H = hazard index or expected number of fatal plus non-fatal injury accidents per year;
V = vehicle exposure;
PE = probability of encroachment;
PCE = probability of a collision, given an encroachment; and
PIC = probability of an injury (fatal or non-fatal), given a collision.

Glennon then calculates the cost-effectiveness ratio defined as the annualized cost for the reduction of one fatal or non-fatal injury accident. Here, data are needed for all the probability terms, because much of this work is based on theory. Indeed, the probability of encroachment is based on the old work by Hutchinson and Kennedy (6).

In models like this, site layout considerations come into play. For example, a pole (breakaway or non-breakaway) is more likely to be struck if closer to the edge of pavement. The same would be true for median barrier placement. Barriers placed close to the pavement yield more hits at shallower angles, while more severe, higher-angle collisions result when distance from the pavement edge is greater. And while such considerations about site layout and impact conditions are important, what we are trying to focus on here are the inherent capabilities or limitations of the appurtenance and the relative severity of the collision.

CONCLUSION

It should be stated that some excellent work has been performed in developing or reviewing procedures for ranking alternatives by the Texas Transportation Institute (7) for FHWA. These methods include incremental benefit/cost techniques with improved algorithm, dynamic programming and inter programming--techniques that lead to optimal budget packages. However, one problem here is that much of the work has focused on fairly meticulous cost calculations (i.e., costs of accidents for various roadway and traffic situations). The accompanying knowledge about treatment effectiveness (frequency or severity reduction) can be stated with nowhere near the same precision. Indeed, the effectiveness factors could be orders of magnitude different.

Thus, we have a good handle on the economic techniques for ranking programs. It is time to develop research methodologies that will produce the needed estimates of effectiveness for our design hardware.

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Part 2: Session 1, Physical Testing and Analysis

Jarvis D. Michie, Southwest Research Institute, Moderator

This session was devoted to seven aspects of roadside hardware development, principally the design, laboratory and crash test evaluation and assessment of the hardware potential. The presenters were asked to critically evaluate a specific area with respect to generating data needed in the benefit/cost analysis procedure. As it was felt that the positive features of the seven areas have been emphasized in previous meetings and in the literature, the presenters were asked to concentrate on limitations. Accordingly, the reader is advised that the following purposely stresses the negative and should not be viewed as a balanced appraisal of highway safety technology.

BASELINE DATA NEEDS

Hayes E. Ross, Jr., Texas Transportation Institute, Texas A&M University

Benefit/cost analyses of roadside safety programs generally involve (a) an estimate of accident frequency and (b) an estimate of the severity of the predicted accidents. In most such analyses these estimates, through no fault of the analyst, are crude and statistically unsound. Data on which reliable predictions can be based are sparse. Numerous variables influence accident frequency and severity, further complicating data needs.

Attempts have been made to develop accident prediction models based on regression techniques utilizing accident data. These have met with little success for the reasons given above. In the absence of accident data bases, researchers have formulated probabilistic models based on observed and/or assumed vehicle encroachment data. Although widely used, the latter technique has relied on very limited encroachment data, and the results obtained are generally suspect.

The nature and frequency of inadvertent encroachments by a motorist are functions of numerous factors, including the motorist himself. Data are needed to determine this interrelationship. With regard to roadway variables, encroachments are believed to be a function of roadway type (interstate, divided, two-way undivided, urban arterial, etc.), roadway and roadside geometry (vertical and horizontal alignment, shoulder and curb, enbankment, etc.), traffic control devices (delineation, signing, lighting), traffic conditions (vehicle mix, volume, operating speed, environmental conditions, etc.) and vehicle size. An encroachment data base should be gathered sufficiently to develop a statistically reliable accident prediction algorithm with capability to predict the following:

1. Number of times an object will be struck in a given time period,
2. type of vehicles expected to strike object in a given time period,
3. speeds at which vehicles will strike object,
4. angle at which vehicles will strick object, and
5. attitude at which vehicles will strike object.

