Development of an Economic Model to Compare Median Barrier Costs

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New York State specifies concrete safety-shaped barriers in narrow medians on high-volume urban expressways where frequent impact repairs would result in traffic delays and high repair costs if steel barriers were used. Because of the higher initial cost of the concrete barrier, its cost-effectiveness has been questioned. In this paper a model is described that was developed to compare the total costs of concrete safety-shaped barriers and heavy-post blocked-out W-beam median barriers. This model considers construction, repair, and user accident costs, using input values selected from construction and repair cost, and accident data compiled by New York and others. The model was used to determine which barrier system is the best economic choice for various situations. A manual worksheet and computer spreadsheet solutions were developed to permit designers to solve the model for other highway situations and to use alternative values for the input parameters. A sensitivity analysis was performed to determine the effects of the various input parameters on the break-even traffic volume at which the two systems provide equal cost. Because it has a higher initial cost but lower repair cost, the concrete barrier is the more economical at higher traffic volumes.

Existing warrants require installation of traffic barriers in narrow medians to prevent cross-over accidents on multilane highways *(1, 2)*. In high-volume urban New York situations, most often in New York City and on Long Island, light-post median barriers—W-beam and box-beam—are generally not used because frequent accidents and the resulting barrier damage make it virtually impossible for maintenance forces to keep the barrier in operational condition. Further complicating the situation are the resulting disruptions to traffic flow and the safety hazards for both motorists and workers when narrow median widths require a lane closure to accomplish the repairs.

The normal choice for these situations thus is to specify either a heavy-post blocked-out steel W-beam (MB-4S) or a concrete median barrier (CMB). Although the MB-4S system offers lower first cost and improved impact protection for high-angle impacts, it too has the same drawbacks as light-post systems on narrow medians under heavy traffic. Thus, New York State Department of Transportation policy *(3)* provides for use of CMB where clearance between barrier and pavement edge is less than 10 ft, free-flow speeds are 50 mph or higher, and the highway operates at or below Level-of-Service C as defined in the *Highway Capacity Manual (4)* during average daily peak hours. For other situations, a steel barrier must be used. This policy is based on the high maintenance costs resulting from frequent repairs of steel barriers in these situations, coupled with the disruption to traffic flow and the safety hazard caused by closing a lane to repair steel barriers.

Highways proposed for rehabilitation or reconstruction frequently warrant the installation of median barriers where none currently exist, or where the existing median must be rebuilt. In addition, existing median barriers may require extensive rehabilitation to bring them into compliance with current standards. Because of the relatively high initial cost of CMB compared with that of MB-4S, the cost-effectiveness of the current policy has been questioned by department management. The Engineering Research and Development Bureau was requested to perform an economic analysis to determine whether the current policy is justified.

This economic analysis, described in detail in this paper, is intended to answer two specific questions concerning median barrier installation:

1. Should existing MB-4S median barriers in deteriorated condition be repaired, replaced in kind, or replaced with CMB?
2. Given the decision to install a new median barrier on an urban expressway, should MB-4S or CMB be selected?

This analysis was pursued in three separate steps. First, an economic model was developed to determine the total cost of the alternative courses of action. Second, the necessary input parameters for the model were developed from available data on accidents, construction costs, and repair costs. Third, the model was exercised to develop a set of design guidelines that specify those situations in which each alternative should be implemented. As a corollary to the third step, a set of graphs and a worksheet were developed to permit use of alternative input parameters to develop solutions to the economic model. Finally, a sensitivity analysis was performed to determine the effect on model output of varying the input parameters.

DEVELOPMENT OF AN ECONOMIC MODEL

A complete economic analysis of a median barrier installation typically involves comparing the total cost of the barrier with the benefit derived from it. The benefit is simply the cost of median cross-over accidents that are prevented. If it is assumed that both the MB-4S and CMB systems are essentially totally effective in preventing cross-over accidents, then the benefits for each barrier system are equal, and the analysis is reduced to comparing the costs of the systems. In-service experience with both systems has demonstrated that these median barriers are rarely penetrated, even by large trucks, and it is therefore reasonable to assume that the benefits derived from installation

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of either system are essentially equal. Thus, this analysis was simplified to comparing total costs of the two systems.

