# Motor Vehicle Operating and Accident Costs And Benefits Arising from Their Reduction Through Road Improvement 

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- HIGHWAY benefit studies are concerned with those vehicle operating costs which are susceptible to change through highway improvement. The costs of fuel, oil, tires, maintenance, and depreciation are of this nature while other items of operating costs, insurance charges, registration levies, and garage fees, are generally unaffected by highway conditions. Driver costs, a vehicle operating cost of particular importance in commercial operations, is affected by those highway improvements which change travel time, but the benefit to vehicle operators associated with the time factor is of such importance that it is generally treated in benefit studies as a separate element of benefit. The benefits of time-saving will not be discussed in this paper.

The aggregate cost of highway accidents is determined by three factors: the number of accidents, the average accident severity, and the unit monetary value of the losses whether by death, injury, or property damage. Only the first two factors can be reduced through highway improvement since the unit values of the losses due to accidents are independent of highway conditions. Benefit studies include consideration only of cost reductions through reduction in the number and severity of highway accidents.

This paper will deal primarily with the determination of the motor vehicle operating and accident cost values that are pertinent to an analysis of highway benefits and will deal largely with the reductions in these costs which can be achieved through highway improvement. Except in connection with benefits brought about through change in route length, no attention will be given to the problem of predicting what the absolute or total operating and accident costs will be for operation on a given highway. Accurate predictions of this type are almost impossible since the absolute cost is the result of the interplay of many factors: speed, traffic conditions, grades, etc.

The benefit to users of highway improvement equals the cost of operation on the road if it is not improved less the cost if it is improved and can be expressed by the formula $A=T L\left(C_{o}-C_{n}\right)+T C_{o}$ a where $A$ is annual benefit for a given vehicle type, $T$ is annual number of such vehicles expected to use road, $C_{o}$ is unit cost per mile for these vehicles if the highway is not improved, $\mathrm{C}_{\mathrm{n}}$ is unit cost per vehicle mile if it is improved, $L$ is the original length of route, and a is the change in route length brought about by improvement (shortening, if positive). The first term of this formula is the product found by multiplying the vehicle miles of travel for the new length of road after improvement by the reduction in cost or the benefit per vehicle mile. The second term, the benefit due to shortening of route, is the product of vehicle miles of travel eliminated through route shortening multiplied by the average unit operating cost for the route before improvement.

Thus the determination of annual benefits requires that four values be known for each type and weight of vehicle: (a) an accurate prediction of the vehicle miles of travel for the route after improvement (TL); (b) the reduction in cost in cents per vehicle mile which will be brought about through each kind of road improvement ( $\mathrm{C}_{0}-\mathrm{C}_{n}$ ); (c) an estimate of the absolute operating costs for the route as it exists before improvement $\left(C_{0}\right)$; and ( $d$ ) the vehicle miles of travel saved through route shortening. The remainder of this report will describe methods of determining the second of these items ( $\mathrm{C}_{\mathrm{o}}-\mathrm{C}_{\mathrm{n}}$ ) for motor vehicle operating and accident costs.

The motor vehicle operating cost affected the most by highway improvements is the cost of fuel which is determined by the magnitude of fuel use and unit cost of fuel. Since the unit cost of fuel cannot be changed by highway improvement, it will not be considered further. A decrease in the number and frequency of accelerations, number and steepness of grades, degree of road roughness and amount of curvature decreases fuel consumption at any given running speed. Reducing the amount of time vehicles are stopped with engine idling also saves fuel. On the other hand, highway improvements which result in higher operating speeds such as lane widening, an increase in the number of lanes, resurfacing, and sight distance improvement, usually bring about increased fuel consumption.

A reduction in the number of stops that must be made for traffic lights, stop signs, and access points saves both the amount of fuel consumed while idling at stop and the extra fuel needed during accelerations after stops. Similarly, a reduction of the number of access points, curves and caution situations which require vehicles to slow down will save on fuel use by decreasing the number of accelerations necessary.

