Upgrading Existing Highways for Safety

BOB L. SMITH, Ph.D.
Professor of Civil Engineering
Kansas State University
Manhattan, Kansas

INTRODUCTION

We are addressing a very complex problem; i.e., when to make a highway safety improvement and what improvement to make. We really don't know the cost effectiveness or safety effectiveness of various highway improvements one might make. Thus it is nearly impossible to make a rational decision regarding the improvements.

It is of interest to note that recently (mid-February, 1975) a request for proposal was issued by the Transportation Research Board's National Cooperative Highway Research Program (NCHRP); the research project title was "Cost and Safety Effectiveness of Highway Design Elements." The stated objectives of the 30-month, $260,000 project are:

This research should cover applicable design elements on various highway facilities, including both high and low volumes and urban and rural conditions. The general objectives are: (1) to quantify the effect of varying the magnitude, size, or dimension of each roadway and roadside design element (and/or combination of elements where they are interactive) on accident frequency and severity; and (2) to develop methodology to measure the cost-effectiveness of the various levels of each element.

The results of the proposed research should be of tremendous help in upgrading existing highways for safety.

Today I want to discuss very briefly some considerations for safety redesign or upgrading. Some of the items I will discuss are taken from the Dynamic Design for Safety Seminars. Eighteen such three- to four-day seminars have been presented in the U.S. and Canada since 1971.

Let us assume that we believe we have a safety problem on x miles of road y. Why do we believe this? It may be for any of the following reasons: (a) the section of road rated very high on the improvement priority list; (b) accident rates are higher than the average of similar
class roads; (c) a spectacular, fatal accident; and (d) public complaints.

Given that we will improve the section of road, we must decide on the extent of improvement; i.e., what is the most important improvement, second most important, etc., with due regard to improved safety and limited funds.

In other words, we must (a) analyze the problem, (b) generate alternative solutions and (c) select cost effective solutions for implementation.

There are some techniques, some approaches, which hold considerable promise as aids in a, b, or c above. This paper addresses some of them.

SPEED PROFILE DEVELOPMENT AND ANALYSIS

It has been suggested that a highway facility be analyzed for safety from four basic points of view: sight distance; speed differential; horizontal alignment; and cross-section. The discussion in this paper is limited to consideration of speed differential vs safety, and the development and suggested use of a speed profile for existing highways.

Speed Differential and Safety

A number of studies have shown that the greater the differential in speed of a driver and his vehicle from the average speed of all traffic, the greater the chance of that driver being involved in an accident. For example, a driver traveling at 40 mph or one traveling at 80 mph in relation to an average speed of 60 mph for all traffic, has a substantially greater chance of being involved in an accident than a driver traveling at the average speed of 60 mph.

The graph in Figure 1 compares the results of analyses done by Solomon on rural highways with those done by Cirillo on interstate highways. The graph shows that the accident involvement rate is more sensitive to speed differential on the interstate highways than on other rural highways. The involvement rate increases rapidly for both cases for speed differentials in excess of 10 mph. Similar results were found by researchers in Britain and at the Research Triangle Institute.

Researchers at Texas A & M developed a curve, using Solomon's findings, relating the accident involvement rate of trucks to speed reduction from the average of all vehicles on a highway. This curve is shown in Figure 2. The graph exhibits the sharp increase in involvement rate of trucks when the speed reduction exceeds 10 mph. These relationships raise questions concerning the desirability of creating design guidelines to encourage minimization of speed differentials between vehicles on a road. It has been suggested by the Texas A & M
study that a differential of 10 mph be used as a maximum acceptable level for safety.

The AASHO design policy uses a 15 mph speed reduction as the criterion for the “critical length” of grade for alignment design and establishment of a truck climbing lane.

The relative accident involvement rates as determined from Figure 2 have been superimposed in Figure 3 on the AASHO criteria for design of critical lengths of grade. The two sets of data on the same chart

Fig. 1. Accident Involvement Rate by Variation from Mean Speed. Source: "Public Roads, August, 1968."
Fig. 2. Accident Involvement Rate Versus Speed Reduction from the Average of All Vehicles on a Highway. Source: Glennon, John C. and Charles A. Joyner, Jr., Texas Transportation Institute, Research Report No. 134-2, August 1969.

indicate the need for careful analysis of a design with regard to deviations from the average speed of traffic on the highway.