The total cost of a barrier is the sum of its initial cost, accident repair costs, accident costs, traffic-delay and accident-hazard costs during repairs, and routine maintenance costs. The last two terms may represent a significant portion of the total cost in certain situations, but in this analysis neither was considered important. Under current policy, lane closure is rarely required to repair median barriers, because the CMB (which is specified for narrow medians under heavy traffic) rarely requires accident repair. Under light traffic, a lane closure to repair MB-4S would not result in significant traffic delay or safety hazard. Thus, this cost element was not deemed necessary for inclusion in this analysis as long as the guidelines developed did not result in the use of MB-4S on narrow medians under very heavy traffic. Similarly, routine maintenance requirements are very low for both barrier types, and thus were not considered to affect the results of this comparison significantly. In developing warrants for median barrier installations, all costs associated with the barrier, including these two elements, must be compared with the benefits derived. However, if the premise is accepted that existing warrants requiring the installation of barriers were rationally derived, then elimination of these two relatively minor elements from the analysis should not significantly affect selection of a barrier system to meet the warrants.

The total cost of the three major elements can then be computed from the following equation:

$$T_t = T_c + T_r + T_a \tag{1}$$

where

T_t = total cost of the barrier (\$/mi),
T_c = total construction cost (\$/mi),
T_r = total repair cost (\$/mi), and
T_a = total accident cost (\$/mi).

Construction cost is incurred at the time of construction, but repair and accident costs accrue over the length of the analysis period selected. Thus, the appropriate compound interest factors must be applied to sum these time-dependent costs. This can be done by computing either the current present worth or the equivalent annual costs. For this analysis, the comparison was made in terms of current present worth.

Each of the three cost elements in Equation 1 can similarly be stated in appropriate equations. Construction cost is computed from the following equation:

$$T_c = C_c \times 5{,}280 \text{ ft/mi} \tag{2}$$

where C_c is the unit construction cost in dollars per foot.

Because construction cost is incurred at the outset, no compound interest factor is required. Repair cost is computed from the following equation:

$$T_r = PWF_{iy} \times R \times V \times C_r \tag{3}$$

where

PWF_{iy} = present-worth factor for interest rate I and analysis period of Y years,
R = accident rate [number of accidents/1,000 annual average daily traffic (AADT)-mi-year],
V = traffic volume (1,000 AADT) (at midpoint of analysis period), and
C_r = unit repair cost (\$/accident).

For simplicity, the following term can be substituted in Equation 3:

$$H = R \times V \tag{4}$$

where H is the number of accidents per mile-year.

Calculation of accident costs is complicated by the presence of barriers unrepaired from earlier accidents, because accident severity is higher if the barrier is not maintained in good condition. Thus, the accident cost element must be dealt with in two parts:

$$T_a = T_{ar} + T_{au} \tag{5}$$

where T_{ar} is the total cost of all accidents occurring on the barrier, assuming that the barrier is in good repair, and T_{au} is the total additional cost of accidents occurring on damaged barriers.

Each of these subelements can then be computed as follows:

$$T_{ar} = PWF_{iy} \times R \times V \times C_{ar} \tag{6}$$

where C_{ar} is the average accident cost on barriers in good repair in dollars per accident, and

$$C_{ar} = P_{pir} \times C_{pi} + P_{pdr} \times C_{pd} \tag{7}$$

where

P_{pir} = proportion of personal injury accidents on barriers in good repair,
P_{pdr} = proportion of property-damage accidents on barriers in good repair,
C_{pi} = average cost of personal injury accidents in dollars per accident, and
C_{pd} = average cost of property damage accidents in dollars per accident.

$$T_{au} = PWF_{iy} \times L \times R \times V \times (C_{au} - C_{ar}) \tag{8}$$

where L is the proportion of barriers unrepaired and C_{au} is the average accident cost on unrepaired barriers in dollars per accident.

$$L = R \times V \times l_u \times t \tag{9}$$

where l_u is the average length of barrier damaged per accident in miles, and t is the average lag time before repairs are completed in years.

$$C_{au} = P_{piu} \times C_{pi} + P_{pdu} \times C_{pd} \tag{10}$$

where P_{piu} is the proportion of personal-injury accidents on unrepaired barriers, and P_{pdu} is the proportion of property-damage accidents on unrepaired barriers.