The unit fuel use benefit or disbenefit ( $\mathrm{C}_{\mathrm{o}}-\mathrm{C}_{\mathrm{n}}$ ) which can be realized through the above improvements can be found if, in addition to knowing the unit cost of fuel, the magnitude of fuel use for all vehicle types and weights is known as follows:

1. The fuel use per mile at constant speed at various running speeds on level, paved, straight road.
2. The additional fuel consumption per event to come to a stop and accelerate back to speed for various running speeds.
3. The additional fuel consumption per event to reduce speed by given amounts and accelerate back to speed for various running speeds.
4. The additional fuel consumption per mile to operate on a straight, level, gravel road rather than on a paved surface.
5. The fuel consumption per minute while stopped with engine idling.
6. The additional fuel consumption per mile to operate upgrade rather than on a level road at various running speeds.
7. The additional fuel consumption per curve to operate on curves of various degrees of sharpness at various running speeds.
8. The fuel consumption per mile to operate on paved level road of 2, 4, and 6 lanes at various ranges of traffic volume while floating with traffic.

Current studies being conducted by the University of Washington and the Bureau of Public Roads seek to determine values for each of these items. When the data for these studies have been analyzed, it should be practicable to predict accurately the net fuel saving to be achieved through highway improvements.

In addition to the above studies of fuel consumption as affected by separate items of highway change, the over-all difference in fuel consumption of passenger cars operating on high type highways (toll roads) and on alternate routes of older and hence inferior location and design (parallel free routes) was investigated at 14 different locations in 9 states. The difference in fuel consumption measured on the comparison routes reflects the net result of change in length, grade and curve reduction, elimination of both access points and intersections at grade, increase in number of lanes and lane width and surface improvement. The results of this study will be useful as a means of guarding against large errors in fuel consumption benefit determinations as found through item by item computations.

Other motor vehicle operating costs which may be reduced through highway improvement are those for oil, tires, maintenance, and depreciation. Highway improvement can reduce the rate of oil consumption through shortening of distance and improvement of road surface conditions. However, the large number of variables affecting oil consumption make it very difficult to assign oil use benefits to any highway improvement with the possible exception of distance reduction. Most vehicle users change oil after their vehicle has traveled some particular distance usually according to recommendations of the manufacturer. For example, the Federal Government has issued instructions that the engine oil of its passenger cars be changed each 4,000 miles. Many users must add oil between changes, usually because of some non-highway condition that increases
oil use. The most satisfactory way of including oil consumption in benefit studies is to compute the cost of oil per mile, based on the average number of miles of travel between oil changes and on the average cost of an oil change, and assign it as a benefit due to shortening of distance.

Tire wear is determined largely by tire use or travel distance, surface conditions, and operating speeds. Highway improvements that result in route shortening and/or improved surface conditions will save on tire cost while improvements that provide for higher operating speeds will increase tire cost. The amount of wear per mile is affected by several highway factors that can be changed through highway improvements in addition to surface condition and speed potential. These are number and steepness of grades, amount of curvature, and number of stop and go and slowdown operations required. The saving in tire wear per vehicle mile which can be achieved through any one of these highway improvements is so small that no practical method is available for measuring it accurately.

The literature contains considerable information on tire wear as affected by distance, surface condition, and speed. This information is useful in benefit studies although much of it is based on data collected a number of years ago and probably not accurate for the tire, road, and vehicle conditions as they exist today.

Maintenance costs include costs of parts such as air and oil filters, mufflers, lamps, fan belts, spark plugs, shock absorbers, springs, distributor and carburetor parts, parts for the electrical and cooling systems, pistons, valves, and the labor cost for lubrication, brake adjustment, tuneup, engine overhaul, transmission overhaul, replacement of worn parts and washing.

