APPLICATION OF EQUATION FOR ANNUAL ROAD COSTS

By Sigvald Johannesson

Designing Engineer, New Jersey Highway Commission

SYNOPSIS

The equation for annual road cost proposed in the Ninth Proceedings of the Highway Research Board is simplified by replacing the factors

$$\frac{r}{(1+r)^n - 1}, \frac{r}{(1+r)^{n'} - 1} \text{ etc}$$

by k, k' etc , which are constants depending on the length of life (n) of the item in question and on the rate of interest (r) Considering that within the probable limits of the value of r there are no serious differences in the value of k for a given value of n, and eliminating values of n less than 10 and greater than 20 he reduces the general equation to

$$C = Ar + B + 0\,085E_{10} + 0\,052E_{15} + 0\,035E_{20}$$

in which E_{10} represents the estimated replacement cost of such items as have an expected life of from 10 to 14 years, E_{15} from 15 to 19 years and E_{20} from 20 to 30 years

In considering construction costs the interesting conception is offered that since highways were originally built as means of communication and in later years have also become means of transportation in some cases the costs incident to the two purposes should be separately considered

EQUATION FOR ANNUAL ROAD COST

In the report of the Committee on Highway Transportation Costs of the Highway Research Board for 1929,[1] the average annual road cost is expressed by the equation

$$C = r\left(A + \frac{B}{r} + \frac{E}{(1+r)^n - 1} + \frac{E'}{(1+r)^{n'} - 1} + \quad\right) \qquad (1)$$

where

C = average annual road cost
A = cost to construct
B = yearly maintenance cost (every year)
E = (or E') = expenditure for periodic maintenance every n (or n') years (Replacement is an "E" value)
r = the rate of interest prevailing in current state financing

This equation may be simplified in the following manner

Let

$$k = \frac{r}{(1+r)^n - 1}, \text{ and } k' = \frac{r}{(1+r)^{n'} - 1}, \text{ etc ,}$$

then equation (1) may be written

$$C = Ar + B + kE + k'E' + \qquad (2)$$

[1] Ninth Proceedings Highway Research Board, page 360

in which k, k' etc are constants depending on the length of life, n, of the item of highway construction in question and on the rate of interest, r When these two values are estimated or known, the corresponding value of k may be found in Table I

For general purposes equation (2) may be simplified as follows

Considering the figures in Table I it is apparent that within the probable limits of the values of r there are no serious differences in the values of k for a given value of n It is possible, therefore, without material error to substitute Table II for Table I

TABLE I

VALUES OF k FOR VARIOUS VALUES OF n AND r

n in years	r in per cent							
	2 5	3	3 5	4	4 5	5	5 5	6
5	0 1903	0 1883	0 1865	0 1846	0 1828	0 1810	0 1792	0 1774
10	0 0893	0 0872	0 0852	0 0833	0 0814	0 0795	0 0777	0 0759
15	0 0558	0 0538	0 0518	0 0499	0 0481	0 0463	0 0446	0 0430
20	0 0391	0 0372	0 0354	0 0336	0 0319	0 0302	0 0287	0 0273
25	0 0293	0 0274	0 0257	0 0240	0 0224	0 0210	0 0195	0 0182
30	0 0228	0 0210	0 0194	0 0178	0 0164	0 0151	0 0138	0 0126
40	0 0148	0 0133	0 0118	0 0105	0 0093	0 0083	0 0073	0 0065
50	0 0103	0 0089	0 0076	0 0066	0 0056	0 0048	0 0041	0 0034
60	0 0074	0 0059	0 0051	0 0042	0 0035	0 0028	0 0023	0 0019
80	0 0040	0 0031	0 0024	0 0018	0 0014	0 0010	0 0008	0 0006
100	0 0023	0 0016	0 0012	0 0008	0 0006	0 0004	0 0003	0 0002

TABLE II

APPROXIMATE VALUES OF k FOR VARIOUS VALUES OF n

n	k	n	k
5	0 185	40	0 012
10	0 085	50	0 007
15	0 052	60	0 005
20	0 035	80	0 002
25	0 025	100	0 001
30	0 019		