As an indication of the importance of this aspect of the operational safety problem, a study of freeways in San Antonio, Texas, showed that more than half of the violations contributing to accidents were directly related to speed differential, or to stream friction between vehicles moving in the same direction.\textsuperscript{9}

Trucks generally travel slower than passenger cars. In many cases, the presence of slow moving trucks in the traffic stream can slow passenger vehicles, thus creating a greater number of speed differentials in a traffic stream. The deviation of the average speed of trucks from the average speed of passenger cars is about the same as the deviation from the average speed of all vehicles because of the low percentage of trucks usually present. The deviation of average truck speed from average
Fig. 3. Accident Involvement Due to Speed Reduction (Texas Experience) as Related to (AASHO) Critical Lengths of Grade for Design. Source Data From: (1) "A Policy on Geometric Design of Rural Highways", by the American Association of State Highway Officials, 1965; and (2) "Re-Evaluation of Truck Transportation Institute Research Department 134-2, 1969.

passenger car speed could therefore be used in relation to the involvement rate of vehicles whose speed deviates from the average speed.

A study of seven tollways in a number of states during 1962 to 1964 indicated an accident involvement (per 100 million vehicle-miles) ratio of cars to trucks to vary between 1.1:1 and 2.8:1.\textsuperscript{10} A speed deviation of 5 mph from average speed in the study by Solomon shows an involvement ratio to the average of 1.4:1, and in the one by Cirillo, a ratio of about 1.7:1.

Generally, the mean deviation of average truck speed from average passenger car speed seems to be about 5 mph.\textsuperscript{11}

Observations of freeway characteristics suggest the following as causes of in-stream friction due to trucks or slow-moving vehicles.\textsuperscript{9}

1. Slow entering speeds of trucks and the resultant tendency of many through vehicles to change from the right-hand lane in advance of an entrance ramp;
2. Apparent avoidance by some vehicles of the right-hand lane where truck traffic is densest, as evidenced by frequent entrance and exit maneuvers to and from other lanes; and
3. The presence of slow-moving vehicles which have moved into the
teil lanes to avoid trucks in the right lanes. This causes queuing
of faster moving vehicles, creating short headways and frequently
resulting in improper passing maneuvers.

Factors Affecting Speed

Upgrades have generally been recognized as the largest factor
contributing to a speed differential between trucks and passenger
vehicles. The main factors affecting truck speed are the weight,
horse power ratios, the steepness of the grade, and the length of the grade.
The effect of grade on passenger cars is generally negligible up to grades
of 6 or 7%.

Horizontal curvature is the main factor affecting the speed of
passenger cars on many highways. Modern freeways generally have hori­
zontal curvature of such high standard that it would not have a major
effect on vehicular speeds.

Vehicle Type—Trucks are the main group of vehicles having the largest
deviations from the average speed of all vehicles (or the average
speed of passenger cars). It is suggested that the operational character­
istics of trucks and passenger cars be handled separately in an analysis
of speed. Buses seem to follow the same general average speed as
passenger cars.

Acceleration—If a driver must slow his vehicle to negotiate a curve, he
usually wishes to return to that initial speed at which he was traveling
before being slowed. It is not clear what factors affect the driver's
acceleration from that limiting curve. Some suggested factors affecting
the acceleration of a passenger car from a limiting curve are:

1. The distance and degree of restrictiveness of geometry in view
upon departing from a limiting curve; and
2. The difference between the limiting speed on the curve being
departed and the speed preceding the curve.

The hypothesis is that a driver will accelerate faster after leaving a
limiting curve if he can see the road as having unrestricted geometry
for a considerable distance in front of him, than in the situation where
he leaves a curve and sees another limiting curve just ahead. In addi­
tion, the more a driver has to decelerate to the limiting condition of the
curve, the faster he will accelerate to regain or exceed his previous speed.
Trucks will probably correlate more closely with vehicular ability, but
the driver may also be affected by the above considerations.
When the driver must decelerate for a limiting curve, it may be correct to assume that the deceleration for a limitation such as a horizontal curve would be by deceleration in gear when the speed reduction would be less than 20 mph and by deceleration while braking at a leisurely rate when the speed reduction would be 20 mph or more.

One might also assume that trucks would require a distance 50% greater than passenger cars to decelerate. It was found in research that the minimum stopping sight distance required for trucks was 1.5 to 2.0 times the length required for passenger cars.\textsuperscript{12, 13}

When there are no geometric limitations to restrict the speed, (or any surface defects) it is believed that the major factors determining the speed are the speed limit, the type of highway, and the vehicle limitations.

