FITTING ROAD IMPROVEMENT PRACTICES TO TRAFFIC DEMANDS

By P. M. Tebbs, Assistant Chief Engineer, Pennsylvania
Department of Highways, Harrisburg, Pennsylvania

Traffic demands maximum highway service for least cost. The problem is divided into two phases—how to determine what to build, and how to build it. We will consider the first phase.

No highway system can be worked out economically without a thorough knowledge of the traffic; and therefore a comprehensive traffic survey is fundamentally necessary.

The basic present-day practices in the inauguration and upkeep of highway improvements are a result of merged economic and social demands and a development of experience and expediency.

Localized responsibility within narrow territorial limits, such as our Pennsylvania townships, having in the sparsely settled sections inadequate resources for required expenditures, at an early date became intolerable with respect to principal roads. Privately-owned toll road companies, encouraged by subsidy to furnish urgent necessities in highway transport, were not fully successful. No effective solution of the difficulty appeared until federal and state governments combined to aid the counties and townships.

The one great question has been that of financing. It has been recognized that the cost of public roads is necessarily a public charge, but the distribution of the charge has been and still is a problem.

Road expenditures have always been considered in a different light from the costs of civil government, of national defense, or of education. It has been considered that road expenditures are for special benefit and that identification of interests benefited indicates proper assessment of costs. This assessment is necessarily governed by the limitation of ability to pay or willingness to accept the tax burden. So the realty and personal tax funds are supplemented or superseded by payments from road users, and in the interest of consistent development there is, in limited scope, encouragement from the national treasury.

There has been general approval of the idea that the principal highways are a direct responsibility of the states, and the trend of opinion appears to be that the responsibility of the states should be extended to cover the general field of highway transport. There is almost unanimous agreement that the principal sources of revenue for the financing of state highway improvements are properly provided by motor license fees and liquid fuels taxes. Since the road users constitute the majority of the voting strength, it appears that the limits of these charges are fixed less by ability to pay than desire for benefit. The conclusion is that when service within reasonable limits is demanded by traffic, it is deserved, since traffic pays the bills.

In past years the financing of highway improvements has often been taken care of by bond issues. During the years when the use of motor vehicles was rapidly increasing, there was very little objection to mortgaging the future within reasonable limits. At that time, when inadequate road facilities were responsible for large annual losses to road users, when currently available funds were insufficient for required expenditures, and when rapid increases of revenues were anticipated, borrowing from the future seemed sound. Now that the annual increase in the number of motor vehicles is small, and the prospect of surface replacements as well as of maintenance in the approaching years, looms large, there is less justification for the issuance of bonds, and good business practice points to the "pay as you go" method of financing.

In highway administration it is not always possible to plan and build for greatest economy in the expenditure of road funds. The consideration of economy for road users is a fundamental responsibility of highway administration. When the need of improvement is greater than can be financed at once, some compromise is desirable between economy in road expenditures and economy in operation costs to the road users.

HIGHWAY COSTS

As an example, let us assume a fund of $10,000,000 available for a construction program with a choice of either bituminous surface treated macadam or reinforced concrete as a pavement type. At an average cost of $27,400 per mile for the former, a total of 365 miles could be constructed. If concrete were selected at an average cost of $31,640 per mile, a total of 316 miles could be paved leaving a balance of 49 miles of unimproved roads as compared to the first case.

Including the costs to the users of the road on the annuity basis, the comparative total annual costs of the two types will now be presented. Assuming:

(1) Annual average daily traffic of 500 vehicles.

(2) Interest rate 4½%.

(3) Bituminous surface treated macadam construction at $27,400 per mile, including;

  (a) Grading and drainage $11,500 with a life of 40 years.

  (b) Surface $15,900 with a life of 20 years. (Must be resurfaced at end of 10 years at a cost of $9,000).

(4) Reinforced concrete construction at $31,640 per mile, including;
   (a) Grading and drainage $11,500 with a life of 40 years.
   (b) Pavement slab $20,140 with a life of 20 years.