It is not likely, however, that any item of work with an expected life of less than 10 years will be placed in the permanent highway structure, and consequently the value of k for $n = 5$ may be omitted Further, the values of k for n greater than 20 may be omitted, because first, it is scarcely possible to predict that the life of a certain item will be 20, 25 or 30 years, and it is better, keeping in mind the purpose for which the equation is to be used, to select the lowest and most conservative figure, and second, if the expected life is more than, say, 30 years, the value of k is so small that no material error is committed in omitting all items having an expected life of more than 30 years

For general purposes, therefore, equation (2) may be written

$$C = Ar + B + 0\,085E_{10} + 0\,052E_{15} + 0\,035E_{20} \qquad (3)$$

in which E_{10} represents the estimated replacement cost of such items as have an expected life of from 10 to 14 years, E_{15} the replacement cost of items having an expected life of from 15 to 19 years, and E_{20} the replacement cost of items having an expected life of from 20 to 30 years

Equation (3) may be used under all ordinary circumstances If, however, in specific cases the interest rate may have an exceptional value, or if construction items of relatively high cost may be estimated to have an unusually long life, it is proper to refer to Equation (2) in conjunction with Table I

COST OF CONSTRUCTION

(a) If the equation for annual road cost is used in connection with the study of the economics of a projected highway improvement, the symbol A in the equation represents the estimated cost of construction of the improvement It does not include any previous expenditures on the highway

The estimated cost of construction of the improvement will include the cost of additional right-of-way, if such is required to carry out the improvement It will include also cost of damages on account of the improvement, for which payments may have to be made It will further include the estimated cost of actual construction work contemplated together with engineering and legal expenses

For a complete economic study there are other items, which should be included under the heading "Cost of Construction," such as General Office Expenses, Interest during Construction etc , but in many cases the value of these items may be quite uncertain or difficult to obtain The simplest way of including these items, therefore, may be to add to the total estimated cost of construction an amount of from 5 to 10 per cent of this total The possible error incurred will be immaterial

(b) If the equation for annual road costs is used for evaluating a highway in a study of proper taxation of motor vehicles, cost of previous construction work should be taken into account It is the opinion of the writer, however, that only cost of improvements, which were made at or subsequent to the time, when improvements were made for transportation purposes, should be considered This opinion is based on the following reasoning

There are two reasons for constructing highways One is to provide a means of communication and the other to provide a means of transportation Until comparatively recently the communication purpose was overwhelmingly predominant on all highways It is still pre-

dominant on some secondary roads, but on primary roads the transportation purpose is now of the greater importance

At the time a highway was constructed for communication purposes, there was undoubtedly little or no thought of it becoming eventually of material importance as a means of transportation Its social and economic value as a means of communication, therefore, must have been of sufficient importance to warrant the cost of its construction and maintenance from the time it was originally built to the time when it became important as a means of transportation The Appian Way was constructed for military and administrative reasons and not for transportation as we now understand this term The Boston Post Road was constructed originally as a line of communication between New York and New England, as implied by its name Other roads were built originally to serve as a means of communication and access to land and settlements adjacent to them In fact, it is almost certain that the value of all such roads as a means of communication remains, even though they may now also be used as means of transportation

It appears, therefore, that it is unnecessary, and perhaps even improper, when determining the cost of a highway for the purpose of vehicle taxation, to include in the cost determination the cost of any right-of-way, grading, structures and other items, which were provided prior to the time that the highway changed in character from a means of communication to a means of transportation These items were socially and economically justified to provide a means of communication and should not be charged to transportation

(c) If, on the other hand, the equation for annual road costs is used for valuation of the highway as a whole, it is necessary to include all the items of right-of-way and permanent construction in the manner indicated in the report of 1930.

