cost of the installation and the number of impacts it can withstand before replacement is required.

The study's principal findings are that

1. Guiderail and median barrier performed well in 392 accidents recorded in this study.
2. The barrier penetration rate recorded was significantly lower than in an earlier New York study of barriers.
3. Twenty-eight barrier end-section accidents resulted in no injuries.
4. No large differences in barrier accident repair costs were recorded.
5. Only ten impacts were recorded on slip-base sign supports. Although two resulted in minor injuries and a third in a hospitalization injury, secondary impacts were involved in all three.
6. Seventy-eight impacts on frangible-base luminaire supports resulted in minor injuries in 12 cases, and hospitalization injuries in three more. Several of these injuries probably resulted from secondary collisions with other fixed objects or vehicles.
7. Of 393 impacts recorded on impact attenuators, only 17 minor injuries, 6 hospitalization injuries, and 1 fatality were recorded.
8. Accident repair costs were highest for the sand-barrel units and lowest for the cell-sandwich units, but this may be offset by the higher initial cost of both types of water-filled cells, and the possible need for major reconstruction or replacement after a limited number of impacts.

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Abridgment

Cost-Effectiveness Model for Guardrail Selection

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In view of the problems of ever-increasing highway construction costs and the limited funding available, it is critical to guardrail selection and installation that a cost-effectiveness formulation be included as an aid in the decision-making policy. This is particularly true for the rural, low-volume highway. For such roads, strict adherence to the conventional guardrail warranting and selection procedures could lead to the installation of guardrails of maximum effectiveness at some sites and no installations at other sites because of the lack of available funds. Thus, a need exists for effective criteria for the selection of guardrail types based on a cost-effectiveness analysis. A typical cost-effective procedure can be used to evaluate the options of (a) removing or reducing the hazard so that the guardrail is no longer warranted, (b) installing the most cost-effective guardrail systems that funds permit, or (c) leaving hazards unshielded at sites where guardrail installation is not cost-effective. This report focuses principally on the second of these options; the guardrail is assumed to be warranted. However, the third option (c) can also be exercised for the included hazard types of fixed objects or embankments. Of course, the value of such a cost-effectiveness decision-making policy need not be limited to low-volume roads and could result in more efficient use of available funds for all types of highway systems.

The objective of this program was to develop a cost-effectiveness model for guardrail selection that would include cost parameters for various guardrail configurations as well as criteria for analysis of system effectiveness under various dynamic impact conditions. Eleven guardrail types were selected for inclusion in the program. Five of the designs (G1, G2, G3, G4S, G4W) were included in NCHRP Report 118 (1). The remaining six systems were arbitrarily selected from commonly used designs and some of the newer designs coming into use. Most of the systems have now been included in the 1977 American Association of State Highway and Transportation Officials (AASHTO) Guide (2). The corresponding system notations follow (1 m = 3.3 ft):

System in This Report	Notation in AASHTO Guide
A	GR2, except for post size
B	G4(1W), except for round rather than square posts
C	Not included (W-beam on 0.2 x 0.2-m wood posts with blockouts at 3.8-m spacing)
D	G4 (2W)
E	G4 (2S)
G1	G1
G2	G2
G3	G3
G4S	G4 (1S)
G4W	G4 (1W)
Thrie	G9

Selected impact category values used in the study for vehicle sizes, vehicle speeds, and angles of impact are shown in the following table (1 kg = 2.2 lb; 1 km/h = 0.6 mph):

Category	Value
Vehicle weight (kg)	
Intermediate and standard-size vehicles	2041
Subcompacts and compacts	1021
Vehicle speed (km/h)	
Less than 64.4	48.3
64.4 to 96.5	80.5
Over 96.5	112.7
Angle of impact (°)	
Less than 10°	7
10 to 20°	15
20 to 30°	25
Over 30°	30

A present-worth probabilistic formulation was used in the development of the cost-effectiveness model. This method combines the guardrail installation cost and all annual maintenance and accident costs into a single equivalent sum at zero time. Of the alternatives compared, the one with the lowest present worth is the most economical. With this approach, the total government or state cost, converted to present dollars, is given by C_G = cost of installation + cost of maintenance and repair - salvage value, and the total societal cost by C_S = severity costs per accident (fatalities, injuries, guardrail and vehicle damage, and traffic delay) × probable number of accidents.

