Vol. 48, No. 2
September 1984

Public Roads

U.S. Department of Transportation

Federal Highway Administration

A Journal of Highway Research and Development

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September 1984 Vol. 48, No. 2

U.S. Department of Transportation
Elizabeth Hanford Dole, *Secretary*

Federal Highway Administration
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U.S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

COVER: The National Bridge Inventory is a valuable aid in determining the safety of bridges such as the William Preston Lane, Sr., Memorial Bridge spanning the Chesapeake Bay in Maryland.

Public Roads is published quarterly by the Offices of Research, Development, and Technology

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The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this Department. Use of funds for printing this periodical has been approved by the Director of the Office of Management and Budget through March 31, 1985.

Bridge Safety

by
Charles F. Galambos

Introduction

Highway bridges are a vital link in the Nation's transportation network. Occasionally, however, a bridge collapses or must be closed for safety reasons, lessening the public's confidence and raising some penetrating questions about the safety of the Nation's bridges. The most recent example of a bridge collapse was the June 1983 failure of the Mianus River Bridge in Connecticut, which caused three deaths and resulted in untold expense, traffic delays, and detours. This sudden, unexpected catastrophic failure, surprising even to the bridge engineering community, was investigated by the National Transportation Safety Board. This article generally discusses the safety of public highway bridges.

National Bridge Inventory

The National Bridge Inventory, a valuable aid in determining the safety of bridges, was established by Congress through the 1968 Federal-aid Highway Act *(1)*[1] after the collapse in 1967 of the Silver Bridge near Point Pleasant, West Virginia. The law required each State to maintain a current inventory of all bridges on the Federal-aid System. In the 1970 Federal-aid Highway Act *(2)*, Congress directed the U.S. Secretary of Transportation, in consultation with the States, to inventory all bridges, classify them according to their serviceability, safety, and essentiality for public use, and assign each deficient bridge a priority for replacement.

As a result of these laws and other highway legislation, the National Bridge Inventory contains data on virtually all of the approximately 260,000 bridges on the Federal-aid Highway System and on 98 percent of the approximately 314,000 bridges on all other public roads. Current requirements stipulate that bridges on public roads must be reinspected and the inventory updated every 2 years. *(3)* For all bridges on the Federal-aid Highway System and other public roads a sufficiency rating between 0 (least safe) and 100 (safest) is assigned and is, in essence, a measure of the "safety" of the bridge.

Two general deficiencies are rated—whether bridges are structurally deficient and/or functionally obsolete. Structurally deficient bridges cannot sustain the live loads for which they were designed or to which they are now subjected. This is determined by

[1] Italic numbers in parentheses identify references on page 47.

comparing the American Association of State Highway and Transportation Officials' (AASHTO) Bridge Specifications with the condition of the bridge determined by an inspection crew. Functionally obsolete bridges usually have some geometric deficiency such as being too narrow for modern truck traffic, located on a sharp curve or sharp curve approach, or in some other way restricted in their original intended function.

Because the National Bridge Inventory data constantly change, it is difficult to quote inventory information with lasting value. However, table 1 summarizes the condition of the deficient bridges in the United States as reported in the U.S. Secretary of Transportation's July 1983 report to Congress. *(4)* As shown, many bridges are both structurally deficient and functionally obsolete according to the definitions of these terms given in the table. About 25 percent of the Nation's highway bridges are either structurally deficient or have some structural condition, and about 19 percent of the approximately 553,000 bridges inventoried are functionally obsolete. Even though about 44 percent of the Nation's bridges are in some way deficient, the other 56 percent are not guaranteed to be serviceable forever. In fact, many conditions and loadings can harm a bridge and cause it to collapse, and it is not possible to guarantee the safety of any bridge. The following examples illustrate some of these conditions that can cause bridge failure.

Table 1.—U.S. highway deficient bridge summary, July 1983[1]

	Kind of highway					
	Interstate	Arterials	Collectors	Local roads	Total deficient	Percent of total bridges
Structurally deficient[2]	1,857	11,703	24,793	88,414	126,767	23
Structural condition[3]	260	3,143	8,503	—	11,906	2
Functionally obsolete[4]	2,806	15,163	24,354	63,245	105,568	19
Total bridges in the United States	46,377	116,170	151,578	239,185	553,310	—

[1]A bridge is counted only once.

[2]Bridge closed, light vehicles only, or in need of immediate rehabilitation to stay open.

[3]Original design load is less than current standard.

[4]Bridge has inadequate deck geometry, underclearance, waterway, approach load alinement, or some other functional inadequacy.

Examples of Bridge Failures

Tacoma Narrows Bridge, Tacoma, Washington. The original long and slender girder-stiffened suspension bridge was opened to traffic on July 1, 1940, and collapsed on November 7 of the same year (fig. 1) because of aerodynamic instability. Under the present National Bridge Inventory rating and evaluation system, this bridge would not have been rated as structurally deficient or functionally obsolete, yet the design itself was unsafe in light of what is now known about aerodynamic excitation of suspension bridges. *(5)* The bridge collapsed during a steady 40 mph (64 km/h) wind that blew for hours and contributed to torsional instability of the structure.

Figure 1.—Tacoma Narrows Bridge collapse.

Silver Bridge, Point Pleasant, West Virginia. This suspension bridge (fig. 2) spanning the Ohio River also probably would not have been rated as structurally deficient or functionally obsolete; however, it collapsed suddenly without warning on December 17, 1967, killing 46 people (fig. 3). *(6)* The cause of the collapse was a brittle fracture of one of two eyebars making up an eyebar chain, again a deficiency in the design itself. A similar bridge about 100 miles (161 km) up the Ohio River at St. Mary's subsequently was dismantled without proof that it was in any way deficient. Apparently, it was felt that it was impossible to inspect the bridge and find the same kind of small cracks that caused the collapse of the Silver Bridge.

Figure 2.—Silver Bridge, Point Pleasant, West Virginia.

Yadkin River Bridge, Winston Salem, North Carolina. This simple span truss bridge was destroyed on February 23, 1975, when a single car, not even traveling at a very high rate of speed, hit one end post (fig. 4). *(7)* The


Figure 3.—Silver Bridge after collapse.

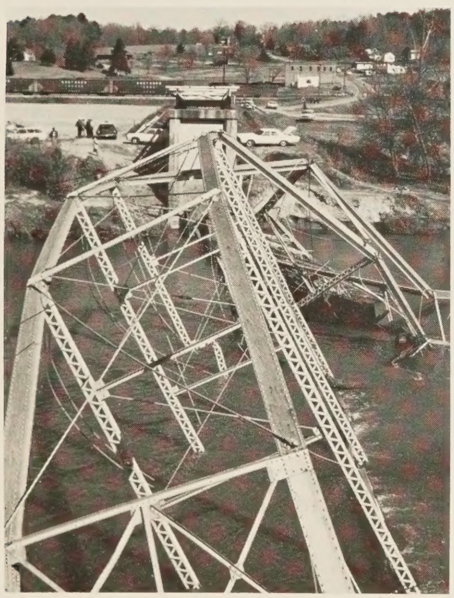
Figure 4.—Yadkin River Bridge after collapse.

damaged end post is shown in the lower truss on the right in figure 5. Such simply supported trusses have been destroyed in other cases when one or more of the end posts were damaged. There were no other cars on the Yadkin River Bridge at the time of the collapse; however, the traveling public was not warned about the collapse and several people drove into the river and drowned after the bridge had failed. This bridge was labeled functionally obsolete because it had a very narrow, single lane roadway of only 12 ft (3.7 m).

Sunshine Skyway Bridge, Tampa, Florida. There are many instances of water traffic, such as barges, damaging and even destroying bridges. One of the most dramatic examples of a ship-bridge collision was the destruction of a large portion of the Sunshine Skyway Bridge in May 1980. Again, the bridge was judged structurally adequate and functionally suitable for the traffic it carried; however, because it was over a waterway and had inadequate protection against ships out of control, it was not safe. We can say this now in retrospect.

Mianus River Bridge, Greenwich, Connecticut. This bridge collapsed on June 28, 1983, causing three deaths (fig. 6). The bridge was judged to be safe for traffic; the cause of the collapse was investigated and appears to be a combination of an inadequate design detail and environmental effects of rust.

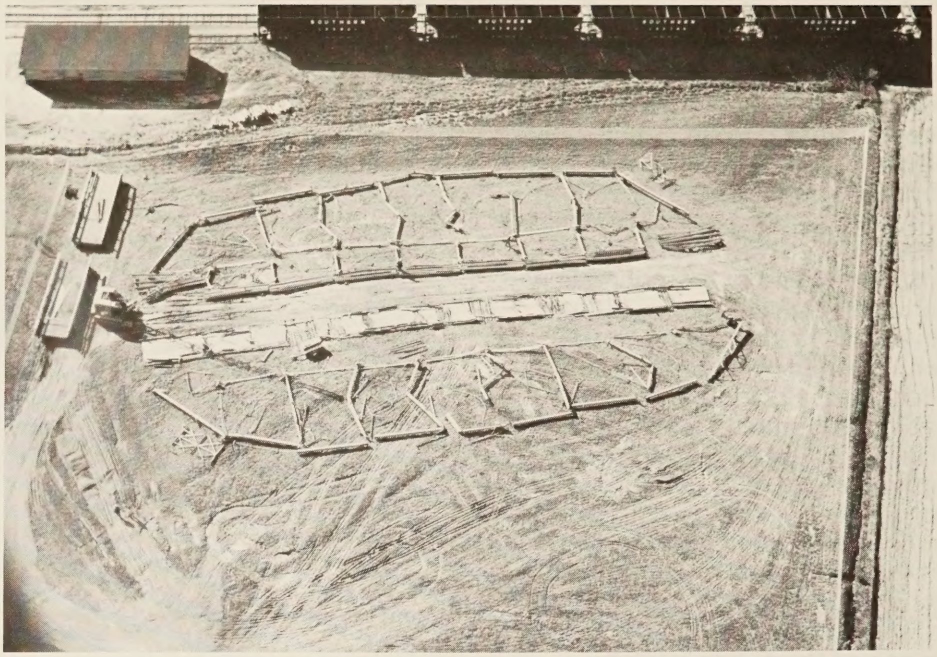

Figure 5.—Yadkin River Bridge reassembled.

Figure 6.—Mianus River Bridge after collapse.

Figure 7.—Typical bridge damage from flooding.

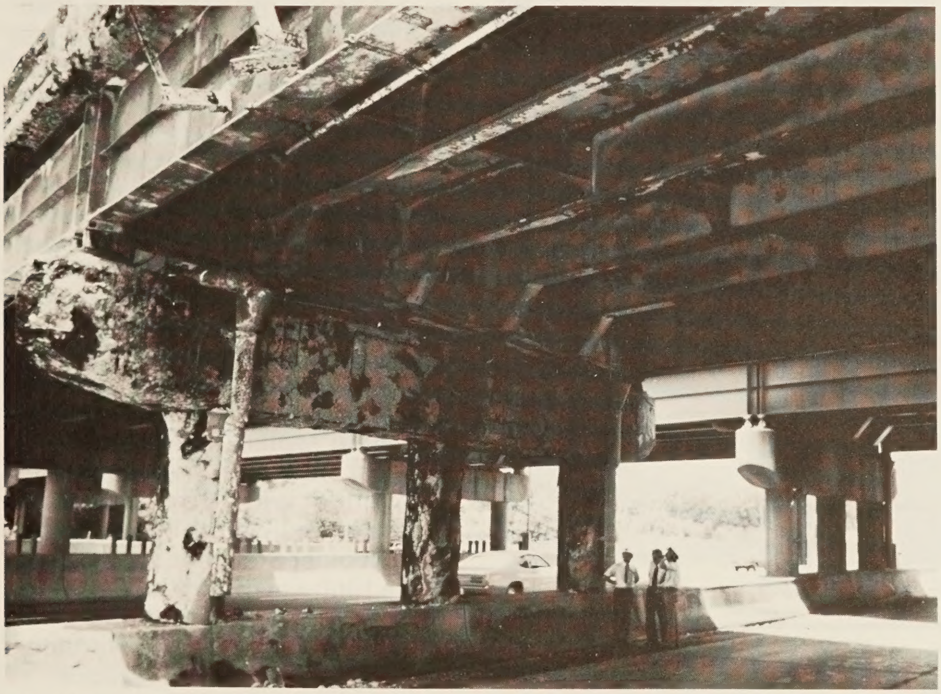

Figure 8.—Typical bridge damage from a fire.

Flood, Fire, and Accident Related Collapses. By far, floods destroy the highest number of bridges each year—approximately 150 (fig. 7). Many of these bridges are judged structurally and functionally adequate but cannot withstand extreme flooding. Similarly, fires and earthquakes also destroy bridges that otherwise are structurally and functionally adequate (figs. 8 and 9).

Bridge Safety Research

Each time a catastrophic failure occurs, inspection methods are sharpened, research is undertaken to find the cause of the failure, specifications are revised, and the whole profession learns from these failures—making bridges today safer than ever before. For example, as a result of the 1971 San Fernando, California, earthquake, comprehensive highway bridge seismic design specifications have been completed and now are part of the AASHTO Bridge Specifications. Work continues on the definition of foundation movements

Figure 9.—Bridges damaged by earthquakes—California, 1971.

and the interaction of the soil and the foundations during earthquakes. Also, aerodynamic design improvements continue to be made. This is especially important because a number of suspended bridges in the United States still exhibit aerodynamic problems during high winds. The Golden Gate Bridge in California and the Deer Isle Bridge in Maine are examples of bridges that have had to be closed during winds of certain magnitudes, although modifications to the Golden Gate Bridge have lessened the problem.

The fatigue and brittle fracture behavior of bridge steels is being studied. This includes developing methods to improve existing fatigue-prone details to lengthen the fatigue life of bridges. Remelting a weld or peening and grinding cover plate ends, for instance, will improve the fatigue life of the bridge. Gluing and bolting members together also is being pursued to replace welding, especially for minor attachments where welding often has triggered failure in such members. In the fields of hydraulics and hydrology, work continues on establishing stream stability using spur dikes, and work also is underway on flood forecasting, waterway design improvements, and determining the causes and prevention of scour.

In addition to the above, probabilistic design approaches and load and resistance factor concepts for bridges are being proposed. Another area of bridge research vigorously being pursued is corrosion protection using newer coating systems such as epoxy coatings.

To further insure bridge safety, approximately 5,000 bridges are constructed in the United States each year to replace deficient bridges. In recent years, Federal legislation has provided more money to replace deficient bridges; however, the needs are great and it will be many years before all deficient bridges have been replaced or rehabilitated. Some highway bridge economists claim that to keep a country's bridge stock in adequate service, 1.5 to 2 percent of the replacement value of the entire stock must be spent per year for maintenance, repair, rehabilitation, and replacement as needed. *(8)* In the United States, this would represent an expenditure of $2 billion to $3 billion per year.

Conclusion

Although about 44 percent of the Nation's highway bridges are structurally or functionally inadequate, fewer fatalities are associated with bridge failures than with fatalities caused by drunken drivers or air, rail, and marine accidents. However, every effort should be made to inspect and maintain bridges and to strengthen, rehabilitate, replace, or protect those bridges that are vulnerable to damage from accidents and those bridges in which the destruction of one member can cause the collapse of the entire bridge.