![Diagram](image-url)

**Fig. 4. Estimating Speed Differential Profile for Trucks and Passenger Vehicles.**
Profile Development Technique

Prior to the preparation of reference (1), no technique had been published for estimating the speeds of passenger vehicles and trucks at a point along a road. An initial attempt was made at this and is reported in Chapter 9 of reference. Chapter 9 presents an example problem and solution using various curves developed and adapted by Jack E. Leisch and Associates. A flow chart representing the process is shown in Figure 4. The resulting speed profile is plotted as shown in Figure 5.

Baluch carried out further refinement of some of the curves and further verified and refined parts of the base data in 1973.

It appears that with some updating of the basic data, the speed estimates can be quite realistic; thus giving very usable speed profiles.

Fig. 5. Speed Profile Analysis.
Speed Profile Analysis

The speed profile of both trucks and passenger vehicles can be of immense value in analyzing and reviewing a design together with the sight distance profile as mentioned above. The following are some of the ways in which the speed profile can be used in design:

1. The level of the design speed can be reviewed and raised (preferably) or lowered as appropriate. This may be done by comparing the average running speed for the design section with the estimated running speeds of the passenger vehicles and trucks.

2. The consistency of the design speed can be evaluated by considering the variation in estimated operating speed over the design section.

3. The points where the design speeds are changed may be checked and adjusted.

4. The vertical and horizontal alignment can both be evaluated by considering speed differentials which are estimated from the speed profile. Decisions can be made as to whether grades should be flattened, curve radii increased, and curvilinear alignment used in place of tangents. The need for truck climbing lanes can be studied and, if warranted, the starting and ending points can be selected to control speed differentials in the traffic stream.

5. The speed differential and rate of change of the speed differential can be used to rate the safety of the design and indicate where adjustments in the coordination of horizontal and vertical alignment can be made.

6. Decisions can also be made with respect to multilane highways as to where auxiliary lanes, warranted primarily by level of service considerations, should be started and ended so that speed differentials in the traffic stream are minimized.

We hypothesize that the speed profile can be used in a very similar fashion in the redesign or upgrading of an existing highway section. It is believed that it can be of considerable benefit in helping identify the types of remedial action required.

POSITIVE GUIDANCE IN TRAFFIC CONTROL

Alexander and Lunenfeld propose that a high pay off, short-term way to enhance the safety and operational efficiency of substandard facilities is through positive guidance. This approach represents a joining of the traffic engineering and human factors technologies to
produce an information system matched to the facility characteristics and driver attributes. It is based on the premise that the driver can be given sufficient information, where he needs it, and in the form that he can best use it, to avoid hazards. Thus, properly designed and located traffic control devices guide the driver positively and safely.

The application of positive guidance requires an understanding of the driver's task and his use of information. Decision-making failures attributable to information system deficiencies are identified as factors in accidents and inefficient operations.

Drivers gather information from many sources, handling it in a decision-making process, and translating their decisions into control actions. Their task is comprised of many discrete activities which may be grouped into three levels. The control level encompasses activities relating to the physical operation of the vehicle. Guidance level activities relate to selecting and maintaining a safe speed and path. Here the driver gathers information from many sources and relies on experience, judgment, estimation, and prediction. Navigational level activities relate to trip planning, route following, and direction finding. Information handling is usually intermittent and highly verbal. Failures at the control and guidance level increase the probability of accidents (catastrophic system failures). Failures at the navigation level lead to delay, confusion, and other inefficiencies (noncatastrophic system failures).

Positive guidance is of greatest benefit to guidance tasks where the driver must perceive and properly respond to situations and events which are often hazardous. The basic guidance task is lane placement and road following. Obstacle avoidance is part of and integrated into this task. Superimposed on the basic task are more complex guidance tasks including car following, overtaking and passing, pedestrian avoidance, etc. These tasks are time shared with each other, and with control and navigation activities. When events occur in close time proximity, time to receive and process information is limited, and margin for error reduced.

Guidance failures are failures to decide on a correct speed and path. This is often caused by inadequate information display. Inadequacy may be due to too little or too much information, message ambiguity, conflicting information, poor visibility, poor location, etc. Assessment and evaluation of the information system is a part of the positive guidance procedure.