Because all accidents occurring on the barrier were already included in Equation 6, Equation 8 includes only the differential cost between accidents on barriers in good repair and those on damaged barriers. That differential cost is simply the numerical difference between the two average costs.

Substituting the equations for each of the individual cost elements into Equation 1 yields the following economic model to compute total barrier cost, in terms of the basic input parameters:

$$\begin{aligned} T_t = {} & C_c \times 5{,}280 + PWF_{iy} \times R \times V \\ & \times C_r + PWF_{iy} \times R \times V \times C_{ar} \\ & + PWF_{iy} \times (R \times V)^2 \times l_u \\ & \times t \times (C_{au} - C_{ar}) \end{aligned} \tag{11}$$

Equation 11 shows that accidents on unrepaired barriers become particularly significant for higher accident rates and traffic, but only if some delay occurs in repairing previous accident damage. The *R* and *V* parameters are especially important, because as they increase, the proportion of unrepaired barriers and the likelihood that another accident will occur both increase. If accident damage is repaired quickly, this cost element is very small.

SELECTION OF INPUT VALUES

Accident Frequency

A recent large-scale analysis of traffic barrier accidents conducted by this bureau *(5)* yielded two estimates of barrier accident frequency. First, 3,302 first-event barrier accident reports were recorded statewide over a 1-year period. Based on an estimated inventory of 4,200 mi of barrier and an average AADT of 5,000 vehicles, this yields a first-event reported accident frequency of 0.16 impact/1,000 AADT-mi-year. A hit-run accident survey conducted in the same study yielded a sample of 83 reported first-event impacts, 36 reported second-event impacts, and 616 unreported impacts in 1 year for a sample length of 114 mi and an average AADT of 8,920. This yields a total accident frequency of 0.72 impact/1,000 AADT-mi-year, with 11.3 percent reported first-event accidents. Adjusting the reported first-event accident rate from the statewide sample by the first-event reported-accident proportion of 11.3 percent yields a total impact frequency of 1.39 impacts/1,000 AADT-mi-year. Although these two estimates are not in perfect agreement, they are reasonably close.

Several points were then considered in adjusting these estimated impact frequencies to arrive at a value of 1.0 impact/1,000 AADT-mi-year for use in this analysis. Although the statewide estimate is based on a much larger sample than the other, it is also based heavily on rural two-lane roadways with narrower shoulders and less favorable geometrics than those of typical urban expressways. Further, on a two-lane road, 50 percent of the traffic is in the lane adjacent to the barrier. On a four-lane roadway, the typical lane distribution results in somewhat less than half the traffic in the lane adjacent to the median barrier, and thus a lower probability of an impact on the barrier. In addition, about one-third of the reported accidents in the statewide sample occurred on snow- or ice-covered roads. Because of the milder climate in the New York City–Long Island area, fewer such accidents would be expected, resulting in a lower accident rate. Finally, the statewide barrier inventory and traffic estimate used are several years old, and have undoubtedly increased, which would further decrease the calculated rate. The statewide-sample estimated rate of 1.39 was thus adjusted downward to 1.0 impact/1,000 AADT-mi-year for four-lane roadways in this analysis.

It should be noted that the rate for median barriers is based on the entire two-way AADT, the same as for roadside barriers on a two-lane roadway. For roadside barriers on a multilane facility, however, exposure would be based on one-way AADT for most situations, because traffic from only one roadway can strike the roadside barrier.

On highways with more than two lanes in each direction, an additional reduction must be applied to the exposure rate to reflect the additional distance between some of the traffic and the median barrier. The lateral encroachment distribution developed by Cooper *(6)* indicates that a six-lane highway would experience about 75 percent as many median encroachments as a four-lane facility carrying the same traffic volume. Applying this correction yields an impact rate of 0.75 impact/1,000 AADT-mi-year for six-lane facilities.