(5) Comparative annual maintenance costs;

	Earth	*B.S.T.M.	Reinforced Concrete
General Maintenance	$500	$500	$400
Surface Treatment	$100	$240	....
Total	$600	$740	$400

(6) Savings in operating costs over the macadam or concrete as compared to earth equals $10 per year per vehicle.

The comparative total cost based on above assumptions are as follows:

COMPARATIVE ANNUAL COSTS

Fixed Charges	*365 mi. B.S.T.M.*	*316 mi. R.C. & 49 mi. Earth*
40 Yr. Capitalization	365 x $11,500 x .0524 = $219,949.00	316 x $11,500 x .0524 = $190,421.60
20 Yr. Capitalization	365 x $6,900 x .0752 = $189,391.20	316 x $20,140 x .0752 = $478,590.85
10 Yr. Capitalization	365 x $9,000 x .1248 = $409,968.00	
Total Fixed Charges	$819,308.20	$669,012.45
Maintenance Charges	365 x $740 = $270,100.00	(316 x $400) + (40 x $600) = $126,400.00 + $29,400.00 = $155,800.00
Total Road Costs	$1,089,408.20	$824,812.45
Diff. in Operation Costs		49x 500 x $10.00 = $245,000.00
Total Comparable Costs	$1,089,408.20	$1,069,812.45
Difference		$ 19,595.75

This shows such a slight economy in favor of the concrete and earth group that for all practical purposes the annual costs may be considered as equal.

The problem of deciding the desirability of a low first-cost type as compared to a high first-cost type faces a great many highway engineers.

* Bituminous surface treated macadam.

Suppose the improvement of a 3,000-mile trunk line system is being planned on an annual construction budget of $10,000,000. In the same period of time required to improve the entire system using the low first-cost type, only 2,595 miles could be improved with the high first-cost type, therefore 405 miles or 13.5 per cent of the system would still be unimproved. There are many other factors entering the problem, and all must be given due consideration in each set of circumstances. Traffic demands the completion of the trunk line system in the least possible time; and upon this consideration only the lower cost type should be used. Surface smoothness and losses incidental to the surface treatment of the lower cost type are factors not given values here and are difficult to evaluate, but are less favorable to the lower cost type. The answer to this problem is found in applying these same principles of analysis to the individual sections of the system, with proper values for cost, life, and maintenance. These are dependent upon materials, traffic, and stability of subgrade. It is generally economical to use the lower cost type upon the more stable subgrade under the less severe traffic conditions. Some engineers undertake to design a highway from one city to another many miles away, upon a cursory traffic survey and considering the whole problem upon the same basis. More often than not, the conditions for design vary greatly. In Pennsylvania, traffic is found to be much heavier within five to ten miles of the cities than over sections between, and considerations of design must be treated accordingly.

In all phases of engineering there is a critical relationship between cost and effect. The magnitude of total expenditures for road improvement and maintenance and the close connection between adequate highway facilities and public welfare impose upon the highway engineer due regard for economy and efficiency. The need for highway improvement is so extensive that consideration of ultimate costs is most serious even to the wealthiest states. It is imperative that each project be planned carefully not only as to first cost but with proper regard to depreciation and maintenance.

On the basis of expenditure from current funds, actual road costs are chargeable to depreciation and maintenance. Annual actual road charges may be explained as average annual depreciation plus average annual maintenance cost. For analysis or estimate of expenditures this simple method of determination is sufficient. For an economic study, however, there is significance in deferred expenditures, the best practice being to compute average annual cost of deferred expenditures in terms of annuity with the reciprocal of the formula $A = \dfrac{(1+i)^n - 1}{i}$

where A equals amount of annuity
n equals the number of periods
i equals simple interest per period.