In performing guidance tasks, drivers sample information from the roadway, the environment, traffic, and traffic control devices. They receive and process relevant information, synthesize it, and select the
speed and path that is considered proper. Correct speed and path deci-
sions often require drivers to interpret and evaluate information.
Guidance information sources include the highway and traffic and the
formal information carriers of marking, delineators, regulatory and
warning signs, signals, and guide signs. Positive guidance information
is provided when information is presented unequivocally, unambiguously,
and conspicuously enough to meet decision sight distance criteria and
enhance the probability of appropriate speed and path decisions.

Successful performance at the guidance level requires the selection
of a speed and path to negotiate location safely and efficiently. Hazards
are objects, conditions, or situations which, when the driver fails to
perform successfully produce accidents. Object hazards may be of two
types, fixed and moving. Of the two, fixed objects are generally easier
for the driver to perceive as hazardous and avoid. The condition of the
highway, its design features which may be substandard, its state of
maintenance all may contribute to the roadway being a highway condi-
tion hazard. Included are such things as lane drops, tangential off ramps,
inadequate superelevation, etc. This type of hazard is generally more
difficult to recognize and more complex to deal with. The most complex
and difficult to recognize and deal with is the situation hazard. They
are essentially combinations of conditions with or without object hazards.

As hazards become more difficult to recognize and more complex to
deal with, more driver mental processing time is required and the likeli-
hood for error increases. Positive guidance must aid the driver in these
instances. It must help the driver see a hazard that cannot otherwise
be seen; it must help the driver identify a hazard when identification
is difficult or subject to error; and it must help the driver avoid a
hazard if selection of appropriate speed and path is difficult or time
consuming or prone to error.

The extent and nature of the positive guidance to be applied is
dependent on the hazard and its interaction with the driver’s information
processing characteristics. Application of positive guidance therefore
requires an appreciation of the process by which drivers handle informa-
tion and two of the mechanisms that help them organize and process it—
primary and expectancy.

At a hazardous location, several hazards may be close to each other.
Information associated with these essentially competing hazards, as well
as other information associated with guidance and navigational tasks
may compete for the driver's attention. Drivers can only attend to one
thing at a time. In situations where information competes, attending to less important information could result in driver failure. Drivers may not be able to select the most important information source for themselves. Positive guidance emphasizes the most important information. Guidance information always assumes a higher primacy. When hazards compete for the driver's attention, the criteria of severity and closeness are applied to assess primacy in terms of the results of nonreceipt of competing information.

Expectancy relates to the predisposition of the driver to respond to events, situations, or information presentation. Based on driver experience, when expectancies are met, performance tends to be error free. When expectancies are violated, longer response time and driver errors are the usual result. Positive guidance is responsive to expectancies. It restructures them when they are violated, and reinforces when they are proper.

Information handling leading to successful performance is dependent on the driver’s ability to: detect a hazard, recognize it as such, decide on an appropriate speed and path, and act on the speed and path decision. Positive guidance requires the driver to be given all the information needed to make the correct decision.

The detectability of a hazard is dependent on the interaction between its visibility, conspicuity, primacy, the number of competing information sources, driver's expectancies, and their visual and knowledge attributes. Its recognizability is dependent on visibility factors and on driver’s prior knowledge and experience. Positive guidance can enhance detectability and recognizability when either or both are difficult for the driver.

Selection of appropriate speed and path is a three-part process of: identifying an alternative course of action, evaluating the probability of success of each alternative, and then selecting the most appropriate alternative. Many factors enter into this process and many factors degrade the driver’s opportunity to select the appropriate alternatives. These include insufficient time to choose among alternatives, inability to identify adequate alternatives or choose between equally attractive or unattractive alternatives, and insufficient information to make the right choice. Positive guidance can, through suitable traffic control devices, be used to advise or regulate speed and path selections.

Positive guidance has been formalized into a system analysis methodology. A procedure has been developed consisting of six major functions. The first three functions, data collection at problem locations, specifications of problems, and definition of driver performance factors
serve as analytical and diagnostic tools for determining the location and nature of safety and operational problems. The next two, *definition of information requirements* and *determination of positive guidance information*, aid in the design of remedial information system corrections. Finally, *evaluation*, provides the means for determining the effectiveness of the solutions.