Accident Severity

In the statewide barrier accident sample referenced earlier, 59 percent of the reported first-event barrier collisions resulted in personal injury, which agrees almost exactly with the 60 percent injury rate for first-event reported accidents experienced in the hit-run sample. Injury rates in the statewide sample were 70 percent for heavy-post steel barriers—G-4S and MB-4S—and 73 percent for CMB, based on samples of 94 and 90 accidents, respectively. In the hit-run sample, second-event barrier collisions representing 4.9 percent of all accidents resulted in 61 percent personal injuries. Because the MB-4S and CMB are stiffer than most barriers included in the statewide sample, the slightly higher personal injury rates for these two barriers are considered in good agreement with the statewide and hit-run sample estimates. Further, because of the small sample sizes for these two barriers, the injury rates were considered essentially equal. Finally, it was assumed that half the second-event injuries were attributable to the barrier impact, at the same overall injury rate as that for first-event accidents. Using these values, a preliminary value for injury rate was calculated for each barrier as 70 percent of the sum of all first-event collisions plus half the second-event collisions:

0.70 (personal injuries) × 0.113 (first event) = 0.079, $^1/_2$ × 0.70 (personal injuries) × 0.049 (second event) = 0.017,
total personal injury rate = 0.096

The statewide accident sample showed that fatal accidents involving traffic barriers were extremely rare for first-event midsection barrier impacts unless a secondary collision involving a fixed object or overturning was experienced. Because these second events are rarely experienced in expressway median accidents, it is reasonable to assume that the fatality rate will be extremely low for the accidents considered in the analysis. Thus, excluding fatal accidents when calculating the severity index has no practical effect on this analysis.

Another adjustment to the preliminary injury rate was considered necessary to account for barrier offset differences in the statewide sample, because offset from the pavement edge to the barrier was found to affect the injury rate. The average offset was 9.6 ft for the heavy-post W-beam sample but only 3.8 ft for CMB. Because this analysis compares MB-4S and CMB at equal offsets, it was necessary to adjust the MB-4S injury rate downward to account for the difference between offsets of the barrier samples. The statewide sample indicated a 13.7 percent increase in injuries for offsets of 9 to 10 ft compared with 3 to 4 ft. Thus, the injury rate for MB-4S was adjusted downward to 0.084.

Finally, it was necessary to compute a second injury rate for accidents occurring on damaged barriers. Because CMB is rarely damaged by vehicle collisions, it is necessary to establish this rate only for MB-4S, which experiences damage in many impacts. The statewide accident sample revealed that serious injuries increase from 10.6 percent for barriers in good condition to 14.0 percent and 17.4 percent, respectively, for barriers with minor and major damage. This represents an average 48 percent increase in serious injuries for damaged barriers. Thus, it was assumed that the overall injury rate on damaged MB-4S would increase by this same amount, yielding an injury rate of 0.124 for damaged MB-4S.

Construction Costs

For 1985 the average price for MB-4S installed on Long Island and in Metropolitan New York City was $29.14/ft, plus $1,914 per anchor. Because anchors are typically widely spaced on expressway medians, their contribution to total cost is small. The average installed cost of MB-4S thus was set at $30/ft for this analysis. The average price for CMB for the same time and locality was $59.82/ft, and was rounded to $60/ft for this analysis.

It should be pointed out that several variations of CMB are sometimes used to accommodate special situations, such as differential roadway elevations, mounting luminaires, or sign structures. Although CMB costs are higher for these situations, those costs are attributable to other purposes and thus were not considered in this analysis, which is intended to compare only the costs of providing median cross-over protection. The cost of upgrading existing MB-4S to current standards is dependent on its condition, and varies from project to project. Thus it was not possible to select a typical reconstruction cost for existing MB-4S. Rather, a range of values was used to develop solutions for the model. This permits a project designer to estimate reconstruction cost for a particular project and then select the appropriate barrier alternative on the basis of that cost.