A formula recently developed by Professor Agg and Professor Breed in committee for the Highway Research Board, modified slightly to correspond with the practice of the Pennsylvania Department of Highways in computing depreciation and maintenance charges, is as follows:

$$A = i\left[\frac{B}{(1+i)^m - 1} + \frac{C}{(1+i)^n - 1} + \frac{D}{(1+i)^p - 1}\right] + E + \frac{F}{p}$$

where A is average annual charge
i is applicable annual interest rate
B is cost of grading and structures
m is period of charging off cost of grading and structures in years
C is cost of durable type surface or salvage value in surface
n is estimated life of durable type surface or term preceding resurfacing in years
D is cost of resurfacing (as appropriate)
p is period of resurfacing in years
E is annual general maintenance cost
F is the total amount of periodic maintenance costs, preceding resurfacing or between resurfacings.

For the comparison of costs of different types of pavement it is generally considered proper to add to the amount of the annual charges indicated above, the equivalent of interest on the initial investment at the rate applicable to the agency responsible for financing.

The method that has been used for a number of years in the Pennsylvania Department of Highways is based on the formula for the "annuity which one will buy."

$$\frac{i}{(1+i)^n - 1} + i$$

which combines annual interest with the reciprocal of the formula for amount of annuity, the equivalents of this extended formula being directly available in tabular form in handbooks of accounting and finance.

The Pennsylvania formula with an example for illustration follows:

$A = Bb + Cc + Dd + M + N$

where

	Example, One Mile of Surface Treated Macadam
A is average annual total charge	
B is grading and drainage cost. .	\$10,000.00
b is $\frac{i}{(1+i)^n - 1} + i$ for the period of years in which the grading and drainage cost is to be charged off.	.07522 (4¼%, 20 years)
C is cost of durable type surface or salvage value anticipated in temporary or semi-durable type surface	\$6,000.00
c is $\frac{i}{(1+i)^n - 1} + i$ for the years of economic life of surface	.07522 (4¼%, 20 years)
D is resurfacing cost.	\$10,000.00
d is $\frac{i}{(1+i)^n - 1} + i$ for the years period preceding resurfacing	.12483 (4¼%, 10 years)
M is average annual cost of general maintenance	\$500.00
N is average annual cost of periodic maintenance (3 retreatments at \$800 in ten years) . .	\$240.00

$$
\begin{aligned}
\$10{,}000 \times .07522 &= \$752.20 \\
6{,}000 \times .07522 &= 451.32 \\
10{,}000 \times .12483 &= 1248.30 \\
&\ 500.00 \\
&\ 240.00 \\
\hline
&\ \$3{,}191.82
\end{aligned}
$$

\$3,191.82 — Total of average annual charge A

THE FUNDAMENTAL MEASURE OF TRAFFIC IS IN A SINGLE LANE

The most conservative method of computing maximum traffic is based upon a safe driving interval computed from braking distances. Braking distances vary with the square of the rate of speed and are affected by gradient. Basic figures for four-wheel brakes are a six-foot braking distance for zero per cent.

Assuming the average of motor vehicles as the braking distance plus seventeen feet and multiplying the factor 5280 over interval by speed rate per hour in feet the theoretical maximum capacity of one traffic lane is found to be 2,264 vehicles per hour at fifteen miles per hour on zero per cent gradient, 2,006 vehicles per hour at fifteen miles per hour on -2 per cent gradient, 1,821 vehicles per hour at ten-mile speed on -4 per cent, 1,703 at ten miles per hour for -6 per cent, and 1,600 vehicles per hour at 10 miles on -8 per cent.

Practically speaking, the maximum carrying capacity of a single traffic lane is difficult to check, there being very few existing examples. There is a record, however, of 1,900 vehicles moving in a single line, in one hour, in the Holland Tunnel. This appears to verify theoretical calculations sufficiently to establish them for application in congested areas where there is segregated traffic under almost ideal control.

More generally, interest in traffic capacity relates to two or more lanes with the complication of opposite direction of travel and of overtaking and passing.