Positive guidance is not a magic cure-all; first, those guidance failures which are caused by driver failure are not covered by positive guidance. In that category fall drivers whose perceptual and cognitive processes are functioning improperly. Drugged, drunken, or drowsy drivers and drivers whose normal performance is otherwise impaired, are serious human factors problems that cannot be solved by providing better highway information. Secondly, there are those highway design features that exceed driver response capabilities. Where the complexity of the design is such that drivers do not have enough time to make all the judgments required, no solution short of redesign will eliminate the frequency of catastrophic system failures—i.e., if you can’t sign it, don’t built it!

*Example Application—Narrow Bridge Locations*

One high payoff application of the positive guidance technique lies in providing drivers with information to enable them to negotiate narrow bridge locations safely and efficiently.\(^{16}\) The narrow bridge problem is a serious one. Although estimates range to as many as 20,000 deficient-width bridges, little has been done to ameliorate the high accident rates associated with narrow bridges. Some widening and replacement is in progress, however the high cost (estimate: $6 billion) and long lead time make this countermeasure both economically unfeasible and too long term to have immediate nationwide impact.\(^{17}\)

Lunenfeld\(^ {16}\) describes a program undertaken to determine suitable traffic control systems that would enable drivers to safely negotiate narrow bridges. The program was based on a human factors analysis of the narrow bridge problem augmented by inputs from highway and traffic engineers. Prevalent narrow bridge configurations were specified in accordance with engineering parameters, attendant hazards were identified, and the driver’s task was described at these locations. A determination of driver information needs and potential sources of error led to the design of the traffic control device system.

*Locations*—The human factors analysis of the narrow bridge problem required a dynamic assessment of the driving task at and in the vicinity of the problem location. Accordingly, the narrow bridge situation was divided into the five zones as shown in Figure 6. These are:
a. Zone 1—The advance area upstream of the bridge approach. Zone 1 is variable in length depending on the nature of the roadway. For the purposes of this analysis, this zone is assumed to start approximately one mile upstream of the bridge and end at the start of Zone 2.

b. Zone 2—Zone 2 is the approach. The approach begins at the location where, if action is required to avoid a hazard, information pertaining to this action must be perceived. The length of Zone 2 is a function of the amount of time required from detection of hazard to the completion of the maneuver. This is generally equal to the stopping sight distance. At the end of Zone 2, evasive action cannot be successfully completed. The location of Zone 2 (the beginning of Zone 3) varies because it depends on conditions, sight distance, and whether the hazard is fixed (e.g., a bridge railing) or moving (e.g., a slow-moving vehicle being overtaken and passed).

c. Zone 3—This is the nonrecovery zone, where it is too late to initiate an evasive maneuver to avoid an accident. The length of Zone 3 is less than a driver’s perception-reaction time. In Zone 3, which extends from the end of Zone 2 to the start of the bridge, the motorist may still have an opportunity to lessen the effects of a collision.

d. Zone 4—Zone 4 is the narrow bridge.
e. Zone 5—Zone 5 is the sum of the "bridge approach" and "non-recovery" zones for opposing traffic.

**Driver Tasks**—The following tasks were considered:

a. Road Following (Compensatory Tracking)—Steering and control of speed are required to follow the roadway alinement and grade. Obstacle avoidance is part of and integrated into the road following task.

b. Car Following—Maintaining a safe headway in relation to lead traffic.

c. Overtaking and Passing—Closing headway with a lead vehicle, changing lanes to pass and returning to lane. Included in this task is determining a safe path in the passing lane, free of fixed and moving hazards.

d. Meeting—Approaching and passing traffic in the opposite direction of travel.

**Expectancy Violations**—A serious problem associated with the narrow bridge is that the bridge itself violates the driver's expectancies. A driver does not expect the narrow bridge and is thus unprepared to change his driving behavior. That is, the driver expects the roadway and shoulder to be of constant cross-section. When there is a restriction in cross-section, as in the narrow bridge situation, and if the narrow bridge does not even look like a bridge (as is the case with most very short spans), the motorist not only may not be prepared for the restriction, but may not even realize that it has occurred.

Traffic control devices should structure the motorist's expectancy. The driver should be prepared for the narrow bridge situation, the narrowing of the shoulder and/or roadway, the potential need to yield the right-of-way if a one-lane bridge, and any other attendant hazards. In terms of the philosophy of positive guidance, restructuring motorist expectancies aids the driver to detect a hazard, perceive it as a threat, and identify alternative courses of action.