Accident Damage and Repair Costs

Repair costs for MB-4S in this analysis were derived from repair costs for heavy-post blocked-out W-beam guardrail (G-4S) developed by Southwest Research Institute under NCHRP Project 22-5 *(7)*. Their estimate provided repair costs for containment hits and for hits resulting in barrier deflections of 5 and 8 ft. Assuming that all property damage accidents are equivalent to containment hits, and the more severe personal-injury accidents are equally divided between 5- and 8-ft deflections, accidents resulted in an average repair cost of $254 for G-4S. Costs for MB-4S can be expected to be higher, because this system uses twice as many rails and block-outs. Further, repair costs on urban expressways with narrow medians and greater traffic volumes will undoubtedly be higher than average because of increased traffic protection requirements. Thus, the average repair cost for MB-4S was set at $500 per impact for this analysis. Using barrier damage estimates from NCHRP Project 22-5, adjusted as described earlier for impact severity, resulted in an average damage estimate of 58 ft for G-4S. Based on this value, a rounded damage length of 0.01 mi (52.8 ft) was selected for MB-4S in this analysis.

No data were available on CMB damage or repair costs, so it was necessary to assume values for this analysis. Because CMB is rarely damaged, the results of this analysis are not highly dependent on these assumed values. The same damage length selected for MB-4S, 0.01 mi, was assumed for CMB, but it was further assumed that only 1 percent of all impacts require repair. The repair cost was assumed to be twice the construction cost. This results in an average repair length of 0.0001 mi and an average repair cost for all impacts as follows:

$$2 \times \$60/\text{ft} \times 0.01 \times 52.8 \text{ ft} = \$63.36 \text{ per impact.}$$

This value was rounded to $60 per impact for the analysis.

Analysis Period and Interest Rate

Traffic barriers can be expected to have very long service lives if accident damage is properly repaired. In some cases, barriers in serviceable condition are replaced because changing traffic conditions require reconstruction of the highway. However, it is rare that barriers must be replaced because they are simply worn out. Thus, it was considered inappropriate to select a service life for these barriers. Instead, an analysis period of 20 years was selected, because this value is typically used by this department in economic analysis of other major highway investments. This period does not represent total service life of the facility, but rather the period over which the investment is amortized. An interest rate of 4 percent was selected, also based on current department practice for other types of analysis. This value represents the real-time cost of money, with inflation deducted from the total interest rate. Based on the 20-year analysis period and 4 percent interest rate, compound interest equations yield a present worth factor of 13.59. Multiplied times the annual costs—repair and accident—this value yields the equivalent present worth of these cost elements.

Accident Costs

This department's Traffic and Safety Division uses accident costs of $8,200 for injury accidents and $2,400 for property damage accidents in urban areas. These values thus were used in this analysis.

Repair Lag Time

Average time between an accident and the completion of repairs depends on the availability of maintenance resources. Rather than typical value, the model was exercised for a range of values. To select a barrier system using the model, the designer must select an appropriate average barrier repair lag time based on local conditions.

Barrier Offset

It is generally recognized that accident frequency and severity are related to the distance between the pavement edge and the barrier. In this analysis, known relationships were used to adjust accident frequency for six-lane highways and to normalize offset distances in computing average severity rates for the two barrier types. Further consideration was given to adjusting accident frequency and severity on the basis of the actual median width in consideration. Unfortunately, reliable data are not available to establish the necessary relationships with good confidence. Furthermore, accident frequency would be expected to decline with wider barrier offsets, but severity would increase, although the rates of increase may be different for the two barriers. To a certain extent, these effects are self-cancelling. In addition, the difference in accident severity between the two barriers was small for the average values selected, and the rate of change as offset changes would be even smaller. The net result is that some slight improvement in the cost estimate might be achieved if actual barrier offsets were considered throughout the analysis. However, given the lack of reliable data to define those relationships, and their relatively small effect on cost, the proposed model is thought to provide reasonable results.