It is further emphasized that overloads should be strictly controlled to protect those bridges that cannot carry a static overload and to prolong the fatigue life of many details that are especially sensitive to high stresses. It is recommended that fatigue-prone details be identified in the inspection process and that life-enhancement techniques such as shot peening be applied when the cracks are still small. In general, systematic and scientific monitoring of bridge behavior should be pursued vigorously.

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(8) "Bridge Rehabilitation and Strengthening," *Organization for Economic Co-Operation and Development*, Paris, France, 1983, p. 97.

Charles F. Galambos is Chief of the Structures Division, Office of Engineering and Highway Operations Research and Development, FHWA. He has been active in bridge research for over 25 years, being especially interested in bridge loadings and fatigue and fracture problems. Mr. Galambos continues to actively participate in national and international bridge committees concerned with bridge safety.

Two-Lane Rural Highway Safety[1]

by
Charles Philip Brinkman and Steven A. Smith

Introduction and Background

This article discusses the principal findings of a Federal Highway Administration (FHWA) study to identify safety problems on two-lane rural highways in the United States and to determine the cost-effectiveness of possible highway-related solutions to those problems. The emphasis of the study was to provide general guidance for investing highway safety funds for two-lane rural highways in future years.

An extensive literature review was conducted and existing accident data bases were analyzed to provide current information on the safety performance of two-lane rural highways and the potential benefits of highway improvements or accident countermeasures. The entire two-lane rural highway system was considered as were the range of safety improvements that ordinarily would be considered for use on the system. Although the emphasis of the study was on safety, operational characteristics also were considered. The study should provide the means for designing a two-lane rural highway system that is more integrated, consistent, and safe in light of current and forecasted economic constraints.

Following are some of the important physical and safety characteristics of the two-lane rural highway system:

- The approximately 3.1 million miles (5.0 million km) of two-lane rural highways in the United States represent 97 percent of rural mileage and 80 percent of all U.S. highway miles.
- Two-lane rural highway travel constitutes an estimated 66 percent of rural highway travel and 30 percent of all U.S. highway travel.
- An estimated 38 percent of all two-lane rural highways have average daily traffic (ADT) volumes less than 50 vehicles per day; approximately 80 percent have ADT volumes less than 400 vehicles.
- Two-lane rural highways have a higher accident rate than all other kinds of rural highways except four-lane undivided roads. Two-lane rural highways have a higher percentage of head-on collisions than any other kind of rural highway and also have a higher percentage of single-vehicle accidents. Average accident severity of two-lane rural highways is about the same as that for other kinds of rural highways.
- The probability of an accident on two-lane rural highways is highest at intersections, horizontal curves, and bridges. Compared with other kinds of rural highways, however, two-lane rural highways have a lower percentage of accidents at intersections and a higher percentage of accidents on curves.

[1]This article summarizes "Identification, Quantification, and Structuring of Two-Lane Rural Highway Safety Problems and Solutions, Volumes I and II," Report Nos. FHWA/RD–83/021 and –83/022, Federal Highway Administration, Washington, D.C., June 1983. Unpublished reports.

Stratification of Two-Lane Rural Highways

In an effort to study and classify two-lane rural highway safety problems and potential solutions, a system of stratifying the rural two-lane highway system primarily on the basis of safety performance was developed. The stratification system was not intended as a substitute for administrative functional classification but was intended to distinguish sections of highway from one another based on past and projected accident experience and the potential cost-effectiveness of safety improvements.

The two-lane rural highway system can be stratified by characteristics of longitudinal sections of highway and by characteristics of spot locations. The safety and operation of a section of two-lane rural highway were found to be related to traffic volume, intersection frequency, horizontal curve frequency, and lane width, which describe, to a great extent, the accident rates, accident severities and kinds, and vehicle operating characteristics of the section.

However, much of the safety problem of two-lane rural highways was traced to circumstances at spot locations. Intersections, for example, acquire a different pattern of accident occurrence than do tangent sections of highway or horizontal curves. Therefore, the stratification system included a breakdown for four kinds of spot locations with distinguishable safety characteristics—intersections, horizontal curves, bridges, and railroad grade crossings. The most important factors describing the safety and operation of these locations also were identified.

The stratification system was used to structure cost-effectiveness and programing analyses and was used as the basis for specifying safety goals. It should prove useful in structuring future research and safety programs as well.

Results of the Cost-Effectiveness Analysis

Nearly 60 countermeasures for two-lane rural highways (for example, improvements to the highway geometry, delineation, and signing) were examined in a cost-effectiveness analysis. Research results on the accident-reduction effectiveness of countermeasures were assembled as were data on countermeasure costs and service life, the costs associated with traffic accidents, and forecasted conditions such as traffic volume, demographic trends in the driver population, and trends in vehicle safety features. Operational benefits consisted of reduced delay and lower vehicle operating costs.

Because of wide variation in accepted values of countermeasure effectiveness, a sensitivity analysis was conducted using different assumed accident-reduction factors, accident costs, discount rates (the real cost of borrowing money), and forecasted conditions. Both the 4 percent discount rate recommended by the American Association of State Highway and Transportation Officials (AASHTO) and the 10 percent rate recommended by the U.S. Office of Management and Budget were used, along with the assumption of 1980 constant dollars.

In addition, assumptions were made in the favor of safety. For instance, although both the National Highway Traffic Safety Administration's (NHTSA) higher accident costs and the National Safety Council's lower accident costs were used in a preliminary cost-effectiveness analysis, only NHTSA accident costs were used in the final analysis. This safety-conservative analysis yielded the expenditures reasonably justified for safety on two-lane rural highways.

A benefit-cost ratio was used to compute countermeasure cost-effectiveness. A prime determinant of the cost-effectiveness of a given countermeasure was the traffic volume level assumed—the greater the traffic volume, the more likely a countermeasure will be justified, all other conditions being the same. The traffic volume level at which the benefit-cost ratio equals 1.0 for the various countermeasures and forecasted conditions can be used in a general first-cut analysis of where safety improvements may be justified on two-lane rural highways and also can be used to develop an approximate ranking of countermeasures.

The cost-effectiveness analysis was very sensitive to the choice of accident-reduction factors for countermeasures. Thus, these accident-reduction factors are the weakest link in the study because of the wide variation found in countermeasure evaluations, which are sometimes even contradictory. Discount rate also has a significant impact on the relative cost-effectiveness of accident countermeasures. The use of a 10 percent discount rate makes those countermeasures with higher capital costs substantially less cost-effective than does the use of a 4 percent discount rate. Other assumptions such as accident costs and forecasted conditions have less impact on countermeasure cost-effectiveness.

The most conclusive result of this analysis was the overwhelming preference for low-cost safety improvements, such as signing and delineation. Although the accident-reduction effectiveness of these improvements may be small sometimes, the improvements are so inexpensive compared with higher cost countermeasures, such as geometric changes, that benefit-cost ratios often are well over 1.0 even at the lower ADT levels.

Signing projects and other low-cost improvements to the driver information system potentially are the most cost-effective kinds of improvements for two-lane rural roads. If a signing project reduces accidents to any degree, usually it also will be cost-effective. High priority should be placed on bringing traffic control devices up to standard on the two-lane rural system, being careful to avoid unnecessary signs.

Other highly cost-effective improvements include selective removal of trees, particularly on the outside of horizontal curves; placement of centerlines on curves; and placement of guardrail on the outside of curves with qualifying fill slope and height. Pavement markings and low-cost sight distance improvements at intersections also are highly cost-effective.

General highway upgrading involving pavement and shoulder widening, with some alinement changes, may be justified on the basis of safety for two-lane rural highways with ADT volumes equal to or greater than 3,000 to 5,000 vehicles (assuming a 4 percent discount rate). An estimated 2,000 miles (3 200 km) of two-lane rural highways in the United States may qualify for such major improvements. Widening pavement within the existing cross section may be justified for substantially more miles.

More serious thought should be given to spot application of certain countermeasures. Certain locations of the highway system, such as intersections and curves, experience a disproportionate share of accidents and therefore have a greater potential payoff for safety improvement. Improvements such as centerlines and edgelines, pavement and shoulder widening, and resurfacing, traditionally implemented only for sections of highway, would increase the safety of these spot locations to levels closer to those for other sections of highway.

This idea is compatible with the concept of highway design consistency in that the locations where drivers are more prone to error are given preferential treatment to make the probability of an accident closer to that for other highway sections. However, spot locations on the given section of highway must be treated similarly. For example, widening all narrow bridges except one could create severe adverse safety consequences at the remaining narrow bridge.

Results of the Safety Programing Analysis

Comparison of total benefits and costs

One of the major tasks of this study was to determine the levels of safety attainable over the next 2(years given different levels of investment in safety projects on the two-lane rural highway system. To accomplish this, the results of the cost-effectiveness analysis were used in a linear programing optimization process that maximized benefits for a range of funding levels. Only safety projects that had a benefit-cost ratio of at least 1.0 at a given traffic volume level were eligible for selection.

Curves representing the total 20-year benefits derived from different levels of investment over that same period are shown in figure 1. Each curve ends at the point where there are no further safety improvements having a benefit-cost ratio of at least 1.0. Although total benefits could continue to increase beyond that point, the benefits will not increase as fast as the additional costs incurred.

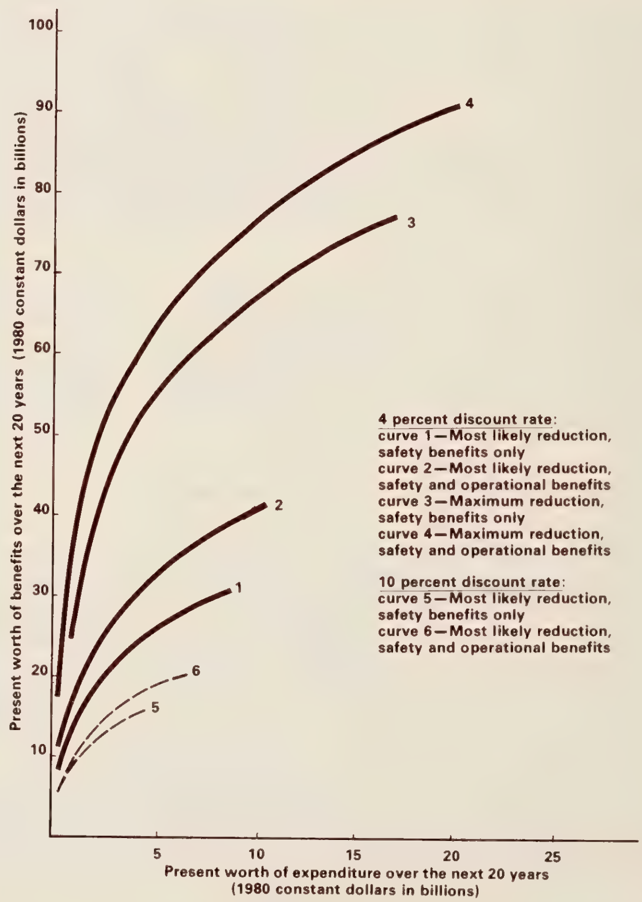

Figure 1.—Dollar benefits from different levels of investment on safety improvements for two-lane rural highways over the next 20 years.

At the 4 percent discount rate, total benefits for the assumed "maximum" accident reductions (curves 3 and 4) are nearly twice that for the assumed "most likely" accident reductions (curves 1 and 2) at the same budget level. If these accident reductions can be achieved, the maximum accident reductions indicate that nearly twice as great an expenditure can be justified for cost-effective safety projects. Operational benefits comprise approximately 25 percent of the benefits in curve 2. For curves 5 and 6, representing the 10 percent discount rate, total benefits for a given cost are approximately 30 to 50 percent lower than for the comparable 4 percent curves.

Also indicated are the diminishing returns for additional investment, typical of economic analyses of this kind. At very low budget levels, the very high payoff countermeasures are selected first, mostly at the higher ADT volumes. This is further illustrated in figure 2 by the benefit-cost ratio curves which are very high at the low funding level and decrease rapidly as the funding level increases. The benefit-cost ratio levels out where the curves end (ranging between 3 and 6) as the expenditure level increases.

For curve 2 (4 percent discount rate), funding of countermeasures would not be cost-effective beyond $9.2 billion over 20 years, leaving the benefit-cost ratio at approximately 5. For curve 6 (same assumptions as curve 2 but with a 10 percent discount rate), funding of countermeasures would not be cost-effective beyond $6.8 billion, leaving the benefit-cost ratio at 3. The benefit-cost ratios are substantially higher for curves 3 and 4 because the maximum accident reductions are assumed.

Implications on funding levels

These results indicate that $4 to $9 billion (1980 constant dollars) in safety funds for two-lane rural highways may be justified over the next 20 years depending on the discount rate and assuming most likely accident reductions. Additional expenditures would force many non-cost-effective countermeasures to be implemented. The 1980 annual Federal safety expenditure on two-lane rural highways was estimated at $0.74 billion. This expenditure alone, without additional State and local funding, is sufficient for cost-effective safety funding over the next 20 years. However, this does *not* necessarily mean

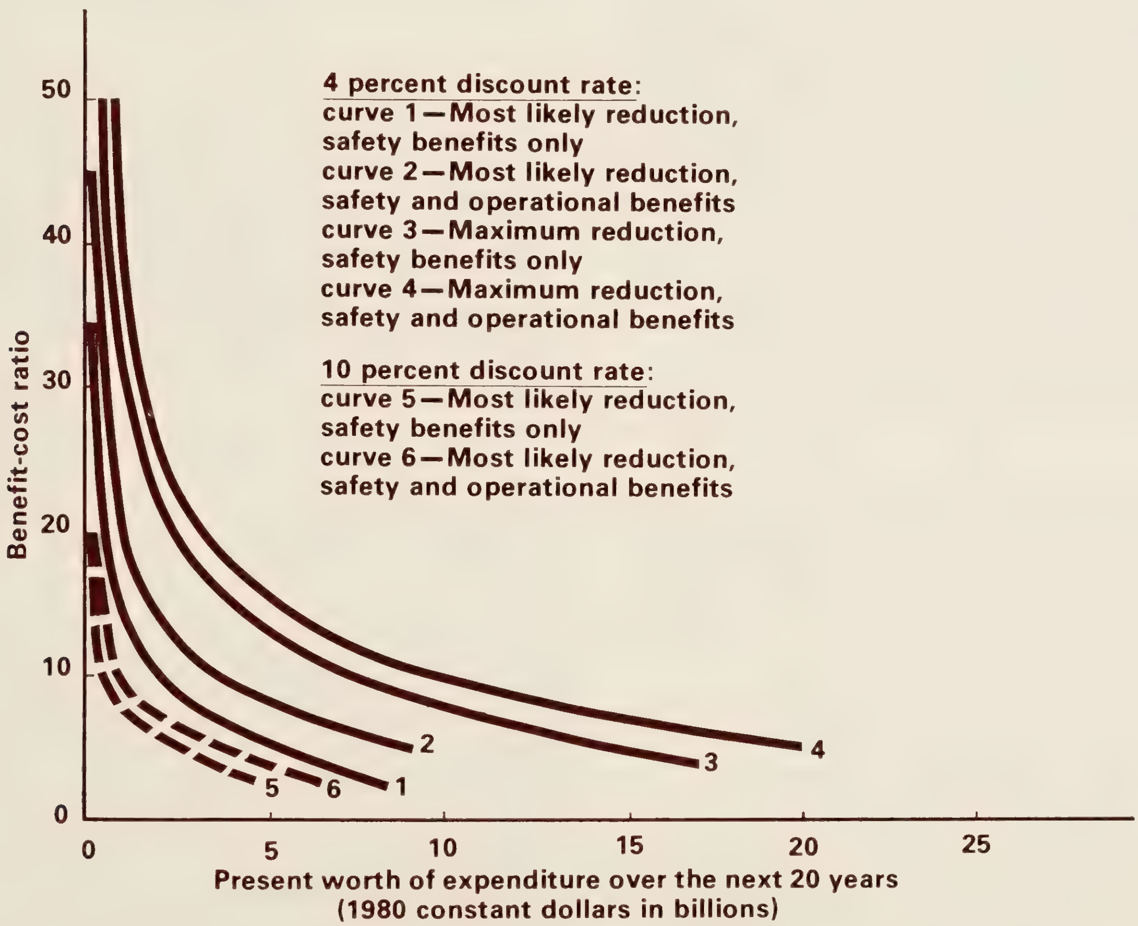

Figure 2.—Benefit-cost ratios from different levels of investment on safety improvements for two-lane rural highways over the next 20 years.

that this high a level of funding should be maintained for two-lane rural highways. Many programs, including safety programs on highways other than two-lane rural as well as other highway and non-highway programs, continually are competing for available funds. Ideally, the cost-effectiveness of all programs should be quantified and the optimum combination for all selected. Highways other than two-lane rural, for example, have 10 times the travel density as two-lane rural highways and therefore have substantially higher cost-effectiveness potential for similar safety projects. Finally, the wide variation in total funding justified based on discount rate and other assumptions indicates these results should be used only as a general guide.

