Highway Cost Allocation Methodology for Pavement Rehabilitation and Capacity-Related Costs Occasioned by an Increment in Heavy Truck Traffic

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ABSTRACT

A methodology is outlined for estimating incremental pavement rehabilitation and capacity-related costs that would be occasioned by loading an increment of bulk commodity traffic on a highway link. The cost estimates are referred to as "build-sooner costs" because they represent the financial impact of the increment of traffic on the future timing of pavement rehabilitation and capacity improvement projects. The analysis encompasses eight bulk commodity truck movement scenarios in the Province of New Brunswick, Canada. The build-sooner costs are compared with incremental user fee revenues that would be generated by these movements if they were to be captured by the truck mode.

The methodology described in this paper was developed as part of a much larger research project on incremental costs and revenues occasioned by the trucking of bulk commodities on selected highway links in the Province of New Brunswick, Canada (1). That study examined five broad categories of incremental cost and three categories of incremental revenues, with the objective of the basis of highway trucking firms enjoy an inherent advantage in competing for the movement of bulk commodities in the province. Such an advantage would exist if the incremental public costs of these truck movements were not fully recovered through highway user fees.

The focus of this paper is on describing the methodology developed to estimate one of the five categories of incremental cost. The cost component in question shall hereafter be referred to as "build-sooner costs."

Build-sooner costs related to the hypothesis that loading a large increment of heavy traffic on a link will cause two conditions to evolve. First, pavement life cycles are likely to become shorter, and, second, future capacity improvements will be needed sooner. Because both kinds of improvements require substantial expenditures, the cost of investing the capital "x" years sooner because of the increment of heavy traffic can legitimately be assigned to that traffic.

Before outlining the methodology used to estimate these costs, a review of other highway cost allocation studies from the perspective of their treatment of pavement and capacity costs is instructive.

LITERATURE REVIEW

Growing interest in highway finance has given rise in recent years to a significant research effort to resolve the question of the cost responsibility of various classes of highway users.

In Canada the recent work of Bunting (2) examined highway expenditures and revenues at three different levels—all of Canada, the Province of Ontario, and Highway 401. At the national and provincial levels, expenditures were allocated on the basis of highway usage patterns, with 40 percent of construction and maintenance costs and 30 percent of other costs assigned to heavy trucks (2,p.23).

In the Highway 401 analysis, 45 percent of pavement-related costs was assigned to trucks. This estimation of pavement costs was based on the assumption that 40 percent of highway construction expenditures were pavement-related (2,p.29). The remaining 55 percent of construction costs was allocated according to the trucks' share of capacity use, estimated at 50 percent.

Many of the cost estimation and cost allocation formulas used in Bunting's work were drawn from the most recent U.S. Highway Cost Allocation Study completed in 1982 (3). This study was concerned with the allocation of U.S. federal program expenditures to users of federal-aid roads. This research attempted to correct often-cited deficiencies of two previous U.S. investigations of highway costs, the Section 210 study on highway cost allocation, conducted between 1956 and 1965, and the AASHO Road Test, conducted between 1958 and 1960.

The major criticism of the Section 210 study is that it focused on capital expenditures for new pavement. Although this may have been appropriate for that period when the Interstate system was being constructed, it had become anachronistic with the current emphasis on rehabilitation of the system.

The AASHO Road Test, conducted in Illinois, attempted to measure the relationship between pavement deterioration and repetition of axle loadings. Although the results of this test have been widely used as a basis for pavement design, it has been strongly criticized as a method for assigning cost responsibility to classes of vehicles. One of the major criticisms is that it does not account for the effect of environmental conditions on pavement deterioration.

The 1982 highway cost allocation study uses a so-called "modified incremental cost allocation approach." First, a distinction is made between new pavement and pavement rehabilitation. In the case of the former, costs are allocated as follows (3,p.IV-43).

New pavement costs are assigned based on current pavement design practice. Ve-
Vehicles from each class are hypothetically removed in equal proportions until further removal would not reduce pavement thickness requirements.

