washington Parkway and one inbound ramp from US 1. A direct tie to the Washington Channel Bridge is coordinated with present connections in the District of Columbia (Fig. 5).

Since the choice of alternatives was clear and the limits of influence could be reasonably well defined, it was decided to make an economy study for the various river crossing proposals. The purpose of the study was twofold. One was to answer the project formulation question of which alternative should be recommended as the more economical solution of vehicular access across the river. The other, and perhaps more important, purpose was to determine the relative strengths and weaknesses of the recommendation. This could only be accomplished by testing the sensitivity of the variables involved in the problem. The study considered these three questions:

1. What is the minimum attractive rate of return for this type of investment, considering no direct monetary return will be realized?
2. What is the value of time?
3. What is the probable value of traffic volumes that will utilize these facilities?

TABLE 1

CAPITAL COSTS FOR VARIOUS ALTERNATIVES CROSSING POTOMAC RIVER (× $1,000)

| Alternative | Virginia Approach | Potomac River Crossing | D. C. Approach | Total |
|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 |
| 2 | 1,890 | 3,936 | 350 | 6,176 |
| 3 | 2,390 | 7,029 | 100 | 9,519 |
| 4 | 6,766 | 9,586 | 750 | 17,102 |

## HIGHWAY COSTS

### Capital Costs

Estimates of cost were developed for each alternative by the respective highway departments. The capital investment necessary to build each bridge and its approach roadways is given in Table 1. The annual capital cost for each scheme given in Table 2 was calculated using a selected number of vestcharge[1] rates for an analysis period of 20 yr. No salvage value was assumed for any alternative (2).

### Maintenance Cost

Maintenance costs were recognized as being those necessary to housekeep each facility. Typical items may include roadway and structure repair, snow removal, landscape and drainage maintenance, painting, lighting and necessary law enforcement. At this point it was assumed that all alternatives will incur the same annual maintenance costs.

## TRAFFIC MAINTENANCE COSTS

During the period of construction, another charge may arise. In this study it is referred to as the traffic maintenance cost and can be separated into two categories, capital and operational. The capital costs are those borne by the contractor necessary to maintain traffic. Examples may be temporary roadways, drainage structures, signs and signalmen. These are assumed to be included in the capital costs and will not be discussed further. Operational traffic maintenance costs are those incurred by existing vehicles during the period of construction. They involve items of additional expense due to slowdowns, stops, detours and operating over temporary roadways. Time costs, as well as operating costs, are included in this category. In this problem, for example, Alternative 3 will probably accrue more of these costs than Alternative 4 because the plan calls for widening existing bridges which will disrupt the present traffic flow during construction. The bridge in Alternative 4 is on a new location. These costs are presently considered equal for each scheme and will not be further discussed until the conclusion.

## TRAFFIC

### Forecast of Growth

The traffic volumes assigned to the various alternatives were for the year 1980. The derivation of numbers was a result of trip generation by regression analysis. The basic forecast figures such as population, employment, retail sales and school acreage

[1] Vestcharge is a word coined by Robley Winfrey, U.S. Bureau of Public Roads, meaning the charge for the use of money invested in physical assets; it is in lieu of return on invested capital wherein operational money returns are received from business ventures, but the concept of vestcharge assumes that there is no direct money return. Rate of vestcharge is used in the same sense as rate of interest or rate of return.

TABLE 2

ANNUAL CAPITAL COSTS FOR VARIOUS VESTCHARGE RATES AND ALTERNATIVES
n = 20 years (x $1,000)

| Alternative & Capital Cost | Vestcharge Rate | | | | |
|---|---|---|---|---|---|
| | 1% | 6% | 10% | 15% | 20% |
| 1 - Do nothing or null condition $0 | 0 | 0 | 0 | 0 | 0 |
| 2 - Reversible express lane bridge $6,176,000 | $ 342 | $ 538 | $ 725 | $ 987 | $1,268 |
| 3 - Six-lane bridges $9,519,000 | 528 | 830 | 1,118 | 1,521 | 1,955 |
| 4 - Roaches Run Bridge $17,102,000 | 948 | 1,491 | 2,009 | 2,732 | 3,512 |

were obtained from various planning agencies throughout the Washington metropolitan area. Trip distribution was made by the gravity model and assigned to the highway network by a minimum time path algorithm (7). Since the assigned volumes were for 1980, it was necessary to know something about the increase of traffic during the study period. Two methods were used to obtain the growth factor for the period 1960 to 1980 and are shown by the following equations:

Vehicle trip growth factor (1960-1980) =

$$\frac{\text{1980 zone population}}{\text{1960 zone population}} \times \frac{\dfrac{\text{1980 area vehicle registrations}}{\text{1980 area population}}}{\dfrac{\text{1960 area vehicle registrations}}{\text{1960 area population}}} \times \frac{\dfrac{\text{1980 region fuel consumption}}{\text{1980 region vehicle registrations}}}{\dfrac{\text{1960 region fuel consumption}}{\text{1960 region vehicle registrations}}} \quad (1)$$

Minimum vehicle trip growth factor = 1.38 x 1.29 x 1.00 = 1.78

Maximum vehicle trip growth factor = 1.53 x 1.38 x 1.05 = 2.20

Average vehicle trip growth factor = 2.00

Vehicle trip growth factor (1959-1980) =

$$\frac{\text{1980 Potomac River vehicle crossings}}{\text{1959 Potomac River vehicle crossings}} = \frac{578,000}{264,000} = 2.19 \quad (2)$$

Assuming a straight-line growth, the first method provides for a yearly increase of 5.0 percent of the 1960 volume and the second method yields 5.7 percent. Initially, it was concluded that 5.0 percent on a linear basis would be satisfactory for estimating purposes.

## Equivalent Annual Traffic

To evaluate trip growth properly during the study period, the following formula (4) was used to find the equivalent annual traffic:

$$E.A.T. = a + b + \frac{b}{i} - \frac{nb}{i}(crf - i) \quad (3)$$

where

a = present or initial trips,
b = average trip increase per year,
i = interest or vestcharge rate,
crf = capital recovery factor, and
n = study period in years.

Table 3 gives the relationship between 1960, 1980 and the equivalent annual traffic volumes for selected rates of vestcharge by assuming that a = 1 = 1960 traffic volume, b = 0.05, and N = 20 yr.

If traffic grows exponentially rather than linearly, it could be assumed that the volumes compound at a rate approximately equal to 3½ percent per year. This would result in the same volume of 1980 traffic as the 5 percent linear growth. The resultant change in Table 3 would reduce all factors by less than 5 percent. However, it is the differences in alternatives that are meaningful and little change in the final recommendation would result by using an exponential growth.

## Trip Distribution

Since the same basic traffic was used in each alternative, it was felt that the study should show the benefit of building extra bridges for peak volumes as well as that of not building additional capacity for off-peak trips. Several distribution curves plotted for the existing Potomac River bridges had generally standard shapes. Figure 6 was plotted from data gathered during the first 10 mo of 1963. The "best curve" showed that 9.2 percent of the traffic occurred in the peak hour. It also showed less than 1 percent occurred in the 24th hour. Judging by the general shape of the distribution curve, the following breakdown of time was used:

High 4 hr = 34.5 percent,
Next 8 hr = 42.5 percent, and
Low 12 hr = 23.0 percent.

In terms of 1980 Potomac River crossings, this would mean that 13,989 veh/hr cross in the highest 4 hr. Likewise, 9,232 and 3,331 veh/hr cross in the next 8 and lowest 12 hr, respectively, for a total of 173,784 veh/day.

Each alternative was broken into the three study periods reflecting different operating conditions. Each roadway section volume was converted to a per lane basis and a

TABLE 3

EQUIVALENT ANNUAL TRAFFIC FACTORS IN TERMS OF 1960 AND 1980 VOLUMES FOR LINEAR TRIP INCREASE OF 5 PERCENT OF 1960 TRAFFIC PER YEAR

| Vestcharge Rate | 1960 Traffic | 1980 Traffic |
|---|---|---|
| 1 | 1.508 | 0.754 |
| 6 | 1.430 | 0.715 |
| 10 | 1.375 | 0.688 |
| 15 | 1.318 | 0.659 |
| 20 | 1.273 | 0.637 |

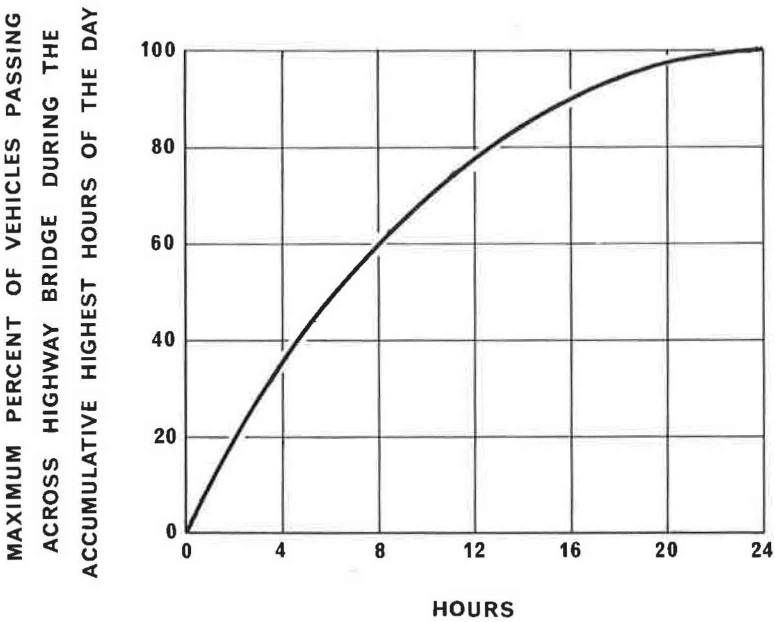


Figure 6. Maximum percent of vehicles passing across highway bridge during accumulative highest hours of day.

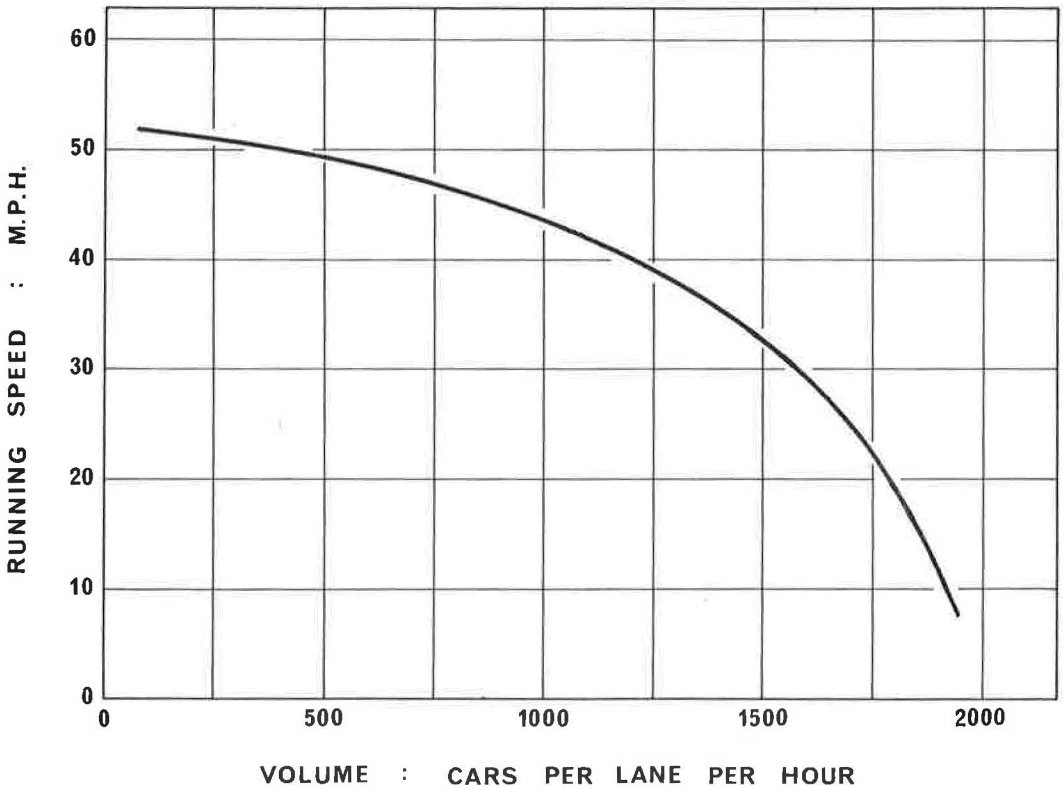


Figure 7. Roadway capacity.

corresponding speed was assigned according to Figure 7. Constrictions in lane design were examined in obtaining operating conditions. For example, if a roadway contained three lanes for the majority of its length but necked down at the outbound end to two lanes because of a ramp connection, two lanes were considered to be the capacity of that section. In general, this had its greatest effect on traffic operation during the high 4-hr period, causing some trips to divert to optional routing.

In the case of alternatives utilizing express lanes, the reversible roadway was assumed closed for 2 hr each day, one during the 8-hr period and one during the low 12-hr period.

Commercial Traffic

Trucks and buses were considered in the problem and again the peak condition reflected a different situation than the off-peak. Table 4 reveals that approximately 13 percent of the traffic using the Shirley Highway between Glebe Rd and the Pentagon network was commercial. However, only 7 percent occurred during the peak hour. The following breakdown of commercial traffic was used in the problem:

High 4 hr = 7 percent,
Next 8 hr = 14 percent, and
Low 12 hr = 20 percent.

In all cases, no trucks were assigned to the George Washington Memorial Parkway or its connecting ramps.

So that unit automobile operating costs could be used in this problem, a truck-car cost relationship was established. A ratio was developed based on the operating costs of trucks and automobiles at different speeds. The resultant curve is shown in Figure 8. This should not be confused with truck-car ratios concerning space or headway requirements.

## ROAD-USER COSTS

Unit operating costs (8) were assumed for passenger cars and specifically refer to gasoline, oil, tires, maintenance and depreciation attributable to mileage for composite 1 percent grades. Unit accident costs (3) for this study were assumed to have a direct relationship to operating speed. Both curves are shown by Figure 9 and reveal that the most economical operating speed occurs between 35 and 40 mph. It was felt that all

TABLE 4

COMMERCIAL TRAFFIC ON SHIRLEY HIGHWAY BETWEEN GLEBE ROAD (Va. Rt. 120) AND PENTAGON NETWORK[a]

| Year | Percent |
|---|---|
| 1955 | 12 |
| 1956 | 13 |
| 1957 | -- |
| 1958 | 10 |
| 1959 | 13 |
| 1960 | 13 |
| 1961 | 12 |
| 1962 | 13 |

[a]Calculated from: Commonwealth of Virginia Department of Highways, Average Daily Traffic Volumes on Interstate and Rural Primary Routes.

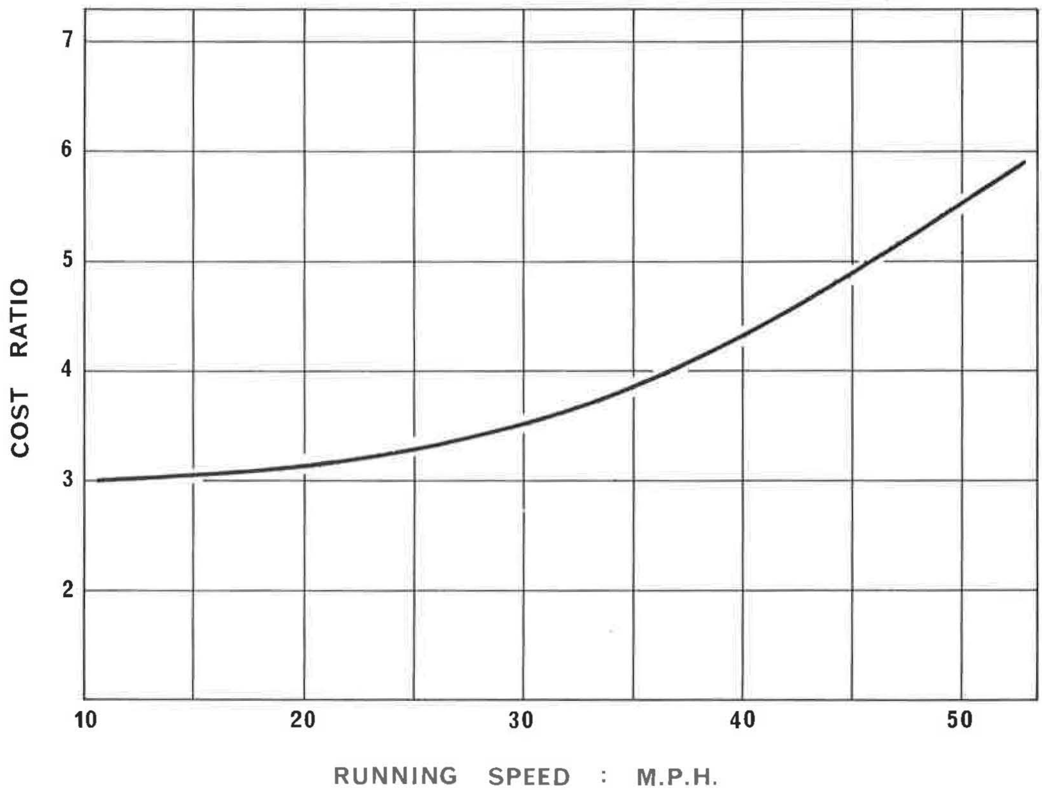


Figure 8. Truck-car cost ratio for divided highways with grades averaging flatter than 2 percent.

alternatives exhibited generally the same grades, curvature and potential accident hazards and, therefore, no detailed breakdown of operating and accident costs was used. The 1980 annual operating and accident costs for the four alternatives are given in Table 5.

The value of time and the appropriate vestcharge rate are two rather elusive but very important factors in determining the proper selection of alternatives. Utilizing the factors developed in Table 3 for the selected vestcharge rates and the four values of time, the equivalent annual vehicular cost for each alternative was computed (Table 6).

## ECONOMIC ANALYSIS

The benefit-cost ratio method of analysis was initially employed in the study through use of the following equation:

$$B.\ C.\ R. = \frac{(Ub - Up) - (Dp - Db)}{Iap - Iab} \qquad (4)$$

where

Ub = base user costs,
Up = proposed user costs,
Db = base maintenance costs,
Dp = proposed maintenance costs,
Iab = base annual capital costs, and
Iap = proposed annual capital costs.

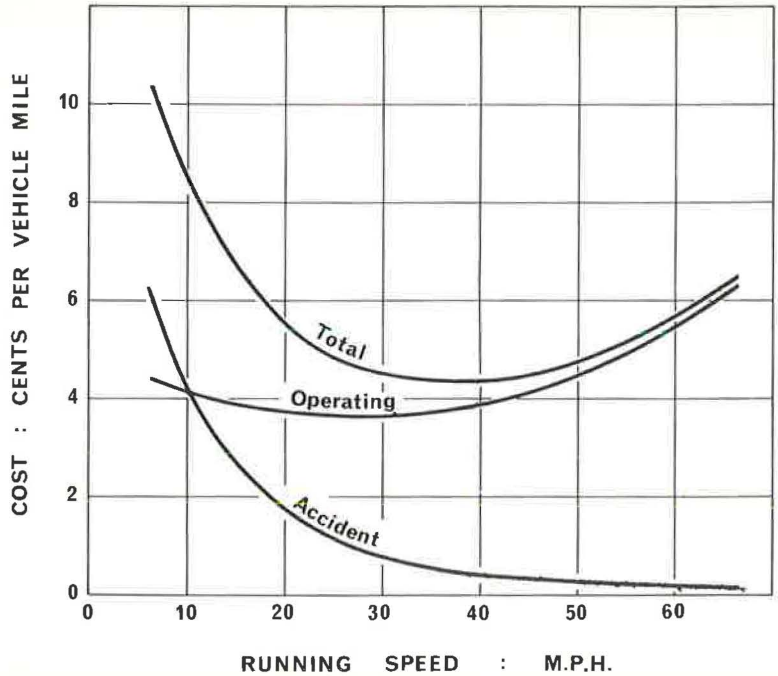


Figure 9. Automobile operating and accident costs.