Figure 3 indicates the number and percent of the 34 million accidents[2] that the highway safety improvements considered in this study might be expected to reduce, over the next 20 years, based on the funding level. For the most likely accident reduction assumption and 4 percent discount rate (curve 1), an expenditure of $9.2 billion on two-lane rural highway safety over the next 20 years would reduce accident rates by approximately 4.5 percent, or about 1.5 million accidents over 20 years. However, the total number of accidents would continue to increase, primarily because of traffic volume growth. For the most likely accident reduction assumption and 10 percent discount rate (curve 3), an expenditure of $6.8 billion would reduce accident rates by slightly more than 2 percent, or about 0.8 million accidents, over the next 20 years. Although these percent reductions may appear small, the benefit-cost ratio is still well above 1.0 (assuming NHTSA accident costs). If the maximum accident reductions are assumed, the percent reduction more than doubles. It is doubtful whether an observed reduction in accident rate of 5 percent or less could be attributed through future evaluations to such highway accident countermeasures. Too many other factors change simultaneously, and the inability to trace accident reporting levels further compounds the situation.

Assuming the most likely accident reduction and the 4 percent discount rate, the potential percentage of accidents reduced through cost-effective safety improvements are as follows for each ADT volume:

0 to 400 ADT—1 percent;
400 to 1,000 ADT—3 percent;
1,000 to 2,000 ADT—3 percent;
2,000 to 5,000 ADT—7 percent;
5,000 to 10,000 ADT—6 percent; and
over 10,000 ADT—8 percent.

As indicated, accident reduction generally is less on lower ADT volume roads than on higher volume roads because more cost-effective projects can be found at the higher volume levels. Although the higher volume roads generally have a better design, driver expectancies also are higher, many deficiencies still exist, and the exposure levels are much higher than their low-volume counterparts.

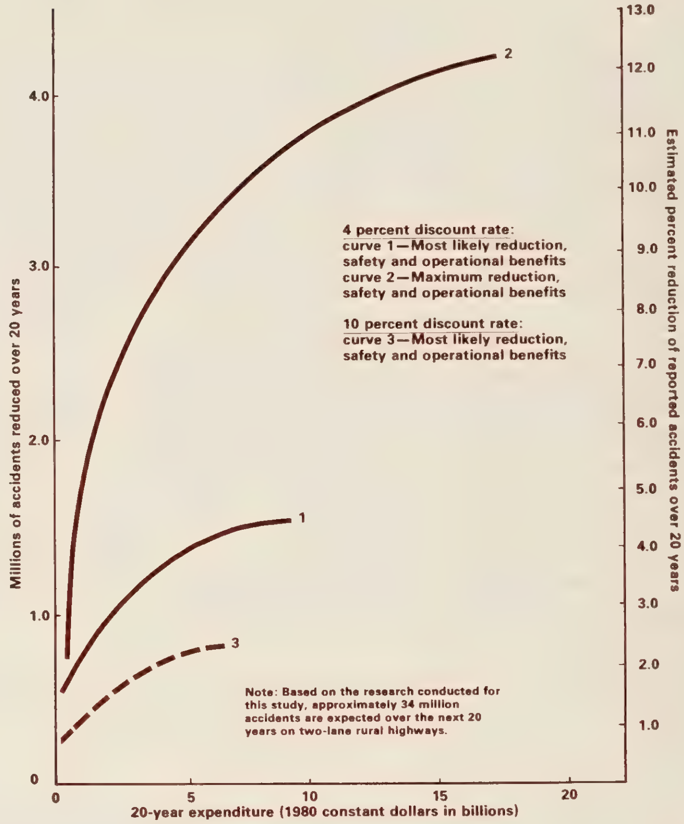

Figure 3.—Number and percent of accidents reduced on two-lane rural highways over the next 20 years.

These percent reductions assume that the optimum combination of safety improvements actually is implemented and that non-cost-effective countermeasures are avoided. It is important to identify the highest priority projects to avoid investing in non-cost-effective safety improvements.

Maintaining the existing safety devices and two-lane rural highway system should, in most cases, take priority over new safety construction. Hopefully, the locations with the greatest safety problems have been improved in the past and greater benefit therefore can be achieved by maintaining these locations rather than installing new safety devices at more recently identified less hazardous locations. Mechanisms should be available to insure that such maintenance funds are available. Maintenance funding needs are very large and will increase with the addition of new safety improvements. The development of lower cost materials and devices also should be given high priority to maximize safety dollars.

[2]Based on the research conducted for this study, approximately 34 million accidents are expected over the next 20 years on two-lane rural highways.

Safety Goals

One important question addressed in this study was the need for and approach to establishing highway safety goals. Without such goals, funding requirements cannot realistically be established because it is never clear when the objectives of a safety program have been met. One of the primary reasons for conducting the programing analysis was to further develop the idea of establishing safety goals for two-lane rural highways.

The programing analysis identified a cost-effective program for implementing safety improvements on two-lane rural highways over the next 20 years. Certain quantities (in terms of number of miles or projects) of potentially successful 20-year safety goals for two-lane rural highways are specified for future implementation on a national scale (table 1). The selected examples are not necessarily the highest payoff improvements. These goals are not intended to be a rigid set of implementation targets but are meant to provide general guidance as to where safety funds should be invested over the next 20 years, given different levels of funding. Although the goals should be revised periodically based on updated inventory information, the general conclusions should remain valid unless innovative thinking and research produce radically new safety concepts.

The ultimate goal to be achieved with implementing safety improvements is optimizing benefits for a given cost. Because of the many varied highway geometrics, kinds of traffic control devices, and traffic factors that can influence the cost and effectiveness of a particular safety improvement, and because no adequate inventory of safety problems and devices exists at the national level, those closest to the problems—State and local highway agencies—should be responsible for the optimization process.

Table 1.—Typical 20-year system goals

Improvement	Number of miles or projects	
	4 percent discount rate	*10 percent discount rate*
Shoulder widening	9,500 miles	5,100 miles
Pavement widening	30,700 miles	17,500 miles
Add left turn lane	43,400 projects	28,400 projects
Railroad-highway grade separations	900 projects	480 projects
Intersection beacons	1,640 projects	440 projects
Striping and delineation	85,200 miles	86,900 miles

1 mile = 1.6 km

The problems and needs of agencies having jurisdiction over two-lane rural highways are unique. A vast mileage of highway must be managed and on most of the highway the occurrence of an accident is rare. Determining whether a section of or particular spot on a highway truly constitutes a safety hazard is difficult, and treating such a hazard often is not cost-effective.

The goal at the Federal level then is to support the optimization process at the State and local levels by providing training in processes for improving safety; analysis procedures and programs; general guidelines on countermeasure cost-effectiveness; and detailed statistical data on accident rates, accident severities and kinds, accident-reduction factors, operational benefits, and improvement costs and service lives.

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Implications of Small Passenger Cars on Roadside Safety[1]

by
John G. Viner

Introduction

The safety implications of passenger car downsizing are of much current interest. Vehicle-vehicle collisions and vehicle-roadside accidents are the two major accident modes that may be affected by passenger car downsizing. This article reviews the roadside fatal accident problem[2] and the implications of passenger vehicle downsizing on major kinds of roadside fatal accidents.

Currently, overturn accidents comprise the largest category of roadside fatalities, and these accidents are likely to increase greatly as the size of passenger vehicles decreases. Also expected to increase significantly because of the trend to smaller passenger cars is the number of fatalities resulting from collisions with utility poles—currently accounting for more fatalities than from collisions with any other fabricated roadside object. Other significant categories of roadside fatalities, such as guardrail and bridge rail collisions, may show a much lesser change as cars become smaller; however, significant changes in vehicle impact behavior are being identified in individual vehicle designs.

The implications from current information suggest that the outside of horizontal curves may require special attention when deciding whether to clear obstacles, flatten roadside slopes, or install guardrails. Also, guardrails may be cost-effective in front of more roadside slope combinations than has been indicated by past accident research. Finally, guidelines on undesirable geometrics and on the maximum desirable breakaway levels of signs and luminaire supports may need to be adjusted. Research planned or now underway is intended to clarify these issues.

[1]This article is a condensation of an article in the Proceedings of the Twenty-Seventh Conference, American Association for Automotive Medicine, San Antonio, Tex., Oct. 3–6, 1983.

[2]In this article, roadside fatalities do not include fatalities that occur on the roadway or shoulder.

General Accident Effects of Small Cars

In collisions between vehicles of different weights, the occupants in lighter weight vehicles generally are at a greater risk. Figure 1 shows a cumulative distribution of the weights of passenger vehicles in single-vehicle, police-reported accidents and in all passenger vehicles involved in all police-reported accidents in Texas in 1981. The cumulative distribution of the weights of passenger vehicles registered in Texas in 1981 is shown for comparison.[3] The weight distributions of passenger vehicles involved in single-vehicle accidents are nearly identical to the weight distributions of passenger vehicles involved in all police-reported accidents. The accident-involved vehicles tend to be lighter than the vehicles registered in the State, although care must be taken in such comparisons because the curb weight estimation methods used in conjunction with the accident data may differ from the method used in the Texas registration file. Fifty percent of the passenger vehicles registered in Texas weighed less than 3,550 lb (1.61 Mg); however, 58.2 percent of all single-vehicle accidents and 57.2 percent of all 1981 Texas police-reported accidents involved vehicles that weighed less than 3,550 lb (1.61 Mg). The percent of vehicles with curb weights less than 2,250 lb (1.02 Mg) will be used as another point of reference in this article because most roadside safety hardware was designed for vehicles in the 2,250 to 4,500 lb (1.02 to 2.04 Mg) range. *(1)*[4] At the 2,250 lb (1.02 Mg) weight range in figure 1, no difference is seen between the registration figures, the vehicles involved in single-vehicle accidents, and all vehicles involved in accidents—each distribution shows approximately 11.4 percent of vehicles weigh less than 2,250 lb (1.02 Mg).

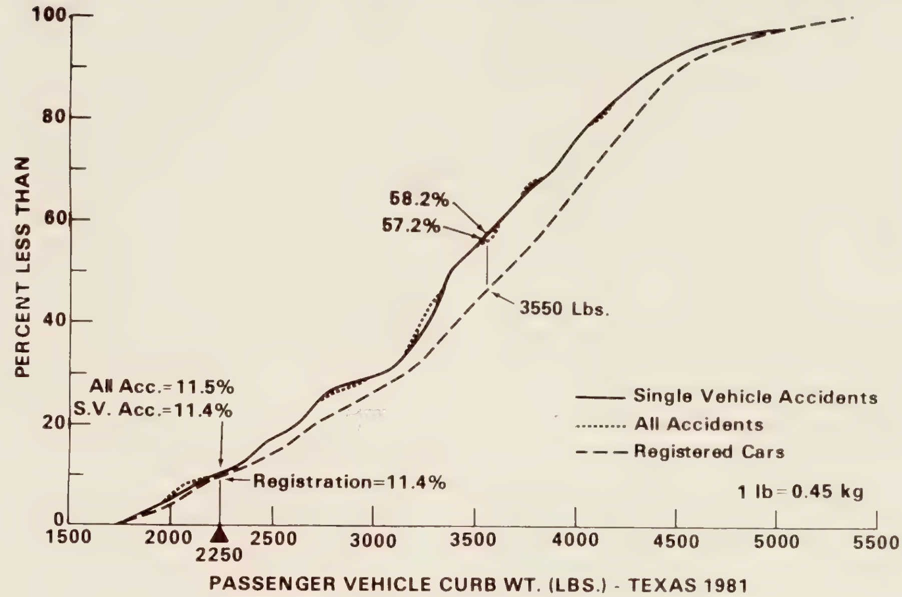

Figure 1.—Curb weight of passenger vehicles in police-reported accidents, Texas 1981.

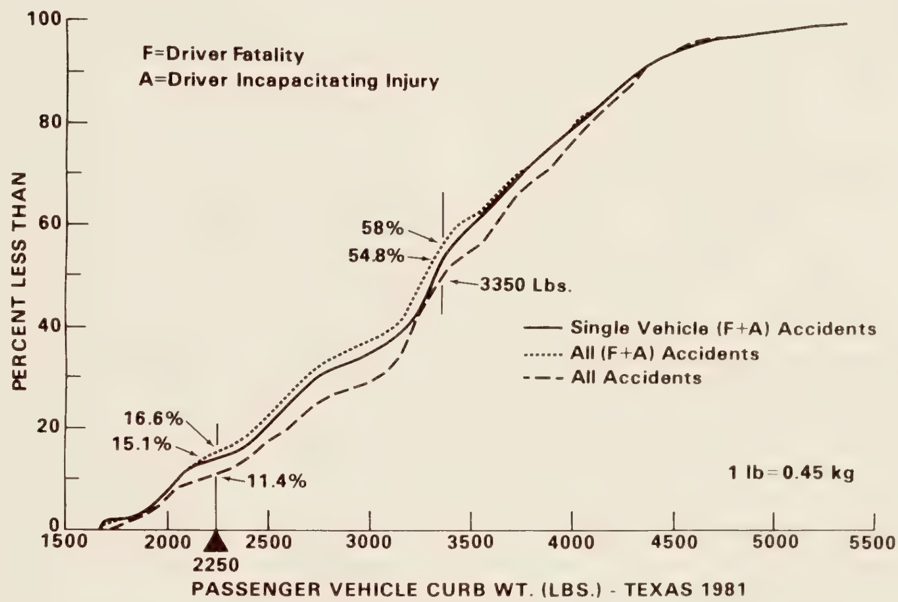

Figure 2.—Curb weight of passenger vehicles in driver fatal and incapacitating injury accidents, Texas 1981.

Figure 2 compares similar distributions for vehicles in which the drivers suffered fatal and incapacitating injuries with the weight distribution of vehicles in all police-reported accidents shown in figure 1. Driver injury is used to assign collision severity outcomes to individual vehicle occupants in multivehicle collisions. Fifty percent of the accidents involved vehicles weighing less than 3,350 lb (1.61 Mg); however, these vehicles accounted for 58 percent of all driver fatalities and

[3]National Vehicle Population Data Base, R. L. Polk and Company.