ANNUAL COST OF MAINTENANCE

In equation (2) or (3), the term B represents the annual cost of maintenance This item includes all repairs made on the various parts of the highway structure in order to retain it as nearly as practicable in the condition it was in at the time the construction was just completed It includes also the annual expenditures for such items as lighting, attendants at tunnels or movable bridges, operating cost of machinery and equipment of tunnels or movable bridges It may include further the cost of street cleaning and snow removal The item, however, does not include additional surfacing for the purpose of widening the paved roadway, additional drainage facilities or other similar work, because such work is a new and additional improvement

Presuming that the maintenance is such as to keep the highway structure in good condition at all times, the maintenance cost will depend on the length, width and type of pavement, the volume of

traffic, the climate, the geographical location and many other conditions The cost of maintenance probably will vary with the age of the surface, but for convenience of computation, the average annual cost may be used

The maintenance cost is an important item in the annual cost of the highway and deserves careful study A highway department making a study of the economic justification of a highway improvement usually will have records of previous work on which an estimate of the cost of maintenance may be based, unless the improvement contemplates types of construction items not previously used by that department To take care of this condition, which may frequently occur, it would be of material value to collect, classify and publish records of the cost of maintenance of all highway departments and other similar bodies, if such records are available for this purpose

PERIODIC MAINTENANCE (REPLACEMENTS)

The replacement items E, which may enter the equation for annual road cost may be determined by considering all the various construction items of the highway These items may be enumerated as follows·

a Right-of-Way
b Grading
c Shoulders, Curbs, Sidewalks
d Surfacing
e Drainage
f Culverts
g Guard Rails and Signs
h Lighting
i Bridges
j Tunnels
k Landscaping

Each of these items will be considered separately

(*a*) *Right-of-Way* The right-of-way is permanent Additional right-of-way may be acquired in the future to take care of traffic conditions that may develop, but this will involve a new improvement, which is not within the scope of the improvement considered Right-of-Way, therefore, is not a replacement item

(*b*) *Grading* Grading is permanent It is probable that the elements will continuously deteriorate the grading work, but the repairs necessary on this account will come under the heading Maintenance It is possible also, that from time to time changes will be made in the grading to take care of new traffic conditions, but that again will involve a new highway improvement, outside of the scope of the improvement considered Grading, therefore, is not a replacement item

(*c*) *Shoulders, Curbs and Sidewalks* Unpaved shoulders may be considered permanent with proper maintenance If at a later time

they are paved to take care of new traffic conditions, this will be a new improvement, not within the scope of the improvement considered Unpaved shoulders, therefore, are not a replacement item Paved shoulders will deteriorate in time and may have to be rebuilt Paved shoulders, therefore, is a replacement item for which the lifetime must be estimated The same applies to curbs and paved sidewalks

(*d*) *Surfacing* Almost any kind of surfacing will wear out in time this, therefore, is a replacement item for which the lifetime must be estimated To facilitate this estimate it would be of material assistance to collect, classify and publish records of the actual lifetime of various types of surfaces under various traffic, climatic and geographical conditions

(*e*) *Drainage* The drainage system of a highway, including ditches, pipes, inlets, manholes, etc , may usually be considered permanent Damaged sections of pipe, broken grates etc , can be taken care of under the heading Maintenance If the drainage system for any reason should be found inadequate, or should fail in part on account of heavier loads being carried on the highway than originally contemplated, the reconstruction cost of such work should be charged to a new improvement and not to periodic maintenance Drainage, therefore, is not a replacement item

(*f*) *Culverts* Usually culverts may be considered permanent In special cases, where either the material used or the soil conditions may limit their life, they may be considered as a replacement item, for which the lifetime must be estimated

(*g*) *Guard Rails and Signs* As guard rails and signs will deteriorate, they must be considered as replacement items, for which the lifetime is to be estimated New or additional guard rails or signs, or changes made on account of subsequent developments should not be considered here, as they are actually new improvements, but for convenience, it may be proper to consider them as maintenance items

(*h*) *Lighting* It is probable that in most cases the cost of lighting highways, if any, is an annual charge, which may be included under the heading Maintenance If otherwise, it will be necessary to classify Lighting as a replacement item and estimate the lifetime of wires, cables, poles, fixtures, etc , entering into the system