**Problem Analysis**

An analysis has been performed of the driver's task for a Type STT (short, two lane, on tangent) bridge a nominal case. In the course of these analyses, driver and engineering factors have been identified and assessed in terms of potential and real problems. The human factors considerations have been applied to develop driver information needs. Based on this analysis, "within the state-of-the-art" traffic control device countermeasures have been developed.
1. **Type STT**—This is short two-lane bridge approached on tangent. To facilitate the analysis, certain additional factors have been assumed.

- The bridge is on the secondary system in a rural area.
- The road approaching the bridge consists of two 11-foot paved lanes with a full shoulder. It is essentially straight and flat.
- The bridge is 22-feet wide and 200-feet long with a concrete parapet.
- Traffic volume is 350 ADT with 10% commercial traffic, mostly farm-to-market and bus.

a. **Zone 1**—Zone 1, being on tangent, presents no unusual road following, car following, or passing task difficulty to the driver. It is essentially an uncommitted zone, and thus a prime location for the placement of advance warnings.

   Traffic control devices in the advance zone can serve to structure the driver’s expectancy of the narrow bridge. For this case, a warning sign with demonstrated effectiveness should suffice. Because it is also important, particularly under adverse weather conditions, to keep road speeds to a reasonable limit commensurate with the surface characteristics of the approach and the bridge deck, such a device might also serve to reduce excessive speed.

b. **Zone 2**—The bridge approach is the most critical zone from a safety and information presentation standpoint. The approach is the location where the driver must receive information needed to avoid any hazards.

   (1) **Road Following**—This task requires that the driver be provided with continuous information both to follow the road and to avoid fixed obstacles. Continuous edge and center reflectorized markings are suggested for this purpose. Further, to aid night-time driving, roadside delineators are suggested. These standard treatments are important in that they relieve the motorist of having to devote too much attention to searching for high primacy lateral placement information, thus enabling him to attend to other important information gathering activities.

   Obstacle avoidance is the most critical of the road following sub-tasks. The bridge and bridge ends must be marked and delineated so that they can be clearly seen. It is important that the warning devices have high target value and be clearly understood as signifying a threat.

   (2) **Car Following**—In this case, car following should not be a problem, since any lead vehicle should always be in view.
(3) Overtaking and Passing—This maneuver is one which always has elements of hazard wherever it is performed. In the vicinity of a narrow bridge, it is particularly hazardous, for several reasons. First, the driver executing the pass may pay so much attention to the maneuver that he does not perceive the bridge as either a hazard or a threat. Second, the driver being overtaken will, on perception of the narrow bridge, move toward the left of the roadway, thereby reducing the passing vehicle’s clearance. This will pose an even greater problem if the passed vehicle is a commercial vehicle. A third potential hazard is to vehicles in the opposing lane. If the vehicle performing the passing maneuver appears, to opposing traffic, to have marginal clearance time, then the opposing traffic, if on the approach to the other end of the bridge, might view this vehicle as a threat and take evasive action. This, in turn, could cause the opposing vehicle to collide with the bridge end or, if the opposing vehicle is on the bridge, he might be forced to hit the bridge curb with resulting loss of control.

Sound human factors principles require that the information carrier, i.e., the traffic control device(s), should identify a hazard and a threat if the driver is unlikely to perceive it as such and to mandate the appropriate course of action if the driver cannot make the decision. In this case, it is unlikely that a driver in the passing situation will perceive the hazard because he probably does not expect the lead vehicle to move left. Further, there is evidence to support the fact that oncoming vehicles cannot correctly judge rapidly closing meeting headways. There is thus justification to mandating the appropriate course of action for the passing driver by prohibiting passing in the approach zone, even though sight distance criteria for passing zones are met.

(4) Meeting—Vehicles meeting in Zone 2 should not pose a problem, provided the drivers are given clear path identification in the form of edge and center marking and delineators.

c. Zone 3—Zone 3 has been defined as the nonrecovery zone, from the end of Zone 2 to the bridge. For purposes of information needs and treatments, the analysis of Zone 2 is applicable to Zone 3. Guardrails, if installed, will be in this zone, and should be clearly delineated, as much as for supplemental path guidance as for hazard identification.

d. Zone 4—Zone 4 is the bridge. On the bridge, the narrowing of the traveled way will have occurred, and the driver will therefore be driving in a different environment. Since the bridge is “short,” the assumption is that the driver will not be able to adjust to the restriction in clearance as he could on a “long” bridge. Further, being a bridge, there is a likelihood that the surface may be more hazardous when wet and may freeze in cold weather.
(1) Road Following—On the bridge, the driver's primary task should be to maintain a safe path relative to the railing and curb, and relative to oncoming traffic (see “Meeting” below). During daylight hours, the problem is not too great. However, at night, and under adverse weather conditions, the driver must be given continuous path information so he can safely position his vehicle. For short spans, edge markings and rail markings should suffice. For longer spans, it may be necessary to provide lights on the bridge.