Table 7 shows the benefit-cost ratios for the various alternatives compared to the null condition utilizing different rates of vestcharge and values of time. If the ratios are plotted graphically and the value of 1.0 is interpolated for each condition, a series of curves will result (Fig. 10). Analyzing each curve separately or comparing the proposed facility against the existing condition shows that it would be unacceptable to recommend any scheme for combinations of values that fall beneath the curve. If any combination of values converge above the curve, it would mean that the proposed facility has benefits in excess of the capital investment and might be recommended. Judging by the more or less acceptable ranges of time values and vestcharge rates, only Alternative 4 does not appear in a favorable position. Alternative 2 exhibits higher ratios than Alternative 3 for any combination of values and, therefore, should be the choice solution. However, since Alternative 3 does show favorably, it was decided to see if the additional investment of $3,343,000 ($9,519,000 - $6,176,000) provides any benefits over Alternative 2. Table 8 shows the benefit-cost ratios for Alternatives 3 and 4 compared to the new base condition of Alternative 2. These values are plotted in Figure 11 and reveal that neither the six-lane bridges or the Roaches Run Bridge is acceptable.

TABLE 5

1980 ANNUAL OPERATING AND ACCIDENT COSTS (× $1,000)

| Alternative | Annual Operating Cost | Annual Accident Cost | Total Annual Operating & Accident Cost |
|---|---|---|---|
| Alternative 1 | | | |
| High 4 hours | $1,364 | $ 676 | $2,040 |
| Next 8 hours | 2,260 | 212 | 2,473 |
| Low 12 hours | 1,705 | 107 | 1,812 |
| Total | $5,329 | $ 995 | $6,324 |
| Alternative 2 | | | |
| High 4 hours | $1,389 | $ 280 | $1,668 |
| Next 8 hours | 2,346 | 210 | 2,556 |
| Low 12 hours | 1,719 | 106 | 1,825 |
| Total | $5,454 | $ 596 | $6,050 |
| Alternative 3 | | | |
| High 4 hours | $1,413 | $ 215 | $1,628 |
| Next 8 hours | 2,411 | 192 | 2,603 |
| Low 12 hours | 1,719 | 105 | 1,824 |
| Total | $5,543 | $ 513 | $6,056 |
| Alternative 4 | | | |
| High 4 hours | $1,462 | $ 243 | $1,705 |
| Next 8 hours | 2,442 | 196 | 2,638 |
| Low 12 hours | 1,729 | 106 | 1,835 |
| Total | $5,633 | $ 545 | $6,179 |

TABLE 6

EQUIVALENT ANNUAL VEHICULAR COSTS FOR SELECTED VESTCHARGE RATES AND VALUES OF TIME FOR THE PERIOD 1960 TO 1980 (x $1,000)
(Growth Rate = 5 Percent of 1960 Traffic per Year)

| Values of Time in Dollars per Passenger Car Hour | 1980 Annual Cost | Equivalent | | Annual | | Cost |
|---|---|---|---|---|---|---|
| | | i = 1% | i = 6% | i = 10% | i - 15% | i = 20% |
| Alternative 1 | | | | | | |
| Time = $0.00 | $ 6,324 | $ 4,768 | $ 4,522 | $ 4,349 | $ 4,168 | $ 4,026 |
| = 0.50 | 8,302 | 6,260 | 5,936 | 5,710 | 5,472 | 5,285 |
| = 1.55 | 12,456 | 9,392 | 8,906 | 8,566 | 8,210 | 7,930 |
| = 3.00 | 18,219 | 13,737 | 13,027 | 12,529 | 12,008 | 11,598 |
| Alternative 2 | | | | | | |
| Time = $0.00 | $ 6,050 | $ 4,561 | $ 4,326 | $ 4,160 | $ 3,987 | $ 3,851 |
| = 0.50 | 7,677 | 5,789 | 5,489 | 5,280 | 5,060 | 4,887 |
| = 1.55 | 11,093 | 8,364 | 7,931 | 7,628 | 7,311 | 7,062 |
| = 3.00 | 15,812 | 11,923 | 11,306 | 10,874 | 10,422 | 10,066 |
| Alternative 3 | | | | | | |
| Time = $0.00 | $ 6,056 | $ 4,566 | $ 4,330 | $ 4,165 | $ 3,991 | $ 3,855 |
| = 0.50 | 7,562 | 5,701 | 5,407 | 5,200 | 4,984 | 4,814 |
| = 1.55 | 10,824 | 8,161 | 7,739 | 7,443 | 7,134 | 6,890 |
| = 3.00 | 15,285 | 11,525 | 10,929 | 10,512 | 10,074 | 9,731 |
| Alternative 4 | | | | | | |
| Time = $0.00 | $ 6,179 | $ 4,659 | $ 4,418 | $ 4,249 | $ 4,072 | $ 3,933 |
| = 0.50 | 7,756 | 5,848 | 5,545 | 5,333 | 5,112 | 4,937 |
| = 1.55 | 11,067 | 8,345 | 7,913 | 7,611 | 7,295 | 7,046 |
| = 3.00 | 15,643 | 11,795 | 11,184 | 10,757 | 10,310 | 9,958 |

At this point it should be sufficient considering the data and results to recommend Alternative 2, the reversible express lane bridge. However, it was decided to test the sensitivity of a change in the growth of traffic volumes. This was done by assuming rates of growth for the study period different than the first assumption of 5 percent. The two alternate growths chosen were 4 and 6 percent. This would indicate a ±20 percent difference in 1980 traffic volumes.

The manner in which this was accomplished was approximate and does not reflect true operational characteristics for the different volumes. Instead of reevaluating actual volumes, speeds, truck-car ratios and costs, a relationship of the different rates of growth was established by substituting appropriate values into Eq. 3. The results are shown by Table 9.

TABLE 7

BENEFIT-COST RATIO OF VARIOUS ALTERNATE SOLUTIONS COMPARED TO ALTERNATIVE 1

| Values of time in Dollars per Passenger Car Hour | Vestcharge | | | Rate | |
|---|---|---|---|---|---|
| | 1% | 6% | 10% | 15% | 20% |
| Alternative 2 | | | | | |
| Time = $0.00 | 0.60 | 0.36 | 0.26 | 0.18 | 0.14 |
| = 0.50 | 1.38 | 0.83 | 0.59 | 0.42 | 0.31 |
| = 1.55 | 3.00 | 1.81 | 1.29 | 0.91 | 0.68 |
| = 3.00 | 5.29 | 3.20 | 2.28 | 1.61 | 1.21 |
| Alternative 3 | | | | | |
| Time = $0.00 | 0.38 | 0.23 | 0.17 | 0.12 | 0.09 |
| = 0.50 | 1.06 | 0.64 | 0.46 | 0.32 | 0.24 |
| = 1.55 | 2.33 | 1.41 | 1.00 | 0.71 | 0.53 |
| = 3.00 | 4.19 | 2.53 | 1.80 | 1.27 | 0.96 |
| Alternative 4 | | | | | |
| Time = $0.00 | 0.12 | 0.07 | 0.05 | 0.04 | 0.03 |
| = 0.50 | 0.44 | 0.26 | 0.19 | 0.13 | 0.10 |
| = 1.55 | 1.10 | 0.67 | 0.48 | 0.34 | 0.25 |
| = 3.00 | 2.05 | 1.24 | 0.88 | 0.62 | 0.47 |

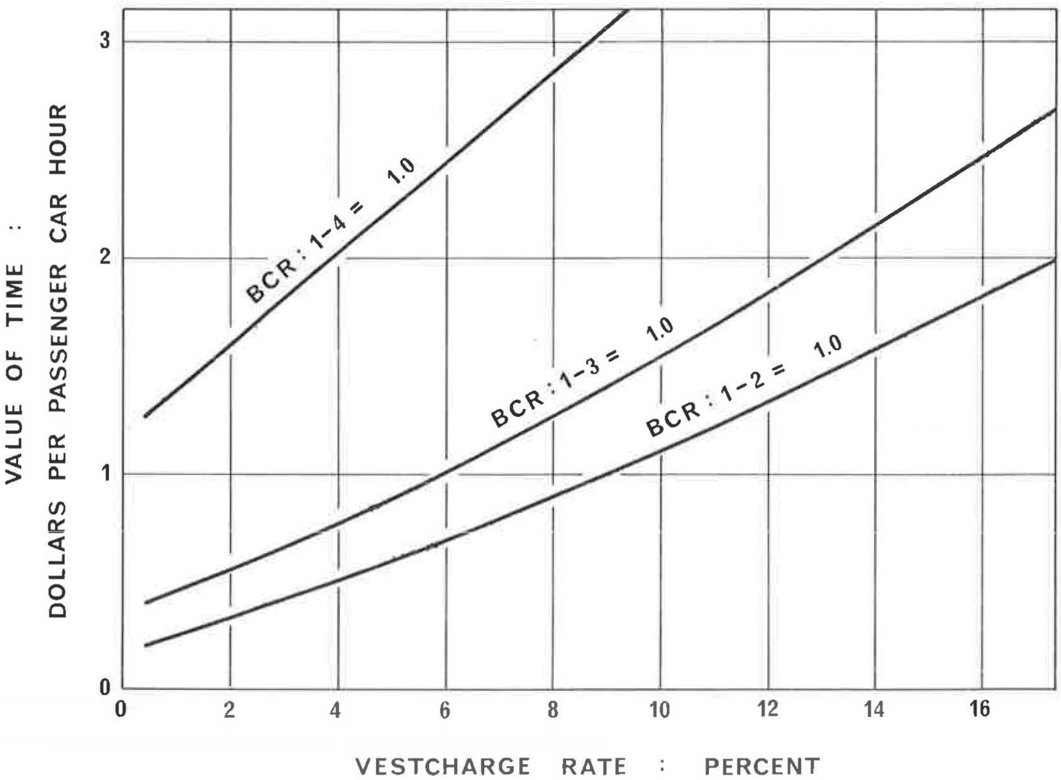


Figure 10. Benefit-cost ratio, base condition = Alternative 1.

The rate-of-return method of analysis was employed for this part of the study utilizing the following equation:

$$[(Ip - Ib) - (pwf' - i - n)(Sp - Sb)](crf - i - n) = (Ub - Up) - (Dp - Db) \quad (5)$$

TABLE 8

INCREMENTAL ANALYSIS, BENEFIT COST RATIO OF VARIOUS ALTERNATE SOLUTIONS COMPARED TO ALTERNATIVE 2

| Values of Time in Dollars per Passenger Car Hour | Vestcharge Rate 1% | 6% | 10% | 15% | 20% |
|---|---|---|---|---|---|
| Alternative 3 | | | | | |
| Time = $0.00 | - | - | - | - | - |
| = 0.50 | 0.47 | - | - | - | - |
| = 1.55 | 1.09 | 0.66 | 0.47 | - | - |
| = 3.00 | 2.15 | 1.30 | 0.92 | 0.65 | - |
| Alternative 4 | | | | | |
| Time = $0.00 | - | - | - | - | - |
| = 0.50 | - | - | - | - | - |
| = 1.55 | 0.03 | - | - | - | - |
| = 3.00 | 0.21 | 0.13 | - | - | - |

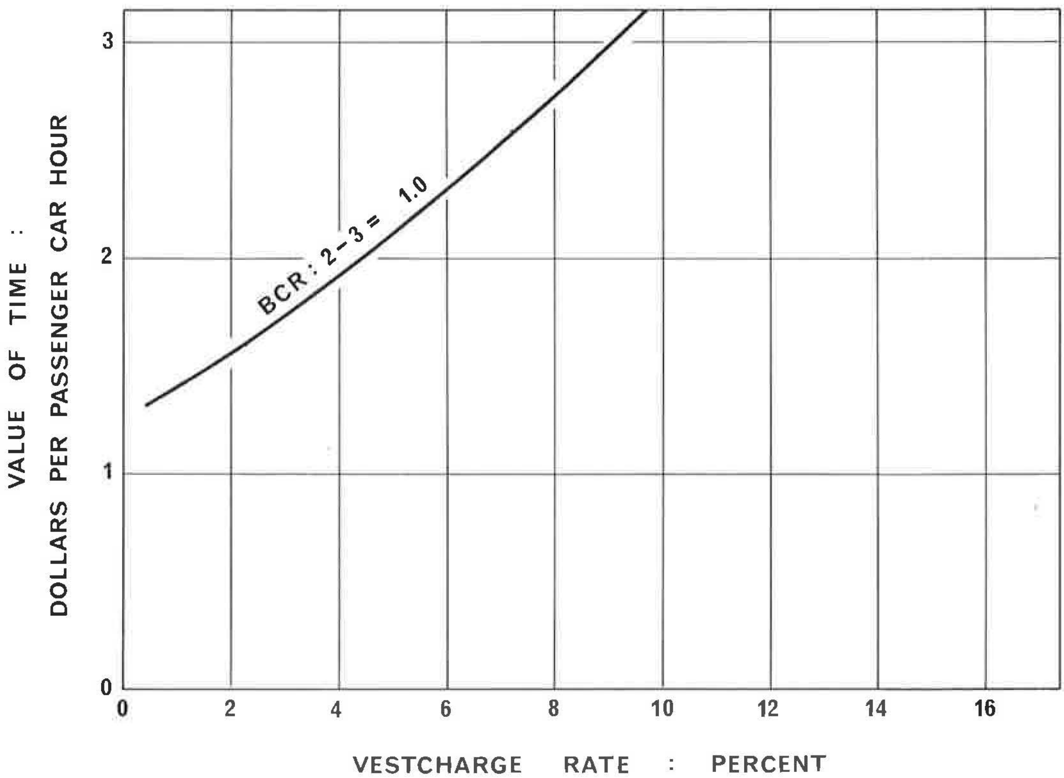


Figure 11. Benefit-cost ratio, base condition = Alternative 2.

where

Sb = base salvage value,
Sp = proposed salvage value,
Ib = base capital costs, and
Ip = proposed capital costs.

The results of the calculations given in Table 10 revealed that in each case Alternative 2 exhibited the higher rates of return over the base condition of Alternative 1. An

TABLE 9

EQUIVALENT ANNUAL TRAFFIC FOR VARIOUS LINEAR GROWTH RATES IN TERMS OF 1960 VOLUMES

| Vestcharge Rate | Linear Traffic Growth per Year | | |
|---|---|---|---|
| | 4% | 5% | 6% |
| 1% | 1.406 | 1.508 | 1.610 |
| 6% | 1.344 | 1.403 | 1.516 |
| 10% | 1.300 | 1.375 | 1.451 |
| 15% | 1.255 | 1.318 | 1.382 |
| 20% | 1.219 | 1.273 | 1.328 |

## TABLE 10

## RATE OF RETURN OF VARIOUS POTOMAC RIVER CROSSING ALTERNATIVES COMPARED TO ALTERNATIVE 1

| Value of Time in Dollars per Passenger Car Hour | Alternative 2 Reversible Express Lane Bridge | Alternative 3 Six-Lane Bridges | Alternative 4 Roaches Run Bridge |
|---|---|---|---|
| Traffic Growth: 4% | | | |
| Time = $0.00 | less than 1% | less than 1% | less than 1% |
| = 0.50 | 3.25% | less than 1% | less than 1% |
| = 1.55 | 12.75% | 9.29% | 1.24% |
| = 3.00 | 20+% | 17.27% | 7.67% |
| Traffic Growth: 5% | | | |
| Time = $0.00 | less than 1% | less than 1% | less than 1% |
| = 0.50 | 3.93% | 1.47% | less than 1% |
| = 1.55 | 13.53% | 10.28% | 1.84% |
| = 3.00 | 20+% | 19.13% | 8.39% |
| Traffic Growth: 6% | | | |
| Time = $0.00 | less than 1% | less than 1% | less than 1% |
| = 0.50 | 4.57% | 2.03% | less than 1% |
| = 1.55 | 14.29% | 10.72% | 2.40% |
| = 3.00 | 20+% | 19.94% | 9.07% |

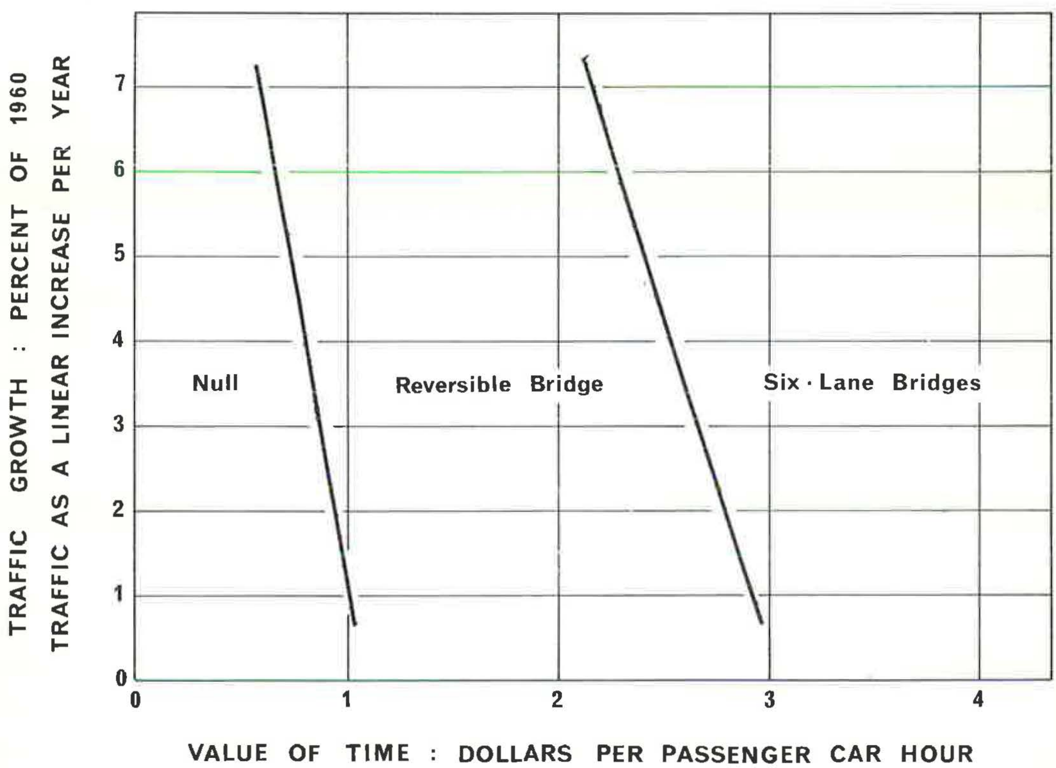


Figure 12. Optimal decision map, minimum attractive rate of return = 6 percent.

incremental analysis comparing Alternatives 3 and 4 to Alternative 2 showed merit in their consideration for certain values of time, vestcharge rate and traffic volumes. The problem of limiting values for the choice of Alternative 2 prompted the following questions:

1. If the minimum attractive rate of return is known, at what minimum value of time would Alternative 3 still be acceptable over Alternative 2?
2. If the minimum attractive rate of return is known, at what maximum value of time would Alternative 1 still be acceptable over Alternative 2?

The answers to these questions were readily available through interpolation of the incremental analysis. Assuming two separate and acceptable values for the minimum attractive rate of return (1), optimal decision maps (6) were plotted (Figs. 12 and 13), revealing that the choice of Alternative 2 still remains valid for generally accepted values of time and limits of probable traffic volumes.

## CONCLUSIONS

The information contained in the figures of this study presents many interesting results. For example, the lowest annual operating costs were achieved by the null condition. This was primarily due to a lower operating speed which, according to the figures used, optimized around 25 mph. However, it should be remembered that the low speeds are probably in the stop-and-start category and, therefore, the costs are probably unjustifiably low. Of the other three more comparable alternatives, Table 5 reveals that the reversible express lane bridge offers approximately the same operating cost conditions as those of the two six-lane bridges.