Summation of Input Values

Input values for this analysis are summarized as follows:

1. Accident rate: four lanes, $R = 1.000$ impact/1,000 AADT-mi-year; six lanes, $R = 0.75$ impact/1,000 AADT-mi-year.
2. Accident severity: MB-4S, $P_{pir} = 0.084$, $P_{pdr} = 0.916$, $P_{piu} = 0.124$, and $P_{pdu} = 0.876$; CMB, $P_{pir} = 0.096$, $P_{pdr} = 0.904$, $P_{piu} = 0.096$, and $P_{pdu} = 0.904$.
3. Construction costs: MB-4S, $C_c = \$30$/ft; CMB, $C_c = \$60$/ft.
4. Repair costs: MB-4S, $C_r = \$500$/accident; CMB, $C_r = \$60$/accident.
5. Barrier damage: MB-4S, $l_u = 0.01$ mi/accident; CMB, $l_u = 0.0001$ mi/accident.
6. Accident costs: $C_{pi} = \$8,200$/accident; $C_{pd} = \$2,400$/accident.
7. Analysis period: $Y = 20$ years; $I = 4$ percent.

In addition to these values, a range from $0 to $20/ft was used for the cost to reconstruct or repair existing MB-4S, and a range of 0 to 1 year was used for repair lag time.

DEVELOPMENT OF DESIGN GUIDELINES WITH SELECTED INPUT VALUES

With development of the economic model and selection of input values, the model was exercised to develop design guidelines for selection of median barriers. Table 1 shows the break-even traffic volumes for MB-4S and CMB for selected input values at various levels of repair lag time. On the basis of the input values just discussed, Table 1 gives the traffic volumes at which the present worths of total costs are equal for the two systems. For lower traffic volumes, MB-4S is the more economical choice, and above this volume CMB is more economical. Traffic increases are often assumed to occur over the life of a project. Thus, average traffic over the analysis period—assuming a straight-line increase—or traffic at the midpoint of the analysis period—assuming a geometric or compound increase—should be used to select the more economical barrier from Table 1. Because MB-4S has a lower initial cost but higher unit-repair cost, MB-4S is more economical when a low number of impacts, that is, less traffic, is expected. Although the MB-4S has a lower unit-accident cost than CMB, this difference is not so great as the difference in repair costs. Further, this lower accident cost is offset by the differential cost of impacts on unrepaired barriers, which adds

TABLE 1 BREAK-EVEN TRAFFIC VOLUMES FOR SELECTION OF STEEL AND CONCRETE MEDIAN BARRIERS

Repair Lag Time, months	Break-Even Traffic, two-way AADT	
	Four-Lane	Six-Lane
MB-4S COST = $30/FT		
0	31,500	42,000
2	30,500	40,700
4	29,650	39,550
6	28,850	38,500
12	26,900	35,900
MB-4S COST = $20/FT		
0	41,950	55,950
2	40,250	53,650
4	38,800	51,800
6	37,550	50,050
12	34,500	46,000
MB-4S COST = $10/FT		
0	52,450	69,950
2	49,850	66,450
4	47,700	63,600
6	45,850	61,150
12	41,600	55,400
MB-4S COST = $0/FT		
0	62,950	83,900
2	59,250	79,000
4	56,350	75,100
6	53,800	71,800
12	48,300	64,350

NOTES: 1) Construction cost for new MB-4S is $30/ft; lower values in this table represent costs to reconstruct or repair existing MB-4S. 2) For more economical solutions use MB-4S below break-even traffic, CMB above break-even traffic. 3) Based on CMB - $60, I = 4%, Analysis Period = 20 years, etc. 4) Traffic volume is taken at midpoint of the analysis period

to the total cost for MB-4S. At higher traffic volumes and longer repair lag times, this cost differential for accidents on unrepaired barriers becomes large, and represents a substantial advantage for CMB. Above the break-even traffic volume, the higher repair costs and unrepaired-barrier-accident cost differential for MB-4S more than offset its lower initial and normal accident costs.

Level-of-Service C begins at about 51,000 and 76,000 AADT for four- and six-lane divided highways, respectively. Table 1 shows that the break-even volumes for the selection of CMB on new construction are well below these levels for both four- and six-lane facilities. This carries two important implications. First, if the guidelines in Table 1 are followed, MB-4S would not be selected for highways operating at Level-of-Service C or lower, so the necessity of closing a traffic lane to complete barrier repairs will not result in major traffic delays. This complements the assumption made in developing the economic model that traffic delay costs during repair are not a major element. Second, the break-even traffic volumes in Table 1 show that the current policy for median barriers is very conservative in the use of CMB. In effect, higher repair and accident costs over the economic life of the barrier are now being accepted to achieve lower construction costs.