[4]Italic numbers in parentheses identify references on page 62.

incapacitating injuries and 54.8 percent of the single-vehicle driver fatalities and incapacitating injuries. Vehicles weighing less than 2,250 lb (1.02 Mg) were involved in 11.4 percent of accidents but accounted for 15.1 percent of single-vehicle fatalities and incapacitating injuries and 16.6 percent of fatalities and occupant injuries in all police-reported accidents.

Figure 3 shows a National Highway Transportation Safety Administration (NHTSA) sales weighted projection of the weights of all cars produced in model year 1985.[5] This projection is based on information provided in August 1980 by manufacturers representing about 90 percent of U.S. automobile passenger sales. California 1979 and Texas 1981 passenger car weight distributions are shown for comparison. It can be seen that one effect of the downsizing of passenger vehicles is a smaller spread in the weight distribution of passenger cars. It has been argued that this trend is likely to reduce weight-related effects in the severity of vehicle-vehicle collisions.

Specific Ran-Off-Road Accidents

Ran-off-road accidents are a major safety problem. In 1981 a roadside feature was judged to be the most harmful event in 35.1 percent of all U.S. traffic fatalities and in 37.5 percent of fatalities on the Interstate System.[6] Table 1 provides a breakdown of fatalities in which a roadside feature was the most harmful event.

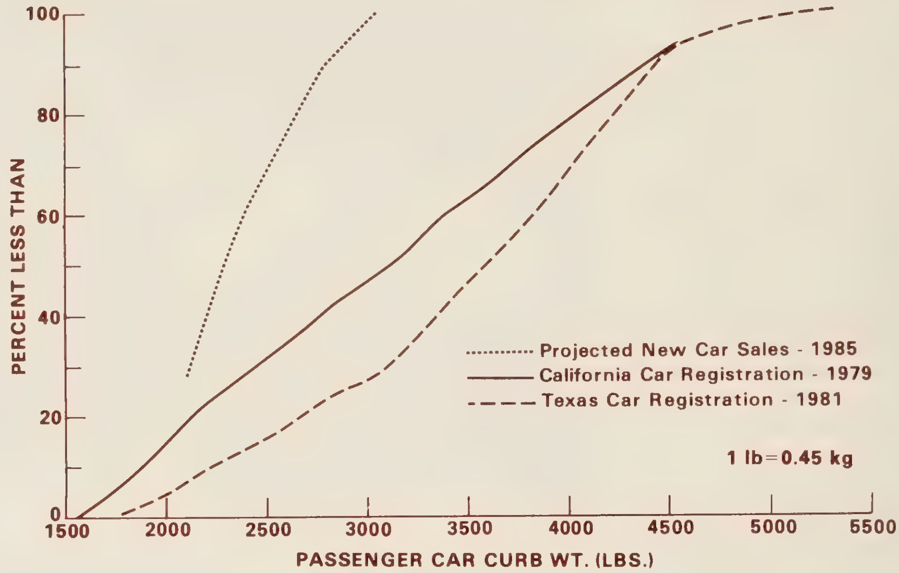

Figure 3.—Passenger vehicle curb weights—California 1979, Texas 1981, and projected 1985 model year sales.

Table 1.—Most harmful event in 1981 roadside fatalities

Event	Interstate		Total	
	Number	*Percent*	*Number*	*Percent*
Overturn	759	44.7	5,848	33.8
Tree	94	5.5	3,388	19.6
Utility pole	26	1.5	1,636	9.5
Embankment	58	3.4	663	3.8
Culvert/ditch	53	3.1	638	3.7
Guardrail	201	11.8	616	3.6
Bridge rails	76	4.5	509	3.0
Immersion	23	1.4	429	2.5
Fire/explosion	64	3.8	353	2.0
Curb or wall	37	2.2	324	1.9
Bridge piers	79	4.7	258	1.5
Object not fixed	33	2.0	236	1.4
Building	—	—	203	1.2
Light support	16	0.9	190	1.1
Sign support	33	2.0	164	0.9
Fence	9	0.5	164	0.9
Other poles	7	0.4	160	0.9
Divider	34	2.0	90	0.5
Unknown/other	95	5.6	1,415	8.2
Total	1,697	100.0	17,284	100.0

[5]Memorandum on vehicle weight projections from R. L. Strombotne, Director, Office of Automotive Fuel Economy Standards, National Highway Traffic Safety Administration, to C. F. Scheffey, Director, Office of Research, Federal Highway Administration, May 26, 1981.

[6]Fatal Accident Reporting System (FARS) Data, National Highway Traffic Safety Administration, 1981.

Overturns

Table 1 indicates that overturn was the leading cause of roadside fatalities in 1981, accounting for 33.8 percent of roadside fatalities and 44.7 percent of Interstate roadside fatalities. A strong relationship exists between passenger car curb weight and probability of overturn—the lighter the vehicle the higher the probability of overturn (fig. 4). *(2)* National Accident Sampling System (NASS) data indicate that fatalities are 5.7 times more likely in single-vehicle overturn accidents than in nonoverturn single-vehicle accidents.[7] In single-vehicle, police-reported accidents in Texas in 1981, 2.32 percent of overturn accidents resulted in driver fatality, as compared with 1.21 percent for nonoverturns—a ratio of 1.9. In overturn accidents, no vehicle size effect was found in driver fatalities or incapacitating injuries (fig. 5). An estimate of likely changes in passenger vehicle overturn fatalities as a result of downsizing can be made by comparing overturn to nonoverturn single-vehicle fatalities with the data from figures 3 and 4. For example, a change in passenger vehicle fleet weights from California 1979 registration values to the projected 1985 model year sales distribution increases expected Interstate overturn accidents 1.6 times and based on 1981 Texas accident data increases expected Interstate overturn fatalities and incapacitating injuries 3.0 times.

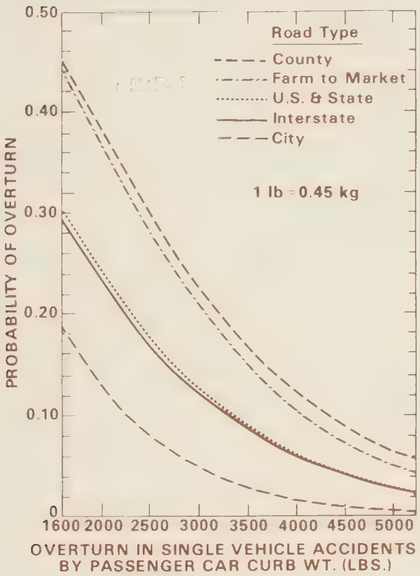

Figure 4.—Probability of overturn in single-vehicle accidents as a function of road type and passenger car curb weight.

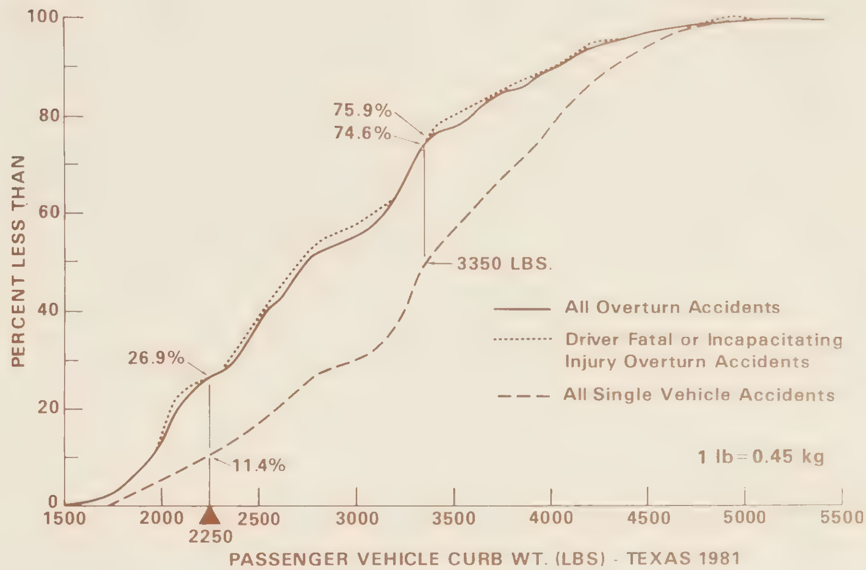

Figure 5.—Curb weight of passenger vehicles in overturn accidents, Texas, 1981.

[7]National Accident Sampling System, 1981 case data provided by S. Partyka, National Highway Traffic Safety Administration.

Utility poles

Utility poles are the most frequently struck fixed objects in fatal collisions, accounting for 1,636 fatalities in 1981 (table 1). Figure 6 shows that the severity of small car collisions with utility poles is significantly greater than the severity of large car collisions with utility poles. *(3)* A change in passenger vehicle fleet distributions from the California 1979 distribution to the projected model year 1985 sales distribution would indicate a 50 percent increase in the probability of fatalities and incapacitating injuries in utility pole collisions.

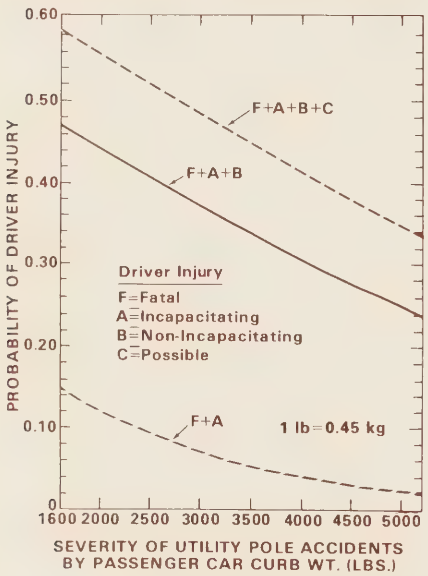

Figure 6.—Probability of driver injury in collisions with utility poles.

Traffic railings

Traffic railings (616 guardrails, 509 bridge rails or ends, and an unknown fraction of curbs or walls and dividers) were the most harmful event in over 1,100 fatalities in 1981 (table 1). From physical research on traffic railings it would be expected that the importance of passenger vehicle size on the severity of traffic railing collisions would be a function of specific guardrail, median barrier, bridge rail, and traffic railing terminal design. That is, passenger vehicle size effects in traffic railing collisions, such as vehicle snagging on traffic railing posts, overturn, and the deflection of a traffic railing in a given impact, will vary with the design of the specific railing and would be difficult to identify from a study of police-reported accidents.

For shaped concrete median barriers, the effects of passenger vehicle size on the likelihood of vehicle overturn has been questioned. An earlier research study has shown that variations in concrete median barrier profile affect overturn potential and that 2,250 lb (1.02 Mg) vehicles are more prone to overturn than 4,500 lb (2.04 Mg) vehicles in impacts with these barriers. *(4)* Table 2 lists the overturn outcome of all 1979 police-reported median barrier accidents for the three most common barrier designs used on California freeways. Passenger vehicle overturns from impacting the shaped concrete barrier occurred at 1.9 times the rate of the cable median barrier (which is no longer used on new construction) and at 3.8 times the rate of the metal beam barrier. For all vehicle classes, overturns occurred from impacting the shaped concrete barrier at 2.5 times the rate of the metal beam barrier.

Table 2.—Median barrier accidents on California freeways, 1979

Accident type	Median barrier type Concrete (MB5)		Cable (MB1)		Metal beam (MB4W)	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*
Total accidents	1,796	100.0	2,305	100.0	2,004	100.0
Total overturn	177	9.9	143	6.2	78	3.9
Passenger vehicle overturn	123	6.8	83	3.6	37	1.8
Nonpassenger vehicle overturn	54	3.0	60	2.6	41	2.0

The cumulative weight distribution of 123 passenger vehicles that overturned from colliding with the New Jersey shaped concrete median barrier is shown in figure 7 along with the weight distribution of passenger vehicles registered in California in 1979. Fifty-one percent of the overturned vehicles weighed less than 2,250 lb (1.02 Mg), although these vehicles only account for 24 percent of passenger vehicle registrations. The overturn and registration curves diverge up to a weight of about 2,700 lb (1.22 Mg) and converge as weight increases, which means that concrete median barrier accidents are overrepresented for vehicles lighter than 2,700 lb (1.22 Mg). This figure, as well as the 6.8 percent passenger vehicle concrete median barrier overturn rate of table 2, is a function of the weights of all passenger vehicles actually impacting the barrier. In the absence of these data, the registration data have been used as a surrogate measure in this article. Because the 1979 California passenger vehicle fleet was lighter than the 1981 Texas fleet (median curb weight of 3,100 lb [1.41 Mg] versus 3,550 lb [1.61 Mg]), a lower overturn rate would be expected if Texas 1981 accident data were examined.

Figure 8 shows the weight distribution of vehicles that overturned on impact with each of the three California freeway median barrier designs. The cable median barrier also shows a vehicle size effect—50 percent of overturns occurred at weights less than 2,250 lb (1.02 Mg). The metal beam barrier distribution is much closer to the registration weight distribution.

Fatal plus injury (F+I) accident rates are comparable for these three kinds of median barriers at 0.07 per million vehicle-miles (0.04 per million vehicle-kilometres) for 1981 accidents in California. Data for the 5-year period from 1977 to 1981 are available; however, it is not possible from this information to determine which fatal plus injury rates if any may be changing significantly with time because complications such as removal of significant amounts of cable barrier and construction of significant amounts of concrete barrier occurred simultaneously with changes that possibly could be attributed to the characteristics of the vehicle fleet using these facilities.

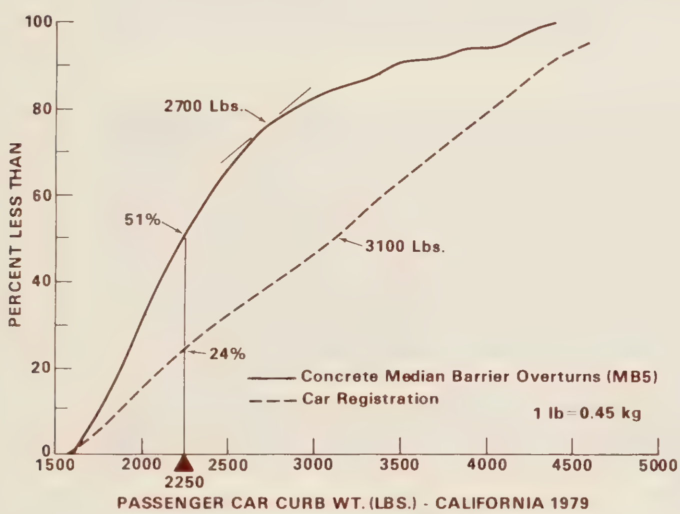

Figure 7.—Curb weight of passenger vehicles that overturned after impacting concrete median barriers, California freeways, 1979.