To apply this formulation in developing the computer algorithm, it was necessary to estimate the following items:

1. Traffic mix [fractions of total traffic by 1021-kg (2250-lb) and 2041-kg (4500-lb) vehicles];
2. Number of encroachments;
3. Probabilities of out-of-control vehicles traversing the offset distance to the guardrail or obstacle;
4. Distribution of vehicle speeds;
5. Distribution of impact angles;
6. Accident severities in terms of guardrail damage, number of occupant injuries or fatalities, and vehicle damage for each combination of the category vehicle speeds and impact angles;
7. Travel delay time for accident blockage and guardrail repair;
8. Costs of injuries, fatalities, vehicle damage, travel delay, and guardrail installation, repair, maintenance, and salvage value; and
9. Service life of the guardrail and rate of interest.

For the most part, these parameters were quantified from available historical data. Exceptions included estimates of traffic mix and unit construction costs, which were obtained from the states, and impact angle distributions, which were obtained analytically from geometric and vehicle properties with limited supportive field data. Also, in the most radical departure from usual practice, accident severity estimates were based on full-scale test results rather than analysis of accident data. Available test results were first carefully correlated with the BARRIER VII computer simulation. Once satisfactory correlation was achieved, the program was used to obtain extrapolation predictions for the 24 category impact combinations from the second table and each of the 11 guardrail types. For illustrative purposes, a guardrail service life of 15 years and a current interest rate of 8 percent were used.

A COCOST program for comparative cost-effectiveness values and ranking of the 11 included guardrail types with given roadway conditions was developed in the program. The following definitions were used with regard to the cost-effectiveness values:

1. State cost—money spent by the state in installing and maintaining the guardrail;
2. Societal cost—costs associated with accidents, including costs of injuries and fatalities, costs of guardrail and vehicle damage, and cost of traffic delay;
3. Total cost—the sum of state and societal costs;
4. Benefit—the difference between societal cost with no guardrail installation and societal cost with the guardrail installed (hazard types include fixed objects or embankments); and
5. Benefit-to-cost ratio—the ratio of the benefit to the state cost (to effect a savings in societal costs greater than the state cost of the guardrail installation, a benefit-to-cost ratio greater than unity must be realized).

The COCOST user's manual includes the basis and limitations of the program, computer program descriptions and listings, a series of site selection tables based on the representative costs and input values, and sample problems for applying the computer program for the following: (a) selection at a particular site of the most cost-effective guardrail system of the 11 included types, (b) guardrail placement at a site for the optimum location and guardrail type, and (c) priority ranking of several site selections for appropriation of available funds.

COCOST was prepared with a view to producing a product that has the desired flexibility but is as simple to use and as easy to implement as possible within the limitations imposed by the specified scope of the study. Program inputs are simple to prepare with familiar engineering terms and format. If preselected representative inputs are acceptable to the user, only four COCOST cards per set are required, the second of which

Figure 1. A sample COCOST output sheet.