An examination was made of vehicle-hours. This could possibly be interpreted as an indication of service level. Table 11 compares time for each alternative by study

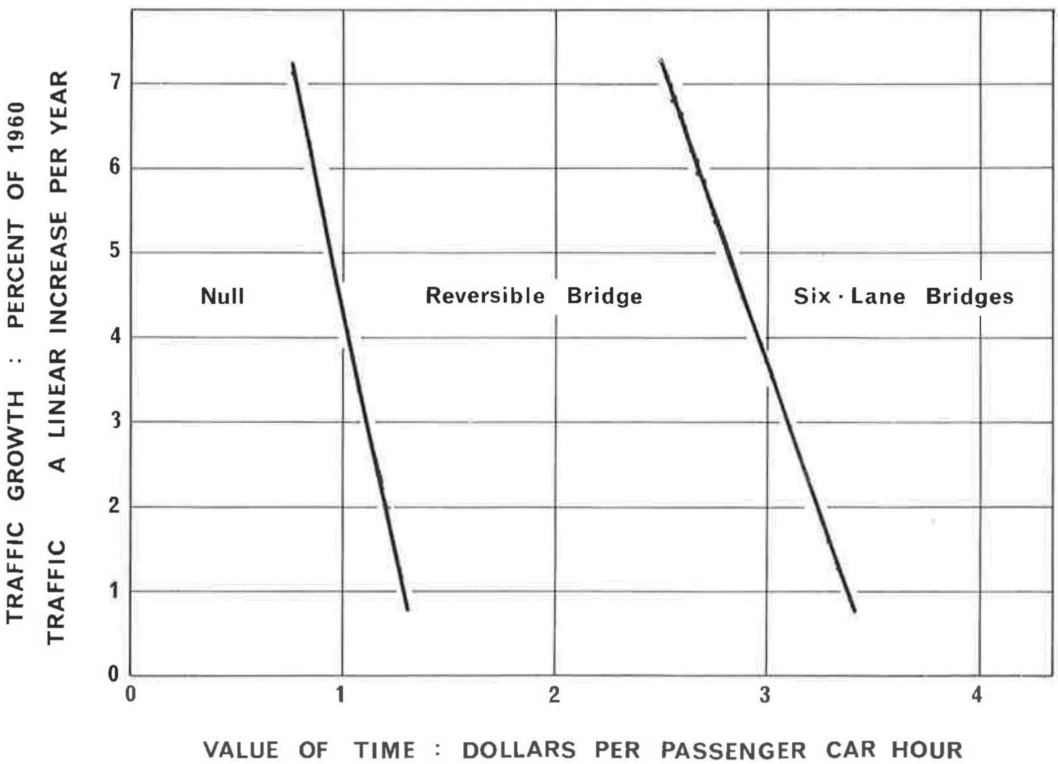


Figure 13. Optimal decision map, minimum attractive rate of return = 8 percent.

TABLE 11

1980 DAILY VEHICLE-HOURS

| Alternative | Daily Vehicle Hours | Relative Service Level by Percent |
|---|---|---|
| Alternative 1 | | |
| High 4 hours | 5,609 | 57 |
| Next 8 hours | 4,083 | 95 |
| Low 12 hours | 2,300 | 99 |
| Total | 11,992 | 78 |
| Alternative 2 | | |
| High 4 hours | 3,544 | 90 |
| Next 8 hours | 4,032 | 95 |
| Low 12 hours | 2,285 | 100 |
| Total | 9,861 | 95 |
| Alternative 3 | | |
| High 4 hours | 3,195 | 100 |
| Next 8 hours | 3,859 | 100 |
| Low 12 hours | 2,278 | 100 |
| Total | 9,332 | 100 |
| Alternative 4 | | |
| High 4 hours | 3,372 | 95 |
| Next 8 hours | 3,908 | 99 |
| Low 12 hours | 2,281 | 100 |
| Total | 9,561 | 98 |

period. The dark hours showed no particular advantage to any scheme in terms of service level. Alternative 3 proved to be the better choice during the daylight hours with Alternative 4 a close second.

In summary, high capital investment is probably the chief reason why Alternative 3 is rejected. This study, as is usually the case, showed that low vestcharge rates tend to benefit high capital investment. The better service in terms of vehicle-hours offered by the two six-lane bridges was not great enough to override the initial cost differential with Alternative 2. The Roaches Run Bridge showed no significant benefit attached to any feature studied. High capital costs coupled with high operating costs eliminates this alternative. Since Alternative 2 is the apparent best recommendation, the questions of maintenance and traffic operational maintenance costs previously discussed are now relatively easy to answer. In both cases, the preferred alternative exhibits the least costs and thereby lends weight to the decision. The selection of the reversible bridge alternative can be attributed to two factors: low capital investment and low operating costs directly related to the efficient express lanes carried across the Potomac River and into the District of Columbia.

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# Inflation and Highway Economy Studies

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The nature of inflation and other price changes is investigated to determine procedures for treating them in highway economy studies. Long-and short-term trends of general inflation and highway costs are calculated to aid in future prediction. Current prices should be used for estimates of future costs and benefits because it is difficult to predict inflation or differential highway cost trends. In instances of great certainty of differential price trends, they should be used, but only in a sensitivity analysis.

•THE FACT that inflation has been a feature of the American economy for many years is a matter of record. For example, food purchased for $1.00 in 1940 cost about $2.60 in 1963. Clothing prices increased about 110 percent during the same period. In the highway field, construction costs had an average compounded annual increase of about 4 percent for the same period (Tables 1 and 2). Figure 1 shows the general rise in prices as measured by the Consumer Price Index, the Wholesale Price Index and Gross National Product Deflators.

TABLE 1

WHOLESALE PRICE, CONSUMER PRICE, AND GNP DEFLATOR INDEXES, 1913-1963

| Year | Wholesale[a] Price | Consumer[a] Price | GNP[b] Deflator | Year | Wholesale Price | Consumer Price | GNP Deflator |
|---|---|---|---|---|---|---|---|
| 1913 | 38.2 | 34.5 | - | 1938 | 43.0 | 49.1 | 48.7 |
| 1914 | 37.3 | 35.0 | - | 1939 | 42.2 | 48.4 | 48.1 |
| 1915 | 38.0 | 35.4 | - | 1940 | 43.0 | 48.8 | 48.9 |
| 1916 | 46.8 | 38.0 | - | 1941 | 47.8 | 51.3 | 52.9 |
| 1917 | 64.3 | 44.7 | - | 1942 | 54.0 | 56.8 | 59.6 |
| 1918 | 71.7 | 52.4 | - | 1943 | 56.5 | 60.3 | 64.9 |
| 1919 | 75.8 | 60.3 | - | 1944 | 56.9 | 61.3 | 66.5 |
| 1920 | 84.5 | 69.8 | - | 1945 | 57.9 | 62.7 | 68.0 |
| 1921 | 53.4 | 62.3 | - | 1946 | 66.1 | 68.0 | 74.6 |
| 1922 | 52.9 | 58.4 | - | 1947 | 81.2 | 77.8 | 83.0 |
| 1923 | 55.1 | 59.4 | - | 1948 | 87.9 | 83.8 | 88.5 |
| 1924 | 53.6 | 59.6 | - | 1949 | 83.5 | 83.0 | 88.2 |
| 1925 | 56.6 | 61.1 | - | 1950 | 86.8 | 83.8 | 89.5 |
| 1926 | 54.8 | 61.6 | - | 1951 | 96.7 | 90.5 | 96.2 |
| 1927 | 52.3 | 60.5 | - | 1952 | 94.0 | 92.5 | 98.1 |
| 1928 | 53.0 | 59.7 | - | 1953 | 92.7 | 93.2 | 99.0 |
| 1929 | 52.1 | 59.7 | 57.4 | 1954 | 92.9 | 93.6 | 100.0 |
| 1930 | 47.3 | 58.2 | 55.4 | 1955 | 93.2 | 93.3 | 101.2 |
| 1931 | 39.9 | 53.0 | 49.9 | 1956 | 96.2 | 94.7 | 104.6 |
| 1932 | 35.6 | 47.6 | 44.9 | 1957 | 99.0 | 98.0 | 108.4 |
| 1933 | 36.1 | 45.1 | 44.2 | 1958 | 100.4 | 100.7 | 110.8 |
| 1934 | 41.0 | 46.6 | 46.9 | 1959 | 100.6 | 101.5 | 112.6 |
| 1935 | 43.8 | 47.8 | 47.4 | 1960 | 100.7 | 103.1 | 114.2 |
| 1936 | 44.2 | 48.3 | 47.7 | 1961 | 100.3 | 104.2 | 115.7 |
| 1937 | 47.2 | 50.0 | 49.5 | 1962 | 100.6 | 105.4 | 116.9 |
| | | | | 1963 | 99.9 | 106.2 | 118.7 |

[a]Data derived from Ref. 8.
[b]Data derived from Ref. 6.

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TABLE 2

CALCULATION OF AVERAGE ANNUAL COMPOUND PRICE INCREASES[a]

| Year | Index No. | Period | n | Ratio | $(1+i)^n$ | i (%) |
|---|---|---|---|---|---|---|
| (a) Consumer Price Index | | | | | | |
| 1913 | 34.5 | 1913-1963 | 50 | 106.2/ 34.5 | 3.08 | 2.3 |
| 1929 | 59.7 | 1929-1963 | 34 | 106.2/ 59.7 | 1.73 | 1.6 |
| 1940 | 48.8 | 1940-1963 | 23 | 106.2/ 48.8 | 2.18 | 3.5 |
| 1957 | 94.7 | 1940-1957 | 17 | 94.7/ 48.8 | 1.94 | 4.0 |
| 1963 | 106.2 | 1957-1963 | 6 | 106.2/ 94.7 | 1.12 | 1.9 |
| (b) Wholesale Price Index | | | | | | |
| 1913 | 38.2 | 1913-1963 | 50 | 99.9/ 38.2 | 2.61 | 1.9 |
| 1929 | 52.1 | 1929-1963 | 34 | 99.9/ 52.1 | 1.92 | 1.9 |
| 1940 | 43.0 | 1940-1963 | 23 | 99.9/ 43.0 | 2.32 | 3.7 |
| 1957 | 99.0 | 1940-1957 | 17 | 99.0/ 43.0 | 2.3 | 5.0 |
| 1963 | 99.9 | 1957-1963 | 6 | 99.9/ 99.0 | 1.01 | 0.2 |
| (c) Engineering News-Record Construction Cost Index | | | | | | |
| 1913 | 100.0 | 1913-1963 | 50 | 900.7/100.0 | 9.01 | 4.5 |
| 1929 | 207.0 | 1929-1963 | 34 | 900.7/207.0 | 4.34 | 4.4 |
| 1940 | 242.0 | 1940-1963 | 23 | 900.7/242.0 | 3.72 | 5.9 |
| 1957 | 723.9 | 1940-1957 | 17 | 723.9/242.0 | 2.99 | 6.7 |
| 1963 | 900.7 | 1957-1963 | 6 | 900.7/723.9 | 1.25 | 3.8 |
| (d) U. S. Bureau of Public Roads Highway Cost Index | | | | | | |
| 1913 | - | - | - | - | - | - |
| 1929 | 55.0 | 1929-1963 | 34 | 101.7/ 55.0 | 1.85 | 1.8 |
| 1940 | 42.8 | 1940-1963 | 23 | 101.7/ 42.8 | 2.38 | 3.9 |
| 1957 | 103.1 | 1940-1957 | 17 | 103.1/ 42.8 | 2.41 | 5.3 |
| 1963 | 101.7 | 1957-1963 | 6 | (103.1/101.7) | (1.015) | -0.3 |
| (e) Gross National Product Deflators | | | | | | |
| 1913 | - | - | - | - | - | - |
| 1929 | 57.4[b] | 1929-1963 | 34 | 118.7/ 57.4 | 2.07 | 2.5 |
| 1940 | 48.9[b] | 1940-1963 | 23 | 118.7/ 48.9 | 2.42 | 3.9 |
| 1957 | 108.4[b] | 1940-1957 | 17 | 108.4/ 48.9 | 22.2 | 4.8 |
| 1963 | 118.7[b] | 1957-1963 | 6 | 118.7/108.4 | 1.095 | 1.5 |

[a]Values for indexes given in Tables 1, 3, and 4.
[b]Index = deflator.

The problem is how to consider inflation in highway economy studies. Should general trends in prices be included or only differential price changes, i.e., the difference between the price trend of the goods and services being analyzed and the general rate of inflation? Should all price trends, general and differential, be ignored? The answers to these questions are important because the procedure adopted for the treatment of inflation can have a decided effect on decisions between alternatives and on the justification of expenditures.

To answer these questions, we must have an understanding of inflation: its causes and cures, its future outlook, its measurement, and its effects on decisions.

This paper deals primarily with the treatment of inflation in economy studies, not in studies of financial feasibility. Economic analysis helps answer the questions "Why do it at all?" "Why do it this way?" "Why do it now?" Financial analysis helps answer the questions "Can it be financed?" "Who will bear the burden?" Both economic and financial studies are required before rational decisions can be reached; but the handling of inflation should be different for these

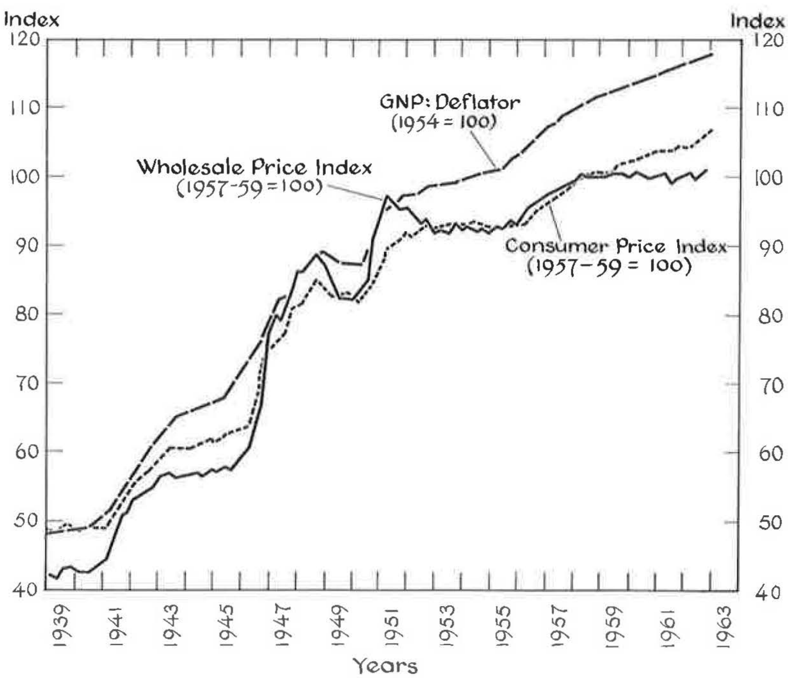


Figure 1. General price trends (24).