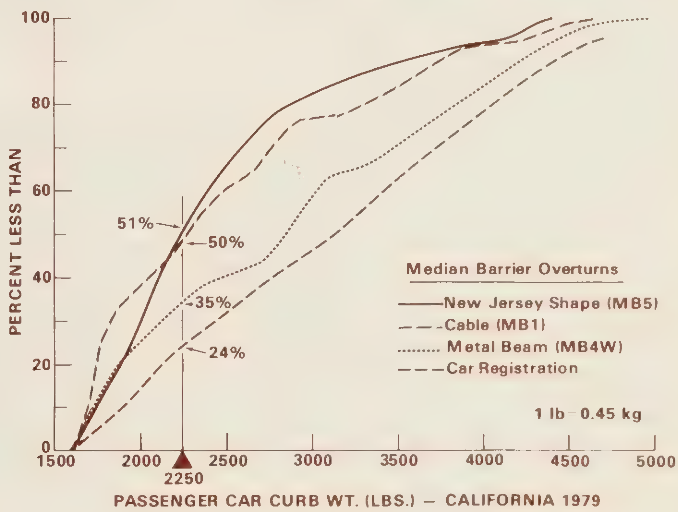

Figure 8.—Curb weight of passenger vehicles that overturned after impacting median barriers, California freeways, 1979.

Snagging of passenger vehicles on bridge rail posts has been investigated in a research study.[8] Figure 9 shows a vehicle from each of the weight classes against an open railing, the Indiana 5A bridge rail. Figures 10–13 show vehicles from each weight class after 60 mph (97 km/h), 15° impact tests with a New Hampshire two-bar aluminum bridge rail. Overall resultant accelerations (highest 50 msec averages) were 15.1 g for the Honda, 10.9 g for the Vega, and 7.2 g for the Plymouth. The New Hampshire bridge railing is open in design and thus relatively prone to snagging, so the test results cannot be generalized to all bridge rails. Snagging clearly varied with the vehicle in these tests. The geometry and strength of the front corners of these vehicles thus are important to the outcome of these tests.

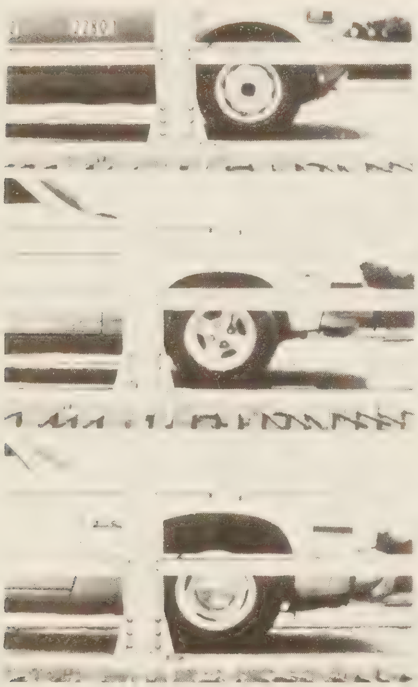

Figure 9.—Honda Civic (1,800 lb [0.82 Mg]), Vega (2,250 lb [1.02 Mg]), and Plymouth (4,500 lb [2.04 Mg]) against Indiana 5A bridge rail.

[8]E. Buth, "Safer Bridge Railings, Volume 1: Summary Report," Report No. FHWA/RD–82/072, Federal Highway Administration, Washington, D.C., January 1983. Not yet published.

Figure 10.—Honda Civic after 60 mph (97 km/h), 15° impact with New Hampshire bridge rail.

Figure 11.—New Hampshire bridge rail after crash tests.

Figure 12.—Vega after 60 mph (97 km/h), 15° impact with New Hampshire bridge rail.

Figure 13.—Plymouth after 60 mph (97 km/h), 15° impact with New Hampshire bridge rail.

Ongoing research is examining the snagging potential of several of the more widely used guardrails with 1,800 lb (0.82 Mg) class vehicles. The modified thrie beam guardrail (fig. 14) has been found to have less snagging potential than the widely used strong post "W" beam (fig. 15) based on 60 mph (97 km/h) tests. No snagging problems were found with either railing in 60 mph (97 km/h), 15° tests with an 1,800 lb (0.82 Mg) Honda Civic. The difference between the snagging potential of these two railings is likely to be more important on the outside of horizontal curves. In a study of accidents on nonfreeways, 73 percent of the 2,808 ran-off-road accidents on horizontally curved alinements occurred on the outside of the curve, thus, this is an important location. *(5)*

Figure 14.—Modified thrie beam guardrail after test with Honda Civic.

Figure 15.—Strong post "W" beam guardrail after test with Honda Civic.

Supports

Sign and luminaire supports were the most harmful events in 354 fatalities in 1981 (table 1). It is not known how many of these fatalities involved breakaway supports as opposed to nonbreakaway supports. The severity of collisions with breakaway sign and luminaire supports is, however, known to increase as the weight of the colliding vehicle decreases. An ongoing research study examining the current specifications for these supports has found that overturns may result from high-speed, offcenter collisions with supports that just meet current breakaway criteria and that side impacts with such supports may be severe.[9] A pole especially designed to represent the limiting breakaway behavior of these specifications was used in these tests. *(6)* Figure 16 shows the alinement of this pole with an 1,850 lb (0.84 Mg) Volkswagen Rabbit in a 60 mph (97 km/h) offcenter impact test. The structure did break away; however, the vehicle yawed and rolled over violently (fig. 17).

Figure 16.—Alinement of current specification breakaway pole for 60 mph (97 km/h), 1,850 lb (0.84 Mg) vehicle test.

Figure 17.—Vehicle after test.

[9]"Laboratory Procedure to Determine the Breakaway Behavior of Luminaire Supports in Minisized Vehicle Collisions," Federal Highway Administration research study in progress.

Summary

Ran-off-road collisions, which currently comprise the largest category of traffic fatalities, are likely to increase as passenger vehicles become smaller. In particular, overturn fatalities may increase dramatically, and utility pole fatalities may increase significantly. The impact behavior of minisized cars is different with various designs of roadside safety devices. The projected increase in overturns suggests that guardrails may be cost-effective in more locations, such as the outside of horizontal curves, than indicated by past accident research studies. Because of higher impact angles more likely on horizontal curves than on tangential alinements, consideration should be given to the use of guardrails with superior resistance to snagging minisized cars, such as the modified thrie beam, on the outside of horizontal curves. Research on single-vehicle overturns will explore these and other such issues.

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(5) K. Perchonok et al., "Hazardous Effects of Highway Features and Roadside Objects, Volume 2: Findings," Report No. FHWA–RD–78–202, *Federal Highway Administration*, Washington, D.C., September 1978. PB No. 295824.

(6) "Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals," *American Association of State Highway and Transportation Officials*, 1975.

[10]Reports with PB numbers are available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, Va. 22161.

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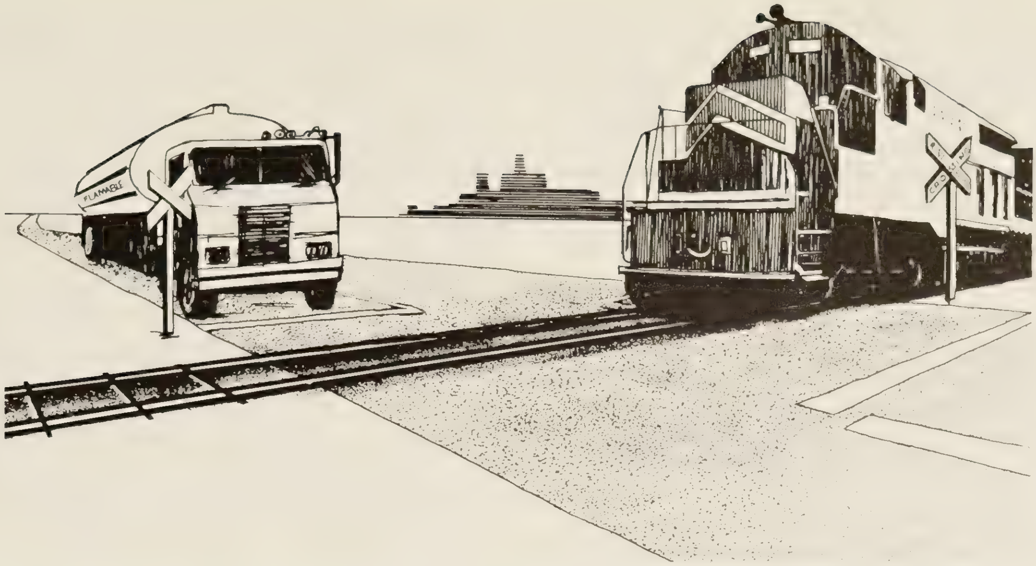


Railroad-Highway Crossings and Route Selection for Transporting Hazardous Materials

by
Janet A. Coleman

A 1980 Federal Highway Administration (FHWA) study investigated the hazardous materials routing problem and developed route selection criteria based on the probability of a hazardous materials accident. ***(1)*** [1] **In this study, which was documented in the September 1983 issue of** ***Public Roads (2)*****, Federal, State, and local laws and regulations were studied to determine the factors to be considered in evaluating alternative routes for transporting hazardous materials. The criteria developed were field tested and evaluated in two communities. The methodology was well received and a supporting report was prepared to assist users in applying the criteria.** ***(3)***

One omission from the FHWA study, however, was the consideration of railroad-highway crossings along the routes being evaluated. This article, a followup to the September 1983 article, addresses this omission by identifying how the previously developed guidelines for designating routes for transporting hazardous materials can be expanded to include railroad-highway crossings and identifying special considerations to be analyzed when a route includes a railroad-highway crossing.

Introduction

Each year there are approximately 62 railroad-highway crossing accidents involving a highway user carrying hazardous materials. *(4)* Many of these accidents result in the release of poisonous gases or in oil spills. In some cases, whole communities have to be evacuated until the danger subsides. Although the number of fatalities and injuries resulting from these accidents has not been large, railroad-highway crossing accidents involving hazardous materials have the potential of inflicting severe damage on the local environment and population. This is partly because many railroad-highway crossings are located in highly populated urban and industrial areas.

Currently there are no nationwide estimates on the number of crossings regularly used by vehicles carrying hazardous materials, and this kind of use needs to be considered by States and railroad companies in identifying crossings for improvement and in selecting the kinds of improvements to be made. Also, there are no precise figures on the portion of commercial vehicles on the road that regularly carry hazardous materials; however, the National Transportation Safety Board (NTSB) estimates this figure to be between 5 and 15 percent. *(5)*

[1] Italic numbers in parentheses identify references on page 71.

In 1980, the NTSB initiated a special study to investigate railroad-highway crossing accidents involving trucks carrying bulk hazardous materials. *(4)* The study identified specific deficiencies in the existing crossing accident and inventory data bases. The data available from all sources were summarized and the following observations were made:

- Hazardous materials truck accidents most often occurred on Mondays.
- Most hazardous materials truck accidents occurred in two regions of the United States—in the South along the Gulf of Mexico and in the Midwest, including Illinois, Indiana, and Ohio.
- Texas had the most accidents, with 30 in a 5-year period.
- Most accidents occurred in the late fall and winter months when there is a high demand for heating fuel and in the summer months when there is a high demand for gasoline.
- In the 14 accidents investigated by the BMCS, none of the truckdrivers was found to be under the influence of alcohol.

As a result of this special study, NTSB recommended that the information contained in the 1980 FHWA study on hazardous materials routing selection be expanded to specifically address the hazards at railroad-highway crossings.

Expansion of Hazardous Materials Routing Criteria—Analysis Procedure and Example

The hazardous materials route selection criteria (fig. 1) described in the September 1983 *Public Roads* article easily can be expanded to include the effects of railroad-highway crossings on identifying and selecting the best route for transporting hazardous

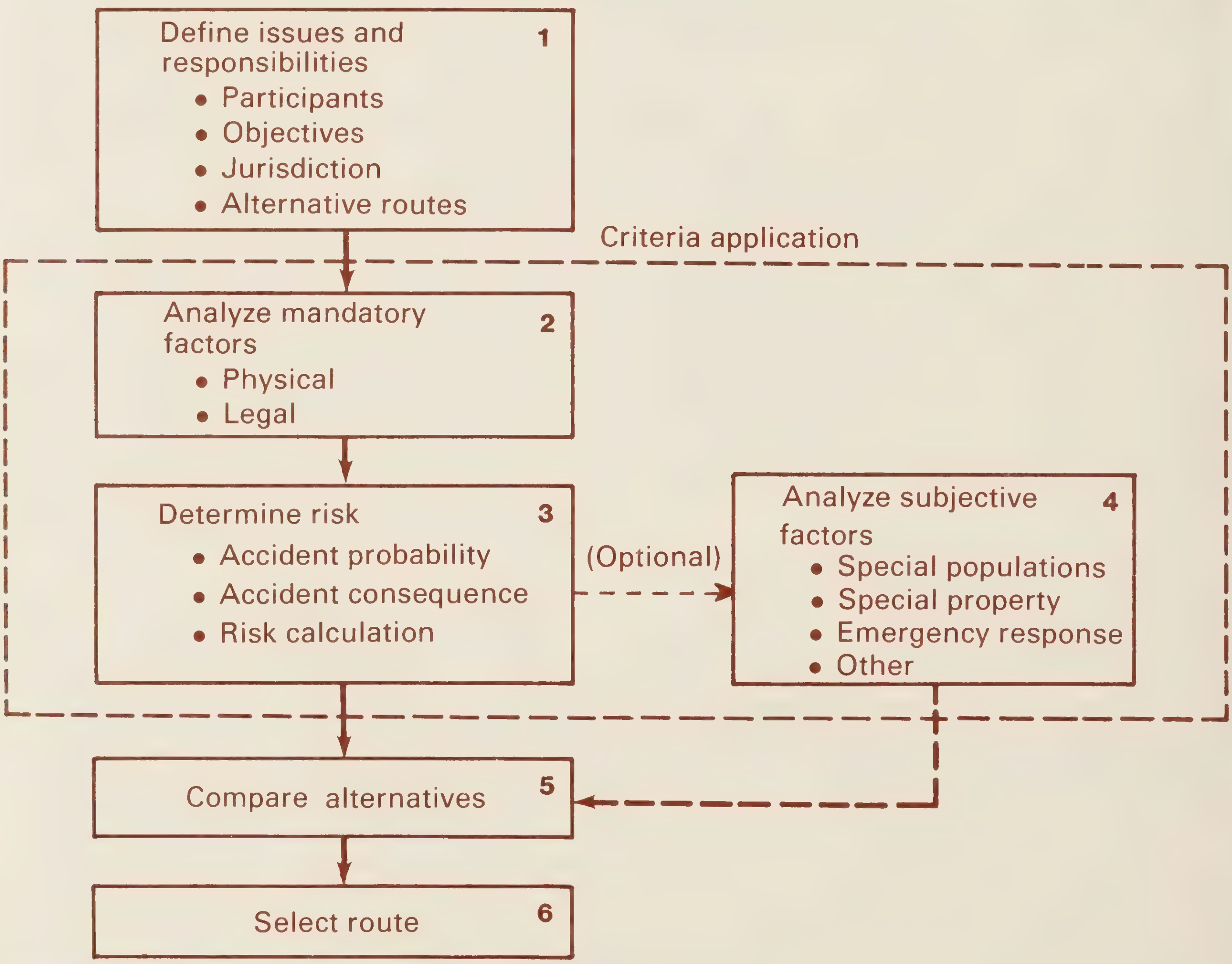


Figure 1.—Hazardous materials routing method.

materials. A modified version of the Routing Analysis Worksheet developed in the 1980 FHWA study can be used to include railroad-highway crossings in the routing analysis procedure. Grade-separated crossings are added to alternative routes 1 and 3, and an at-grade crossing is added to alternative route 2 on the map of Plainfield (fig. 2), the hypothetical city used in the 1980 FHWA study. Figure 2 also shows special populations and properties along the alternative routes. The definitions established in the 1980 FHWA study and the specific values established for the Plainfield example are used again in the present analysis.