An early analysis of the passing problem appearing in the proceedings of the seventh meeting of the Highway Research Board indicated 1,320 vehicles per hour as a maximum capacity of the two-lane road with freedom for vehicles to overtake and pass others moving at a lower speed.

Later activity of the Highway Research Board furnished more extensive data. It was decided that traffic capacity is overtaxed when congestion occurs, and that congestion occurs when the number of vehicles reaches a total great enough to fill the road and make turning out impracticable. One minute is the mimimum amount of time considered. Using the criterion above, observations show that the two-lane road is frequently free from congestion with up to 1,000 per hour and the three-lane road is practically free from congestion with up to 1,600 vehicles per hour. No reliable indication of overtaxed capacity of a four-lane road under rural conditions has been secured.

Observations on two- and three-lane roads were as follows:

ANALYSIS OF TRAFFIC

Based on all traffic counts for 5-minute intervals on 2-lane roads

No. of vehicles per 5 minutes	Rate per hour	Percentage of time congested under all conditions	Percentage of time congested Maximum percentage of traffic one way			
			50-60%	60-70%	70-80%	80-100%
50-70	600-840	0	0	0	0	0
70-90	840-1080	8	6	13	13	0
90-110	1080-1320	33	42	43	53	0
110-130	1320-1560	73	78	100	67	80

Based on all traffic counts for 5-minute intervals on 3-lane roads

No. of vehicles per 5 minutes	Rate per hour	Percentage of time congested under all conditions	Percentage of time congested Maximum percentage of traffic one way			
			50-60%	60-70%	70-80%	80-100%
70-100	840-1200	0	0	0	0	0
100-130	1200-1560	10	20	4	0	0
130-160	1560-1920	21	33	18	40	0
160-190	1920-2280	53	71	90	100	0
190-220	2280-2640	80	100	100	100	40

Considering that some degree of congestion is to be tolerated at peak hours, approximate annual daily average traffic being four times the volume of maximum hour flow, the working traffic capacity of roads under rural conditions appears to be as follows:

Width	Maximum Hour Capacity	Annual Daily Average Capacity
2-lane	1100 to 1320	4400 to 5280
3-lane	2200 to 2300	8000 to 9200
4-lane	4000 to 4400	16000 to 17600

Of the Pennsylvania state highways at the present time there are approximately 81 miles of 3-lane width and 40 miles of 4-lane width, principally within the areas of urban influence of Philadelphia and Pittsburgh, fairly consistent with the above capacity estimates.

A type of three-lane traffic road has been developed in recent years in Pennsylvania which has proved almost ideal for traffic control and promises to vindicate the three-lane road from the charge of involuntary manslaughter. A considerable mileage of Pennsylvania's three-lane highways is composed of two new 10-foot concrete lanes with a 10-foot lane of salvaged macadam in the center. The macadam lane has a crown of from two to two and one-half inches and the concrete supports the edges of the macadam so as to keep the maintenance charges relatively low. The contrast of macadam and concrete serves to segregate traffic to the outer lanes most effectively. Color, crown, and surface smoothness all appear to be contributing factors. These sections are readily seen to be almost free of the overlapping of traffic from one lane to the other by which free use of the center lane for passing only is so often obstructed. I recommend your consideration of this type of design.

PENNSYLVANIA'S PROGRAM

I can not conclude without giving you some idea of what Pennsylvania is doing to meet its present traffic demands. The state highway system consisted of 13,560 miles on May 15, 1931, of which 10,448 miles were improved, leaving an unimproved mileage of 3,114 miles. During Governor Pinchot's campaign in 1930, he pledged his best efforts to place approximately 20,000 miles of additional rural highways on the state system as a tax relief to the local communities. As soon as he took office he caused legislation to be introduced which proved to be quite popular, and, by practically unanimous vote, the legislature added approximately 20,285 miles of rural roads and 307 miles of city streets to the state highway system, to be effective August 15, 1931. As a result, our state highway system now comprises 34,252 miles.