# TABLE 3

## PRICE TRENDS FOR FEDERAL-AID HIGHWAY CONSTRUCTION, 1957-1959 BASE[a]

| YEAR | COMMON EXCAVATION | | SURFACING | | | | | STRUCTURES | | | | | | | COM-POSITE INDEX |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | PORTLAND CEMENT CONCRETE | | BITUMINOUS CONCRETE | | SURFACING INDEX | REINFORCING STEEL | | STRUCTURAL STEEL | | STRUCTURAL CONCRETE | | STRUC-TURES INDEX | |
| | BID PRICE (CU. YD.) | INDEX | BID PRICE (SQ. YD.) | INDEX | BID PRICE (TON) | INDEX | | BID PRICE (LB.) | INDEX | BID PRICE (LB.) | INDEX | BID PRICE (CU. YD.) | INDEX | | |
| INDEXES CONVERTED MATHEMATICALLY FROM 1925–29 BASE TO 1957–59 BASE | | | | | | | | | | | | | | | |
| 1922 | $0.40 | 102.5 | $2.28 | 56.9 | - | - | 56.9 | $0.050 | 38.1 | $0.074 | 37.8 | $20.18 | 36.6 | 37.2 | 63.2 |
| 1923 | .47 | 119.3 | 2.43 | 60.6 | - | - | 60.6 | .057 | 43.4 | .078 | 39.4 | 23.37 | 42.4 | 42.5 | 70.4 |
| 1924 | .43 | 109.4 | 2.40 | 59.9 | - | - | 59.9 | .057 | 43.4 | .077 | 38.8 | 22.91 | 41.6 | 41.9 | 67.6 |
| 1925 | .39 | 98.5 | 2.36 | 58.9 | - | - | 58.9 | .056 | 42.6 | .067 | 33.8 | 22.53 | 40.9 | 40.6 | 64.2 |
| 1926 | .36 | 92.8 | 2.29 | 57.1 | - | - | 57.1 | .053 | 40.3 | .074 | 37.3 | 22.76 | 41.3 | 40.6 | 61.8 |
| 1927 | .35 | 89.8 | 2.29 | 57.1 | - | - | 57.1 | .051 | 38.8 | .071 | 35.8 | 22.65 | 41.1 | 39.7 | 60.9 |
| 1928 | .34 | 85.9 | 2.10 | 52.4 | - | - | 52.4 | .049 | 37.3 | .067 | 33.8 | 21.22 | 38.5 | 37.6 | 56.9 |
| 1929 | .32 | 80.6 | 2.05 | 51.1 | - | - | 51.1 | .048 | 36.5 | .059 | 29.8 | 21.58 | 39.2 | 37.2 | 55.0 |
| 1930 | .30 | 77.3 | 1.86 | 46.4 | - | - | 46.4 | .045 | 34.2 | .061 | 30.8 | 20.08 | 36.4 | 35.0 | 51.2 |
| 1931 | .27 | 69.5 | 1.68 | 41.9 | - | - | 41.9 | .040 | 30.4 | .054 | 27.2 | 18.02 | 32.7 | 31.3 | 45.9 |
| 1932 | .18 | 49.2 | 1.44 | 35.9 | - | - | 35.9 | .034 | 25.9 | .046 | 23.2 | 15.33 | 27.8 | 26.6 | 36.4 |
| 1933 | .26 | 66.2 | 1.67 | 41.6 | - | - | 41.6 | .038 | 28.9 | .046 | 23.2 | 16.15 | 29.3 | 28.2 | 45.8 |
| 1934 | .29 | 74.6 | 1.90 | 47.4 | - | - | 47.4 | .043 | 32.7 | .053 | 26.7 | 17.73 | 32.2 | 31.6 | 50.2 |
| 1935 | .26 | 65.6 | 1.90 | 47.4 | - | - | 47.4 | .044 | 33.5 | .052 | 26.2 | 17.78 | 32.3 | 31.9 | 48.1 |
| 1936 | .26 | 67.0 | 1.91 | 47.6 | - | - | 47.6 | .046 | 35.0 | .060 | 30.3 | 20.25 | 36.8 | 35.2 | 49.5 |
| 1937 | .24 | 61.8 | 1.89 | 47.1 | - | - | 47.1 | .048 | 36.5 | .066 | 33.3 | 19.76 | 35.9 | 35.8 | 47.4 |
| 1938 | .21 | 53.5 | 1.72 | 42.9 | - | - | 42.9 | .045 | 34.2 | .063 | 31.8 | 19.06 | 34.6 | 34.1 | 43.5 |
| 1939 | .21 | 53.5 | 1.73 | 43.1 | - | - | 43.1 | .044 | 33.5 | .059 | 29.8 | 19.13 | 34.7 | 33.6 | 43.4 |
| 1940 | .21 | 53.0 | 1.68 | 41.9 | - | - | 41.9 | .045 | 34.2 | .063 | 31.8 | 19.17 | 34.8 | 34.3 | 42.8 |
| 1941 | .24 | 62.0 | 1.87 | 46.6 | - | - | 46.6 | .054 | 41.1 | .076 | 38.3 | 21.44 | 38.9 | 39.4 | 48.6 |
| 1942 | .37 | 93.2 | 2.39 | 59.6 | - | - | 59.6 | .065 | 49.5 | .090 | 45.4 | 26.16 | 47.5 | 47.8 | 65.0 |
| 1943 | .44 | 111.0 | 2.71 | 67.6 | - | - | 67.6 | .067 | 51.0 | .095 | 47.9 | 30.19 | 54.8 | 52.6 | 74.6 |
| 1944 | .37 | 95.4 | 2.45 | 61.1 | - | - | 61.1 | .064 | 48.7 | .089 | 44.9 | 31.94 | 58.0 | 53.4 | 67.6 |
| 1945 | .36 | 91.0 | 2.38 | 59.4 | - | - | 59.4 | .062 | 47.2 | .077 | 38.8 | 31.62 | 57.4 | 51.8 | 65.1 |
| 1946 | .35 | 88.7 | 2.65 | 66.1 | - | - | 66.1 | .075 | 57.1 | .113 | 57.0 | 38.79 | 70.4 | 64.4 | 71.1 |
| 1947 | .38 | 97.0 | 3.01 | 75.1 | - | - | 75.1 | .093 | 70.8 | .132 | 66.6 | 45.84 | 83.2 | 77.0 | 80.6 |
| 1948 | .42 | 106.8 | 3.37 | 84.0 | - | - | 84.0 | .108 | 82.2 | .158 | 79.7 | 51.00 | 92.6 | 87.6 | 90.3 |
| 1949 | .38 | 96.2 | 3.40 | 84.8 | - | - | 84.8 | .104 | 79.1 | .146 | 73.7 | 47.36 | 86.0 | 82.3 | 87.1 |
| 1950 | .33 | 84.6 | 3.32 | 82.8 | - | - | 82.8 | .100 | 76.1 | .139 | 70.1 | 44.62 | 81.0 | 78.0 | 82.3 |
| INDEXES COMPUTED FROM 1957–59 BASE QUANTITIES AND PRICES | | | | | | | | | | | | | | | |
| 1950 | .32 | 75.7 | 3.62 | 82.7 | 5.89 | 88.5 | 85.7 | .099 | 76.2 | .129 | 66.1 | 42.62 | 78.7 | 74.2 | 78.3 |
| 1951 | .40 | 96.2 | 3.92 | 89.6 | 7.33 | 110.1 | 100.3 | .119 | 92.0 | .176 | 90.4 | 50.72 | 93.6 | 92.3 | 96.1 |
| 1952 | .43 | 102.4 | 4.19 | 95.7 | 6.98 | 104.8 | 100.5 | .119 | 92.4 | .178 | 91.3 | 52.24 | 96.4 | 94.1 | 98.9 |
| 1953 | .40 | 96.2 | 4.07 | 93.0 | 6.53 | 98.1 | 95.6 | .121 | 93.8 | .172 | 88.6 | 52.82 | 97.5 | 94.0 | 93.3 |
| 1954 | .38 | 91.4 | 3.98 | 90.9 | 5.97 | 89.7 | 90.3 | .112 | 86.7 | .159 | 81.5 | 50.15 | 92.6 | 88.0 | 89.9 |
| 1955 | .35 | 84.0 | 3.96 | 90.5 | 6.07 | 91.2 | 90.8 | .110 | 85.2 | .157 | 80.9 | 50.01 | 92.3 | 87.4 | 87.3 |
| 1956 | .40 | 96.0 | 4.26 | 97.3 | 6.58 | 98.8 | 98.1 | .127 | 97.9 | .212 | 108.9 | 53.74 | 99.2 | 102.0 | 98.8 |
| 1957 | .42 | 100.7 | 4.34 | 99.2 | 5.75 | 101.4 | 100.3 | .134 | 104.0 | .228 | 117.0 | 55.98 | 103.3 | 107.8 | 103.1 |
| 1958 | .43 | 102.9 | 4.41 | 100.8 | 6.67 | 100.2 | 100.5 | .129 | 99.9 | .186 | 95.7 | 54.10 | 99.9 | 98.5 | 100.6 |
| 1959 | .40 | 95.7 | 4.40 | 100.5 | 6.58 | 98.8 | 99.6 | .126 | 97.2 | .169 | 86.8 | 53.00 | 97.8 | 94.2 | 96.4 |
| 1960 | .39 | 93.8 | 4.33 | 98.9 | 6.37 | 95.7 | 97.2 | .119 | 92.1 | .167 | 85.6 | 51.72 | 95.5 | 91.7 | 94.1 |
| 1961 | | | | | | | | | | | | | | | |
| 1st Qtr. | .41 | 98.3 | 4.18 | 95.5 | 6.19 | 93.0 | 94.2 | .115 | 89.0 | .162 | 83.4 | 52.14 | 96.2 | 90.8 | 94.4 |
| 2nd " | .39 | 92.6 | 4.13 | 94.4 | 6.38 | 95.8 | 95.1 | .116 | 89.6 | .163 | 83.9 | 53.25 | 98.3 | 92.2 | 93.2 |
| 3rd " | .41 | 98.1 | 4.16 | 95.0 | 6.47 | 97.2 | 96.2 | .113 | 87.4 | .161 | 82.8 | 52.96 | 97.8 | 91.1 | 95.1 |
| 4th " | .41 | 98.6 | 4.38 | 100.1 | 6.34 | 95.2 | 97.5 | .116 | 89.5 | .172 | 88.5 | 55.40 | 102.3 | 95.6 | 97.2 |
| Average | .41 | 96.7 | 4.20 | 96.0 | 6.35 | 95.4 | 95.7 | .115 | 88.9 | .165 | 84.8 | 53.38 | 98.5 | 92.4 | 94.9 |
| 1962 | | | | | | | | | | | | | | | |
| 1st Qtr. | .45 | 106.2 | 4.28 | 97.8 | 6.20 | 93.1 | 95.3 | .111 | 86.2 | .161 | 82.7 | 52.66 | 97.2 | 90.6 | 97.4 |
| 2nd " | .42 | 101.0 | 4.23 | 96.6 | 6.42 | 96.4 | 96.5 | .114 | 88.2 | .168 | 86.2 | 54.28 | 100.2 | 93.6 | 97.0 |
| 3rd " | .45 | 106.2 | 4.16 | 95.0 | 6.37 | 95.7 | 95.4 | .113 | 87.6 | .165 | 84.6 | 54.79 | 101.1 | 93.4 | 98.4 |
| 4th " | .47 | 110.7 | 4.42 | 101.0 | 6.16 | 92.5 | 96.6 | .112 | 86.5 | .172 | 88.3 | 56.65 | 104.6 | 96.1 | 101.2 |
| Average | .45 | 106.2 | 4.28 | 97.8 | 6.28 | 94.3 | 96.0 | .113 | 87.1 | .166 | 85.5 | 54.62 | 100.8 | 93.5 | 98.6 |
| 1963 | | | | | | | | | | | | | | | |
| 1st Qtr. | .45 | 106.7 | 4.29 | 98.0 | 5.47 | 97.2 | 97.6 | .112 | 86.8 | .171 | 87.9 | 55.08 | 101.7 | 94.6 | 99.6 |
| 2nd " | .43 | 102.6 | 4.22 | 96.3 | 5.57 | 98.6 | 97.6 | .113 | 87.6 | .181 | 53.1 | 57.47 | 106.1 | 98.6 | 99.6 |
| 3rd " | .44 | 105.0 | 4.39 | 100.3 | 5.37 | 95.6 | 97.9 | .116 | 89.6 | .196 | 100.7 | 58.24 | 107.5 | 102.1 | 101.7 |
| 1957-59 Base | 0.42 | 100.0 | 4.38 | 100.0 | 5.66 | 100.0 | 100.0 | 0.129 | 100.0 | 0.195 | 100.0 | 54.18 | 100.0 | 100.0 | 100.0 |

[a]Data derived from Ref. 10.

two types of analysis. The treatment of inflation in financial studies is briefly discussed later in the paper.

## PRICE CHANGES DEFINED

Two types of price changes may be distinguished: inflation and differential price changes.

Although more elaborate definitions are sometimes use (1), (pp. 510-511), it is sufficient for our purposes to define inflation as an increase in the general level of prices and income throughout the economy, i. e., general price trends. No single index has been devised which can accurately measure inflation. The usual approach is to consider together the Consumer Price Index, the Wholesale Price Index and the Gross National Product Deflators.

By differential price changes we mean the difference between the price trends of the good or service being analyzed and the general price trend. During inflation some prices decrease, whereas others remain fairly constant, keep pace with, or exceed the general trend in prices. Some authorities recommend that differential price changes should be projected and included in the economic analysis; hence their relevance to this discussion.

Aside from inflation, prices may appreciate either because of an increased demand for a particular good or service or because of a diminished supply. This increased demand is often caused by changing consumer tastes. The diminished supply may occur because resources are being depleted in a particular area. An important factor in maintaining stable prices for certain goods and services is the improvement of technology which prevents unit costs from increasing in spite of inflation. This has been the case in the highway field, where average excavation costs were about $0.40/cu yd in 1922 compared with about $0.44/cu yd in 1963 (Table 3). These stable prices can be attributed to the advances in earthmoving equipment and techniques. Therefore, there has been a differential decrease in the cost of highway excavation when compared to the rate of inflation over the same period.

## CAUSES OF INFLATION

Two primary causes of inflation have been identified (1, pp. 511-516, and 2). One is the demand for goods and services increasing much more than the available supplies. The price rise thus stimulated is sometimes called demand-pull inflation. This often occurs when governments undertake large expenditures to finance war or national defense, or to encourage a rapid rate of economic growth. However, individuals and business also contribute to inflation by demanding more than can be produced at a given time. The inflation immediately following World War II is thought to have been caused mainly by pent-up consumer demands for goods and services. Competition for available supplies caused general price level increases.

The other cause of inflation has been attributed to wage increases exceeding increases in labor productivity. The inflation which occurs has been termed cost-push inflation (3). The relative effect of cost-push vs demand-pull factors in causing inflation is a matter of controversy, but it seems evident that inflation would have been less severe during the past decade if wages had not increased more rapidly than the productivity of labor.

## ECONOMIC EFFECTS OF INFLATION

Unexpected inflation favors debtors at the expense of creditors. Suppose someone had borrowed $1,000 a year ago to be repaid now. If prices have doubled in that period, he will be repaying only 50 percent of the real purchasing power received. He is benefiting at the expense of his creditor. Those receiving fixed incomes (from fixed pensions, life insurance annuities and interest) are injured by inflation and those receiving profits (from real estate, common stocks or commodities) are benefited. Similarly, a government agency which borrowed funds for public works projects during a period when inflation was not anticipated finds that its debt is more easily repaid with inflated dollars.

From the national viewpoint, the transfers that take place between debtors and creditors during periods of inflation tend to cancel one another. Therefore, unless

such transfers influence the production of goods and services (as they do during rapid inflation), they have no effect on the national income. In a period of creeping inflation, such as we have experienced in the United States, transfers of this type need not be considered in an economy study. It follows that there is no economic gain to the nation in accelerating the building of public works because inflation is anticipated. Nor is there any ground for public officials to congratulate themselves on having built projects when money costs were lower. If the purchasers of the bonds fail to anticipate inflation, they lose and the debtors gain. If inflation is anticipated correctly by the bond holders, they will probably demand a higher interest yield to compensate for inflation. There is still no net change from the national viewpoint (4).

On the other hand, from a local viewpoint, an area can benefit from having built public works during periods of low prices, provided that an inflation increment was not included in the interest rate on the bonds. In this case, the repayment of the debt can be made with inflated dollars which means that the real cost to the area is less than it would have been had inflation not occurred. A loss occurs to the creditors who failed to anticipate inflation, but this is generally of little concern to the local area.

## CURES FOR INFLATION

The techniques to be used by government to cope with demand-pull inflation are well known (5, pp. 22-24). To diminish demand to bring it into equilibrium with supply, the Federal Government can use both fiscal and monetary policy. Fiscal policy is concerned with taxation and expenditure measures, whereas monetary policy concerns actions affecting credit and the money supply. When serious inflation appears imminent, the government can increase taxes and reduce its expenditures or it can impose credit restrictions through the Federal Reserve Board. One problem in using these measures is that they may be politically unpopular since many groups gain during inflation. Another is that it is difficult to know to what extent and in what combination these measures can be applied to have stable prices and not deflation. There is the very real possibility that an overzealous dedication to the elimination of inflation will lead to depression and unemployment.

There are no similar stabilization tools available to the government to minimize the threat of cost-push inflation. Restraint on the part of business and labor is called for so that their actions will not contribute to inflation. When this restraint is not evident, the government may feel it necessary to intervene, as witnessed by President Kennedy's dramatic encounter with United States Steel in the spring of 1962. President Johnson has given clear warning that he is watching closely the actions of business and labor with regard to wage demands and price increases:

> In the face of a 44 percent increase in corporate profits in less than three years and the prospect of further increases to come with the tax cut, I see no warrant for inflationary price rises.
>
> On the heels of solid increases in real wages, plus the rise in take-home pay under the tax cut, I see no warrant for inflationary price rises. Accordingly:
>
> I shall keep a close watch on price and wage developments, with the aid of an early warning system which is being set up in the appropriate agencies.
>
> I shall not hesitate to draw public attention to major actions by either business or labor that flout the public interest in non-inflationary price and wage standards. (6, p. 1)

## FUTURE OUTLOOK FOR INFLATION

Notwithstanding increased knowledge of the causes and cures of inflation, few economists would be willing to predict that the problem has been eliminated. According to Musgrave:

> No one can predict whether the bias in years ahead will be toward inflation or deflation. Much depends on the outlook for peace and war and the resulting level of military expenditures in the budget. In any case, there is little reason to expect that stabilizing policy will become unnecessary. While much has been said in recent years about built-in stabilizers, these remain to be tested; and contrary to current belief, the inherent tendency toward instability may increase rather than decline as the economy develops and gains in complexity. (5, pp. 22-23)

Another economist, John Kenneth Galbraith, is of the opinion that inflation, not depression, is the greatest threat to the American free-enterprise system, since most of the forces in the economy are of an inflationary nature (7).

## MEASUREMENT OF PRICE CHANGES

Numerous indexes have been devised to measure past price trends for different goods and services. We are concerned with those used to (a) indicate general price trends and (b) gage price changes in the highway field. These may help in predicting future price trends.

### Measuring General Price Trends

Unfortunately, there is no single index completely satisfactory for measuring the general trend in prices, i. e., inflation or deflation. The three indexes commonly used are the Consumer Price Index, the Wholesale Price Index and the Gross National Product (GNP) Deflator. Each has certain shortcomings and cannot be relied on exclusively for measuring changes in price levels (3, pp. 9-14). Therefore, it is customary to look at all three when estimating what past inflation has been and what the future might hold.

The U. S. Department of Labor, Bureau of Labor Statistics, publishes regularly the Consumer Price Index and the Wholesale Price Index (8, pp. 348-358). The Department of Commerce publishes implicit GNP deflators which are included annually in the Economic Report of the President (6, pp. 214-215).

The Consumer Price Index measures:

> the average change in prices of goods and services purchased by city wage-earner and clerical-worker families. The weights used in calculating the index are based on studies of actual expenditures by families of wage earners and clerical workers. The quantities and qualities of the items in the "market basket" remain the same between consecutive pricing periods, so that the index measures the effect of price change only on the cost of living of these families. The index does not measure changes in the total amount families spend for living; city indexes do not measure relative differences in prices or living costs between cities....
>
> The list of items currently priced for the index includes approximately 300 goods and services. For some items, several different qualities are priced. The items priced are described by detailed specifications to insure that, as far as possible, the same quality is priced each time, and that differences in reported prices are measures of price change only. (8, pp. 348-350)

The Wholesale Price Index has been described by the Bureau of Labor Statistics as follows:

> This index, dating from 1890, is the oldest continuous statistical series published by the Bureau of Labor Statistics.

> It is designed to measure average changes in prices of commodities sold in primary markets in the United States.
>
> The index has undergone 4 major revisions....It is now based on nearly 2,200 commodity price series instead of the nearly 1,900 included in the 1947-60 period and the 900 included for the period prior to 1947. Prices used in constructing the index are collected directly from sellers, if possible, and apply as nearly as practicable to the first large volume commercial transaction for each commodity. (8, p. 350)

Gross National Product (GNP) is the total of all final goods and services produced by the economy in any period of time, usually quoted in yearly figures. GNP figures reflect inflation; therefore, the U. S. Department of Commerce has combined a number of price indexes to be used to remove general price level changes so that a true picture of economic growth can be given. This combined index has been described in this manner:

> By combining a number of appropriate price indexes, the U. S. Department of Commerce calculates price series which are comparable in coverage with the GNP. These measure the price changes in GNP from year to year and are known as "implicit price deflators." They can be used to remove the price element from the current dollar GNP series, resulting in GNP totals in constant dollars, often known as real income. (In economics, "real" means that changes in value have been eliminated.) In these terms, inflation would be the condition in which the deflator was rising, i.e., where national money income is rising faster than national real income. (3, p. 12)

Measuring Price Trends in the Highway Field

Price indexes commonly used in the highway field are the Engineering News-Record Construction Cost (ENR) Index, the U. S. Bureau of Public Roads Highway Cost Index and individual state highway cost indexes. From these indexes we hope to gain some idea of the price trends in the highway field for comparison with the general price trend to calculate a differential price change, if any.

The ENR Index (Table 4) was created in 1921 to "diagnose the wild gyrations of prices during and immediately following World War I and to appraise their effect on construction costs." The components and weighting of the index are "25 cwt structural steel shapes, base mill price; 6 bbl portland cement, 20-cities average, bulk; 1.088 Mfbm 2 × 4, S4S lumber, 20-cities average; 200 hr common labor, 20-cities average" (9, p. 79).

The ENR Construction Index does not adjust for "productivity, black or grey markets, competitive conditions, mechanization, design changes or other 'intangibles' that affect the final cost to the owner, or the contractor's 'selling price'" (9, p. 80). Although this index may be satisfactory for some purposes, it should not be used uncritically. For example, it should not be used in the highway field because it neglects so many matters that influence highway costs. Better indexes are available to measure highway construction cost trends, e.g., the U. S. Bureau of Public Roads Highway Construction Cost Index. For the 1957-1959 base period, the index includes 3,641,885,000 cu yd of roadway excavation, 154,953,000 sq yd of portland cement surfacing with average thickness of 9.1 in., 111,516,000 tons of bituminous concrete surfacing, 2,206,879,000 lb of reinforcing steel for structures, 2,581,462,000 lb of structural steel, and 14,583,000 cu yd of structural concrete (10, p. 174). This is a nationwide index and should only be used when state highway cost indexes are not available. A sample of state highway price indexes can be found in Engineering News-Record (9, p. 98).

Figure 2 shows that the overall trend of highway prices appears to be fairly stable since 1957, as indicated by both the U. S. Bureau of Public Roads Index and the

TABLE 4

ENGINEERING NEWS-RECORD CONSTRUCTION COST INDEX,[a] 1903-1963

| Year | Annual Indexes | Year | Annual Indexes |
|---|---|---|---|
| 1903 | 93.90 | 1933 | 170.18 |
| 1904 | 87.40 | 1934 | 198.10 |
| 1905 | 90.55 | 1935 | 196.44 |
| 1906 | 95.10 | 1936 | 206.42 |
| 1907 | 100.55 | 1937 | 234.71 |
| 1908 | 97.20 | 1938 | 235.83 |
| 1909 | 90.92 | 1939 | 235.51 |
| 1910 | 96.33 | 1940 | 241.96 |
| 1911 | 93.43 | 1941 | 257.84 |
| 1912 | 90.70 | 1942 | 276.30 |
| 1913 | 100.00 | 1943 | 289.95 |
| 1914 | 88.56 | 1944 | 298.72 |
| 1915 | 92.58 | 1945 | 307.75 |
| 1916 | 129.58 | 1946 | 346.04 |
| 1917 | 181.24 | 1947 | 413.16 |
| 1918 | 189.20 | 1948 | 460.72 |
| 1919 | 198.42 | 1949 | 477.02 |
| 1920 | 251.28 | 1950 | 509.62 |
| 1921 | 201.82 | 1951 | 542.62 |
| 1922 | 174.45 | 1952 | 569.40 |
| 1923 | 214.12 | 1953 | 599.99 |
| 1924 | 215.36 | 1954 | 627.96 |
| 1925 | 206.68 | 1955 | 659.72 |
| 1926 | 208.03 | 1956 | 692.37 |
| 1927 | 206.24 | 1957 | 723.85 |
| 1928 | 206.78 | 1958 | 759.16 |
| 1929 | 207.02 | 1959 | 796.91 |
| 1930 | 202.85 | 1960 | 823.55 |
| 1931 | 181.35 | 1961 | 847.05 |
| 1932 | 156.97 | 1962 | 871.84 |
| | | 1963 | 900.73 |

[a]Data derived from Ref. 9.

California Highway Cost Index. It also shows how the ENR Index, which fails to reflect technological change, is without value in any study of trends in highway costs.

Techniques for Calculating Price Changes

Two techniques used for measuring price changes are the arithmetic rate method and the compound rate method. The latter is employed here. However, both techniques will be briefly explained.