All of these costs will be reduced through highway improvements which reduce route length. In addition, the cost of some items such as for parts and labor for replacement of filters, brake parts, shock absorbers and springs and the labor cost for adjusting brakes, lubrication and washing will be reduced through improvement of road surface and improvements which reduce number of stop and go and slowdown operations.

Limited information is available in the literature on the cost of maintenance as a function of travel distance and on the difference in maintenance costs for operation on dusty, rough roads as compared to operation on paved surfaces. The magnitude of these costs warrants further study.

Depreciation cost, as a motor vehicle operating expense, is the reduction in value of a properly maintained vehicle that occurs during the period of ownership by a highway user; it is equal to the difference between the purchase price and the price received at the time it is later sold. The magnitude of depreciation is determined by the change in ownership that takes place at the time of purchase, length of time between purchase and re-sale, appearance and running condition of vehicle at time of re-sale, and the number of miles use accumulated between time of purchase and time of re-sale. For the private passenger vehicle the change in value is almost entirely caused by ownership change, duration of ownership, and appearance and running condition at time of re-sale. In the case of trucks the value reduction is primarily due to duration of ownership, appearance and running condition, and mileage accumulation.

The depreciation cost of a properly maintained passenger car can be reduced through road surface improvements, but the amount of such benefit is small and practically impossible to evaluate. The benefits passenger car users achieve through reduction of depreciation cost through highway improvement can be neglected.

In the case of trucks and buses, however, mileage accumulation is much more important in the mind of the purchaser and highway improvements which reduce route length as well as those which result in an improved road surface will be reflected in lower depreciation cost for a given amount of use. A convenient and logical means of computing the benefits due reduction of depreciation costs for trucks is to compute the depreciation cost per mile as equal to the average difference between the purchase and re-sale prices of properly maintained trucks divided by the number of miles use accumulated between purchase and re-sale and assign this as a benefit achieved through route shortening.

Motor vehicle accident costs depend on the number of accidents or the incidence of accidents, the average severity of accidents, and the unit costs incurred through
accidents such as those for vehicle repairs, hospitalization, and insurance premiums. Only the first two of these can be changed through highway improvement. The relation between the incidence of accidents and separate highway items, such as intersections at grade, curves, and number of lanes, has been investigated by a number of researchers. It is possible with the information available in the literature to estimate the total number of accidents which will be avoided through highway improvements for several types of improvement.

Accident severity or the number of accidents of various kinds (head-on collisions, rear-end collisions, etc.) as related to highway factors is at present under investigation by the Bureau of Public Roads. The Bureau study seeks to determine accident costs in general as well as accident severity. It is expected that this study will provide the information needed to evaluate the benefits resulting from highway improvements that reduce accident severity. Further investigation along these lines is needed.

The evaluation of motor vehicle operating and accident cost benefits arising from highway improvements is dependent on the availability of accurate information on motor vehicle costs and relation of these costs to highway improvement. The Bureau of Public Roads is collecting such data through the several studies mentioned in this paper. In addition, the Bureau is making a search of the literature of motor vehicle costs in order to have easily available all published information on the oil consumption, tire wear, and maintenance requirements of motor vehicles. More information than is being sought at present, however, is needed particularly in connection with vehicular maintenance requirements and accident severity.

## Discussion

Burch. -It is apparent that Professor Claffey's work is bringing together and refining several types of data which we have been seeking for many years. We have all been working in this field, getting ever closer to exact values, but it seems that he has gone further into these refinements and revaluations than anyone who has come to my attention.

It would appear that the procedure described by Professor Lang on the use of digital computers in bringing together some of these interdependent variables would complement the study that Claffey is making to the mutual benefit of both studies.

