Scientific Highway Design for Safer Motoring

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National Safety Council statistics show that there has been a steady reduction in the rate of highway fatalities since 1926 when accurate data were first accumulated. This reduction has come about for many reasons. Drivers have been taught and have learned better driving practices. In the automobile industry we take pride in the fact that our successive yearly models produce safer vehicles—cars which are quieter, smoother, easier to drive, and more responsive in traffic and cars with improved braking systems, steering systems, better acceleration, better visibility, and better packaging of the passenger.

Contributions of significant magnitude have been made by the highway designers and builders. Before 1920, people who made automobiles were concerned primarily with dependability; the manufacturer who could produce a car which would run dependably had a commanding share of the yearly sales. At that time the city or county or state which had a few miles of paved streets or highways had a commanding share of the successful highway transport. Just as dependability was important in the vehicle, so it was also in the highway system. In the highway system this meant all-weather, paved roads. And the provision of a surface which would carry traffic through all seasons of the year was a matter of primary importance and justifiable pride.

As more and more all-weather, all-year roads came into being, the problems of rapid, safe, and efficient transport became differentiated. As soon as the reliability of the vehicle was established and the reliability of the road was established and taken for granted, the refinements of both became of importance. The refinements in highway and traffic engineering appeared early, first in terms of effectiveness. Since the accident always happened to somebody else, it is understandable that the effectiveness of the system became an element of primary interest to the people who drove automobiles and transported goods before safety received much attention.

The effectiveness of the system of highways depreciated early because of the congestion. There were always people in front travelling at a slow rate, people turning into the road from side streets, trucks which could not maintain reasonable speed, traffic in the opposing lane which inhibited passing—endless frustrations about getting anywhere, simply because there were so many people on the road.

Justifiably, the taxpayers began to ask that the highway transportation system be improved because they couldn't get where they wanted to go as rapidly as they wanted to. Traffic engineering emerged as a new profession during this time, in the late 1920s and early 1930s, and highway engineering began to take into account to an increasing degree the functional utility of the highway as a design element.

Before the collection of good accident data began in the middle 1920s, the newspapers—metropolitan, suburban, and rural—began to report more and more people killed in automobile accidents and fewer and fewer people killed because of being kicked in the head by horses or because of bicycles going out of control and the riders plunging into a ditch or breaking their necks from falling over the handlebars.

As the problems of highway effectiveness and safety became more clearly recognized, the design of highways matured rapidly to provide more lanes for the higher volumes of traffic and to remove restrictions on the rapid and safe movement of traffic. Thus, there came into being one-way roads, divided highways, limited access, signal control at intersections, and separation of grade at important highway intersections. Studies of highway capacity and highway safety showed conclusively that additional investments were required to implement the effective, rapid, and safe flow of traffic, particularly in metropolitan areas.

Because the automobile and automotive transport system are revolutionizing our economy, the concept of rapid, effective, and safe highway transport across the nation have become of paramount importance. Thus, the traffic engineering and highway design principles, which first appeared essential in metropolitan developments 35 years ago, became applicable almost immediately to interurban and interstate travel.

These concepts were understood and appreciated by farsighted highway and traffic engineers more than a generation ago. As funds became available in a few metropolitan and suburban areas they were applied even before the depression in 1929. While highway designers and traffic engineers have appreciated the basic principles involved in the construction and operation of a rapid, effective, and safe highway transport

system, funds have never been adequate to meet the requirements. The deficiencies in amounts of money required have been almost paralyzing, and heavy pressures have always been imposed on highway builders to get the most miles of pavement for the money available. Because of public apathy about the highway traffic safety problem and public ignorance about the part that certain design elements play in highway safety, highway designers have never been permitted to incorporate all the safety elements they knew were required.

During the 35 years covered by the accident records there has been a consecrated and dedicated effort by a few, then a few hundred, and then a few thousand people who were convinced that highway accidents are unnecessary and avoidable. This effort has been responsible in a large part for the steady decrease in the fatal accident rate on a travel basis. Sharing in it have been automotive engineers, highway design and traffic engineers, safety experts in many fields, the clergy, and members of the press, radio, and TV. A major accomplishment has been to develop a better public understanding of the importance of the highway traffic safety problem and effective means by which to cope with it. As a result, highway engineers have been permitted to invest increasing proportions of the highway construction funds in those features which reduce hazards; in fact, the public attitude has come to demand incorporation of these features. As a sidelight, it should be noted that many of the design features fundamental for highway safety also improve the flow of traffic and enhance the effectiveness of the highway.

THE INTERSTATE SYSTEM

This movement culminated in the Highway Act of 1956, which provided for accelerated modernization of the National System of Interstate and Defense Highways.