In the arithmetic rate method, the increase in price is divided by the number of years covered and the initial price to arrive at an annual arithmetic rate of increase. For example, if an item cost \$100,000 in 1940 and \$200,000 in 1960, the average arithmetic change in price per year is

$$i = (200,000-100,000)/20(100,000) = 0.05 = 5 \text{ percent}$$

The compound rate method is somewhat more complicated because it assumes that price changes proceed at an exponential rate. For the same data, the compound rate of price change would be

$$(1+i)^{20} = 200,000/100,000 = 2.0$$
$$(1+i) = (2.0)^{1/20}$$
$$i = (2.0)^{1/20} - 1.0$$
$$i = 1.035 - 1.0 = 0.035 = 3.5 \text{ percent}$$

The calculation of compound rates of price changes can be facilitated by referring to compound interest tables which have values of $(1+i)^n$ for various values of i and n (11).

Summary of Past Price Changes

Table 5 gives an indication of the average annual compound rates of price changes for the indexes just reviewed. Rates are also calculated for short periods to show the variation with long-term trends.

Several conclusions can be reached by analyzing Table 5. The long-term general trend of prices as measured by the Consumer Price Index, the Wholesale Price Index and GNP Deflators has varied from 1.6 to 2.5 percent per year. Since 1957, these indexes have indicated rates of price increase from 0.2 to 1.9 percent per year. From 1940 to 1957, prices increased at rates from 4.0 to 5.0 percent per year. What rates may be expected in the future? As indicated earlier, projections of the trend of inflation are beset by great uncertainty. Long-term trends contain figures from periods when price stabilization tools were little understood. On the other hand, the growth of the threat of cost-push inflation and the increasing complexity of the economy prevent the optimistic view that inflation is under control. Since many observers feel that an annual rate of inflation of no more than 2 percent can be tolerated, this may give an upper limit. Since the long-term rates and the recent short-term rates approach

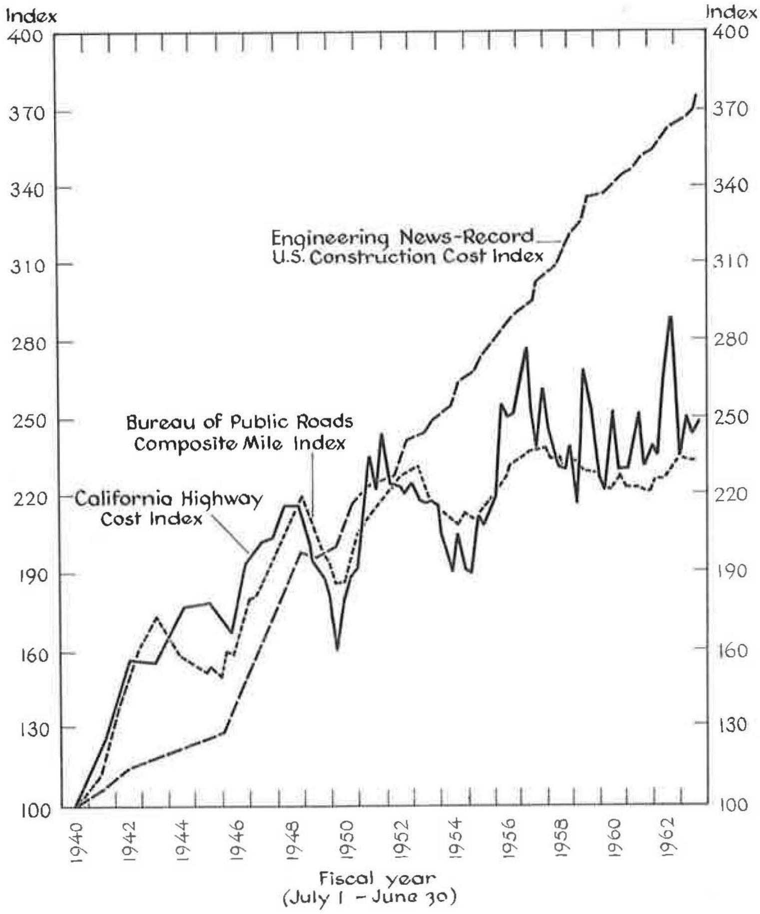


Figure 2. Price index-construction costs (12).

TABLE 5

AVERAGE ANNUAL PRICE CHANGES[a]

| Year | Compound Rates (%) | | | | |
|---|---|---|---|---|---|
| | Consumer Price | Wholesale Price | GNP Deflators | ENR Cost | BPR Highway Costs |
| 1913-1963 | 2.3 | 1.9 | — | 4.5 | — |
| 1929-1963 | 1.6 | 1.9 | 2.5 | 4.4 | 1.8 |
| 1940-1963 | 3.5 | 3.7 | 3.9 | 5.9 | 3.9 |
| 1940-1957 | 4.0 | 5.0 | 4.8 | 6.7 | 5.3 |
| 1957-1963 | 1.9 | 0.2 | 1.5 | 3.8 | -0.3 |

[a]Supporting data and calculations derived from Tables 1 through 4; calculations by slide rule rather than compound interest tables to get more accurate indications of price changes.

2 percent, perhaps this is as good an assumption as any, if a projection is to be made. Whether or not any projection should be made is discussed more fully later.

To find past differential price changes for highway costs, past highway cost trends must be determined for comparison with the general price trend. Table 6 indicates a great variation between price trend rates as computed from the Engineering News-Record Construction Cost Index and the U. S. Bureau of Public Roads Highway Cost Index. Although the ENR Index may be appropriate for some short-term purposes, it is inappropriate for measuring long-term price changes and obviously does not agree with the facts in the highway field. The Bureau of Public Roads Index reveals a long-term rate of about 1.8 percent with practically stable costs since 1957. However, from 1940 to 1957 costs increased by about 5.3 percent per year. Again, it is difficult to predict what future highway cost trends will be over any extended period of time. If we assume highway costs will

TABLE 6

CALCULATION OF SURFACING COST PRICE TRENDS VS HIGHWAY COST TRENDS[a]

| Year | Index No. | Period | n | Ratio | $(1+i)^n$ | i(%) |
|---|---|---|---|---|---|---|
| | | | (a) Composite Highway Cost Index | | | |
| 1929 | 55.0 | 1929-1963 | 34 | 101.7/ 55.0 | 1.85 | 1.8 |
| 1940 | 42.8 | 1940-1963 | 23 | 101.7/ 42.8 | 2.38 | 3.9 |
| 1950 | 78.3 | 1950-1963 | 13 | 101.7/ 78.3 | 1.30 | 2.0 |
| 1957 | 103.1 | 1940-1957 | 17 | 103.1/ 42.8 | 2.41 | 5.3 |
| 1963 | 101.7 | 1957-1963 | 6 | (103.1/101.7) | (1.015) | -0.3 |
| | | | (b) Portland Cement Concrete Index | | | |
| 1929 | 51.1 | 1929-1963 | 34 | 100.3/ 51.1 | 1.97 | 2.0 |
| 1940 | 41.9 | 1940-1963 | 23 | 100.3/ 41.9 | 2.40 | 4.0 |
| 1950 | 82.7 | 1950-1963 | 13 | 100.3/ 82.7 | 1.21 | 1.5 |
| 1957 | 99.2 | 1940-1957 | 17 | 99.2/ 41.9 | 2.36 | 5.2 |
| 1963 | 100.3 | 1957-1963 | 6 | 100.3/ 99.2 | 1.012 | +0.2 |
| | | | (c) Bituminous Concrete Index | | | |
| 1929 | - | - | - | - | - | - |
| 1940 | - | - | - | - | - | - |
| 1950 | 88.5 | 1950-1963 | 13 | 95.6/ 88.5 | 1.08 | 0.6 |
| 1957 | 101.4 | - | - | - | - | - |
| 1963 | 95.6 | 1957-1963 | 6 | (101.4/ 95.6) | (1.06) | -1.0 |

[a]Cost data from U. S. Bureau of Public Roads as given in Table 3.

increase at the long-term rate of 2.0 percent, the differential rate of change is zero percent per year for highway costs, because the rate of inflation and the rate of highway cost increases are equal. If the highway cost trend since 1957 continues, the differential decrease in prices would be approximately 2 percent per year.

The indiscriminate use of composite indexes can lead to serious errors. For example, when performing an economic comparison of pavement types, it might be wholly inappropriate to use a composite highway cost index. Instead, surfacing cost indexes should be used to calculate price trends. It may be that surfacing cost trends parallel the composite highway cost trend, but this should be investigated.

Table 6 presents an analysis of composite highway cost and surfacing cost trends using data from the U. S. Bureau of Public Roads. Unfortunately, surfacing cost data for bituminous concrete were not collected before 1950 and long-term price trends could not be derived for this material. Nevertheless, recent trends can be observed for bituminous concrete surfacing and long-term trends can be ascertained for portland cement concrete surfacing.

A comparison of the portland cement price trends with composite highway costs shows that they have not differed by more than 0.5 percent for any given time period. However, costs of bituminous concrete have recently been changing as much as 1.5 percent less per year than the composite highway costs. This clearly demonstrates the necessity of examining the cost trends of the major elements of highways.

Table 6 also shows that costs of portland cement concrete have increased at an annual rate of about 2 percent since 1929 but have remained fairly stable since 1957. Costs of bituminous concrete have risen by only 0.6 percent per year since 1950 and have been decreasing by about 1 percent per year since 1957.

If the future general price trend is assumed to be about 2 percent per year and surfacing cost trends since 1957 continue, it would be appropriate to decrease future portland cement concrete costs by 2 percent and bituminous concrete costs by 3 percent in the economic analysis.

If the future general price trend is assumed to be level and surfacing cost trends since 1957 continue, there would still be no justification for increasing future surfacing costs. Rather, future portland cement concrete costs would remain unchanged and future bituminous concrete costs would decrease by 1 percent per year, relative to the general price trend.

A word of caution is in order; the Bureau of Public Roads Indexes are nationwide figures and should not be used where accurate state or local data may give better price trends. Nevertheless, a compilation by the Engineering News-Record reveals that of 10 states reporting highway cost trends, only two had price changes greater than those indicated by U. S. Bureau of Public Roads Indexes (9, p. 98). Moreover, a look at surfacing costs in California bears out the same conclusions (12). The 1963 costs of portland cement concrete pavement and asphalt concrete pavement did not change appreciably compared to 1956-1957 levels. These cost trends are remarkably close to the nationwide figures published by the U. S. Bureau of Public Roads. If these cost trends continue in California and the general price level remains constant, it would be erroneous to increase future surfacing costs in economy studies as advocated elsewhere (13).

## TREATMENT OF PRICE CHANGES IN ECONOMY STUDIES

Most of the recommendations for the treatment of inflation and differential price changes have come from those concerned with Federal water resources investments. These recommendations should apply equally well to Federal highway investments. We shall proceed by examining Federal water resources agency practice, the recommendations of certain economists, and the practice of private enterprise.

### U. S. Department of Agriculture

In an article appearing in the 1958 Yearbook of Agriculture, the policy of the Department of Agriculture with regard to dealing with price changes for land and water resources development is expressed as follows:

> Because supply and demand determine prices, each requires careful analysis when one tries to derive estimates of prices. Expected future prices, rather than current or historical prices, should be used in the evaluation of project benefits. (14, p. 546)

That they are writing of differential price changes in this statement rather than general price trends is shown by an ensuing paragraph:

> Inflationary and deflationary trends should be removed from the analysis of commodity and service prices so that a constant dollar may be used in comparing project costs and benefits. (14, p. 547)

The same treatment of price trends is also recommended in a guide for the Soil Conservation Service to be used in performing economic analyses of watershed protection and flood prevention projects (15).

### U. S. Bureau of Reclamation

The Bureau has given the following instructions to those engaged in economic investigations:

> Price levels for project evaluation should reflect the exchange values of the goods and services involved, consistent with assumed general price levels for the period of analysis.

> Long-term projected prices reflect relatively high national employment, increasing population, continued economic growth, and a stable general price level, with production and requirements in balance under competitive conditions. Deferred or recurring benefits and costs should be measured at average long-term prices representative of the period of analysis. Current prices should be used for investment costs to be incurred in the near future. When benefits are based on alternative cost, the price level should be that expected to prevail at the time when the costs would occur. (16)

U. S. Army Corps of Engineers

Federal water resources agencies have not been in agreement on this matter, however, and the Corps of Engineers has stated:

> unless and until research and experience produce techniques for forecasting future prices in such a way as to engender confidence that the price projections are sound and consistent, prices current at the time of the study will generally be assumed for costs and benefits. Price experience to date applicable to each situation will be considered. Possible future changes in prices will be used only in special situations warranting a departure from use of current prices. (17)

Senate Document 97

The most recent Federal statement on recommended price levels is included in Senate Document 97, which is an agreement reached on project evaluation standards for water resources development by the Secretaries of Agriculture, Interior, Army, and Health, Education and Welfare:

> The prices used for project evaluation should reflect the exchange values expected to prevail at the time costs are incurred and benefits accrued. Estimates of initial project costs should be based on price relationships prevailing at the time of the analysis. Estimates of benefits and deferred costs should be made on the basis of projected normal price relationships expected with a stabilized general price level and under relatively full employment conditions for the economy. Pending development of mutually acceptable long-term price projections of this type, normalized current price relationships may be used in estimating deferred project effects. (18)

Recommendations of Economists

A number of economists outside of government have written on the subject of the use of price trends in economy studies and have been unanimous in their rejection of the inclusion of an inflation rate in the analysis. Some, however, would include differential price trends.

McKean suggests that current price levels be used because:

> there seems to be no good reason for having the government bet on inflation in connection with water-resource projects, since a bet on inflation, even if it seems likely to be a good wager, makes projects spuriously attractive to the nation. Furthermore, it is a bet by government on its own failure to win its struggle for stability—a type of wagering that is frowned upon in most contests. (19)

Eckstein also argues for the assumption of stable future prices when making economy studies of water resources projects:

> an assumption of steady inflation is unacceptable because it would mean that government investments would be justified by price increases which, at least in part, would be caused by the program itself; it would be politically immoral for the federal government to operate any expenditure program on the assumption that it will finally be justified by the government's failure to maintain the value of the currency. (20)

Furthermore, Hirshliefer and others, state that:

> it would be a crude error to inflate future revenues in propotion to the price levels expected to govern in those periods and then to weigh these inflated revenues against costs measured in today's dollars. The entire comparison of costs and revenues should be calculated using dollars of constant purchasing power of some convenient period, usually the present period. (4)

A panel of consultants to the U. S. Bureau of the Budget on evaluation standards for the development of land and water resources advised that "In no case should trends in the general price level be incorporated into the economic analysis of projects." Only when values of goods and services associated with a project are expected to rise relative to the general price level do they recommend an escalation of prices and then for only 10 yr in the future because of uncertainty. However, they warn that this advice is not appropriate if sites, such as open spaces for recreational purposes, were preempted for other purposes. In this case, price projections beyond 10 yr might be justified (21).

Private Enterprise

The American Telephone and Telegraph Co. has adopted the following convention with regard to inflation:

> Neither short nor long rates of inflation are predictable with any degree of certainty. To compound the problem, the effects of inflation on individual items of a study become less predictable especially in light of probable technological advances.
>
> While a rigorous evaluation of inflation in studies is not recommended the engineer should consider the possible effects of inflationary trends as a part of uncertainty analysis. If, for example one of two plans has a large labor component compared to the other, it is certainly in order for the engineer to ask, "Which plan is more sensitive to inflation? At what rate, and over what period, would inflation cause the decision to shift to another plant?" (22)

## SUMMARY OF OPINIONS

Most of the sources cited agree that trends in the general price level should not be included in an economic analysis from the national viewpoint. But disagreement is evident when considering relative price changes.

In the first case, that of general price level changes, it is agreed that an inflation rate should not be included because: (a) future dollars to pay for future expenses will likewise be inflated and there is no net change; (b) it is not known what the rate of inflation will be in the future, if any; (c) inflated future benefits may make an uneconomical project appear justified, whereas if constant prices were used it would not be. The resources used and the services rendered are the same in each case; and (d) it would be irresponsible on the Federal level to include an inflation rate when the government is committed to a price stabilization policy. Moreover, Federal expenditures in time of inflation may contribute to inflation.

With regard to relative price levels, the argument seems to rest primarily on our ability to forecast the general price trend and relative price trends of project goods and services. The government's commitment to stabilization policies, the difficulty in measuring price changes, and improved technology make it exceedingly difficult to predict either general or relative price changes. Nevertheless, there may be instances where differential changes are evident and these should be included in a sensitivity analysis. Probably the most common instance is that of changes in land prices. The situation often exists where land prices have been increasing at a greater rate than general price levels, and it is expected that the trend will continue. Projections of land prices must then be made and used (with inflation removed) in the economy study. This, however, is an extremely complex matter and beyond the scope of this paper. It is a subject in need of intensive research.

## THE QUESTION OF VIEWPOINT

The foregoing opinions deal primarily with the national viewpoint. When the viewpoint is nationwide, an estimated general trend in prices should not be included in the economy study. Nevertheless, in principle, expected differential price changes ought to be considered. In contrast, from the state or local viewpoint, a condition may call for the use of the general price trend in the analysis. This occurs when creditors fail to increase the interest rate on borrowed funds in anticipation of inflation. If creditors raise the interest rate on borrowed funds to account for expected inflation, no advantage accrues to the state or local area. (Whether or not interest rates reflect anticipated inflation is a matter of controversy, in need of further investigation.) The reasons for the difference in viewpoint were discussed previously.

## EFFECT OF INCLUDING PRICE CHANGES IN ECONOMY STUDIES

Here we are concerned with the effect of increasing future costs and/or benefits in economy studies. Whether or not any price changes should be included is discussed later.

The use of rates to increase future costs and/or benefits in economy studies will tend to promote greater capital outlays and more capital-intensive projects than would otherwise occur.

The first situation can arise if future benefits alone are increased. This practice will cause projects to be accepted which would be rejected if the benefits were not inflated. Moreover, the practice could have adverse effects when allocating funds among departments if some departments choose to inflate benefits and others do not.

The second situation happens when future capital costs are increased, causing stage construction to appear less desirable than would otherwise be the case. Moreover, longer lived facilities will be favored over shorter lived ones. Thus, a bias occurs which compounds the problem of uncertainty since capital-intensive projects usually allow less flexibility when changes in forecasts arise. This situation is typical of that faced by highway engineers trying to determine which pavement type to use or whether to build highways in stages. For example, increasing future costs might cause a decision to be shifted from asphalt concrete pavement to portland cement concrete pavement. It can also result in the selection of single-stage highway construction when multi-stage highway construction would otherwise appear more economical.

The higher the minimum attractive rate of return (i.e., the interest rate) used in an economic analysis, the less sensitive a decision among alternatives will be to the evaluation of benefits and costs occurring some years in the future. This point was made by Fish over 40 yr ago (23). Therefore, the issue of treatment of prospective price changes is more important in those highways agencies requiring rates of return of 0 to 3 percent to justify investments and less important in agencies requiring, say, 6 percent or more.

## PRICE CHANGES AND FINANCIAL ANALYSIS

General price trends as well as relative price changes are properly a part of the financial analysis of highway programs. Consider the situation where highway costs

are increasing at the same rate as income. For a pay-as-you-go program, the burden on the public of spending more dollars in the future for the same physical amount of highway construction is not increased if inflation occurs. Nevertheless, institutional problems are created in getting the required additional funds because user taxes must be increased. When ad valorem taxes are used, the increase in assessed valuation automatically brings in the necessary additional funds whenever assessors regularly adjust their assessments to recognize inflation.

However, when highway projects are funded by bonds rather than on a pay-as-you-go basis, consideration must be given to inflation; otherwise funds set aside or authorized now to finance future construction may not be sufficient because of price increases. For example, a bond issue of $70,000,000 (based on current prices) to finance a trafficways program may not be adequate when facilities are built in stages. Yet a proper economic analysis may have shown staging to be the more economical solution. To be able to finance the staged project, an allowance for inflation would have to be included in the original bond issue or a future bond authorization would be necessary.

## CONCLUSIONS

From the foregoing analysis we observe that it is difficult to measure past inflation rates since no single index is completely satisfactory. Nevertheless an approximate figure of 2 percent per year compounded is probably a reasonable figure for the long-term rate in the United States. The magnitude of future inflation cannot be known with any certainty.