One point that struck me, and I am not attempting to discuss the paper, is a factor which we all stumble over, and that is the forecasting of accident occurrence. It has very little regularity. In fact, as one person has put it, "accidents are very accidental." At least, on a given stretch of road, it is almost impossible to predict whether you will have one or a dozen accidents within a given year. The accident history on a segment of highway is never uniform or regular.
Hoch. -I have some empirical data from accident studies published by the Chicago $\overline{\text { Area }}$ Transportation Study ${ }^{1}$ which may be of some interest to the group.

One interesting feature is that although accidents and accident rates may not be predictable for a given stretch, they seem to be fairly regular for a system as a whole.

We collected accident information on a total of 10 arterials in the city and compared rates in terms of accidents per million vehicle miles to rates on the Congress Street Expressway. We found that the average rate per million vehicle-miles was 14.3 for the sample of arterial streets, whereas on the Expressway, the rate was 2.8; a difference of approximately five or six times as much on the arterial streets.

We weighed the various accidents involved by estimated accident costs, that is the direct costs as based on the study in Massachusetts. We used $\$ 5,800$ for a fatality, $\$ 960$ for an injury accident and $\$ 225$ for a property damage accident. On this basis we found the cost rate per million vehicle miles in 1958 for the arterial streets to be

[^0]\$6, 202, and for the Congress Expressway only \$1, 282.
Capitalizing this at an assumed life of 25 years and an interest rate of 5 percent yielded a saving per mile (assuming 100, 000 vehicles used a mile of Expressway a year), the computed capitalized value was in the order of $\$ 2$ million. So this is a rough estimate of the benefits derived from accident reduction on Expressways.
Burch. -Of course we all do recognize, the great safety advantages of the Expressway and I did not mean to deprecate it. We do have very good data showing that the control of access and the removal of crossings and traffic turbulence very definitely reduce accident rates and severity.
Van Riper. -I think possibly some figures from this report by the City of Los Angeles, "A Study of Freeway System Benefits," (prepared by Lloyd Aldrich, former City Engineer, Sept. 1954) might be of interest at this time. The data show the minimum benefits to motorists using freeways in lieu of the usual surface streets, with gasoline savings to be about a third of a cent per vehicle mile. Another item due to stop and go travel, and stop signals and stop streets, represents a saving of about a quarter of a cent per vehicle-mile, the exact figure being 0.24 cents. The accident savings per vehicle mile in the use of freeways as compared to travel on surface streets, according to this report, was $56 / 100$ ths of a cent.

So, if we add those three items, we get 1.13 cents per vehicle-mile savings in travel on the freeway as opposed to travel on the surface street, based on the figures developed in this report by the City of Los Angeles.

There is also the question of whether travel time savings should be included in benefits. There seems to be a difference of opinion. There seems to be complete agreement that allowance should be made for time savings in the operation of commercial vehicles; but whether or not there should be a time savings allowance on the operation of passenger cars seems to be questionable. Where time saving is included for the operation of passenger cars on freeways over operation on conventional type city streets, the value is given at 3.73 cents per vehicle mile. That time savings could have quite an influence on the size of the benefits that are computed for any given freeway.
Burch. -I am sure that we have all noted the fact that traffic does not always choose to operate in the most efficient manner, dollar-wise.

We remember Trueblood's diversion curve in which it was found that time saving was the major determining factor in choice of routes, and yet as we know and as Claffey has mentioned here, fuel saving related to distance in terms of dollars is the overriding economic factor. So that the composite driver or the average driver does not seem to be as much concerned with this fuel saving efficiency as he is in the saving of time, even though he may have to go a longer distance at higher operating cost.
Cherniack. - In New York we have made a rough study on the basis of these evaluations, and they indicate that, at the present time, the motorist apparently values time at somewhere between three and five cents. So apparently the motorist does use calculus by intuition. Apparently his logic checks the figures that Van Riper just brought out.
Saal. -I want to make only one comment, that is that Claffey here talked a lot about Public Roads. The inference was that we in the Bureau were doing everything. I want to say that in all this work we are doing, the states are cooperating in a large part of it through the accident studies. We are cooperating in it with the universities and with the state highway departments.