A major research effort was launched to develop relationships to assign pavement deterioration cost responsibilities. Pavement distress models were developed for both flexible and rigid pavements to measure distresses such as loss of serviceability, alligator cracking, rutting, transverse cracking, loss of skid resistance, faulting, pumping, joint deterioration, depression, and swell (3, Appendix D-24). Some of the distresses were found to be a function of traffic, some a function of traffic and other variables, and some independent of traffic. Costs are assigned on the basis of the relative importance of each type of distress in the decision to rehabilitate a pavement.

Capacity-related costs such as steepness of grades and roadway width again are assigned on an incremental basis by hypothetically removing successive classes of vehicles (e.g., vehicles in various weight-to-power ratios in the case of grade costs). Within-group costs (i.e., different vehicle types within a specific group) and residual costs (i.e., costs that cannot be attributed to a particular class of vehicle) were arbitrarily allocated on the basis of vehicle-miles traveled.

One of the criticisms of the most recent U.S. highway cost allocation approach is that it is based on expenditures, not costs. Any expenditures that are incurred in a particular year are allocated to the traffic of that year, even though the benefits arising from the investments are realized over a long period. Such an approach neglects the indivisibilities that are necessarily involved in the provision of highway infrastructure and the resultant excess of capacity.

The major consequence of the existence of this excess capacity is a residual of cost in the cost allocation process, a residual that can only be allocated among components of traffic by some arbitrary means. This is really an issue of cost allocation versus cost assignment. The difference between the two is well presented by Wohl and Hendrickson (4,p.223). They suggest that cost attribution involves "the identification of valid cause-and-effect relationships between highway infrastructure and resultant excess of capacity."

The focus of this research is on cost assignment rather than on cost allocation. The difference between the two is explained by the existence of a residual of costs that can only be allocated according to some accounting rules.

In the remainder of this paper, the methodology for assigning pavement rehabilitation and capacity-related costs to bulk commodity truck traffic will be described and the results of the analysis summarized.

**METHODOLOGY**

Eight bulk commodity movement scenarios were analyzed in this study; none of the commodities are unconditionally moved by truck. The objective was to estimate the incremental public costs that would result if these movements were to be captured by the truck mode. The commodity movements, projected annual tonnages, and length of haul associated with each movement are given in Table 1.

**Build-Sooner Period: Pavement Rehabilitation**

The objective of this analysis is to determine the cycle time for pavement resurfacing with the commodity traffic moving on the highway compared with the pavement life cycle that would occur under existing traffic mix conditions and normal growth. In other words, how much faster will the pavement condition deteriorate to the threshold that triggers a resurfacing requirement? This concept is illustrated graphically in Figure 1. It should be noted that Figure 1 shows only pavement life cycle after the addition of the new commodity traffic.

Subsequent pavement cycles are important not only because each cycle is set ahead by the build-sooner period (BSP) but also because it is reasonable to expect that successive pavement life cycles will get shorter. If the rate of pavement deterioration is due to the cumulative effect of truck traffic, the slope of the deterioration function will increase with each successive pavement life cycle until the slope reaches some theoretical maximum. This is shown in Figure 2.

After a review of the literature on pavement deterioration, it was decided that the Ontario flexible pavement design method would be used to develop a pavement deterioration function for the various highway links and commodity movements under study (5).

The mathematical relationship between the parameters included in the Ontario method are:

\[
RCIF_a = RCIf_i - [(Pt + Pe)]
\]

where

\[
RCIf_a = \text{final road comfort index},
\]

\[
RCIf_i = \text{initial road comfort index},
\]

\[
Pt = \text{loss of RCI due to traffic factors},
\]

\[
Pe = \text{loss of RCI due to environmental factors}.
\]

P is further defined as

\[
P = 2.4455X + 8.805X^2
\]

where

\[
X = 100 \text{ WN},
\]

\[
W = \text{Odemark subgrade deflection},
\]

\[
N = \text{number of ESALs per year},
\]

\[
\text{ESAL} = \text{equivalent single } 18,000\text{-lb axle loads}.
\]

Note that the Odemark subgrade deflection is derived from Dynaffect pavement deflection readings using the following relationship:

\[
D = 0.9W + 40W^2
\]

where D is mean spring deflection and W is Odemark subgrade deflection.