The body of professional opinion is against including an inflation rate in engineering economy studies made from a national viewpoint. The main reasons are

1. Difficulties are inherent in forecasting;
2. The Federal Government is committed to price stabilization;
3. Federal programs, justified in part by inflating benefits, may contribute to inflation;
4. The gains received by debtors are offset by losses to creditors.
5. Future dollars to pay for future expenses will likewise be inflated and there is no net change; and
6. A bias toward capital-intensive and long-lived projects results, making adaptations to future changes more costly than otherwise.

In principle, expected differential price changes should be included in an economy study. Thus, if the inflation rate is expected to be 2 percent per year and estimated project costs are expected to increase at 3 percent per year, the differential rate for increasing project costs would be 1 percent per year. It is likely that the differential rates will vary for each of the cost components of the project and these should be computed separately for the major components such as land.

From the state or local viewpoint, it is appropriate to use the expected general price trend since transfers can be beneficial from these viewpoints, provided inflation is not anticipated by those persons and institutions lending funds.

The indiscriminate use of indexes of price changes to situations where they do not apply can cause serious distortions in the decision-making process. Nationwide composite cost indexes should not be used when state or local indexes are available. Neither should composite indexes be used if component indexes are available. The use of the Engineering News-Record Construction Cost Index may be entirely appropriate in some instances but wholly incorrect in others. The cost of each important item should be carefully examined.

## RECOMMENDATIONS

In view of the findings of this paper there is no justification for including inflation rates in highway economy studies when taking the national viewpoint. Even from the local viewpoint, such a practice is hard to justify because of the difficulties in predicting future inflation rates.

Although differential rates should, in principle, be included in highway economy studies, there are good reasons for using current prices to evaluate costs and benefits.

1. It is extremely difficult to predict relative price changes for most items in highway economy studies.
2. Over the long term, the average highway cost trend and the general price trend have been quite parallel, which indicates a zero differential rate.
3. Future deviations from current prices are not as serious as might appear because the usual purpose of the analysis is to compare alternatives. Moreover, discounting further reduces the effect of actual costs deviating from current prices.

It is, therefore, our recommendation that, as a general rule, current prices be used to evaluate benefits and costs in highway economy studies, regardless of viewpoint. When there is overwhelming evidence that certain inputs or outputs such as land are expected to experience significant price changes relative to the general price level, the engineering economy study might well include a sensitivity analysis. At the point where the decision is reversed, the prices can be carefully examined to determine if there is a high probability that they will prevail.

## ACKNOWLEDGMENTS

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## *Discussion*

A. C. ESTEP, Engineer of Design, California Division of Highways—We agree with the general conclusions of this paper, and concur that inflation factors or price trends should not be used in most highway economy studies. However, the California Division of Highways uses a price trend factor in making economic comparisons to be used as one element in the choice of pavement type. Therefore, it may be of interest to present some of our reasons for this practice.

An economic comparison of pavement types is an unusual economic problem in that most of the decisions have already been made. The project has been found a justifiable expenditure, its priority has been tentatively established, the route has been selected, and the number of lanes required has been determined. With the standard of maintenance we endeavor to accomplish, it can be assumed that the benefits to the motorists will be the same with either pavement type. The only economic problem is to determine the pavement type with the lowest long-term cost.

The California method includes initial cost, maintenance, resurfacing cost including engineering and supplemental work occasioned by the resurfacing, and a salvage value of the last resurfacing applied, if necessary, to bring both costs to the chosen comparison period. A price trend factor is applied to compute the estimated cost of future resurfacing. All costs for both types are reduced to present worth using the appropriate factors for 5 percent compound interest. The comparison periods chosen are 20 yr and upward, based on the life of existing portland cement concrete pavements in the vicinity or under comparable conditions. The estimated time when resurfacing of the asphalt pavement will be required is based on experience in the same general area.

The asphalt concrete resurfacing of an asphalt pavement represents a delayed capital expenditure different in time and amount from all other expenditures for either pavement type. Its entire cost represents a difference in cost between the two types, and there are no balancing cost items to counteract any price trend, up or down, that may occur. The problem is how to determine the best estimate of the future cost of an asphalt resurfacing.

Following the same type of reasoning developed by Lee and Grant, we concluded that a price trend factor for asphalt concrete surfacing should be based on an asphalt concrete surfacing cost index. The statement is made by the authors that surfacing cost data were not collected before 1950. California is fortunate in having asphalt pavement cost data going back many years. Starting in 1940, these costs have been used as one of seven items combined to prepare the quarterly reports on the California Highway Construction Cost Index.

Based on the data for this one item for the 20-yr period from 1941 to 1961 and using the compound rate method, the price trend factor was determined to be 2 percent compounded annually. Data from 1961 to the present support the continued use of this rate. The figure for the third quarter of 1964 is somewhat above our 2 percent trend line. The statement that 1963 costs for portland cement concrete pavement and asphalt concrete pavement did not change appreciably compared to 1956-1957 levels is not applicable to our method. This is a price comparison and does not indicate the trend. A comparison of prices for 1962 and 1954 would show a greater increase than indicated by a trend line.

Economic comparisons of future pavement construction alternates are no better than the estimates of cost used, and past cost data are the best evidence available on which to base these estimates. We believe it is more valid to use the long-range price data extrapolated than to assume that there will be no trend in the future.

ROBERT R. LEE and E. L. GRANT, Closure—The reasons given by Mr. Estep as justification for the use in California of a price trend factor are not valid. The California Division of Highways uses a factor of 2 percent compounded annually to inflate surfacing costs, stating that this is the long-term trend expected in the future. We have no argument with this being the cost trend, but we do argue against the 2 percent figure being used in the economic analysis.

First, the long-term general inflation trend has been approximately 2 percent per year compounded annually. This means that the differential rate to be used to inflate surfacing costs would be 0 percent, not 2 percent. Only if surfacing costs are expected to increase 2 percent more than general price trends would future surfacing costs be increased by 2 percent per year. Since this has not been the case, and there is no evidence to suggest this will be the situation in the future, California should use 0 percent, not the 2 percent price trend factor.

# Use of Traffic Volume Data in Evaluation of Highway User Costs for Economic Analysis

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A method for computing annual user costs for economic analysis of highway improvements is described which takes into consideration the effect of traffic conditions over the entire year. The distribution of traffic volumes over time is used to establish a traffic speed for determining unit costs of vehicle operation and travel time. The method can be applied to proposed route locations where projected traffic volumes are known.

•THE EVALUATION of highway user costs is an important step in the economic analysis of highway improvements. These costs are compared with initial capital and continuing maintenance costs to determine the economic feasibility of a proposed investment. This paper presents a technique for computing annual user costs which takes into account the changes in vehicle operating and time costs resulting from variable traffic flow rates. The technique can be applied to highways in urban and rural areas where large variations in traffic flow rates occur during the year.

Highway user costs are defined in this paper to include the costs of vehicle operation and travel time. Total annual user costs on a highway section may be computed with the equation:

$$TAUC = 365 \cdot (AADT) \cdot L \cdot (uc) \qquad (1)$$

where TAUC is the total annual user cost, AADT is the average annual daily traffic, L is the length of the section in miles and uc is the average unit cost of travel in dollars per vehicle-mile.

The average unit cost represents the operating and time costs incurred by an average vehicle operator and his passengers in traveling 1 mi along the highway under conditions averaged over the entire year. The conditions influencing unit costs, according to AASHO (1), include the types of vehicles, number of lanes, road surface, gradients, highway geometric design, type of operation and the average speed of the traffic. The type of operation and the average speed of traffic are a function of the number of vehicles on the highway. Changes in these variables affect both the operating and time cost components of the average unit cost. However, it is difficult to estimate a single average unit cost which adequately accounts for the wide range of traffic conditions occurring on a highway during a year.

The accuracy with which user costs can be evaluated depends a great deal on the techniques employed to compute them. A computation technique is often formulated with the objective of limiting the number of calculations performed by hand. However, the electronic computer removes this limitation and permits a thorough examination of highway user costs with refined techniques. A method has been proposed by Martin and Manheim (2) for computing an average unit cost which accounts for the changes in traffic conditions over the year. The unit costs are defined for the range of possible

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traffic conditions on the highway. Each unit cost is then weighted by the number of vehicles using the highway under the corresponding traffic condition. These conditions are measured by the volume of vehicles traveling over the highway in 1 hr or the traffic flow rate. The number of vehicles at each flow rate is the product of the flow rate and its frequency of occurrence during the year. In mathematical terms, the total annual user cost for a highway section is

$$TAUC = \frac{L \cdot N}{100} \cdot \sum_{i=1}^{n} \left[ (uc_i) \cdot (V_i) \cdot (P_i) \right] \qquad (2)$$

where

TAUC = total annual user cost in dollars per year;
L = length of highway section in miles;
N = number of hours in the year;
n = number of flow rate intervals;
$uc_i$ = unit cost in dollars per vehicle-mile at i th flow rate;
$V_i$ = i th flow rate in vehicles per hour; and
$P_i$ = percent of hours in the year that i th flow rate occurs.

The total annual operating costs or the total annual time cost could be evaluated with this equation by substituting the unit costs of operation or of time for the total unit cost term ($uc_i$). The user costs for a time period less than 1 yr can be computed by defining $P_i$ as the percent of hours in the year that flow rate $V_i$ occurs during the relevant time period. For example, the time period of interest might consist of all the hours in one month or the peak hours of each day of the year.

The technique requires a definition of the frequency of occurrence of volumes per hour and a description of unit user costs as a function of volume per hour. These data are discussed in the next two sections. Finally, an example application is presented to illustrate the technique.

## TRAFFIC FLOW FREQUENCY DISTRIBUTIONS

Traffic counts at many locations throughout the country have established that repetitive patterns exist in the flow rates as a function of the hour of the day, the day of the week, and the month of the year. These patterns exist because of the repetitive nature of traffic-generating activities. For this reason, they remain as stable as the activities of the people who use the highway.

There are significant differences in the observed patterns at different highway locations. For example, Figure 1 is a plot of the average annual traffic volumes in each hour of the day at three different locations in Massachusetts. The urban-recreation station is located on US 6 in Fairhaven where it serves summer recreation traffic in addition to local traffic. The recreation station is also on US 6 but is located near Barnstable on Cape Cod. (Volumes for only one direction, eastbound, are plotted.) The third location is at Sterling on Rt. 12 in the central corridor of Massachusetts. There are significant differences in the average volumes per hour in each case. The daily traffic volumes vary in magnitude throughout the year. The ratios plotted in Figure 2 relate the average daily traffic in each month to the average annual daily traffic for each station. The considerable increase in daily volumes during the summer months on the recreation routes is quite evident. At these stations, the highest volume hours occur only during the short summer season.

The differences in the distribution of traffic flow rates at the three stations are summarized in Figure 3 as histograms of the frequency of occurrence of volume intervals. The distribution for the rural route is spread over only a few intervals and has a relatively short tail at the high volume end. This shape follows from the low annual average hourly volumes and the small seasonal fluctuation. The distribution for the urban-recreation route is spread over a wider range of volume intervals because of the larger average annual volumes per hour and a longer seasonal cycle. The frequency distribution for the recreation route (one way, eastbound) is distributed

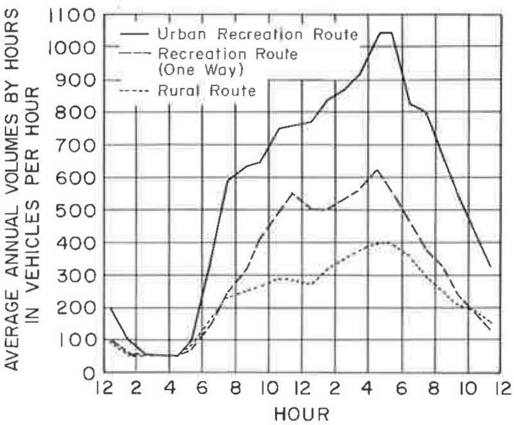


Figure 1. Average annual volumes by hour of day.

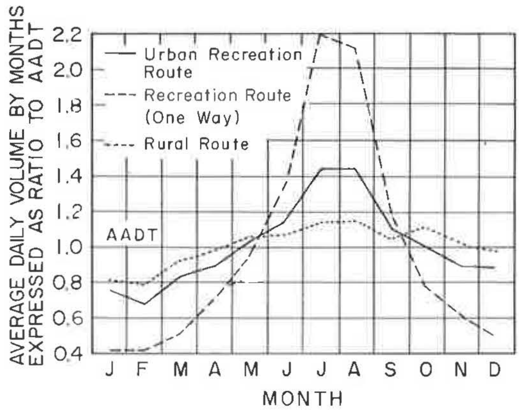


Figure 2. Traffic volume trends by months.

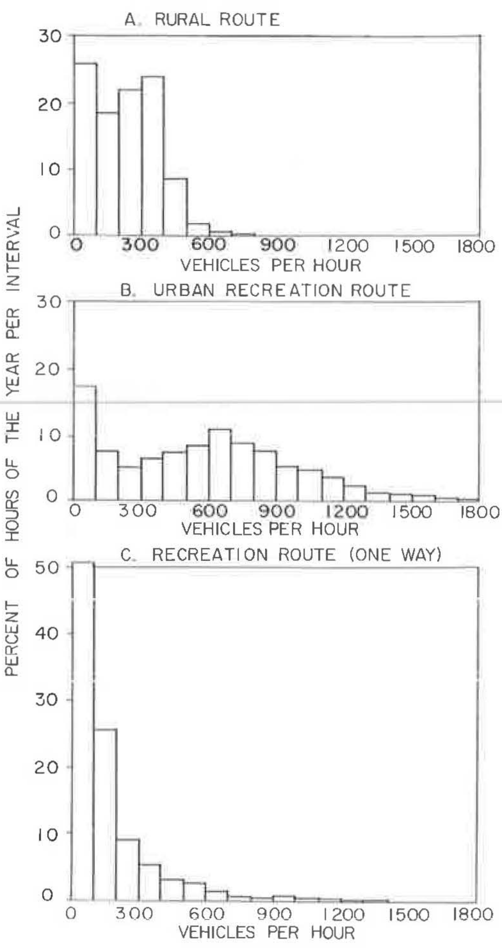


Figure 3. Frequency distributions of traffic counts.

over almost as large a range of volume intervals as the suburban recreation route but the frequency of occurrence of the higher volumes is much lower. The highest hourly volumes occur during the summer season which is only three months of the year. During the remaining months, the traffic volumes are significantly lower.

The preceding discussion has described characteristics of the variation of traffic volumes per hour with reference to three specific cases. The frequency distributions can be prepared directly from traffic count data which have been recorded separately for each direction or recorded as total two-way volumes with directional splits for each time period. The percent of truck traffic and an estimate of future growth in traffic volumes are needed. If it is assumed that the same pattern of flow rates over time will occur in future years, an annual growth rate is sufficient. A more sophisticated analysis of future traffic growth would consider changes in the patterns of traffic-generating activities.

## USER COST FUNCTION

The purpose of a user cost function as referred to here is to relate unit user costs in dollars per vehicle mile to the traffic flow rate in vehicles per hour. This section outlines the development of a user cost function with reference to a particular highway but user cost functions for other highways can be developed using similar techniques.

There are two major consequences of increasing traffic flow rates. First, the

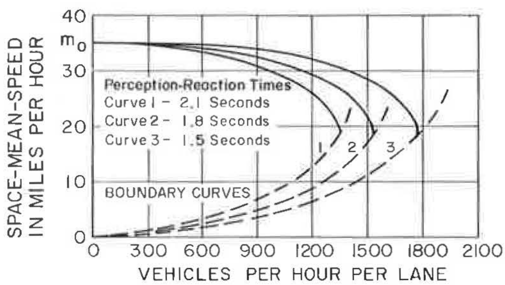


Figure 4. Speed vs volume per hour.

average speed of the traffic stream decreases and changes unit operating and travel time costs. The relationship between speed and volume per hour is developed from theoretical considerations and empirical evidence. The second consequence is an increasing interference between individual vehicles leading to more frequent speed changes, higher fuel consumption, and greater tire wear. It is assumed that these costs are a function of the ratio of the volume to the practical capacity of the highway.

A mathematical expression to relate average speed and volume per hour must satisfy two boundary conditions. First, at very low flow rates, the average speed of all vehicles approaches the mean free speed or average desired speed of traffic on the highway. The second boundary condition is the locus of maximum uninterrupted flow rates which can be maintained on the highway.

The maximum flow rates can be developed by considering the limiting capacity of a single lane of traffic with vehicles moving so that passing is not permitted. As the density increases, all vehicles approach the same speed and the time gaps between vehicles decrease. The limiting gap which each operator would maintain between his vehicle and the one in front of him would be determined by his intuitive evaluation of the time necessary to perceive and react to a change in speed of the preceding vehicle. Studies of minimum vehicle separations (4) have reported that the gaps between moving vehicles are statistically distributed about a mean which is a characteristic of the vehicle operators and the design of the road.

An observer stationed at the side of the road could measure the total time elapsed between the passage of successive vehicles at capacity flow. This total headway is composed of the time gap between the vehicles and the time for the length of the vehicle to pass. The average headway between vehicles is expressed in the following equation:

$$H = t + d/m \qquad (3)$$

where H is the average headway in seconds per vehicle, t is the average perception-reaction time of vehicle operators in seconds per vehicle, d is the average vehicle length in feet per vehicle and m is the average speed of the traffic in feet per second.

The reciprocal of H is the limiting volume flow rate in vehicles per second. This can be expressed in vehicles per hour by multiplying by 3,600 sec/hr:

$$V_c = \frac{m \cdot 3,600}{(m \cdot t) + d} \qquad (4)$$

where $V_c$ is the maximum volume in vehicles per hour for a given speed and the other symbols are as defined in Eq. 3. Since the values of both t and d are assumed to be independently distributed, there is no unique relationship between the flow rate $V_c$ and the speed m. However, boundary curves can be plotted for appropriate values of these parameters for the highway under study. In Figure 4, the three boundary curves are based on an average vehicle length of 16 ft and average minimum perception-reaction times of 2.1, 1.8 and 1.5 sec (curves 1, 2 and 3, respectively).

The shape of a curve to represent the state of flow between the two boundary conditions will depend on the effect of the geometric design of the highway on vehicle operators and the interaction between vehicles. The particular curve chosen should reflect the conditions on the highway under study.

One possible relation suggested for uncontrolled-access facilities has been used in the example problem of this paper. The equation was originally formulated by Guerin (3) on the basis of empirical studies he performed. This form of the equation is due to Haight (5):

$$m = \left[ \frac{m_o \cdot (D' - D)^{1/2}}{A \cdot m_o \cdot D^2 + (D' - D)^{1/2}} \right] \tag{5}$$

where

$m$ = average speed in feet per second;
$m_o$ = mean free speed in feet per second;
$D'$ = maximum density of traffic in vehicles per foot, equal to reciprocal of average vehicle length;
$D$ = density of traffic in vehicles per foot; and
$A$ = constant dependent on parameters of the system.

The constant A can be evaluated using two conditions: (a) the slope of the curve is infinite at maximum capacity, and (b) the headway at maximum capacity derived from Eq. 3. The following expressions can be developed (6):

$$A = \left[ \frac{2 \cdot (D' - D_c)^{3/2}}{m_o \cdot D_c^{\,2} \cdot (2 \cdot D' - D_c)} \right] \tag{6}$$

where symbols not previously defined are

$D_c$ = density of traffic at maximum capacity in vehicles per foot;

$$D_c = D' \cdot \left[ \frac{X - \sqrt{X^2 - 4Y}}{Y} \right];$$

$X = 3.5 + m_o \cdot t \cdot D'$; and
$Y = 3.0 + m_o \cdot t \cdot D'$.

The speed vs volume per hour curves in Figure 4 illustrate the shape of curves derived from Eq. 5. Each curve begins at the same mean free speed but intersects a different boundary curve at capacity flow. The slopes of these curves vary between zero at zero flow and infinite at capacity flow.

A unit operating cost and a unit travel time cost are associated with each point on the speed vs volume per hour curves. An example user cost function is plotted in Figure 5 based on the first speed-volume curve in Figure 4. The operating cost curve was developed using cost data published by AASHO (1) for 0 to 3 percent grades and no commercial vehicles. These cost data are divided into three categories, free, normal and restricted, based on the ratio of the traffic volume in the 30th highest hour of the year to the practical capacity of the highway. Each category is a weighted average for the entire distribution of volumes over the year. For this reason, the unit costs in each category are not necessarily equal to the unit cost in the corresponding 30th highest hour. However, to adapt the data, the volume per hour axis was divided into the same categories, defined by the ratio of the volume to the practical capacity, and the appropriate tabulated data were then used for each category. The free traffic range in this example extends from zero to three-quarters of the practical capacity (720 veh/hr/lane), the normal traffic range extends to 1 ¼ times practical capacity (1,200 veh/hr/lane), and the restricted range extends to higher volumes.