Population and property damage risks

An at-grade crossing has been included in the routing analysis by expanding the risk determination and subjective factors portions of the analysis (steps 3 and 4 in fig. 1). The kinds of crossing characteristics data needed in the risk determination include crossing number and location (to permit access to the inventory data maintained by the Federal Railroad Administration [FRA]), existing warning device, total trains per day, average daily highway traffic, estimate of percent trucks, daily through trains, number of main tracks, highway surface (paved or unpaved), maximum timetable speed, highway functional type, number of highway lanes, number of years of accident history (T), and number of accidents in T years.

The crossing inventory characteristics data may be obtained from either the nationwide crossing data base maintained by the FRA or a State data base. The accident history information for each crossing may be obtained from the crossing accident data reported to the FRA or from the railroad companies using the crossing.

The crossing inventory characteristics data and accident history data are used to calculate the predicted number of accidents for a specific crossing. Any accident prediction formula may be used that provides an absolute prediction of the numbers of accidents per year per specific crossing.

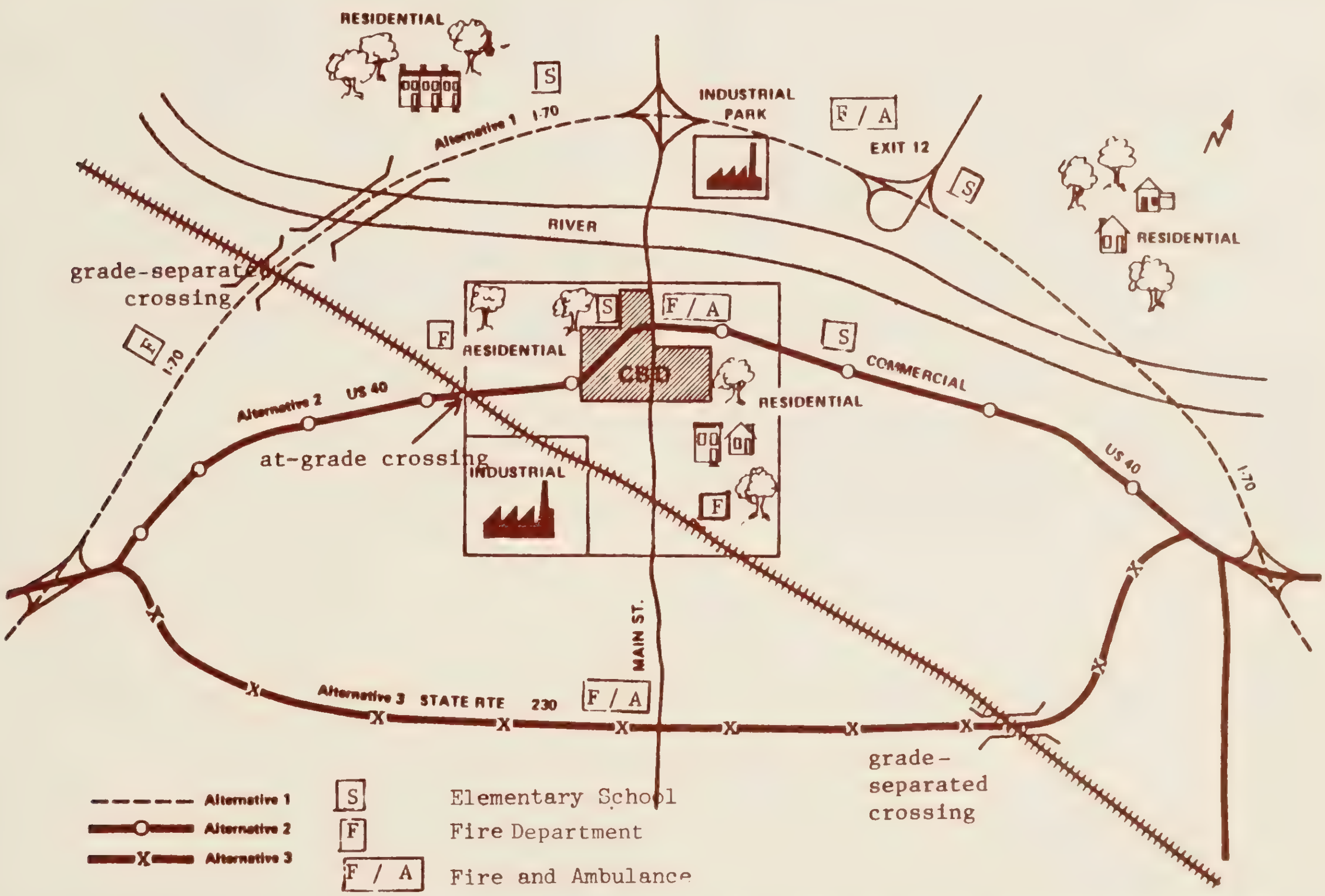


Figure 2.—Hypothetical city of Plainfield—hazardous materials routing alternatives and special populations and properties.

The risk determination for grade crossings involves calculating the probability of a hazardous materials accident and then determining the total population and total property risks. The probability of a hazardous materials accident at a crossing is defined as the expected accident rate at the crossing[2] multiplied by the exposure to hazardous materials vehicles. The exposure of hazardous materials vehicles is determined by multiplying the estimated percent trucks from the crossing inventory data by the portion of trucks estimated to be carrying hazardous materials.

Population and property risk values are calculated separately for each segment of a route and then added to produce the risk value for the total route. The risk value for a crossing is calculated separately and added to the risk values for the segments of a route. *(3)* The numeric risk value is an absolute number. By itself it does not provide much information in helping to select the preferred route; the risk value is only important relative to the risk values of other alternatives.

The population risk is the threat to the total number of people potentially in the impact area (the potential area that might be affected by hazardous materials releases). The population risk is calculated by multiplying the probability of a hazardous materials accident by the potential consequences to nearby populations in the impact area. The actual impact area will depend on the amount and kind of material spilled; various impact areas have been calculated for different kinds of hazardous materials. *(3)* The procedure developed in the 1980 FHWA study is used to calculate the population risk. This procedure involves determining the portion of the census area that falls within the impact area, the area populations, and the share of the area populations within the impact area. The total population in the impact area is the product of the total population times the percent of the census area in the population area. The population risk is calculated by multiplying the probability of a hazardous materials accident by the total population in the impact area.

Calculating property risk is not mandatory for determining the best route for transporting hazardous materials; however, the calculation may be used to help select among routes where the population risks are nearly equal. The total property risk value is the product of the probability of a hazardous materials accident times the value of the potential property in the impact area. The procedure developed in the 1980 FHWA study should be used to determine the total value of property. For a grade crossing, the property includes the value of replacing the crossing warning devices *(7)*, the tracks, the crossing surface, the track circuitry, and other railroad equipment and cargo that might be damaged. The value of the railroad property around a grade crossing would have to be obtained from the railroad company in question.

Subjective factors

Railroad-highway crossings can present numerous highway operational and safety problems, and a railroad-highway crossing on one or more of the alternative routes being considered for hazardous materials transport makes the task of considering subjective factors (step 4 of fig. 1), an option in the 1980 FHWA study, a very important phase of this analysis. Because of the low probability of an accident at a crossing (nationwide average of about 1 accident every 20 to 30 years) *(8)* and the lower chance of a hazardous materials accident, risk values developed may not change significantly with the additional analysis of crossings. However, when there are crossings on more than one of the routes, the analysis of the subjective factors may determine the best alternative. Typical subjective factors to consider when evaluating a grade crossing include the following:

[2]In this article, the accident rate was determined by using the U.S. Department of Transportation accident prediction formula. *(6)*

Unit trains and/or long freight trains. When a crossing is used frequently by unit coal or grain trains and/or long freight trains, the crossing may be blocked for long periods of time. The unit trains may not run on a regular schedule, and local authorities may not always know in advance when a unit train is expected. This is particularly important where railroad tracks separate emergency services (police, fire department, and ambulances) from the rest of the community. Frequent use of the tracks by unit coal or grain trains and/or long freight trains also means a highway vehicle transporting hazardous materials waits at the crossing for long periods of time, increasing the chances of vehicle-vehicle collisions.

Use of a crossing by schoolbuses and passenger trains. The chances of rear end collisions involving a schoolbus or a hazardous materials vehicle with other vehicles in the traffic stream are increased because schoolbuses and all vehicles carrying hazardous materials covered by the Bureau of Motor Carrier Safety (BMCS) regulations are required to stop at all crossings.

The use of a crossing by passenger trains is an additional factor to be considered when analyzing alternative hazardous materials routes. The potential for a large number of casualties in the event of an accident must be evaluated carefully.

Trains carrying hazardous materials. Most freight trains carry some hazardous materials. The collision of a highway vehicle carrying hazardous materials with the portion of a train carrying hazardous materials could be catastrophic. As the lengths of vehicles carrying hazardous materials increase, their lengths, acceleration capabilities, and the amount of advance warning time before the arrival of a train should be checked. The current minimum requirement of 20 seconds of advance warning may be inadequate. If there is a choice between a route without a crossing and one used by trains regularly carrying large amounts of hazardous materials, the route without a crossing would be preferred if all other factors are equal.

Sight distance restrictions. Because the BMCS and most States require vehicles carrying hazardous materials to stop at all crossings, sight distance restrictions at a crossing may be a serious problem for these vehicles. Track geometry (crossing near a curve, for example) also may cause sight restrictions. In many cases, a driver of a truck carrying hazardous materials may have stopped at a crossing with limited sight distance and looked for a train or observed the signals. The driver then may have started across the tracks when a train approaches the crossing. At many crossings, the truckdriver may not have adequate time to clear the tracks before the train reaches the crossing. The requirement to stop at all crossings actually may increase the chances of an accident. Crossings with limited sight distance should be considered carefully when selecting hazardous materials routes.

Kind of warning device at the crossing. Currently the Uniform Vehicle Code (UVC) states that vehicles carrying hazardous materials do not have to stop at a crossing with flashing lights and flashing lights and gates (active warning devices) unless the devices are activated. These vehicles must stop at all other crossings. The BMCS has not adopted the UVC exception, and only about 10 States have adopted the UVC version. The NTSB recently has recommended that, where possible, vehicles carrying hazardous materials use routes that have either grade separations or active warning devices and that State laws and regulations be modified to conform to the UVC.

Active warning devices may minimize the effects of limited sight distance at a crossing because the driver only has to look for the at-crossing devices. Drivers' faith in active devices is important in whether drivers feel the need to look for a train in addition to looking at the at-crossing devices to determine if a train is coming. In the event of a commercial power failure, active grade crossing signals are powered by a standby power source (usually storage batteries).

Tank depots located near crossings. In many cases, vehicles carrying hazardous materials have either as their origin or destination tank depots located near a crossing and thus cannot avoid these crossings. When possible, such crossings should have active warning devices. An additional factor to be considered when tank depots are located near a crossing is the increased number of vehicles carrying hazardous materials and the potential increase of vehicle-vehicle accidents.

Emergency facilities, schools, hospitals, and railroad switchyards. Other factors to be considered in evaluating alternative hazardous materials routes involve special populations, special properties, and emergency facilities and response capabilities. Special populations, such as in schools and hospitals, and special properties near a crossing need to be evaluated carefully because of the potential for severe casualties in the event of an accident. The location of emergency vehicles (police, fire department, and ambulances) should be evaluated to determine if response capability would be hindered seriously if an accident occurred. Also, railroad switchyards adjacent to a crossing may create frequent delays at the crossing because of train movements, increasing the potential of a hazardous materials accident.

Traffic backing up onto a crossing. The potential for traffic backing up onto a crossing because of delays caused by a traffic signal or a stop sign beyond a crossing should be evaluated carefully. When considering alternative hazardous materials routes that include crossings, traffic signals at or near a crossing should be preempted when a train is approaching to avoid vehicles becoming trapped on the crossing.

Also, crossings with a sharp change in grade should be evaluated carefully because of the potential for "low-boy" trailers or trucks low to the road getting caught on the tracks.

In the analysis of subjective factors, there are no costs or numerical values to consider. Subjective factors should be analyzed by someone familiar with the crossing location and surrounding environment and the implications of the presence of any of the subjective factors.

Route selection

The final step in the expanded procedure is to compare the alternatives and select the preferred route. The left portion of table 1 summarizes the characteristics and calculations for the three alternative routes in the Plainfield example (fig. 2). The decision sequence for ranking the routes is as follows:

1. Consider mandatory physical and legal factors.

2. Select the route(s) with the smallest risk values.

3. Apply subjective factors if unable to differentiate on risk.

Table 1.—Alternatives comparison without and with railroad-highway crossing for Plainfield example

Alternative	Route	Length	Travel time	Rank	Mandatory physical factors	Mandatory legal factors	Without crossing: Population risk	Without crossing: Property risk	With crossing: Population risk	With crossing: Property risk
		Miles	*Min*							
1	I–70	15	18	1	No	No	3.93×10^{-7}	3.76×10^{-3}	3.93×10^{-7}	3.76×10^{-3}
2	U.S. 40	12	25[1]	3	No	No	58.20×10^{-7}	25.70×10^{-3}	$14{,}054{,}458.20 \times 10^{-7}$	$288{,}025.70 \times 10^{-3}$
3	S.R. 230	10	15	2	No	No	6.02×10^{-7}	1.15×10^{-3}	6.02×10^{-7}	1.15×10^{-3}

[1]May be longer when a train is present and the route has an at-grade crossing.

1 mile = 1.6 km

In Plainfield, none of the routes was eliminated on the basis of mandatory physical or legal factors. Alternative 1 has the smallest population risk value followed by alternative 3, which has the smallest property risk.

Alternative 1's relatively low population risk is attributed to the low accident rates and low density settlement along Interstate routes. Alternative 2, on the other hand, has both higher accident rates and population density because this urban arterial passes through downtown Plainfield. Alternative 3, a rural highway, passes through sparsely populated areas but has high accident rates because of the lack of access controls on State Route 230. Alternative 2 is ranked last because of its significantly greater population and property risks. Although alternative 3 has the lowest property risk, alternative 1 has the lowest population risk, making it the preferred hazardous materials route.

The inclusion of an at-grade crossing on alternative 2 and grade-separated crossings on alternatives 1 and 3 required changes only to the calculations for alternative 2. The increased population and property risks resulting from the inclusion of the at-grade crossing were determined and added to alternative 2 in the Plainfield example, as discussed below.

Example Calculations and Findings

The railroad-highway crossing added to alternative 2 has cantilevered flashing lights, two through trains per day, and an average daily highway traffic (ADT) volume of 16,500 vehicles, 15 percent of which is truck traffic with 10 percent of the trucks carrying hazardous materials (table 2). The predicted train-highway vehicle accident rate for the railroad-highway crossing is 0.192 accident per year using the U.S. Department of Transportation accident prediction formula. The predicted train-hazardous materials highway vehicle accident rate is 0.00288 accident per year ($0.192 \times 0.15 \times 0.10$ or the predicted train-highway vehicle accident rate multiplied by the estimated portion of the ADT that is trucks multiplied by the estimated portion of the trucks carrying hazardous materials).