There was an immediate demand for the improvement of the rural roads in accordance with the slogan to take the farmer out of the mud. In order to meet these demands with the funds available, old standards were laid aside and the whole organization had to be trained anew for the task before it. Our engineers were called into conference and drew up tentative standards, specifications, and estimates for types applicable to the rural highway improvement program. After laying out a tentative program, the men in the field started a thorough investigation of the individual projects and the most economical supplies of road building materials. Representatives of the testing laboratory then went to the field and made a check on the material situation, submitting reports and recommendations as to satisfactory economic types. Because of the lateness of the season the work was undertaken with the forces of the department, which permitted the state to launch upon a considerable unemployment relief program.

The minimum width of grading section adopted was 20 feet and the minimum width of improved surface was 10 feet, although there were very few sections less than 14 feet in width.

In general, the cost of these rural roads averaged $6,000 per mile. The types vary greatly according to the materials available. Pennsylvania's problem would be very much simpler were it blessed with an abundance of local gravel throughout the state as Indiana is. Where gravel was available, it was used as a base course; slag, red-dog, flint, napped field stone, crushed stone, etc., were also used. As far as practicable a base course of from six to eight inches of napped field stone was used since it proved to be economical and afforded by far the greatest amount of unemployment relief. The surface courses consisted of plain surface treatment for a single course highway of crushed stone or slag, heavy surface treatment with stone chips forming about a one-inch mat over the base course, or a semi-penetration about two inches in depth consisting of a commercial three-quarter inch stone penetrated with approximately one gallon of bituminous material applied in two or three applications. This latter type is similar to the mixed-in-place retread without the manipulation. Naturally, we in Pennsylvania are working along the lines of some former experience and do not represent that our types are superior to those used elsewhere. In fact, we are now studying the low cost surfaces used by contiguous states and expect to obtain valuable information which will result in improvement of our types as well as further economies.

Notwithstanding a late start Pennsylvania was able to complete 3,120 miles of highway improvement during 1931, of which 823 miles were low cost construction on the old system, 1,765 miles were low cost construction on the new rural system, and the remainder, 532 miles, consisted of Federal-Aid, replacement, and new construction of higher type. In addition to this accomplishment according to figures disseminated by the federal government, Pennsylvania led all the states in highway employment for four months with a daily average of 24,500 men employed. The peak of such employment during 1931 was reached during the week ending December 26, when 28,383 men were employed. The mildness of the winter has permitted us to continue this work and last week (January 20, 1932) the number of men employed on our highway work was increased to 30,360.

PREPARATION OF ROAD PLANS

By G. P. Springer, Assistant Professor of Civil Engineering
Purdue University

The outstanding characteristics of a bad road are abrupt curves, steep grades, and uneven surface. The first two are permanent, because of bad location, but might have been eliminated by the proper application of engineering principles. A good set of plans can be prepared only when the field surveys, designing, estimating, and field inspection have been good. The slighting of any one of these preparatory operations in the name of economy will be reflected in error, higher costs, and greater expense for maintenance.

There are six steps necessary in collection of the data and compiling the plans:

(a) careful field surveys, (b) mapping the surveys, (c) designing the roadway, (d) estimating the quantities, (e) careful field inspection of the design, and (f) final completion of the plans.

Care and skill are necessary that the center line as located will be the best possible, with respect to appearance as well as usefulness, so that what is done will be permanent and a part of any future improvement. The selected alignment is not only the basis of an improvement built with taxpayers' money to serve traffic, but it will stand subject to condemnation or commendation as a monument to the incompetence or the skill of the locating engineer. The center line selected may in the future serve as the center of a pavement widened to two or three times the original width.

The field survey follows in general a route tentatively established. It may be along an existing road or over an entirely new route, but the route should have been examined with certain definite ideas in mind by the locating engineer or the chief of party acting under instructions.

Transit notes will show: distances between deflection points, the deflection angles, bearings on tangent lines, P.C., P.I., and P.T. stations, horizontal curve data, and reference ties for the P.I. and P.O.T. points.