In addition to determining the most economical choice for the installation of a new barrier, the model can also be used to compare the cost of repairing or reconstructing an existing MB-4S with that of replacing it with CMB. This is accomplished by substituting the repair cost of existing MB-4S in place of the construction cost. Table 1 also presents the break-even traffic volumes for equivalent repair costs of \$10/ft and \$20/ft. These volumes show that even for low costs to repair an existing MB-4S, CMB becomes the economical choice at relatively low traffic volumes. The reason for this is, again, that the repair costs and unrepaired accident cost differential, which are higher for MB-4S, outweigh its lower initial and accident costs as traffic volumes increase. On the basis of the results shown, replacement of existing MB-4S with CMB will result in lower overall costs even if the cost to repair the existing MB-4S is considerably less than the cost of new MB-4S. Carried to the extreme, Table 1 shows that even if an existing MB-4S requires no expenditure to bring it into good condition, replacing it with a new CMB is the economical choice for high traffic volumes and long repair lag times. For a repair lag time of 12 months, it is seen that it is economical to replace existing MB-4S in good condition with CMB for traffic volumes above 48,300 on four-lane roadways and 64,350 on six-lane roadways. Above these traffic volumes, the high cost of repairs and the unrepaired accident cost differential more than offset the initial cost of the CMB and the lower accident cost of the MB-4S.

It should further be noted that the traffic volumes listed here for Level-of-Service C are approximate values. If the economic analysis yields a break-even traffic volume close to these values, then a detailed capacity analysis may be appropriate to determine whether the highway will actually operate at level C or lower.

SOLUTION OF MODEL FOR ALTERNATIVE INPUTS

The input values used earlier to develop design guidelines represent the authors' selection of the best currently available data on construction and repair costs, and accident frequency and severity. They also reflect current New York State practice for economic factors and accident costs. However, it is recognized that these input values may change over time, and other values may be considered more appropriate for individual projects or by other agencies. Thus, it was desirable to provide an expedient means to exercise this model by using alternative input values. Curves were developed to represent solutions to the four elements of the economic model—construction, repair, accident, and unrepaired accident differential costs. The latter three are presented as annual costs rather than present worth so a designer can select whatever economic factors are considered appropriate. By combining individual inputs into a cost factor and an accident frequency factor, it is possible to use these curves for quick and easy determination of total cost for any desired combination of input values. With a trial-and-error procedure, the model can be exercised for both MB-4S and CMB at various levels of traffic to determine the break-even traffic volume. Further, these curves can be used to examine the sensitivity of the model to any given input parameter.

For simplicity, a worksheet and accompanying step-by-step instructions were developed. The worksheet provides a workable means of manually exercising the model for a limited number of input values. However, for more runs, the model was programmed on a computer spreadsheet to permit exercising the model for a large number of input values. The input format and spreadsheet program were copied onto a floppy disk, which is used with either the Supercalc 3 or Lotus 1-2-3 (Release 1A) software (Supercalc 3 is a registered trademark of Sorcim/IUS Micro Software, a Division of Computer Associates International, Inc.; Lotus 1-2-3 is a registered trademark of Lotus Development Corporation). Any user having this software available on a microcomputer can simply enter the desired input values and use the program disk to exercise the model. Copies of both the worksheet and the computer input formats are available from the authors upon request.

SENSITIVITY ANALYSIS

Like any economic model, decisions based on this model are sensitive to the input values used. These input values can be grouped and discussed in six major categories: construction costs, repair costs, accident costs, accident severity, accident frequency, and economic factors. Although the decisions based on the model are sensitive to each of these inputs, some have a greater influence than others. The sensitivity of the break-even traffic volume to each of the major input variables is discussed here.

Construction Costs

In Table 1 the effects on break-even traffic of varying MB-4S cost from \$30/ft down to zero were examined. For no repair lag, break-even traffic increased from 31,500 at \$30/ft to 62,900 at zero cost. For a 12-month repair lag, the corresponding traffic volumes ranged from 26,900 to 48,300, with intermediate repair lags yielding intermediate traffic volumes. Changing the construction cost for CMB would have the same incremental effect on break-even traffic as changing the cost of MB-4S, because the model in effect considers the difference in cost between the two barriers. It can thus be seen that, for no repair lag, the break-even traffic decreases by about 1,000 AADT for each dollar decrease in construction cost differential and by about 700 AADT per dollar for a 12-month repair lag. This points out the importance of using the best possible estimate of construction cost to determine the break-even traffic volume.