(*i*) *Bridges* Some bridges, such as wooden trestles, have a limited life and are, therefore, a replacement item Other bridges, such as steel and concrete structures, should last indefinitely, as far as the main structure is concerned, if properly maintained The roadway and sidewalk surfaces, of course, are replacement items, and the railings and other minor items of the bridge also may have a limited life, which has to be estimated The same applies to the machinery and equipment of movable bridges Bridges which have to be rebuilt on account of obsolescence, such as those which may have to be reinforced because

of greater loads than originally contemplated, or which may have to be widened on account of increased traffic, are not to be included under the replacement items, because their reconstruction involves additional improvements

(*j*) *Tunnels* Where tunnels occur in highway construction, they may be considered permenent, if built as permanent structures If a wooden lining is used, this will have to be replaced in time, and the wooden lining, therefore, must be considered as a replacement item, for which the lifetime must be estimated. The same applies to the roadway surface, to pumping, lighting and ventilating machinery and equipment and possibly also to other minor items of the tunnel

(*k*) *Landscaping* This item includes such matters as covering slopes with grass, planting trees along the highway and other similar work done for the purpose of securing and beautifying the highway Work of this character should be considered permanent and not as a replacement item Repairs, replacements and renewals are properly to be considered under the heading of Maintenance

Summarizing, the replacement items may be listed as follows

Paved shoulders, curbs and sidewalks
Roadway surfaces
Culverts under special conditions
Guard rails and signs
Lighting system under certain circumstances
Bridges, certain items only
Tunnels, certain items only

It is apparent from this list that under ordinary circumstances paved surfaces are the most important replacement items, and that, except under special circumstances, all other replacement items may be omitted without material error It is advisable, however, in preparing an estimate of this kind, to consider all the items of the list to ascertain whether or not any of the other items may be of sufficient importance to warrant inclusion in the estimate

RATE OF INTEREST

Equation (1) contains the term r, which has been defined as the rate of interest prevailing in current state financing Theoretically, this may not be entirely correct, because it may be a question whether it is proper to use the same interest rate for the money expended on the construction work and for the money set aside for the replacement work The interest rate used for the money spent on construction work may properly be considered as the interest rate prevailing in current state financing, but the interest rate of money set aside to provide a replacement fund may be different, due to legal or other limitations

Actually, however, this condition does not exist, because it is improbable that any highway board sets aside a sum of money at the time

of construction of a certain highway, the proceeds of which are to be applied to future replacement Usually the money required for such replacements is derived from the current funds of the highway board The limitations that may exist on the interest rate of money invested by the highway board for future use, therefore, are not exercised, and it appears proper under the circumstances to apply the same interest rate to the replacement work as that used for the primary construction work

DISCUSSION

ON

EQUATION FOR ANNUAL ROAD COSTS

PROF W W HITCHCOCK, *Michigan State College*· I would like to call your attention to the mention which Mr Johannesson has made of the effect of omitting the reproduction cost of items which are estimated as having life of thirty years or more

By a study of Table I, it will be observed that there is a definite relation between interest rate and the value of the Constant, "*k*" for any fixed time period

The annual interest charge against any portion of the highway investment is an important item in the computation of the annual cost of a highway The annual deposit to reproduce this same portion of the highway then bears the same relation to the interest charge as the value of "*k*" bears to the interest rate To illustrate. Assume an interest rate of four per cent and the life of the improvement as 30 years If replacement cost is omitted the difference or decrease in the computed annual cost is to the interest charge as the value of "*k*" is to the interest rate or equal to 44 5 per cent of the annual interest charge on the same investment

By making use of this simple relation one may determine what effect the omission of the replacement charge will have on any highway in question

Mr. W R COLLINGS, *Dow Chemical Company*: In most of these discussions of the economics of highways and of annual road costs, there is no provision made for payment of the initial investment Should there not be an item included to retire the bonds in a period of say 15 years?