Burch. -Thank you. Of course, that is a chronic situation. People with the states know that when such work is done, the states do much of it.

Newcomb: - I had one question about the assignment formula. Take a simple case such as a new bridge across the Potomac in Washington, D. C. When Ifirst came here there were two inadequate bridges and consequently the suburban residential or bedroom area was Chevy Chase. Then the bridge was built across the Potomac, which resulted in rapid residential expansion. The new traffic to Arlington went less than one-third as far as
the old traffic. This was a tremendous saving as a result of this new bridge at Georgetown. But I don't see any element in this formula where this saving would be revealed.
Claffey. - That formula only compares one route with another. We have all of the information available.
Newcomb. -In other words, if the new facility does save a great deal, in distance-by opening up a new area, the formula wouldn't reveal it?
Claffey. -That formula would not.
Pendleton. -Dr. Claffey, in your comparison of toll roads with alternate routes, what data, in addition to the fuel and other operating expenses did you collect, such as time or inconvenience of driving, that might be later used in making this comparison?
Claffey. -We recorded the fuel consumption, the distance and the total time. We had an electronic device that automatically gave us the speed at every second, and this is stamped out on a tape. The tapes have not been analyzed yet.

But we do have, in addition to fuel data on time and distance, the speed at each second. Also, we made a manual note as to the way everything affected our vehicle as we moved along, stopped at a stop light, trailed a vehicle on a two-lane road unable to pass, access points, etc.
St. Clair. -That would include passing maneuvers on two-lane roads?
Claffey. -That is right.
Grant. -I would like to call attention to the fact that Claffey takes a different viewpoint from the AASHO report with regard to treatment of depreciation on passenger vehicles, and to record the fact that I am in agreement with Professor Claffey on this.
Burch. -Mr. Hoch made a comment with respect to a certain report, and he tells me he has some information about the availability of that report.
Hoch. -There will be a report on the information referred to previously with a much fuller description. This should be out about November 1959, and it is Report No. 36520, "Accident Experience, Arterials Versus Expressways." It can be obtained by writing the Library, Chicago Area Transportation Study, 4812 W. Madison St., Chicago
St. Clair. -I have some observations referring particularly to Professor Grant's treatment (Session 3) of the items of cost, particularly of the interest rate and the depreciation term.

It would seem in a sense that if we have for example, the geometric dimensions of certain kinds of highways as determined by design engineers based on highway capacity research as being the designs most useful to accommodate traffic of a given magnitude; and we have found by the testimony of toll roads that the motorist and the truck operator are willing to pay the price of having such roads, then we have, in a sense, an economic analysis on the basis of supply and demand.

I think probably the reply to that would be that if you subjected such a road to an economic analysis by the rate-of-return or benefit-cost method you would get a very favorable answer, and that the ones that would not meet those specifications would get an unfavorable answer. I am willing to accept that, with qualification about as follows:

We have detached the depreciation rate, or rate of amortization, from any connection with the expected life of the investment and materially shortened it to a perhaps rather indefinite number of years.

Now, if one analyzer were the owner of an oil well, another the owner of a steel mill and a third a railroad president, it seems likely that the oil man would have a shorter depletion allowance than the owner of the steel mill, and the latter would probably have a shorter one than the railroad president. In other words, I think we have something that is rather unstable.

On the interest rates, although Professor Grant seemed to settle on 7 percent as being something to work with, nevertheless we heard figures of around 10 to 18
percent after taxes, or something around double these rates before taxes. That, it seems to me, introduces another unstable element.

I feel that this widening of the brackets on both of these items introduces a consider able element of instability or uncertainity, into the economic analysis. Perhaps it is a good idea for us to be uncertain for a while and to hope that we can settle down.


[^0]:    ${ }^{1}$ Hoch, Irving, "Accident Experience: Expressways vs Arterials," Chicago Area Transportation Study.