Table 2.—Worksheet for railroad-highway crossing hazardous material accidents

Crossing characteristics	Inventory and accident data
Crossing number	740734T
Location	U.S. 40
Existing warning device	Cantilevered flashing lights
Total trains per day	2
Average daily highway traffic	16,500 vehicles
Daily through trains	2
Number of main tracks	2
Is highway paved?	Yes
Maximum timetable speed	20 mph (32 km/h)
Highway type	Minor arterial
Number of highway lanes	4
Number of years of train-highway vehicle accident history (T)	5
Number of train-highway vehicle accidents in T years	0
Estimate percent trucks	15 percent
Estimate of percent of trucks carrying hazardous materials	10 percent
Predicted train-highway vehicle accident rate	0.192 accident/year
Predicted train-hazardous materials highway vehicle accident rate	0.00288 accident/year

The population risk associated with the railroad-highway crossing is the product of the probability of a hazardous materials accident (0.00288 accident/year) and the estimated population exposed to the hazardous material. The total population risk value for alternative 2 of the Plainfield example is shown in figure 3. The estimated population is obtained from census data, and for this example it is 5 percent of the population in each of three census areas in the impact area (72.03, 73.01, and 73.02) for a total of 488 people. The population risk for the railroad crossing added on alternative 2 also is shown in figure 3. The total population risk for alternative 2 with a railroad-highway crossing is the sum of the population risk for the railroad-highway crossing and the original risk value for alternative 2. The change in the population risk value for alternative 2 is shown on the right portion of table 1.

A similar analysis was conducted for potential property risk where the potential property to be exposed, mainly the crossing warning devices, was valued at $100,000. An increase in property risk of $288 was calculated and added to the property risk values for alternative 2, but the new property risk value did not change the original property risk value ranking for alternative 2 (right portion of table 1).

The following subjective factors identify additional special problems associated with alternative 2:

1. Schools and fire departments are near the crossing.

2. Schoolbuses use the crossing.

3. Trains frequently carry hazardous materials.

4. Although the crossing has an active device, one quadrant has sight restrictions.

Schoolchildren could be in the area and, in the event of an accident, may be in the impact area. Emergency response to a fire could be hampered if the crossing were blocked because of an accident. The use of the crossing by schoolbuses means these buses could be in the traffic stream with vehicles carrying hazardous materials in the event of a train-hazardous materials vehicle accident. The fact that trains using the crossing also carry hazardous materials means a potential collision of a vehicle carrying hazardous material and the train may result in a catastrophic accident. Because one quadrant has sight restrictions and vehicles carrying hazardous materials are required to stop at all crossings before proceeding, the sight distance restrictions may limit even a stopped driver's view of an approaching train.

Risk Determination

	Population risk	Property risk
Alternative 2 without crossing	58.2×10^{-7}*	25.7×10^{-3}*
Alternative 2 with crossing	$14{,}054{,}400.0 \times 10^{-7}$	$288{,}000.0 \times 10^{-3}$
Total	$14{,}054{,}458.2 \times 10^{-7}$	$288{,}025.7 \times 10^{-3}$

Subjective Factors

Which of the following are subjective factors in the routing decision?

Factor	YES	NO	Comment
Special populations	(YES)	NO	School near crossing
Special properties	(YES)	NO	School and fire department
Emergency response capability	(YES)	NO	Fire departments
Unit trains	YES	NO	
Schoolbuses	(YES)	NO	Use crossing to get to school
Trains carrying hazardous materials	(YES)	NO	Frequently
Kind of warning device	(YES)	NO	Cantilevered flashing lights
Sight distance restrictions	(YES)	NO	One quadrant has sight restrictions
Passenger trains	YES	NO	
Tank depots near crossing	YES	NO	
Traffic backing up onto crossing	YES	NO	
Trucks getting caught on tracks	YES	NO	
Other	YES	NO	

*From 1980 Plainfield example. (3)

Figure 3.—Modified hazardous materials routing analysis worksheet.

For this hypothetical example, alternative 2 is by far the worst choice considering the increased population risk by including a railroad crossing. After further considering the subjective factors, alternative 2 looks even more risky as a candidate route.

Summary

This article has addressed the importance of considering the presence of railroad-highway crossings when selecting among alternative routes for transporting hazardous materials. Even though the final ranking of the alternative routes in the hypothetical example did not change with the inclusion of a crossing, the population and property risk values greatly increased because of the at-grade crossing. Not all crossings would cause the large increases in the population and property risk values; the final results would depend on the predicted accident rate for the crossing and the population and area surrounding the crossing.

The analysis of the subjective factors identified additional problems for a route with a crossing. Because of the catastrophic potential of an accident involving a train and a vehicle carrying hazardous materials, the subjective analysis should be required when a route includes a crossing.

REFERENCES

(1) Gary L. Urbanek and Edward J. Barber, "Development of Criteria to Designate Routes for Transporting Hazardous Materials, Final Report," Report No. FHWA/RD–80/105, *Federal Highway Administration*, Washington, D.C., September 1980. (Report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161. Stock No. PB 81 164725.)

(2) Charles J. Nemmers and William L. Williams, "Guidelines for Designating Routes for Transporting Hazardous Materials," *Public Roads*, vol. 47, No. 2, September 1983, pp. 61–65.

(3) E. J. Barber and L. K. Hildebrand, "Guidelines for Applying Criteria to Designate Routes for Transporting Hazardous Materials," Report No. FHWA–IP–80–15, *Federal Highway Administration*, Washington, D.C., November 1980. (Report is available from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Stock No. 050–001–00198–5.)

(4) "Railroad/Highway Grade Crossing Accidents Involving Trucks Transporting Hazardous Materials," Special Report No. NTSB–HZM–81–2, *National Transportation Safety Board*, Washington, D.C., April 1982.

(5) "Safety Effectiveness Evaluation—Federal and State Enforcement Efforts in Hazardous Materials Transportation by Truck," Report No. NTSB–SEE–81–2, *National Transportation Safety Board*, Washington, D.C., February 1981.

(6) John Hitz and Mary Cross, "Rail-Highway Crossing Resource Allocation Procedure User's Guide," Report No. FHWA–IP–82–7, *Federal Highway Administration*, Washington, D.C., April 1982.

(7) Jennifer Heisler and Joseph Morrissey, "Rail-Highway Crossing Warning Device Life Cycle Cost Analysis," Report No. FRA–RRS–80–003, *Federal Railroad Administration*, Washington, D.C., September 1980.

(8) "Rail-Highway Crossing Accident/Incident and Inventory Bulletin, No. 5, Calendar Year 1982," *Federal Railroad Administration*, Washington, D.C., June 1983.

Janet A. Coleman is a mathematician in the Traffic Control and Operations Division, Office of Safety and Traffic Operations Research and Development. She has been with FHWA since 1971 and is project manager for FCP Project 1O, "Railroad-Highway Grade Crossings." Ms. Coleman currently is responsible for research studies concerned with improved signing and signals for railroad-highway grade crossings, grade crossing accident analysis, and funding allocation models.

Recent Research Reports You Should Know About

The following are brief descriptions of selected reports recently published by the Federal Highway Administration, Offices of Research, Development, and Technology. The Office of Engineering and Highway Operations Research and Development (R&D) includes the Structures Division; Pavement Division; Construction, Maintenance, and Environmental Design Division; and the Materials Technology and Chemistry Division. The Office of Safety and Traffic Operations R&D includes the Systems Technology Division, Safety and Design Division, Traffic Control and Operations Division, and Urban Traffic Management Division. The reports are available from the source noted at the end of each description.

When ordering from the National Technical Information Service (NTIS), use PB number and/or the report number with the report title.

Production of Calcium Magnesium Acetate (CMA) for Field Trials, Report No. FHWA/RD–83/062

by Materials Technology and Chemistry Division

This report describes the large-scale production of 200 tons (181 Mg) of calcium magnesium acetate (CMA)—a deicing material without the corrosion and pollution problems of chloride ion-containing salts. Most of the CMA produced was shipped to selected State transportation departments for deicing field trials; the rest of the CMA will be used in other FHWA-sponsored studies that will evaluate the technical merits and corrosivity of the CMA.

The report includes a description of the CMA production process (using purchased acetic acid and dolomitic lime), an analysis and characteristics of the product, and an interim manufacturing guide.

The report may be purchased from NTIS.

Automatic Audio Signing, Executive Summary and Final Report, Report Nos. FHWA/RD–84/038 and –84/039

by Systems Technology Division

These reports describe a recent study to develop, install, and field evaluate the Automatic Highway Advisory Radio (AHAR) in a typical traffic application. AHAR is a proposed enhancement of the presently used Highway Advisory Radio (HAR), a manually tuned and operated system that operates in the AM band using the motorist's existing AM radio.

In contrast, the AHAR uses a receiver that automatically mutes the motorist's normal broadcast, tunes to the AHAR frequency, and returns the radio to its initial broadcast after the roadside radio message has been repeated twice. This receiver also has a priority message hierarchy and an automatic override for emergency message transmission.

The reports include a detailed system design analysis, which involves an examination of message transmission and voice synthesis techniques and selection of frequencies; fabrication of an engineering model for test; fabrication of 100 developmental prototype receivers; and a test and evaluation of the system in Tampa, Florida.

The reports may be purchased from NTIS.

Design Considerations for Two-Lane, Two-Way Work Zone Operations, Report No. FHWA/RD–83/112

by Traffic Control and Operations Division

This report presents the results of operational and accident studies of 36 construction sites using either two-lane, two-way operation (TLTWO) or lane closure traffic control. Project cost information for 4 TLTWO sites and 10 lane closure sites also was analyzed. Results of the study were divided into the following areas: Evaluation of centerline treatments on the two-way roadway segment, design of temporary median crossover roadways, and comparison of TLTWO and lane closure operations.

The study of centerline treatments revealed that zones with only a double yellow centerline had higher accident rates, and the vehicle encroachment rate into opposing lanes is much higher than for any other kind of centerline treatments studied. Accident rates with other centerline treatments do not support a requirement for portable concrete barriers in all TLTWO zones.

The study of median crossover design revealed lower accident rates and smoother speed transitions for crossovers with a flat diagonal design compared with those with reverse curve design. In this study, more accidents were observed in entering crossovers, to the two-way roadway sections than in existing crossovers, indicating the design of entering crossovers is critical. The use of portable concrete barriers on both sides of a crossover is potentially hazardous; providing a buffer area on the side of the crossover away from opposing traffic is preferable to extensive use of portable concrete barriers in the crossover.

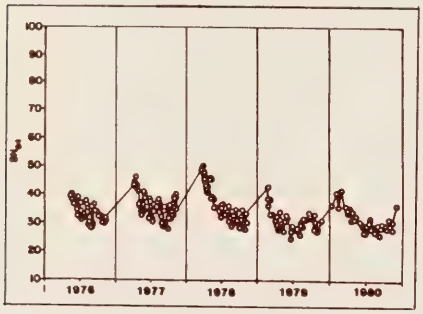
Comparisons of TLTWO and lane closure sites revealed that the lane closure alternative will be more cost-effective than TLTWO traffic control unless substantial construction cost reductions could be realized with TLTWO.

The report may be purchased from NTIS.

Predictor Model for Seasonal Variations in Skid Resistance, Volumes I and II, Report Nos. FHWA/RD–83/004 and –83/005

by Pavement Division

Tire-pavement friction is affected by short term and seasonal weather changes. Variations of 20 or more skid numbers are not infrequent. This report verifies the existence of these effects and presents the first attempt to model the frictional changes as functions of pavement type, traffic exposure, and weather data.



Two different models—one relating the frictional changes only to weather and traffic data and the other including pavement surface characteristics—were developed from data collected over 3 years in a number of Eastern States. The second model gives better predictions but requires additional input data. The accuracy of these models must be verified further, however, and application to other regions of the United States and differing conditions will require additional work.

The reports may be purchased from NTIS.

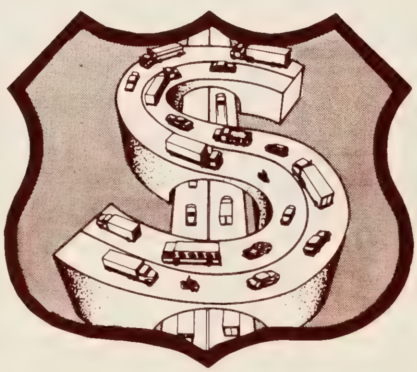
Allocation of Life-Cycle Highway Pavement Costs, Report No. FHWA/RD–83/080

by Pavement Division

This report addresses the highway life-cycle costs (maintenance and rehabilitation) attributable to different vehicle classes. Roadway performance and life-cycle costs were analyzed by simulation to consider variations in initial pavement design, traffic volume and composition, environment, maintenance and rehabilitation policy, maintenance technology, and unit costs. Different economic criteria were applied, including pure efficiency (shortrun marginal cost pricing) and equity-based measures.

The report addresses the general engineering and economic concepts used in this approach and discusses results of several case studies for flexible and rigid pavements in urban and rural regions within two different climatic zones. In general, the results show that heavy combination trucks bear approximately 1,000 times the cost responsibility of automobiles for pavement maintenance and rehabilitation. Differences between flexible and rigid pavements and between climatic zones also are highlighted.

The report may be purchased from NTIS.

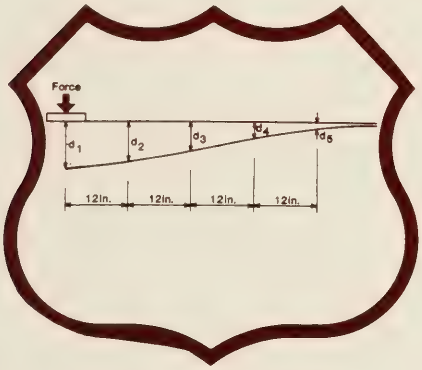


Evaluation of Rigid Pavement Overlay Design Procedures, Report No. FHWA/RD–83/090

by Pavement Division

This report presents a review and evaluation of existing rigid pavement overlay design procedures that resulted in a fully computerized rational overlay design method called OAR. This overlay design method incorporates the latest knowledge on pavement evaluation and structural stress analysis. The thickness of the overlay is determined based on a fatigue cracking distress function developed from the American Association of State Highway Officials Road Test data, with a progressive failure approach applied to the underlying layers. The existing rigid pavement is evaluated with a combination of deflection measurements, laboratory testing, visual survey, and material property correlations. The computer program OAR is simple, fast to use, and the input information can be obtained with a minimum of testing.

The report may be purchased from NTIS.



Synthesis Study of Nondestructive Testing Devices for Use in Overlay Thickness Design of Flexible Pavements, Report No. FHWA/RD–83/097

by Pavement Division

This report provides a ready reference for highway engineers interested in purchasing nondestructive testing (NDT) equipment for use in designing overlays for flexible pavements. All commercially available equipment is described; current prices quoted by the manufacturers/distributors are included.

User comments obtained from a questionnaire sent to nine State agencies and one Federal agency are summarized. The questionnaire was developed to address items thought to be decision criteria for selecting an NDT device.

The report also reviews overlay thickness design procedures for flexible pavements. Important components related to the use of NDT deflection measurements in overlay design are identified and addressed.

The report may be purchased from NTIS.