Pe is further defined as

\[
Pe = (RCI_a - (1 + BW))(1 - e^{-0.06Y})
\]

where Y is number of years of loading and B is 60.
A key feature of these relationships is the road comfort index (RCI). The RCI is essentially a rating scale from 0 to 10 that describes on a subjective basis the comfort or rideability of a pavement surface. As the pavement surface deteriorates, so does the rideability. The mathematical relationship described is in essence an algorithm for forecasting future RCI values, which can be expected to decline because of both traffic and environmental factors. Before the relationship can be used, the values for each of the parameters must be either measured or calculated.

The initial RCI values were made available by the New Brunswick Department of Transportation (NBDOT). The NBDOT periodically conducts rideability assessments of its highways. Each rating section (a rating section is a section of highway that features relatively homogeneous physical characteristics) is assigned an RCI value following a field investigation.

The Odemark subgrade deflection factor is calculated using Dynaflect pavement deflection readings. NBDOT periodically collects this data for each rating section with a Dynaflect that uses a nondestruc-
The capacity analysis is similar in many respects to the build-sooner analysis for pavement resurfacing. In this case the build-sooner period is determined by a traffic growth function (under normal conditions and with the commodity traffic added). The threshold that triggers a decision for a capacity improvement is the capacity of the highway section under study at a given level of service. The capacity analysis methodology is shown graphically in Figure 3.

The capacity analysis was completed using techniques contained in the Highway Capacity Manual (HCM) developed by the U.S. Highway Research Board (1). The HCM techniques are widely accepted by traffic engineers in performing capacity analysis on elements of a highway system.

The HCM methodology is based on the following relationship:

\[ C = CT \times \left( \frac{V}{C} \right) \times (W_L) \times (T_L) \]

where:

- \( C \) = practical capacity of a highway section at a given level of service;
- \( LOS \) = level of service A, B, C, D, or E as described in the HCM;
- \( CT \) = theoretical capacity;
- \( V/C \) = volume-to-capacity ratio;
- \( W_L \) = capacity adjustment factor for lane width and lateral obstructions; and
- \( T_L \) = capacity adjustment factor for trucks.

The objective of this analysis is to determine the relative timing of capacity improvements under normal traffic conditions with the commodity traffic added to the existing traffic. The critical threshold that triggers the need for an improvement is the capacity of the section of highway under study. This capacity threshold varies with the selected minimum level of service desired. After consultations with NBDOT planners it was decided that the boundary between level of service C and D as defined in the Highway Capacity Manual would be used as the threshold for capacity improvements. The rationale for this choice is that when NBDOT plans and designs a highway capacity improvement, the decision is made that the highway should have sufficient capacity to operate at level of service C or better through its design life, given certain traffic growth assumptions. Again it must be recognized that no attempt was made to examine the justification for or priority of each of the capacity projects. A simplifying
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Traffic-versus-time function for normal growth (shown as linear for simplicity of illustration); \( F_2 \) is the traffic-versus-time function following an increment of commodity traffic; \( I_1 \) is the level of traffic at which a capacity improvement is required; \( I_2 \) is the level of traffic at which a capacity improvement is required following an increment of commodity traffic; \( T_N \) is the present time; \( T_c \) is the time when the commodity traffic is added; \( T_{ee} \) is the time when a capacity improvement would be required under normal traffic conditions; \( T_{BN} \) is the time when a capacity improvement would be required when commodity traffic is added; and \( BSP \) is the build-sooner period (i.e., the difference between \( T_{BN} \) and \( T_{BC} \)).

The practical capacity of a roadway section was calculated at the selected level of service using the previously outlined relationship. This was done by reducing the theoretical maximum capacity under ideal conditions (2,000 vehicles per hour) through the application of adjustment factors. These factors attempt to quantify the impact of certain conditions that tend to reduce the capacity of a roadway section. The factors are taken from the Highway Capacity Manual.