SUMMARY OF RESULTS EXAMPLE GUARDRAIL PLACEMENT CASE - 6-FT SHOULDER

PAVEMENT-TO-GUARDRAIL DISTANCE = 6 FT GUARDRAIL-TO-OBSTACLE DISTANCE = 9 FT

PAVEMENT-TO-OBSTACLE DISTANCE = 15 FT SOCIETAL COST WITH NO GUARDRAIL = $ 3561.28

AADT = 5000 GUARDRAIL LENGTH = 276 FT OBSTACLE LENGTH = 200 FT

DEGREE OF CURVE		PREFERRED GUARDRAIL ORDER BY INDICATED CRITERIA 1	2	3	4	5	6	7	8	9	10	11
0	STATE COST	G1	G2	A	C	B	E	D	G4W	G4S	THRIE	G3
	VALUES	768.59	1113.59	1154.99	1292.99	1568.99	1596.59	1637.99	1706.99	1706.99	1982.99	3638.99
	SOCIETAL COST	G2	G4S	G1	D	THRIE	A	E	G3	C	B	G4W
	VALUES	754.82	1669.59	1740.45	1759.36	1815.26	1834.07	1877.61	2017.82	2087.30	2407.57	2412.90
	TOTAL COST	G2	G1	A	G4S	C	D	E	THRIE	B	G4W	G3
	VALUES	1868.42	2509.05	2989.06	3376.59	3380.29	3397.35	3474.21	3798.26	3976.57	4119.89	5656.81
	BENEFIT/COST	G2	G1	A	C	G4S	D	E	THRIE	B	G4W	G3
	VALUES	2.52	2.37	1.50	1.14	1.11	1.10	1.05	.88	.74	.67	.42

is a blank card. Card sets are simply stacked so that as many cases can be run as desired. To facilitate adaptation to a particular computer, both CBC and IBM operational versions of the programs have been prepared. The computer programs are small, and run times are minimal.

Interpretation of the computer output results is not difficult. For example, Figure 1 shows a typical COCOST output sheet, in which it can be seen that the guardrail types are ranked by state cost, societal cost, total cost, and benefit-to-cost ratio in the order of decreasing preference (the best is number 1 and the worst is number 11), along with the corresponding values. Thus, the G2 system is the preferable guardrail for this site from the standpoints of either societal cost, total cost, or benefit-to-cost ratio. The analyst can select the cost-effectiveness measure desired and can extract the indicated values, along with the corresponding state cost, for subsequent analyses to establish priorities for appropriation of funds or for other uses.

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Abridgment

Computerized Inventory and Priority Analysis for Roadside Obstacles

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Highway safety is significantly influenced by the design and maintenance of the roadside environment. During 1976, over 26 percent of all fatal accidents in Michigan involved collisions with fixed objects in or adjacent to the roadway. Recent highway safety programs emphasize hazard-free roadway facilities and have resulted in reduced accident severity associated with single-vehicle collisions with roadside obstacles. Such programs generally involve the removal, relocation, or protection of roadside obstacles. Even though the potential safety benefits derived from roadside improvement programs are substantial, the traffic engineer is faced with the high cost of removal or relocation of roadside obstacles and the need for a practical program for the identification and prioritization of hazardous roadside obstacles.

In order to make informed decisions regarding the allocation of safety funds for roadside hazard removal, the traffic engineer must first establish a comprehensive data base of the type and location of all potential hazards as they exist along the highway and the relative hazardousness of each. With this information, a systematic roadside safety program may be developed to eliminate or protect those obstacles that present the greatest hazard to the motorist.

This paper describes a computerized information system consisting of a comprehensive inventory of all roadside obstacles in the city of Livonia, Michigan. Livonia is located in the northwestern part of the Detroit metropolitan area and covers 92.9 km^2 (36 $miles^2$) with a population of 110 000 persons. The highway system consists of approximately 483 km (300 miles) of roadway.

In 1976, Livonia experienced a total of 3889 accidents, of which 6 percent were collisions with fixed objects. However, these fixed-object accidents accounted for over 33 percent of all 1976 fatal accidents in the city.

The inventory system incorporates a prioritization mechanism that provides the traffic engineer with a measure of the relative hazard potential associated with each type of roadside obstacle and with the priority to be given to eliminating or protecting that obstacle.

INVENTORY OF ROADSIDE OBSTACLES

Data Collection

The data source from which information on roadside obstacles' type and location was extracted for the development of a computerized inventory of roadside obstacles was 35-mm color photologs. Photologging is a photographic data-collection technique that records a pictorial representation of the roadway and its environs. An instrumented vehicle equipped with a 35-mm color movie camera, distance-measuring instrument (DMI), and a camera actuation device were used for the photologging process. Camera actuation was set at 62 frames/km (100 frames/mile) or every 16.1 m (52.8 ft). The distance traveled by the vehicle from predetermined benchmarks was recorded by the DMI and superimposed