Correlation of Quality Control Criteria and Performance of PCC Pavements, Report No. FHWA/RD–83/014

by Construction, Maintenance, and Environmental Design Division

This report documents a study to quantify the relationships between quality control test results and the performance of portland cement concrete (PCC) pavements. Historical and construction data relative to selected quality variables were collected for 104 concrete pavement projects in five States. The pavement condition of these projects then was evaluated to establish the current level of performance. Statistical analyses were performed to establish relationships between the performance rating and the quality indicator data, and 55 quality

control/performance models were developed and tested. The report illustrates the kinds of performance and quality indicator data required to develop statistically reliable relationships, the kinds of results that can be obtained from such analyses, and the impact of missing data on model development and reliability.

The report may be purchased from NTIS.

Evaluation and Improvement of Existing Bridge Foundations, Report No. FHWA/RD-83/061

by Construction, Maintenance, and Environmental Design Division

This report describes new and existing methods for evaluating and improving foundations for replacement or rehabilitated bridges. The report is divided into four parts. Part I deals with deterioration of bridge substructures, effects of loading and unloading on the foundations, time effects on soil properties, and bearing capacity and settlement of foundations. Part II discusses current methods of inspection, substructure analysis, new methods for evaluating soundness and bearing capacity of foundations, and instrumenting foundations for future performance. Part III covers repair methods and techniques to increase the capacity of existing foundations by strengthening the foundation and/or soil and methods for reducing loads on the substructure. Part IV of the report presents case histories of bridge substructures and recommendations for research.

The report may be purchased from NTIS.

Allowable Stresses in Piles, Report No. FHWA/RD-83/059

by Construction, Maintenance, and Environmental Design Division

This report presents new methods for establishing allowable stresses in steel, concrete, and timber foundation piles using load/resistance factor concepts. These methods take into account not only the material properties of the pile itself, but also the individual effects of long term loads, driving stresses and drivability, imperfections in form or material, and various environmental conditions that reduce pile capacity. Based on the results of the study, recommendations for improving the American Association of State Highway and Transportation Officials' Standard Specifications for Highway Bridges are presented.

The report may be purchased from NTIS.

Implementation/User Items "how-to-do-it"

The following are brief descriptions of selected items that have been completed recently by State and Federal highway units in cooperation with the Office of Implementation, Offices of Research, Development, and Technology, Federal Highway Administration. Some items by others are included when they have a special interest to highway agencies. Requests for items available from the Office of Implementation should be addressed to:

Federal Highway Administration
Office of Implementation, HRT–1
6300 Georgetown Pike
McLean, Virginia 22101

Redesign and Field Operation of a Cavitating Concrete Removal System, Report No. FHWA–TS–84–207

by Office of Implementation

This report presents the results of a project to redesign, build, and demonstrate a prototype self-propelled concrete removal system that uses water jet (cavitation) technology. The report includes an indepth discussion of the design considerations, the fabrication and laboratory testing, the field demonstration, a cost analysis and system comparison, and recommendations.

The project has advanced water cavitation technology and has demonstrated its cost-effectiveness and feasibility for large-scale concrete removal. The report should be of interest to maintenance and bridge engineers concerned with bridge deck repair.

The report may be purchased from NTIS.

Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, Report No. FHWA–TS–84–204

by Office of Implementation

Much research has been completed on Manning's roughness coefficients (n) for stream channels; however, little research has been conducted on the selection of roughness values for densely vegetated flood plains. This report provides procedures for determining roughness coefficients and the factors affecting those values. Photographs of flood plain segments where roughness coefficients have been verified are presented as a comparison standard to aid in assigning values to similar flood plains.

Limited copies of the report are available from the Office of Implementation.

New Research in Progress

The following new research studies reported by FHWA's Offices of Research, Development, and Technology are sponsored in whole or in part with Federal highway funds. For further details on a particular study, please note the kind of study at the end of each description and contact the following: Staff and administrative contract research—*Public Roads* magazine; Highway Planning and Research (HP&R)—performing State highway or transportation department; National Cooperative Highway Research Program (NCHRP)—Program Director, National Cooperative Highway Research Program, Transportation Research Board, 2101 Constitution Avenue, NW., Washington, D.C. 20418.

FCP Category 1—Highway Design and Operation for Safety

FCP Project 1T: Roadside Safety Hardware

Title: Updating Methodology for Crash Test Instrumentation and Data Reduction. (FCP No. 31T1392)
Objective: Gain knowledge of internal loads and distribution of distortion upon impact with instrumented barriers and sign supports to create better barriers and sign supports at less cost.
Performing Organization: ENSCO, Inc., Springfield, Va. 22151
Expected Completion Date: March 1986
Estimated Cost: $140,510 (FHWA Administrative Contract)

FCP Project 1Z: Implementation of Safety R&D

Title: Photolog Measuring Techniques. (FCP No. 31ZA014)
Objective: Develop a simple and accurate method for obtaining roadway dimensions from photologs. Use existing photologs and a computerized mathematical program to produce useful dimensions.
Performing Organization: Oak Ridge National Laboratory, Oak Ridge, Tenn. 37830
Expected Completion Date: June 1985
Estimated Cost: $74,880 (FHWA Administrative Contract)

FCP Category 2—Traffic Control and Management

FCP Project 2L: Electronic Devices for Traffic Control

Title: Development of an Overhead Vehicle Sensor System. (FCP No. 42L1102)
Objective: Develop a prototype overhead sensor system for counting and classifying vehicles using largely off-the-shelf components or subsystems. Determine the sensor accuracy under actual

field conditions. Prepare detailed design drawings and specifications for a manufacturer to produce the overhead sensor system.
Performing Organization: Texas Transportation Institute, College Station, Tex. 77843
Funding Agency: Texas State Department of Highways and Public Transportation
Expected Completion Date: April 1987
Estimated Cost: $30,000 (HP&R)

FCP Project 2P: Urban Freeway Management

Title: Freeway Control for Incident Conditions. (FCP No. 42P2082)
Objective: Develop an online algorithm for acceptability of loop detector information. Extend the online energy control strategy to incorporate loop detector information to handle situations involving traffic incidents.
Performing Organization: University of California at Berkeley, Berkeley, Calif. 94720
Funding Agency: California Department of Transportation
Expected Completion Date: March 1987
Estimated Cost: $28,000 (HP&R)

Title: Real Savings to High Occupancy Vehicle (HOV) Preferential Lane Users. (FCP No. 22P3032)
Objective: Determine the actual time, money, and fuel savings that HOV lane users experience when their entire door-to-door trip is considered.
Performing Organization: Federal Highway Administration, McLean, Va. 22101
Expected Completion Date: August 1985
Estimated Cost: $6,300 (FHWA Staff Research)

FCP Project 2Q: Urban Network Control

Title: Directional Weighting for Maximal Bandwidth Arterial Signal Optimization Programs. (FCP No. 32Q1412)
Objective: Determine factors to be inserted into computer signal optimization programs that maximize green bandwidth to give proper weight to the traffic flow rates in opposite directions.
Performing Organization: Texas A&M Research Foundation, College Station, Tex. 77843
Expected Completion Date: June 1985
Estimated Cost: $64,050 (FHWA Administrative Contract)

FCP Category 3—Highway Operations

FCP Project 3A: Maintenance Management

Title: Effects of Reclaimed Water on Highway Plantings, Soils, and Irrigation Equipment. (FCP No. 43A1464)
Objective: Determine the buildup of trace elements and specific ions in the soils, the effects of chlorinated water on landscape vegetation, and the vegetation response to varying nutrient levels in treated effluent. Identify effects to irrigation system components and related maintenance requirements.
Performing Organization: California Department of Transportation, Translab, Sacramento, Calif. 95807
Expected Completion Date: September 1987
Estimated Cost: $167,000 (HP&R)

Title: Moisture Sensors and Their Place in Maintenance of Highway Plantings. (FCP No. 43A1474)
Objective: Conduct field tests and evaluations of existing or modified soil moisture sensors to minimize maintenance and irrigation water for freeway landscape plantings. Develop an essentially maintenance-free moisture sensing system using microprocessors for irrigation of freeway landscape plantings.
Performing Organization: California Department of Transportation, Translab, Sacramento, Calif. 95807
Expected Completion Date: June 1987
Estimated Cost: $112,450 (HP&R)

Title: Assessment of Routine Maintenance Needs and Optimal Use of Routine Maintenance Funds. (FCP No. 43A2042)
Objective: Develop a routine maintenance management system to assess routine maintenance needs and optimally allocate funds.
Performing Organization: Purdue University, West Lafayette, Ind. 47906
Funding Agency: Indiana Department of Highways
Expected Completion Date: July 1987
Estimated Cost: $100,000 (HP&R)

FCP Project 3B: Environmental Management

Title: Porous Pavement for Control of Highway Runoff. (FCP No. 43B1442)
Objective: Design, construct, and monitor a porous pavement structure that will selfstore and dissipate the water from a 10-year frequency storm.
Performing Organization: Western Technologies, Inc., Phoenix, Ariz. 85036
Funding Agency: Arizona Department of Transportation
Expected Completion Date: April 1987
Estimated Cost: $72,295 (HP&R)

FCP Category 4—Pavement Design, Construction, and Management

FCP Project 4B: Design and Rehabilitation of Rigid Pavements

Title: Structural Performance of Rigid Pavement. (FCP No. 44B1174)
Objective: Establish a common denominator for interpretation of deflection data, accounting for ambient condition of temperature gradient and joint load transfer.
Performing Organization: Florida Department of Transportation, Tallahassee, Fla. 32304
Expected Completion Date: September 1986
Estimated Cost: $39,450 (HP&R)

FCP Project 4C: Design and Rehabilitation of Flexible Pavements

Title: Study of Asphalt Aggregate Physical-Chemical Characteristics to Determine Requirements for Antistripping Additives. (FCP No. 44C4114)
Objective: Recommend a laboratory test for determining stripping potential, a laboratory test for determining the effectiveness of additives, and a procedure to verify the presence of antistripping compounds in asphaltic cements. Include the boiling, pedestal, Lottman, and film stripping tests. Detect antistrip agent compounds with polar constituent concentrations or chemical tracer detection.
Performing Organization: Auburn University, Auburn, Ala. 36849
Funding Agency: Alabama Highway Department
Expected Completion Date: March 1986
Estimated Cost: $122,025 (HP&R)

FCP Category 5—Structural Design and Hydraulics

FCP Project 5A: Bridge Loading and Design Criteria

Title: Strength Design Age for Prestressed Concrete. (FCP No. 35A4672)
Objective: Critically review and evaluate current knowledge and criteria associated with the use of the 28-day compressive strength as the design and specification strength for structural concrete members. Develop recommendations for changing the criteria to reflect more accurately strength gain characteristics of concrete and strength requirements during various stages of production, construction, and service life.
Performing Organization: ABAM Engineers, Inc., Auburn, Wash. 98003
Expected Completion Date: February 1986
Estimated Cost: $150,000 (FHWA Administrative Contract)

FCP Project 5H: Highway Drainage and Flood Protection

Title: Flood Depth Frequency Relations for Alabama. (FCP No. 45H3762)
Objective: Develop and describe techniques for estimating flood depths on most natural streams in Alabama.
Performing Organization: U.S. Geological Survey, Alabama District Office, Tuscaloosa, Ala. 35401
Funding Agency: Alabama Highway Department
Expected Completion Date: October 1985
Estimated Cost: $30,000 (HP&R)

Title: Determination of Flood Hydrographs for South Carolina Streams. (FCP No. 45H3772)
Objective: Develop regional relations for determining flood hydrographs of flood peaks and maximum flood volumes for ungaged streams (rural and urban) in South Carolina.
Performing Organization: U.S. Geological Survey, Columbia, S.C. 29201
Funding Agency: South Carolina Department of Highways and Public Transportation
Expected Completion Date: September 1988
Estimated Cost: $240,000 (HP&R)

☆U.S.Government Printing Office: 1984—421—783/305

FCP Project 5Q: Bridge Maintenance and Corrosion Protection

Title: Electrically Conductive Polymer Concrete. (FCP No. 35Q2363)
Objective: Perfect the concrete mixture design to produce a conductive polymer concrete that is permeable to the gas evolved during application of a cathodic protection process. Develop materials and modify equipment to apply electrically conductive polymer concrete to vertical and overhead surfaces in addition to bridge decks.
Performing Organization: Brookhaven National Laboratory, Upton, N.Y. 11973
Expected Completion Date: July 1985
Estimated Cost: $109,940 (FHWA Administrative Contract)

Title: Electrically Conductive Concrete. (FCP No. 45Q2522)
Objective: Develop a concrete mixture that exhibits desirable levels of electrical conductivity (for cathodic protection application), resistance to damage from freezing and thawing, resistance to traffic abrasion, and sufficient bond strength for use as an overlay.
Performing Organization: Virginia Highway and Transportation Research Council, Charlottesville, Va. 22903
Funding Agency: Virginia Department of Highways and Transportation
Expected Completion Date: April 1985
Estimated Cost: $20,000 (HP&R)

Title: Concrete in Aggressive Environment. (FCP No. 45Q2532)
Objective: Identify concrete ingredient materials and formulate mixture design to retard the corrosion of reinforcing steel including the deterioration of concrete from chemical ions present in the environment.
Performing Organization: Florida Department of Transportation, Tallahassee, Fla. 32301
Expected Completion Date: June 1986
Estimated Cost: $19,000 (HP&R)

Title: Review and Analysis of Effects of Coastal Environment in Concrete Highway Structures. (FCP No. 45Q2812)
Objective: Evaluate the effect of concrete cover in preventing corrosion of reinforcing steel in numerous highway structures built in chloride environments.
Performing Organization: California Department of Transportation, Sacramento, Calif. 95807
Expected Completion Date: October 1985
Estimated Cost: $22,100 (HP&R)

FCP Category 0—Other New Studies

Title: Freeze-and-Thaw Durability of Fly Ash Concrete. (FCP No. 40M3824)
Objective: Determine the freeze-thaw durability of concrete made with different fly ashes and coarse aggregates. Investigate D-cracking and non-D-cracking aggregates as various replacements for cement. Evaluate durability with the slow freeze-thaw cycling test (ASTM C 671) at the rate of one cycle per week. Determine compressive strengths and evaluate pore structures by linear traverse methods (air content, air-paste ratio, spacing factor, and other parameters).
Performing Organization: Missouri Highway and Transportation Department, Jefferson City, Mo. 65101
Expected Completion Date: December 1986
Estimated Cost: $40,800 (HP&R)

Title: Influence of Design Characteristics on Concrete Durability. (FCP No. 40M3832)
Objective: Determine the durability and pore structure parameters of about 25 laboratory concrete mixtures using field materials (cement factor, air content, fines content, and nominal coarse aggregate size will be independent variables). Evaluate durability by the "slow" freeze-thaw method (ASTM C 671) at the rate of one cycle per week. Evaluate pore structure by linear traverse methods (air content, air-paste ratio, spacing factor, and other parameters).
Performing Organization: Missouri Highway and Transportation Department, Jefferson City, Mo. 65101
Expected Completion Date: December 1986
Estimated Cost: $50,100 (HP&R)

Title: Effectiveness of Texas Membrane—Curing Compound Quality and Application Requirements. (FCP No. 40M3842)
Objective: Develop a more rapid and easy test for moisture retention. Evaluate field performance reflecting the effects of new materials and application techniques. Test each material for settlement rate of solids, effects of agitation, shelf life, and methods and rates of application. Consider new sampling approaches. Justify keeping Texas' present higher quality standards for curing compounds through field performance determinations.
Performing Organization: Texas State Department of Highways and Public Transportation, Austin, Tex. 78763
Expected Completion Date: August 1985
Estimated Cost: $48,600 (HP&R)

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