The \( T_L \) factor (truck adjustment factor) was a critical component of the capacity analysis in this study. The truck adjustment factors in the HCM are assumed to be valid for trucks within a certain operating performance range (i.e., power-to-mass ratio). A number of parameters affect the truck adjustment factor. Length of grade, magnitude of grade, type of terrain (level, rolling, mountainous), and percentage of trucks in the traffic flow all affect the number of passenger car equivalents (PCE) of trucks on any given section of highway. The PCE is simply the equivalent number of passenger cars of one truck under the existing physical and traffic flow conditions.

Clearly, as the length and magnitude of a grade increase, the number of PCEs per truck will also increase. It is also important to note that as the PCEs or percentage of trucks, or both, increase, the truck adjustment factor decreases. In other words, the increment of truck traffic due to the commodity movement not only increases the traffic, it also reduces the capacity due to a lower \( T_L \) factor. This is shown in Figure 3 in which the capacity threshold for \( F_1 \) is lower than the threshold \( F_2 \).

With the capacity of each section of highway established at a selected level of service, it was possible to project the number of years required to reach capacity under both traffic scenarios (normal traffic growth and with commodity traffic added). The growth rate assumptions applied to obtain forecasts of future traffic volumes were provided by NBDOT planners. In accordance with instructions from the client, the commodity tonnage projections assume zero year-to-year growth and a uniform distribution of truck traffic throughout each day.

When the build-sooner period had been estimated, it was necessary to identify the type of capacity improvement required. The range of alternatives includes improvement of vertical and horizontal alignment, increased lane and shoulder width, provision of climbing lanes, and twinning of the highway. Again it must be recognized that, as in the case of the build-sooner analysis for pavement resurfacing, no attempt was made to examine the justification for each capacity project. The methodology is based on an assumption that each of the capacity projects identified will be implemented when the critical capacity threshold has been reached. It is conceivable that some of the projects identified would either not be undertaken or would perhaps be delayed at the expense of level of service.

To summarize, the build-sooner period for capacity improvements was determined using capacity analysis techniques documented in the Highway Capacity Manual. The effect of an increase in the presence of trucks due to the addition of an increment of commodity traffic is a lowering of the capacity of the highway at a given level of service. This in turn gives rise to the need for capacity improvements sooner than would be the case under normal traffic conditions. When the cost of these improvements is known, a build-sooner cost can be calculated. The methodology for estimating build-sooner cost is outlined in the next section.

### Build-Sooner Cost

The purpose of the build-sooner cost analysis is to determine the financial impact of having to invest in highway resurfacing and highway capacity improvements sooner than would be the case if the commodity traffic were not transported by truck on public highways. In other words, what is the cost of tying up the capital required for the improvement over the build-sooner period? Figure 4 shows a hypothetical example.

The example assumes that a hypothetical improvement costing $1.0 million (1983 dollars) will be required in 1993 under normal traffic conditions. The same $1.0 million improvements will be required in 1990 if the commodity traffic is added. The commodity traffic thus causes a build-sooner period of 3 years.

Because costs are in constant dollars, a real discount rate (in this case 4 percent) is used to determine the present value of each investment. Clearly for Case 2 the present value is higher because the investment is of the same magnitude but occurs 3 years sooner. The build-sooner cost in this example is $84,353 representing the difference between the present values of the two investments. This example calculated the build-sooner cost for only one improvement cycle (e.g., one pavement life.

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FIGURE 3 Build-sooner period: capacity improvements. \( F_1 \) is the traffic-versus-time function for normal growth (shown as linear for simplicity of illustration); \( F_2 \) is the traffic-versus-time function following an increment of commodity traffic; \( I_1 \) is the level of traffic at which a capacity improvement is required; \( I_2 \) is the level of traffic at which a capacity improvement is required following an increment of commodity traffic; \( T_N \) is the present time; \( T_c \) is the time when the commodity traffic is added; \( T_{ee} \) is the time when a capacity improvement would be required under normal traffic conditions; \( T_{BN} \) is the time when a capacity improvement would be required when commodity traffic is added; and \( BSP \) is the build-sooner period (i.e., the difference between \( T_{BN} \) and \( T_{BC} \)).
CASE 1: Normal Traffic Conditions

1983 1993

$1.0 million ($1983)

Present Value: $1,000,000 ($1983); 10 years; 4%
PV = $675,564

CASE 2: With Commodity Traffic

1983 1990

$1.0 million ($1983)

Present Value: $1,000,000 ($1983); 7 years; 4%
PV = $759,917

Build Sooner Cost = 759,917 - 675,564
= $84,353

FIGURE 4 Build-sooner costs.

cycle). It is necessary to calculate build-sooner costs for each subsequent cycle within the study period or until the effects of discounting render the build-sooner cost insignificant.