Once the number and type of vehicle involvements with a given roadside object have been estimated, one must ascertain the probability and level of injuries associated with each involvement. Impact severity can be estimated from physical test data (crash tests, skid tests, laboratory tests, dummy tests, etc.), accident data, computer simulation (vehicle and/or occupant dynamic simulation models), accident reconstruction combining accident data with test data and/or computer simulation, or engineering judgment.

Data from which the severity of a predicted accident can be quantified are also quite sparse. Variables that influence the severity of a given impact include the type of object hit (fixed objects, continuous objects, temporary objects used in work zones, etc.), type of vehicle (automobile, truck, special vehicle, etc.) and impact conditions (speed, angle, attitude, etc.). Impact severity data should be gathered to eventually develop a data base sufficient to evaluate the severity of the accidents predicted by the accident prediction algorithm.

CRASH TEST AND OPERATION EXPERIENCE

Eric F. Nordlin, California Department of Transportation

The procedures for testing and evaluating highway appurtenance performance have become increasingly more complex since 1962 when the original single-page guideline for crash testing guardrail with a 4000-lb. passenger car was first published in Highway Research Board Circular 482. Updated by NCHRP Report 153 in 1974 and Transportation Research Circular 191 in 1978, these guidelines have necessarily and progressively expanded into the present 42-page NCHRP Report 230, Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. The new guidelines cover not only guardrail but also median barriers, bridge rails, crash cushions and breakaway or yielding supports for signs, luminaries and other selected highway appurtenances.

The vehicles of interest now include 1800-lb., 2250-lb. and 4500-lb. passenger cars, a 20,000-lb. utility bus, 32,000-lb. and 40,000-lb. intercity buses and an 80,000-lb. articulated tractor-trailer truck. It also appears that the range of vehicles will be even greater in the foreseeable future as the number of still smaller, lighter passenger cars and still large, heavier and longer tractor-multiple trailer trucks increase as the current trends continue.

Actually, the number of test vehicle variables alone become almost infinite when one considers all of the sizes, weights and shapes of vehicles; their different manufacturers, models and ages; their different mass distributions, location of center of gravity and suspension systems; the location of the engine and type of transmission; the numbers of axles and wheels, wheel and tire sizes and track widths; their general maintained condition and the many other characteristics that affect the structural integrity, stability and dynamic response of an impacting vehicle.

However, the number of potential test variables expands still further when consideration is given to the number of passengers, their physical conditions and ages, how they are restrained and the other occupant protective measures that have been designed into the vehicles; the types of other cargo (gas, liquid or solid), how it is located or stacked and how securely it is restrained; the vehicle velocity, angle, lateral offset and orientation at the time of impact; and the ability of the driver to react to, through and recover from the vehicle/appurtenance interaction situation.

In addition, there also are the many potential variables associated with the location of the appurtenance on the highway; the riding surface leading to and immediately adjacent to the appurtenance; the type and condition of the soil; the horizontal and vertical alignment and other highway geometric design conditions; the point of impact on the appurtenance; the design of the appurtenance and the quality of materials used to construct it; the environmental conditions that affect durability and weatherability; and the general maintenance upkeep efforts expended.

Full-scale vehicle crash tests performed, instrumented and photo documented in accordance with NCHRP Report 230 are very costly; ranging from $10,000 to $20,000 per test at Caltrans. Therefore, an agency must be somewhat restrictive in the number of tests and selective in the variables to be considered.

Structural laboratory tests, analytical procedures, computer simulations and pendulum or bogie vehicle tests are very useful techniques employed to reduce the number of full-scale vehicle impact tests. These less costly complementary procedures frequently serve to screen out the less critical variables and interpolate between the data points generated from a limited number of crash tests.

However, even with these complementary techniques, it is impractical and virtually impossible to duplicate and accurately determine, in a limited number of standardized crash tests, the effect that all of the aforementioned variables will have on vehicles impacting a highway appurtenance. Recognizing this, NCHRP Report 230 establishes normalized test conditions; straight longitudinal barriers are tested although curved installations exist; flat grade is recommended even though installations are sometimes situated on sloped shoulders or behind curbs; idealized soils are specified although appurtenances are often located in poor, frozen or saturated ground, etc. These normalized factors have significant effect on the performance of an appurtenance and may obscure serious safety deficiencies that exist under