The unit time cost curve assumes a value of time of $0.86/person/hr and an average of 1.8 persons/veh. These values are suggested by AASHO as typical but other values could be substituted when more specific data are available. The total unit cost curve is the sum of the unit operating and time cost curves.

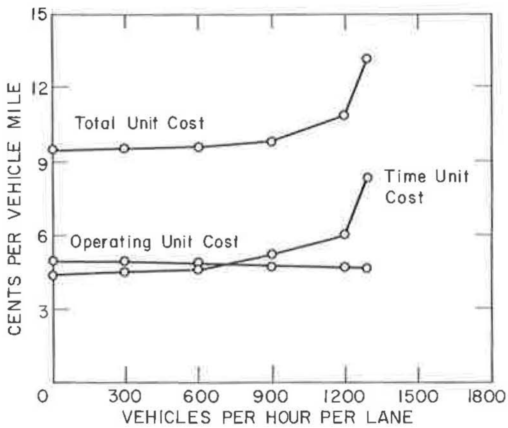


Figure 5. Example user cost function.

TABLE 1

HOURS GROUPS FOR ANALYSIS

| No. | Date From | Date To | Day of Week | Hours From | Hours To | Direction Split (%) | Trucks (%) |
|---|---|---|---|---|---|---|---|
| 1 | 1/1 | 12/31 | M-F | 0 | 6 | 50 | 6.3 |
| 2 | 1/1 | 12/31 | M-F | 6 | 9 | 35 | 5.9 |
| 3 | 1/1 | 6/15 | M-F | 9 | 15 | 50 | 6.9 |
| 4 | 6/16 | 9/15 | M-F | 9 | 15 | 50 | 6.9 |
| 5 | 9/16 | 12/31 | M-F | 9 | 15 | 50 | 6.9 |
| 6 | 1/1 | 6/15 | M-F | 15 | 19 | 58 | 5.5 |
| 7 | 6/16 | 9/15 | M-F | 15 | 19 | 58 | 5.5 |
| 8 | 9/16 | 12/31 | M-F | 15 | 19 | 58 | 5.5 |
| 9 | 1/1 | 12/31 | M-F | 19 | 24 | 50 | 6.3 |
| 10 | 1/1 | 12/31 | Sun | 0 | 12 | 50 | 2.0 |
| 11 | 1/1 | 6/15 | Sun | 12 | 20 | 50 | 2.0 |
| 12 | 6/16 | 9/15 | Sun | 12 | 20 | 50 | 2.0 |
| 13 | 9/16 | 12/31 | Sun | 12 | 20 | 50 | 2.0 |
| 14 | 1/1 | 12/31 | Sun | 20 | 24 | 50 | 2.0 |
| 15 | 1/1 | 12/31 | Sat | 0 | 10 | 50 | 6.3 |
| 16 | 1/1 | 6/15 | Sat | 10 | 20 | 50 | 6.3 |
| 17 | 6/16 | 9/15 | Sat | 10 | 20 | 50 | 6.3 |
| 18 | 9/16 | 12/31 | Sat | 10 | 20 | 50 | 6.3 |
| 19 | 1/1 | 12/31 | Sat | 20 | 24 | 50 | 6.3 |

## EXAMPLE APPLICATION

The purpose of this example application is to illustrate the technique and some computation results. An existing highway is analyzed to determine the annual user costs in the present year and in future years. An alternative highway design for the same location is also examined and compared to the existing condition. All computations for the example were performed on a computer.

The highway selected for study is a section of US 6 in Massachusetts from Fairhaven east to Mattapoisett. This section serves traffic desires in the urbanized area of New Bedford and also summer recreation traffic between southern New England and Cape Cod. The time distribution of traffic is characteristic of an urban recreation route (Figs. 1, 2, and 3) with morning and evening peak periods on weekdays during the off-season. However, from mid-June to mid-September, there is a large influx of recreation traffic on the highway.

The total two-way traffic volumes for each hour of the year 1959 were used to prepare the frequency distributions. These volumes were recorded by a permanent traffic counting station maintained by the Massachusetts Department of Public Works. The recorder is located in Fairhaven approximately 1.8 mi east of the New Bedford town line. The unit costs of travel on the highway have been computed and compared for a number of different traffic conditions by analyzing the frequency distributions of the hours of the year in groups. The breakdown into hour groups in Table 1 reflects low, moderate and high volume hours, and weekday, weekend and seasonal characteristics. The hours from and to are based on a 24-hr clock. All hours of the year are included in the list.

Vehicle classification and directional distribution data were obtained from short count samples made by the Massachusetts Department of Public Works. The average growth rate of traffic over the previous 6 yr was 4.1 percent. This is used to project future volumes in all hour groups. For the purpose of this example, it is assumed that the basic characteristics of the traffic demand and the growth rate would not change in the future.

The existing highway has two 10-ft wide lanes in each direction with no median strip. There is no control of access to the roadway. The geometric design of the vertical and horizontal curves does not permit safe travel at high speeds and, hence, the highway is posted for 35 and 40 mph. In two test trips made over the facility, a speed of 35 mph was found to be reasonably safe at low volumes.

A user cost function similar to the one developed previously and plotted in Figure 5 is used in the computations. An average minimum perception-reaction time of 2.1 sec, an average vehicle length of 16 ft and a mean free speed of 35 mph define the parameters of the user cost function. The length of the highway is divided into subsections with different gradients. These subsections are listed as separate alignments in Table 2.

TABLE 2

ALTERNATIVES AND ALIGNMENTS FOR EVALUATION OF USER COSTS

| Alter- native | Align- ment | Mean Free Speed (mph) | No. of Lanes | Length (mi) | Avg. Gradient (%) |
|---|---|---|---|---|---|
| 1 | 1 | 35 | 4 | 1.6 | 1.0 |
| | 2 | | | 0.8 | 0.73 |
| | 3 | | | 1.6 | 0.75 |
| | 4 | | | 1.3 | 0.57 |
| 2 | 1 | 45 | 4 | 1.6 | 1.0 |
| | 2 | | | 0.8 | 0.73 |
| | 3 | | | 1.6 | 0.75 |
| | 4 | | | 1.3 | 0.57 |

TABLE 3

SUMMARY OF ANNUAL USER COSTS

| Alter- native | Yr from Present | Total Annual User Cost ($ millions) | Avg. Annual Unit Costs (cents/veh-mi) | | |
|---|---|---|---|---|---|
| | | | Operating | Time | Total |
| 1 | 1 | 2.92 | 4.94 | 4.49 | 9.43 |
| | 5 | 3.43 | 4.94 | 4.51 | 9.45 |
| | 10 | 4.21 | 4.94 | 4.53 | 9.47 |
| | 15 | 5.17 | 4.93 | 4.57 | 9.50 |
| | 20 | 6.34 | 4.92 | 4.63 | 9.55 |
| 2 | 1 | 2.75 | 5.41 | 3.49 | 8.90 |
| | 5 | 3.24 | 5.40 | 3.50 | 8.90 |
| | 10 | 3.96 | 5.38 | 3.52 | 8.90 |
| | 15 | 4.84 | 5.35 | 3.57 | 8.92 |
| | 20 | 5.93 | 5.32 | 3.61 | 8.93 |

TABLE 4

SUMMARY OF EQUIVALENT ANNUAL USER COSTS

| Alter- native | Millions of Dollars | | |
|---|---|---|---|
| | 0% Int. | 5% Int. | 10% Int. |
| 1 | 4.44 | 4.14 | 3.90 |
| 2 | 4.15 | 3.89 | 3.67 |
| | (0.29)[a] | (0.25)[a] | (0.23)[a] |

[a]Equivalent annual user cost savings on second alternative existing highway.

An alternative design (No. 2 in Table 2) is assumed to replace the existing highway on the same right-of-way. This design is basically the same as the existing condition but would incorporate necessary improvements to increase the free running speed to 45 mph. In this analysis, it is desired to know what savings to road users would result from the higher travel speeds. If the improvements are to be justified, the present value of these savings must exceed the initial investment. These improvements might include straightening curves, imposing a partial control on access, and widening the pavement. For this alternative, an average minimum perception-reaction time of 1.8 sec is used in the user cost function.

The total annual user costs for each year in the future were computed in accordance with Eq. 2. These total annual user costs have been converted to an equivalent annual user cost at interest rates of 0, 5 and 10 percent. To examine the effect of increasing traffic on user costs, the average unit costs for each year have been computed and serve as output in the analysis.

The total annual user costs are summarized in Table 3 by alternatives for selected years. The existing condition has the higher user cost in all years. The average annual unit operating and time costs are also summarized for the same selected years. For both alternatives, the unit time costs increase as future volumes increase. On the other hand, the unit operating costs decrease slightly with time.

The equivalent annual user costs are summarized in Table 4 at selected interest rates. These costs correspond to the total annual user costs in all years expressed as an equal annual sum. The figures in parentheses represent the equivalent annual user cost savings on the second alternative over continued use of the existing highway.

The trends over time of the computed average annual unit costs per vehicle-mile for each alternative are plotted in Figure 6 as dashed lines. These unit costs were obtained as a weighted average of the unit costs in each hour group. In the first year, the unit cost of the second alternative is 6 percent below those of the existing highway. After 20 yr, the annual unit costs have increased 1.3 percent for the existing condition and 0.3 percent for the second alternative.

The average annual unit costs for the separate hour groups are also plotted in Figure 6. The highest unit costs are associated with the highest volume hours. On the existing highway over a period of 20 yr, the total unit travel costs increase 5.5 percent in the peak hours of the summer season. The rate of increase of travel costs

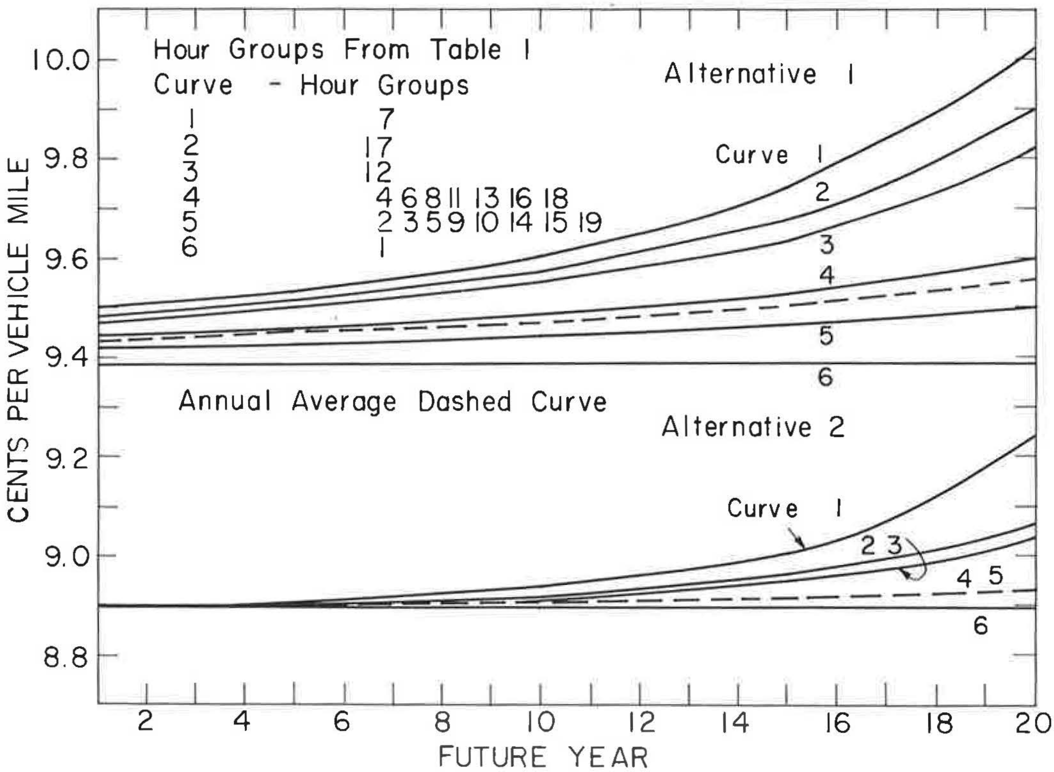


Figure 6. Total unit costs in future years.

during the same peak hours is lower for the assumed alternative and amounts to only 3.8 percent after 20 yr.

## CONCLUSIONS

A method for computing user costs which takes into account the variation of traffic volumes over time has been outlined in this paper. Examples of traffic volume distributions over time at three dissimilar stations have been examined and techniques for obtaining unit costs as a function of volume per hour have been developed.

The annual user cost of the example application increased in future years for two reasons: the traffic volume increases each year and the total unit cost of travel increases each year. The rate of increase of total unit costs is a function of the traffic volume per hour and is highest in the peak volume hours. This particular example was selected because the proposed alternative would not appreciably affect the demand characteristics and the same volumes could reasonably be used for both alternatives. The change in unit costs in this example is not large because the range of operating speeds on this highway is near the optimum speed for lowest total unit cost. Near this point, the variation in unit costs is small for relatively large changes in travel speed.

The advantage of this method is that it provides a rational procedure for selecting a unit cost under conditions of varying traffic flow. The traffic volumes in all hours of the year, not merely the highest hours, are taken into consideration. Use of the method in an economic analysis of a highway improvement should result in a more precise estimate of the costs incurred by road users.

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The computations involved in the example application were performed on the Project MAC time-shared computer at MIT.

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# Estimating a Road-User Cost Function from Diversion Curve Data

HOWARD W. BEVIS, Alan M. Voorhees and Associates

A theory and methodology are presented for estimating a road-user cost function using diversion curve data. The theory of diversion curves is presented as being a probability density function with normal distribution. The point in the density function associated with a given proportion of freeway usage is related to a generalized cost difference equation describing the comparative costs of using the freeway as opposed to the best alternate. The parameters of the cost function are then derived using regression techniques.

The road-user cost equation derived from this analysis agrees quite well with theoretical predictions and with results obtained from other studies where relationships between the various components of road-user cost and speed of travel have been derived and priced out to obtain a user cost function. This general agreement of results implies that drivers tend to behave in a cost-conscious manner and that the cost function of the average driver approximates that obtained from the pricing studies.

•ESTIMATES of road-user costs are valuable to the highway planner in a number of ways. Apart from their use in benefit-cost analysis, other research (1) has indicated the desirability of user costs in predicting zonal interchange volumes and traffic volumes on the various links of an urban network. In fact, research in developing diversion curves for assigning a portion of the zonal interchange volume to an expressway as opposed to the best alternate route (2, 3, 4, 5, 6) indicates that the best results are most likely obtained by using a combination of both comparative distance and comparative time. The relative weighting of distance and time, or some alternative combination where distance and speed are used, may be interpreted as being equivalent to determining the appropriate weighting between out-of-pocket costs associated with distance and the value of personal time associated with travel time.

In developing a road-user cost function, two alternative approaches are available. The first requires itemizing the components of the cost function (e.g., gasoline and oil consumption, tire wear, maintenance and personal time), determining how consumption of these different components varies with respect to speed of travel, establishing prices or costs for the different components and hence component cost functions, and adding up these component cost functions to obtain an overall user cost function. The second approach describes theoretically the expected shape of the user cost function and then attempts to estimate the parameters of the function statistically by using data where the cost function should be operative in determining how drivers behave. The values of the parameters in the function do not necessarily represent the true prices or costs encountered by the driver but only the relative weights between the different components of the cost function. Comparison of these relative weights will, however, indicate the degree of agreement between the two approaches.

The research described in this paper follows the second approach using diversion curve data for the Shirley Highway, the Dallas Central Expressway, the Gulf Express-

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way in Houston and the Alvarado-Mission Valley Freeway in San Diego. In addition, an attempt is made to estimate changes in the value of personal time associated with changes in personal income, at least to the extent that these changes affect driver behavior.

The first section describes the theory behind using diversion curve data and why these diversion curves are S-shaped. The second section describes a generalized road-user cost function of mixed quadratic-hyperbolic form and why the function should take this form. In the third section, the statistical problems of estimating the parameters of the cost function are discussed along with the final form of the estimating equation. Empirical results are given here. Finally, the research conclusions are given along with a comparison of the results derived here and those obtained by the more usual method of pricing out the various components of the cost function.

## THEORY OF DIVERSION CURVES

When faced with the problem of choosing among alternatives, a person generally adds up the gains and costs for the various alternatives according to this value system and picks the alternative that is "best" for him. Best in his sense may be that where gains are greatest if costs are zero, where costs are least if gains are zero, or where the gains-cost ratio is greatest implying the highest rate of return among the alternatives.

However, it is well recognized that different people, when faced with the same problems of choice, act differently. That is, they do not choose the same alternative, as has been adequately demonstrated by diversion curve data. These differences are usually ascribed to two factors: (a) imperfect information concerning what the true gains and costs are among the alternatives, and (b) underlying differences in the value systems used when determining the total gains and costs for each alternative.

In most instances, available data only describe variations in behavior and do not distinguish between the two sources of variation. This lack of differentiation is probably unimportant in predicting behavior in the steady state. However, it could become important in trying to estimate the impact that an improved information system would have on behavior, e.g., how many drivers would change their route of travel given advance warning of an impending bottleneck on their present route along with knowledge of free flow conditions on some alternate. This is the problem with diversion curve data; they only measure total variations in behavior.

The hypothesis used in explaining the variations in behavior evidenced by diversion curves is simply that the variations in individual value functions caused by the two factors mentioned previously are normally distributed. In other words, individual estimates of the cost of travel on a given route, which differ due to these two factors, are normally distributed.

Given a normal distribution of estimates of travel costs on a given route, the distribution of estimates of comparative costs between two alternative routes, i.e., a freeway and best alternate, will also be normal or approximately normal (7), depending on how the cost comparison is made. For an algebraic difference, the comparative cost distribution will be normal, and for a cost ratio, the comparative cost distribution is approximately normal.

Support for this hypothesis is given in Figures 1 and 2 where the percentage of people using the freeway is plotted against distance difference and time difference, respectively. Both distance difference and time difference represent a major portion of a user cost function. Both plot linearly on probability paper, indicating that the comparative cost function is indeed normal.

It is to be expected that this distribution of route preferences with respect to comparative costs would, in addition to being normally distributed, have a zero mean. Even though the distribution may not have a zero mean for distance difference or time difference when considered separately, it should when considering the total cost function. This is because one would expect half the people to use the freeway and half to use the alternate when the comparative costs are equal, always remembering that costs are defined by user value systems.

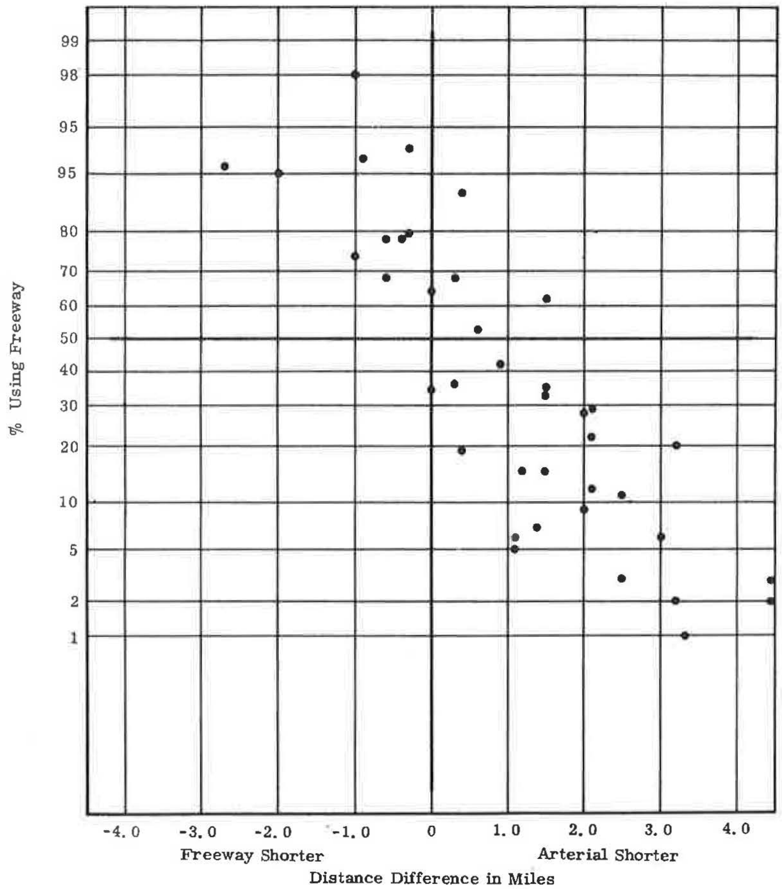


Figure 1. Relationship between percent using freeway and distance difference.