The final step in the analysis involves converting the build-sooner cost into an equivalent annual cost over the life cycle of the improvements using the appropriate capital recovery factor. For each link, sensitivity analysis was done using real discount rates of 3, 4, and 5 percent. The assumption underlying the choice of real discount rates of this magnitude was that a spread of 3 to 5 percent between the yield on long-term government bonds and the inflation rate would be representative of the long-run cost of capital throughout the time horizon of this study.

Summary

Two categories of build-sooner costs were hypothesized in this study. A large increment of commodity traffic will theoretically cause pavement condition to deteriorate faster and will cause a section of highway to reach capacity earlier. To the extent that these phenomena occur, investments in pavement resurfacing and capacity improvements will also be required earlier. The cost of having to commit capital expenditures at an earlier date is the build-sooner cost.

SUMMARY OF RESULTS

Table 3 gives a summary of the results of the build-sooner cost analysis and compares annualized costs to estimated incremental annual user fee revenue that might be expected from each movement. The user fee revenue consists of fuel taxes, registration fees, and license fees, of which fuel taxes represent the largest contribution.

Table 4 gives build-sooner costs as a percentage of incremental revenue. It must be emphasized that Tables 3 and 4 present only the build-sooner costs that would result from the commodity movements. Other cost categories were addressed in the overall study but are not presented here.

Two major observations can be made from these data. First, build-sooner costs exceeded incremental revenues in only one case (Woodchips 1), attributable primarily to capacity-related costs). This can be explained by the fact that the highway link in question has numerous steep grades, many in excess of 10 percent. Accordingly, the passenger car equivalent of each woodchip truck is high, with the result that capacity improvements that would not normally be required for many years on this relatively low-volume highway are advanced several years, creating a high build-sooner cost.

The other noteworthy feature of the data is that in all but two cases, pavement rehabilitation costs...
exceed capacity-related costs by a substantial margin. This appears somewhat surprising given the large expenditures normally associated with capacity enhancements. The explanation lies in the fact that the volume of commodity traffic (expressed in terms of passenger car equivalents) is generally low in comparison with existing passenger car and truck traffic. Hence the impact of the commodity trucks on capacity utilization is such that build-sooner periods were consistently shorter (0 to 3 years).

The sensitivity of results to changes in the discount rate was analyzed using real discount rates of 3, 4, and 5 percent. The higher discount rates do produce higher build-sooner costs. Although this may appear to be counterintuitive, it must be remembered that all build-sooner costs are estimates from the difference in present values of an investment made at two different points in future time. The difference increases even though the absolute magnitudes of the present values fall as the discount rate is increased. Furthermore, the capital recovery factor increases as does the discount rate resulting in higher costs.

The build-sooner costs analysis indicates that the bulk commodity movements studied would have a significant impact on future pavement rehabilitation and capacity-related costs, ranging from a low of 35.2 to a high of 209 percent of incremental revenues that would result from each movement. These costs arise from the need to advance the timing of these kinds of highway improvements because of the presence of the commodity traffic.

CONCLUSION

Previous highway cost allocation studies could, in general, be characterized as attempts to allocate highway expenditures to various classes of vehicles. The allocations are based in part on cause and effect relationships and in part on arbitrary accounting rules.

This study differs somewhat in that it assigns costs, not expenditures, attributable to a hypothetical increment of heavy truck traffic and then compares these costs to the incremental revenues that this same traffic would generate. The costs examined in this paper are those related to the impact of the incremental traffic on the timing of future pavement rehabilitation and capacity enhancement projects.

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REFERENCES


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