(2) Car Following—As in the case of the approach, the task of car following should not pose a difficult task for the driver.

(3) Overtaking and Passing—The potential problems involved in overtaking and passing on the bridge are similar to those associated with Zone 2. An additional problem for the driver is perceived clearance to perform the maneuver. If a commercial vehicle with an eight-foot width is two feet from the bridge rail, then it is taking up ten feet of the 22-foot width. A seven-foot passenger vehicle has five feet of clearance. This is perceived as a tight clearance and could lead to a driver error while passing, even though clearance is adequate. In cases where the bridge is narrower, although still technically two-lane, this problem becomes more severe.

For reasons cited in the Zone 2 discussion and above, it would appear that a prohibition of passing in the bridge zone is strongly

---

**Fig. 7. Traffic Control System for a Type STT Bridge.**
indicated. This is an even stronger requirement if a high percentage of traffic is commercial and if the bridge roadway is narrower than 22 feet.

(4) Meeting—The safety of vehicle meetings on the bridge depends, to a large extent, on the suitability of markings and delineation. There should be adequate clearance, even for two commercial vehicles, on a 22-foot wide bridge. If the bridge is between 18 and 20 feet in width and if there is a strong possibility of two commercial vehicles meeting (i.e., high ADT and percentage of commercial traffic) then the bridge should be considered one-lane.

e. Zone 5—What is most important in Zone 5 is to provide a smooth path transition via good marking treatment.

Figure 7 shows the traffic control system for a Type STT (short, less than 250 feet, two way on tangent) bridge.

Figure 8 shows the possible traffic control devices, after a similar analysis, of a Type SOC (short, less than 250 feet, one way on curve) bridge.

DRIVER EXPECTANCY

As noted earlier, driver expectancy relates to the predisposition of the driver to respond to events, situations, or the presentation of

![Type SOC Diagram](image-url)
information. It is primarily a function of the driver’s experience. If an expectancy is met, the driver performance tends to be error free. When an expectancy is violated, longer response times and incorrect behavior usually result.

Woods has expanded the concept of driver expectancy to include it as a comprehensive principle of highway design. A list of driver expectancies or postulates for various classes of highways can be readily made. Some sample postulates for freeways are: (a) the number of through lanes approaching and leaving a given area will be the same; (b) all freeway exits are on the right; (c) the most important route will be the most direct; (d) there will be no speed reduction on curves; (e) my destination is always signed—etc.

The concept can also be effectively utilized on existing highways.

A team of both professional and lay drivers can be a very effective (and very enlightening) way to identify problems on the highway system. The team should be composed of lay drivers unfamiliar with the roadway section, at least one individual responsible for operating the roadway under study, and representatives from police agencies, professional drivers (truckers, cab drivers, traveling salesmen, etc.) as is appropriate.

The team members should be asked to drive the section in question. An interviewer in the vehicle with the expectancy checklist can observe and record the points where the driver had difficulty (overt actions are good indicators) and question the driver regarding the reasons. The resulting information can be used as an indicator of the type of improvement needed.

A driver expectancy checklist is very helpful as a design review tool and should be equally as helpful as a diagnostic tool for existing highways.

**COMMENT**

The speed profile is primarily an analysis tool in that it indicates the location of potential trouble spots related to speed differentials. The analysis of the speed profile can suggest solutions to the problem.

The positive guidance technique is primarily of use in generating solutions to a problem known to exist.

The Driver Expectancy Checklist is an analysis tool; the violation of expectancies is a potential accident breeder. Alternative solutions are suggested when one considers ways in which expectancies can be met or restructured.
COST-EFFECTIVE IMPROVEMENT PROGRAMS

To the author's knowledge there are no programs for determining cost-effectiveness—safety-effectiveness of total safety improvements. There are, however, three programs related to selected elements of safety that are currently being used.