The problem of estimating the proportion who will use which route then becomes one of determining where the measure of comparative costs falls under the distribution and determining the amount of area under the curve that falls on either side of the comparative cost measure. This is shown in Figure 3. The curve is the normal distribution curve with mean zero corresponding to the case where comparative costs are equal for the freeway and the alternate. Two illustrative cases are given, $\Delta C_1$ and $\Delta C_2$, where $\Delta C$ refers to alternate costs minus expressway costs. In each case, the area under the curve to the left of the line corresponding to a given $\Delta C$ represents the proportion of trips taking the freeway and the area to the right represents the proportion taking the alternate. Thus, for $\Delta C_1$, where freeway costs are lower than arterial costs, the area to the left of the vertical line indicates that a larger proportion of persons will use the freeway than the arterial. The converse holds for the case of $\Delta C_2$.

Estimating the amount of area under the curve on either side of the vertical line ($\Delta$ C) may be accomplished by integrating the equation for the normal curve to some standard score (x) that is equivalent in position to $\Delta$ C. Thus, using the equation for the normal curve with mean zero and unit variance, the probability (or proportion of trips) of using the freeway P(F) or using the alternate P(A) are

$$P(F) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{x^2}{2}} dx \qquad (1a)$$

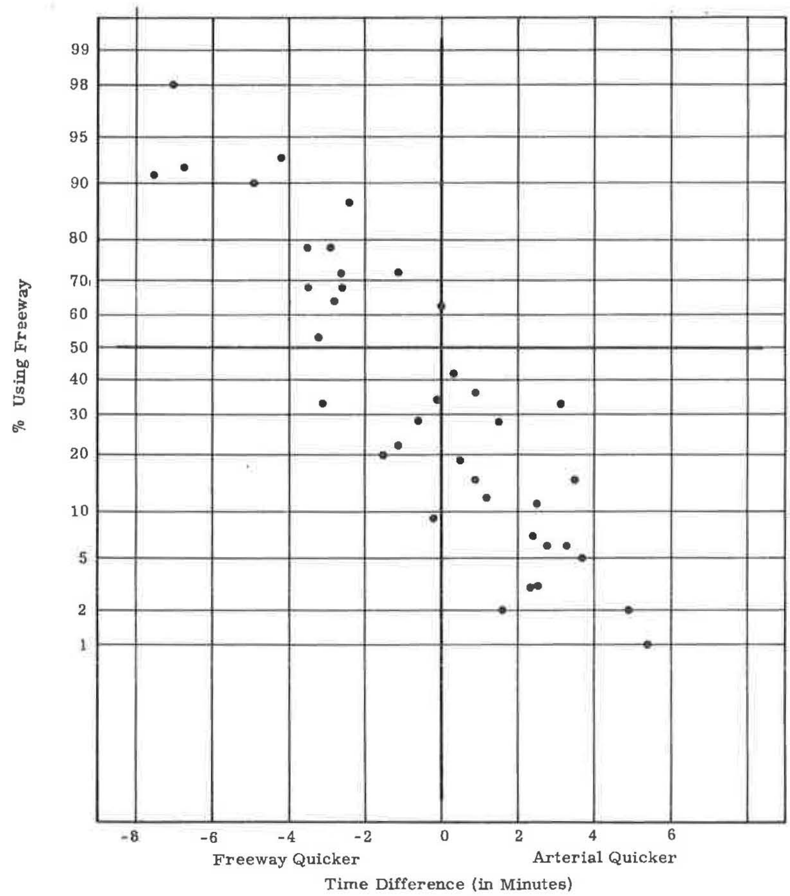


Figure 2. Relationship between percent using freeway and time difference.

$$P(A) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{x^2}{2}} dx \quad (1b)$$

It is clear that P(F) plus P(A) equal one. It is also clear, though not presented here, that similar reasoning could be extended to the multivariate case where more than two alternate routes are considered.

Since P(F) and P(A) are precisely determined for a given value of x, the problem is one of estimating the value of x for corresponding values of $\Delta C$. This is accomplished by determining the value of x, i. e., the standard score, corresponding to the percent of trips using the freeway and relating this to $\Delta C$ using multiple regression:

$$x = f(\Delta C) \quad (2)$$

## GENERALIZED COST FUNCTION

The two major components of user costs are out-of-pocket costs and the value of personal time. Out-of-pocket costs include such items as gasoline and oil consump-

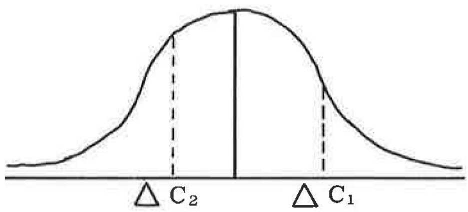


Figure 3.

tion, tire wear, and maintenance. Previous research has indicated that these costs are parabolic with respect to speed (8, 9, 10). This is to be expected because energy requirements for moving a vehicle are proportional to the square of the velocity. The constant and linear terms found in empirical estimating equations result from the loss of operating efficiency at low speeds. This loss is due to stop-and-go travel with the consequent consumption penalties due to idling, acceleration and deceleration and to vehicular design itself. Most automobiles are designed to operate most efficiently in the middle speed range. The value of personal time is usually assumed to be linear so that, for a given distance, its value is hyperbolic with respect to speed. The same assumption is made here.

A generalized cost function can, therefore, be described as follows:

$$C = D[a_0 + a_1S + a_2S^2 + a_3(1/S)] \tag{3}$$

where

$C$ = cost,
$D$ = distance,
$S$ = speed, and
$a_i$ = parameters to be estimated.

In this equation $D(a_0 + a_1S + a_2S^2)$ represents out-of-pocket costs and $D[a_3(1/S)]$represents the value of personal time. In addition, the estimates of the parameters indicate the relative importance of the different parts of the cost function. These can be compared to the estimates obtained by the usual pricing procedures for consistency.

## Empirical Results

The theory has been developed explaining choice between alternative routes of travel in terms of a probability density function whereby the position of the comparative cost of travel on the alternate routes under the normal distribution curve determined the probability of choice of a given route. It was also shown how this probability measure could be linearized by using a standard score corresponding to the percent using the expressway.

This standard score could then be estimated using the usual single equation multiple regression techniques with a set of independent variables representing a comparative cost function. For this analysis, a cost difference equation was used, i. e., cost via alternate minus the cost via the expressway. The cost difference is preferred to the cost ratio because: (a) we see no theoretical basis for choosing one over the other, particularly in urban travel; and (b) use of the cost difference is more tractable mathematically. Thus, we can write a generalized cost function, as in the previous section, for use of the expressway and another function for using an alternate, and take the difference between the two. This yields the following equation used in the multiple regression analysis:

$$P(F) = k + a_0(D_a - D_e) + a_1(D_aS_a - D_eS_e) + a_2(D_aS_a^2 - D_eS_e^2) + a_3(T_a - T_3) \tag{4}$$

where

$P(F)$ = probability of using expressway;
$D$, $S$, and $T$ = distance, speed, and time for the expressway and alternate as denoted by the subscripts a and e;
$a_i$ = parameters of equation to be estimated; and
$k$ = constant term in regression equation which, according to our hypothesis, should equal zero.

TABLE 1

COMPARISON OF PARAMETER ESTIMATES OF COST FUNCTION FOR DIFFERENT REGIONS OF THE COUNTRY

| Parameter | California | Texas | Washington, D. C. | All |
| --- | --- | --- | --- | --- |
| $a_0$ | 0.608 | 0.806 | 0.656 | 0.726 |
| $a_3$ (T) | 0.562 | 0.687 | 0.385 | 0.737 |
| $a_1$ (S) | -0.0174 | -0.0252 | -0.0189 | -0.0158 |
| $a_2$ ($S^2$) | 0.000362 | 0.000648 | 0.000375 | 0.000298 |
| r | 0.820 | 0.867 | 0.946 | 0.813 |

The data used in this analysis were from the Shirley Highway (2), the Gulf Freeway in Houston (3), the Central Expressway in Dallas (4), and the Alvarado-Mission Valley Freeway in San Diego (5). Certain zonal interchange volumes were not used because it was felt that the sample size represented by them was too small to be reliable, regardless of whether or not they fitted the equation well. This provided a total of 197 sample cases.

In testing this hypothesis, both theory and previous experience indicate the range of values the parameter estimates should take. Thus, k, the constant term in the equation, should approximate zero because, if the comparative costs of the two routes are equal, 50 percent of the people should take each route. The standard score associated with 50 percent usage is zero. The three parameters, $a_0$, $a_1$, and $a_2$, are the three parameters in the parabolic equation relating per mile out-of-pocket cost to speed of travel. Thus, $a_0$ should be positive. The value of $a_1$ should be negative and smaller in magnitude than $a_0$. The value of $a_2$ should be positive and smaller in magnitude than $a_1$. Both the sign and relative size of these parameters has been indicated in prior research (8). Finally, the value of $a_3$, which corresponds to an estimate of the value of personal time, should be positive.

In estimating the parameters of the equation a departure from the usual type of multiple regression analysis was done because of the high degree of intercorrelation among the independent variables. Briefly, the procedure followed was to obtain orthogonal estimates of each parameter, assuming independence among the independent variables, and then to multiply these parameter estimates by the variance-covariance matrix for the parameter estimates obtained through the usual multiple regression analysis. The variance-covariance matrix was scalar multiplied by an iterative procedure to constrain the constant term (k) in the equation to be equal to zero.

The final parameter estimates obtained by this procedure are presented in Table 1. For these purposes Dallas and Houston were combined under the assumption that there would be no regional differences in behavior between the two cities and to increase the sample size for that region. It will be noted that there is general agreement among the parameter estimates for the different areas. They are, in fact, statistically not significantly different from each other.

The comparative cost equation was further modified to incorporate median income of the home zone to determine if the value of personal time was related to income. This was accomplished by adding an additional term to the right-hand side of Eq. 3 of the form $a_4YT$ where Y corresponds to median income, and incorporating it in Eq. 4 as $a_4Y(T_a - T_e)$. The results are not presented here because the parameter estimate of $a_4$ was not found to be significantly different from zero; in the three different regional samples and the combined sample, the parameter estimate was in the order of $10^{-10}$ or greater.

## CONCLUSIONS

The theory and methodology have been explained for deriving a road-user cost function using diversion curve data. The correlation coefficients, which all exceed 0.80, indicate that the data fit the theory very well. Indeed, when the sampling error inherent

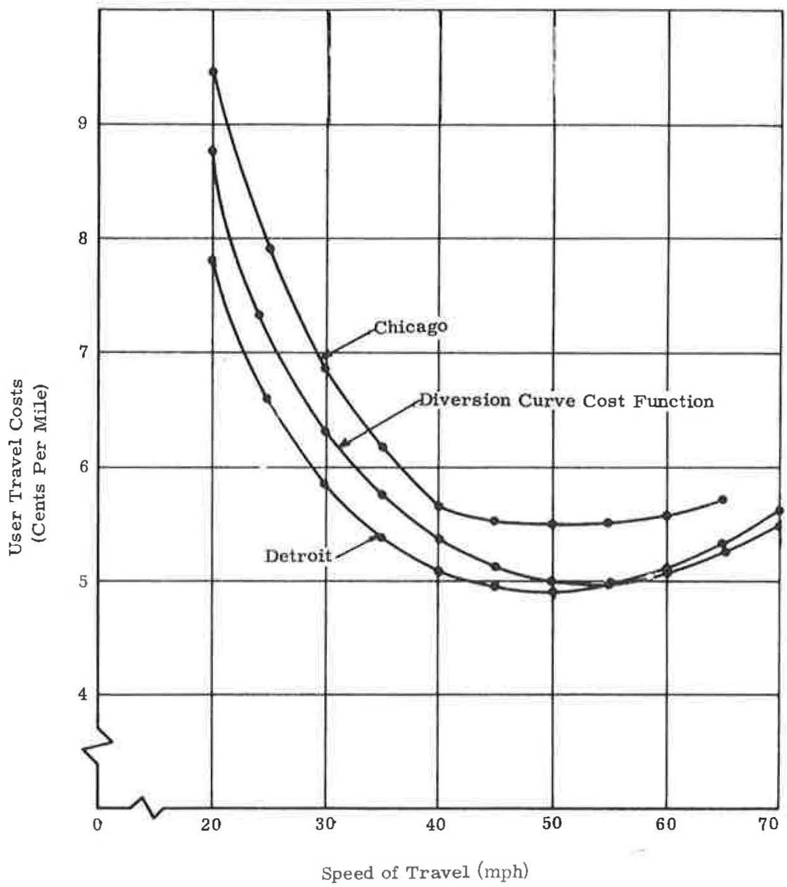


Figure 4. User cost curves for Chicago, Detroit and this study.

in estimating the zonal interchange volumes and, hence, the proportion using the expressway is considered, these correlation coefficients are probably close to the upper limit that could be achieved from the data.

The implications of this research are three-fold. First is the obvious one in using the results obtained for assigning traffic to a proposed new facility where it is desired to use diversion curves. Second, and probably more important, is that the user cost equation developed may be used in predicting zonal interchange volumes or traffic assignment with the minimum path programs currently in use, or both. Finally, user trip costs, which can be estimated using the equation, represent another measure of trip length rather than either distance or time alone and can, therefore, be combined with other data in estimating trends in trip length.

The derivation of the user cost equation from the results is straightforward. Since the hypothesis presented here states that the proportion of trips using the expressway is a function of comparative costs on the two routes and the comparative cost function is well defined, the costs on either route can be arbitrarily set equal to zero and the total cost for the remaining route can be estimated. It should be pointed out that the user costs estimated by this equation are parametric estimates; i.e., the parameters indicate the relative importance of the different components in the user cost equation. The final measurement is not in dollars and cents but in some arbitrary unit—maybe gilders. However, a direct comparison may be made between the user cost equation derived here and that obtained by the more usual methods, such as employed in Detroit (8) and Chicago (10), by multiplying each of the parameter estimates by a constant to

place them in the same range as the Detroit and Chicago equations and then comparing the shape of the curves. This is shown in Figure 4, where each of the parameter estimates was multiplied by 3.2 to place the resulting curve in the same range as the other two. As can be seen, all three curves have a similar shape.

The multiplication by the constant of 3.2 provides a basis for estimating the value of personal time, at least in its relationship to the cost of other portions of the cost function. The precise value of personal time chosen is, of course, dependent on the value of the constant multiplier chosen, but this analysis indicates its value is on the order of $1.25 to $1.40 per hour. The greater steepness of our curve, as well as the fact that it crosses the Detroit curve, indicates that the value of personal time is greater than the $1.20 per hour used in pricing out the latter.

In conclusion, we have developed a road-user cost equation from data reflecting driver behavior where the driver's choice of route is determined from comparative costs on the two routes. There is a high degree of agreement between the cost equation developed from this approach and those obtained in the usual pricing studies. This indicates both that drivers tend to behave in a cost-conscious way and that the cost function of individual drivers approximates that obtained from pricing studies.

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# Research Report on Electronic Highway Scales for Weighing Trucks in Motion

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ABRIDGMENT

•THE NEED for a dependable method of weighing the axle loads of moving vehicles has long been recognized by those agencies and individuals concerned with the planning and operation of the highway system. In the past 15 yr, many researchers in the United States (1, 2, 5, 12, 13, 17, 18) and in Europe (3, 4, 14, 15, 16) have attempted to develop such a method. Several state highway departments have made experimental installations of dynamic weighing devices with varying degrees of success (7, 8, 9, 10, 11).

The paper describes the construction, installation, testing and performance analysis of three types of dynamic electronic highway scales: (a) the Taller-Cooper, a commercially developed four-load cell scale; (b) the broken bridge, an adaptation of a German prototype employing two load cells (16, 21); and (c) the beam-type scale (12, 19), an experimental scale with a pair of instrumented aluminum beams as the weight sensors. The research was done by the Department of Civil Engineering of the University of Kentucky in cooperation with the Kentucky Department of Highways and the U. S. Bureau of Public Roads (23). The project was started in 1960 for the purpose of determining the best mechanical configuration for a scale which would perform the dynamic axle weighing function in an overall data-gathering system.

The testing program was carried out by installing the Taller-Cooper and broken bridge scales in the approach ramp to a truck weighing station on I-64. The program was divided into two phases. The first consisted of a series of runs across the scales with a truck of known axle weights, varying the speed and the amount and method of vertical stabilization (preload). The second series utilized trucks diverted from the I-64 traffic stream; speed was not controlled, but the preloading variables were again introduced. Static weights of the axles of each diverted vehicle were obtained at the weight station. A similar program was conducted for the beam-type scale.

In analyzing the test data, the basis of comparison was the deviation of the dynamic axle weight as measured by each scale from the known static weight. The characteristic output waveforms obtained from the weight measurements by each of the scales were also compared. Because of differing mechanical configurations and methods of mounting the transducers, each scale produced a distinct output waveform for the same applied load.

Some specific conclusions were reached from the study:

1. The deviations of dynamic axle weights from static weights over a range of crossing speeds follow a pattern for a given set of approach and site conditions.

2. The addition of preload to the scale platform does not, in general, reduce the differences between the recorded dynamic and static axle weights, but it does stabilize the weighing system and tends to increase the consistency of the linear relationship between the dynamic weights and the corresponding static weights.

3. Heavy coil springs are more satisfactory than stiff rods and turnbuckles for applying preload to the scale platforms because they do not reduce the sensitivity of the

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recording system (20) and their greater resilience reduces the effect of temperature changes on the preloading mechanism.

4. Under zero preload, the broken bridge scale is more sensitive to high crossing speeds than the Taller-Cooper scale. The addition of a heavy preload is more effective in stabilizing the output of the Taller-Cooper scale than it is for the broken bridge scale.

5. Limited tests of the beam-type scale show it to be a feasible weighing system comparable in performance to the other two scales.

6. Any of the three scale types will do a creditable job of detecting overloaded vehicles.

7. Simultaneous measurement of the dynamic axle weights of a test vehicle by axle housing strain, accelerometer and the electronic scales showed that, within the limits of the probable chart reading error, the output of the scale indicates the actual applied load and that any of the three methods will, if properly calibrated, yield a true measure of the dynamic axle weight. This finding confirmed the results of previous research (6).

8. For an individual axle the dynamic weight measurement is equal to the static only in isolated and unpredictable instances. However, if its characteristic behavior is known, any one of the scales can be used to obtain a reasonably accurate estimate of the gross static tonnage passing over a section of highway during a given period of time.

9. The choice of a particular type of scale for an electronic in-motion weighing system will be determined by the ultimate form of the recorded weight measurements, and by the use to be made of the measurements (22).

10. The actual loads applied to the highway pavement by the wheels of a moving truck vary from the static weights over a wide range; therefore, dynamic axle weights rather than static should be considered in establishing pavement design criteria.

Future research in the field of dynamic weighing should include:

1. The development of a portable scale designed to be installed in the pavement at previously prepared locations in the state and Federal highway systems where the axle load characteristics of the traffic are desired;

2. A feasiblity study of the use of the dynamic scale to measure speed, volume and axle spacing in addition to axle weight;

3. The installation of an electronic scale in the approach to an enforcement weighing installation to test the practicality and desirability of culling out lightly loaded trucks from those required to stop for static weighing;

4. A study of a very large sample of dynamic weight recordings to determine the feasibility of deriving approximate static weights by a statistical consideration of the effects of specific approach conditions, crossing speeds, axle location, scale type and preload; and

5. Studies of the ranges of variation in the amplitude and oscillating frequency of the in-motion axle weights of trucks commonly used including consideration of vehicular variables such as body type, suspension systems, loading, and environmental factors such as temperature, wind velocity vectors, and driver habits.

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