PROF R L MORRISON, *University of Michigan* The item to retire the bonds is included in the term, or terms, covering depreciation In all of the formulae for annual road cost the three items of interest, depreciation and maintenance occur in one form or another In order to make actual payments conform to the theoretical annual cost, the construction must be financed by means of bonds

In the case of Mr Johannesson's formula the term "Ar" would be the annual interest payment on the bonds, "B" would be the actual annual maintenance cost, and the sum of the terms "$kE + K'E' +$" etc would be the annual deposit in the sinking fund

Of course no results obtained by the use of a formula can be any more accurate than the basic data used in the computations In the case under discussion we must assume the interest rate, the annual maintenance cost, and the economic life of each part of the highway, all of which are subject to considerable variation

Considering the difficulty of an accurate determination of these factors, it has seemed to me that, for practical purposes, the simple formula $C = D + I + M$, in which "D" is annual depreciation, "I" is annual interest, and "M" is annual maintenance cost, is about as satisfactory as the more elaborate formulae Also I see little use in trying to foresee the future beyond the estimated life of the original road surface Therefore I would first estimate the residual value of all parts of the highway at the end of the period covered by the estimated life of the surface Subtracting that value from the total original cost would give the total depreciation during the period under consideration That sum divided by the estimated life of the surface would give the annual depreciation, "D." Adding the interest on the original investment to the interest on the residual value, as computed above, and dividing this sum by 2, would give (approximately) the average annual interest "I" The average annual maintenance cost, 'M," would merely be estimated as accurately as possible

To make actual payments correspond with the theoretical costs, as determined by this formula, it would only be necessary to finance the improvement by means of serial bonds, having an amount equal to the depreciation during the life of the surface mature during that period The bonds retired each year, then, would be just equal to the theoretical annual depreciation, "D," and the average interest payment, over the entire life of the surface, would be approximately equal to "I" in the formula

I believe it is generally agreed that, to determine the economic soundness of a proposed improvement, interest must be charged against it even if no interest is actually paid

DEAN ANSON MARSTON, *Iowa State College* I cannot help thinking that when we get studying these things from the standpoint of maintaining a depreciation reserve, just equal to the actual depreciation of the roads, a lot of these questions will clear themselves up We do not in ordinary practice consider that the cost times the interest is a part of the annual cost of production The interest is really a part of the net return on the investment In the case of highways the net return, of which the interest is part, comes to us in the form of equitable charges for road services

In the case of an ordinary utility it is necessary for the utility to make an annual depreciation appropriation out of income to make good the depreciation each year, but they do not set it aside in a sinking fund the way this question assumes They reinvest it, and that is what we are doing with our highways out of current road funds We are making replacements and improvements on old roads and are building new roads, all of which constitute investments of the sums which we collect over and above the cost of maintaining the roads

ANALYSIS OF ROAD COST ON THE STATE HIGHWAYS OF WORCESTER COUNTY, MASSACHUSETTS

By C B Breed

Professor of Railway and Highway Transportation, Massachusetts Institute of Technology

SYNOPSIS

The report presents the methods used in analyzing road costs on the state highways of Worcester County, Massachusetts The complete analysis will include about 300 miles of state highways, which in their physical layout and traffic densities constitute a traffic pattern, such as has been suggested by the author as a unit for studying road costs

Complete data are included for one typical continuous route, comprising 27 miles of state highway in 23 sections of different surface type, width or condition, and with traffic densities ranging between 870,000 and 3,700,000 vehicles per year Three tabulations have been prepared. the first giving descriptions of surfaces and annual maintenance costs, the second giving construction history and computation of capital costs, and the third summarizing the above and showing computation of annual road costs by an approximate method, and in comparison the annual contributions paid in state taxes by vehicles using the different sections

Previous reports of the Committee on Highway Transportation Economics have presented analyses of road cost for a 6-mile section of the Boston Post Road in Connecticut and a 26-mile stretch of the Des Moines-Ames road, Iowa (1930), and for the Concord-Harvard and the Tyngsboro roads (about 7 miles and 3 miles long, respectively) in Massachusetts (1932) Those studies related to isolated portions of roads having different traffic densities They were not intended to develop road costs for general use, their purpose was to develop the application of the fundamental principles set forth in the report of the Committee in 1929

The current study comprises the State System in Worcester County in Massachusetts because it constitutes a traffic pattern centering in the City of Worcester which has a population of 195,300 (See Figure 1) A statewide study could be readily developed by investigating the remaining county highway systems and assembling them Much