Glennon\textsuperscript{20} in NCHRP Report 148 proposed a probabilistic model to be used as a management tool in establishing the priority for roadside safety improvements. It was expected that each state would adapt the research findings to its own specific needs and administrative structure. Texas has done this\textsuperscript{21, 22} and the procedure apparently is working quite well, and as might be expected, a computer is used to analyze the vast amount of data. The procedure to evaluate safety improvements for roadside hazards on the Texas freeway system comprises three related functions:

(a) Conducting a detailed physical inventory of the interstate highway system to identify and locate each hazard.

(b) Recommending feasible safety roadside improvement alternatives for each hazard or group of hazards.

(c) Evaluating the recommended safety improvement alternatives using the cost-effectiveness model.

More recently (1974), the freeway procedure has been adapted and reference\textsuperscript{23} presents a method for the inventory of hazards and to recommend safety improvements alongside both types of rural highways—controlled and noncontrolled access—using one procedure and a common computer program.

The experience of Texas in this area should indeed make it much easier for other states to develop their own cost-effectiveness programs for roadside safety improvements.

In 1969, the state of Illinois was confronted with more than 5,000 miles of pavements on the state system which were less than 22 feet in width and had surface deterioration far beyond the realm of economical maintenance. These factors, together with increasing traffic volumes, presented considerable hazards to traveling motorists.\textsuperscript{24, 25}

The reconstruction of these pavements to the "AASHTO Standards for Highways Other Than Freeways" far exceeded the financial capabilities of retiring these deficiencies at an acceptable rate. It was determined that if these deficiencies were to be corrected within a reasonable period of time, a substantial mileage of these narrow pavements would have to be reconstructed to what we termed "expedient standards."

Under the expedient standards that were proposed, pavements less than 22 feet in width be widened to 24 feet and resurfaced. The exist-
ing right of way and slopes were to be retained. Alinement would be corrected only at known high accident locations. Shoulders would be regarded only to the extent necessary to accommodate the new surface elevation. The resultant shoulder width would range between three and eight feet, which would include a 12-inch bituminous shoulder wedge provided as part of the widening. (Typical cross sections are shown in Figure 9)

Bridges were to remain in place if they were at least 28 feet face to face of curbs, were structurally sound, and had a rating of at least H-15. Bridges less than 28 feet in width and in sound structural condition were widened to 32 feet face to face of parapet or rail. Unsound structures, through trusses and through girders, were replaced to provide a roadway width of 32 feet face to face of parapet.

Illinois’ experience with the expedient standards program was that it resulted in significant improvements that were highly visible to and very well received by the public.

---

**EXPEDIENT DESIGN**

---

**MINIMUM AASHTO DESIGN**

Fig. 9. Typical Cross Sections of Widened Pavements *(substandard alinement corrected only at high accident locations).*
The table on the following page indicates the accident rate reduction per $100,000 invested.

<table>
<thead>
<tr>
<th></th>
<th>Expedient ($86,375 per mile)</th>
<th>Minimum AASHTO ($200,550 per mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Reduction/$100,000</td>
<td>16.55%</td>
<td>13.71%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 305</td>
<td>24.54</td>
<td>22.19</td>
</tr>
<tr>
<td>Under 305</td>
<td>2.78</td>
<td>9.27</td>
</tr>
<tr>
<td>Injury—Fatal</td>
<td>19.00</td>
<td>18.30</td>
</tr>
</tbody>
</table>

Note that there is not much difference in the accident rate reduction per $100,000 of construction funds expended, indicating that the expedient standards, on the roads improved in Illinois, were as cost-effective as AASHTO standards.

Comment

A common argument against the development and use of a roadside improvement cost-effectiveness program, such as is in use in Texas, is that not enough funds are available so why go to the trouble. Actually, this is not an argument against but a justification for such a program. If limited funds are available for roadside safety improvement, using the cost-effectiveness approach rather than a generalized subjective approach should provide considerably greater safety payoff.

CONCLUSION

The concepts of the speed profile, positive guidance, and expectancy checks are not now widely used. It is believed that they have great promise in analysis and will significantly aid in generating solutions to certain safety problems on existing highways. The roadside hazard/cost-effectiveness programs now in use in Texas are excellent guides for use in adapting the programs in other states. The expedient-standards approach of Illinois appears to be cost-effective.

REFERENCES

1 Institute of Traffic Engineers, "Dynamic Design for Safety" seminar notes, to be published, 1975.


19 Rowan, N. J., D. L. Woods, N. C. Ellis, and M. D. Shelby, "Driver Expectancy Checklist," Texas Transportation Institute, Texas A & M University, College Station.