Repair Costs

Because historical repair cost data were not available, estimated repair costs of \$500 and \$60 per impact for MB-4S and CMB, respectively, were used in this analysis, developed as described earlier. The effects of repair costs were examined for both four- and six-lane roadways, as well as four MB-4S construction costs and five repair lags. Repair costs have a major influence on break-even traffic, especially for shorter repair lags. For longer repair lags, the differential accident costs on unrepaired barriers become more influential, reducing the relative effect of repair costs. Reducing the difference in repair costs by half (\$440 to \$220) results in an increase in the break-even traffic on the order of 50 to 100 percent, depending on the values selected for the other parameters.

Accident Costs and Severity

The same unit accident costs were assumed for each barrier, but different severities were used. The difference in accident costs between the two systems was not large, and was overshadowed by the construction and repair costs.

Thus, a substantial change in either the unit accident costs or severities would have a small effect on break-even traffic. Similarly, unrepaired-barrier differential accident cost is not a large component of total cost for traffic volumes near the break-even point, and thus a substantial change in unrepaired-barrier accident severity affects break-even traffic by only a few thousand AADT in the extreme case. For very high traffic volumes, this component becomes important, but this occurs far above the break-even traffic volumes.

Accident Frequency

A major component of cost difference between the two systems is the repair cost, which directly relates to accident frequency. Thus, it follows that accident frequency will have a large effect on break-even traffic. Table 1 presented break-even traffic volumes for four- and six-lane roadways, based on impact frequencies of 1.0 and 0.75. Comparing the traffic volumes for these two rates reveals differences ranging from 9,000 AADT to over 22,000 AADT for these two frequencies, with the larger differences occurring as the difference in construction costs becomes larger. Although accident frequency is thus shown to have a substantial effect on break-even traffic, the scarcity of reliable impact frequency data makes it difficult to obtain more precise values for this parameter. Considering the large accident sample that forms the basis of the values used in this analysis, the substitution of alternative values based on small accident samples for individual projects appears risky and thus is not recommended.

Economic Factors

The effect on break-even traffic of varying the present-worth factor was examined and was found to be large. For example, for a construction cost for MB-4S of \$30/ft, no maintenance lag, and using the same parameters as those in Table 1 for a four-lane highway, increasing the interest rate from 4 to 7 percent results in an increase in the break-even traffic from 31,500 to about 40,000. The use of longer analysis periods or lower interest rates (i.e., higher present-worth factors) favors accepting higher initial investment (construction cost) rather than larger repair and accident costs, which are future costs. Thus, the break-even traffic (i.e., the traffic volume at which the initially more expensive CMB becomes the economic choice) decreases as the present-worth factor increases. Because this factor has a major effect on selection of the most economical barrier system, it is important for the agency selecting the barrier to decide on the relative desirability of increasing initial investment to defer future repair and user costs.

SUMMARY

An economic model was developed to compare the total cost of providing median protection on high-volume urban expressways by using MB-4S and CMB median barrier systems. Input values for construction and repair costs and accident frequency, severity, and cost were selected from the best available data sources. This cost model shows that the high accident repair costs associated with MB-4S and the higher accident costs of unrepaired barriers make the initially more expensive CMB the economic choice for traffic volumes considerably below those specified by current New York State policy. The break-even traffic volumes at which the total costs of the two barrier systems are equal were determined for four- and six-lane highways and various levels of accident damage repair lag time. These break-even volumes were shown to be sensitive to several input parameters, including construction and repair costs and economic factors.

A manual worksheet and a computer spreadsheet solution were developed for the economic model to permit designers to develop solutions for individual projects using alternative input parameters. Although the solutions discussed here are based on the best available input values, designers using this model are encouraged to substitute alternative input values when they are considered more appropriate.

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