By this act some 41,000 miles of highways throughout the country (Figure 1) were established as part of the Interstate System and enlightened standards of design were established. At the time of passage it was intended that this system would be completed in about 15 years.

Figures 2, 3, and 4 show typical examples of highways constructed according to these enlightened concepts.

The standards of the Interstate System provide certain requirements with regard to alignment, profile, cross section lane width, and, particularly, control of access.

Fig. 1. National System of Interstate and Defense Highways.

Control of access is required for all sections of the Interstate System. Grade separations are required, except for those intersections in sparsely settled rural areas where the traffic volumes on both roads are

Fig. 2. Typical scene on New York Thruway showing gentle alignment, wide median, wide traffic lanes, unobstructed view, high capacity.

Fig. 3. Scene on New Jersey Turnpike showing general alignment, paved shoulders, protected opening and overpass, grade separation, unobstructed view, wide median, wide traffic lanes.

low, where no appreciable hazard is created, and where the traffic volume on the intersecting road is less than 50 vehicles per day.

The design speed of all highways in the system is to be at least 70, 60, and 50 mph for flat, rolling, and mountainous topography, respectively, and depending upon the nature of terrain development. Alignment, super elevation, and sight distance are to be correlated with design speed.

For design speeds of 70, 60, and 50 mph, gradients, generally, are not to be steeper than three per cent, four per cent, and five per cent respectively. Gradients two per cent steeper may be provided in rugged terrain. Traffic lanes are not to be less than 12 feet wide and the usable width of the shoulder shall not be less than ten feet, except in mountainous terrain involving high cost for additional width. The usable width of shoulder may be less, but at least six feet.

Side slopes are to be 4:1, or flatter where feasible, and not steeper than 2:1, except in rock excavations or other special conditions. These special conditions include, presumably, certain locations in urban areas where costs of providing this standard would be prohibitive.

Fig. 4. Typical scene on interstate road in Ohio showing wide median with relatively mild median ditch, long sight distances, gentle horizontal and vertical curves, wide traffic lanes, and long guardrail installation protecting opening in overpass structure.

The median is to have a minimum width of 36 feet, except in urban areas where right-of-way costs make this excessive. In any case, it is to be at least four feet.

The design standards listed above are considered minimum for the Interstate Highway System. Higher standards which represent desirable minimum standards are to be used when they are commensurate with conditions and when the use of higher values will not result in excessive cost. In the determination of all geometric features, including right-of-way, a generous factor of safety should be employed and unquestioned adequacy should be the criterion. All known features of safety and utility should be incorporated in each design to result in a National System of Interstate and Defense Highways which will be a credit to the nation. (1)*

During the period from the late 1930s until the Highway Act of 1956, particularly after World War II, there was an urgent demand

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* Numbers in parentheses refer to list of references.

for improved highways in some areas where anticipated usage plus lack of other funds justified financing as toll roads. Some major examples are shown in Figure 5.

Fig. 5. Some examples of major toll facilities.

As these facilities, designed and built according to advanced and enlightened standards, came into use it became evident that in addition to providing a highly effective highway transport system, very favorable accident rates were experienced. (Figure 6)

TURNPIKE	DEATH RATIO 1959	LENGTH MILES	VEHICLE MILES (MILLIONS)
ILLINOIS TOLLWAY	0.5	188	605.7
CONNECTICUT TURNPIKE	1.4	129	790.0
NEW JERSEY TURNPIKE	1.5	132	1343.8
OHIO TURNPIKE	1.8	241	981.8
GARDEN STATE PARKWAY - N. J.	2.1	174	1212.0
SUNSHINE STATE PARKWAY (FLA)	2.6	110	193.8
NEW YORK THRUWAY	2.8	553	2103.4
MASSACHUSETTS TURNPIKE	2.9	123	485.7
PENNSYLVANIA TURNPIKE	3.7	470	2081.0
INDIANA EAST-WEST TOLL ROAD	4.5	157	619.3
MAINE TURNPIKE	5.1	113	196.6
KANSAS TURNPIKE	5.5	242	273.9
WILL ROGERS AND TURNER TURNPIKE (OKLA)	6.1	174	295.7

Fig. 6. Death rates per 100 million miles on 13 toll facilities with greatest length and largest traffic volumes.

The standards for construction of the Interstate System are comparable with those of the toll roads shown here, or higher. It seems

clear that the highway traffic accident problem will be reduced significantly when this program is completed, especially since a large proportion of the total traffic volume will be carried on the Interstate System.

PROVING GROUND ROAD SAFETY PROBLEMS

At the General Motors Proving Ground we have been very much concerned with our road safety problems. As we began to apply industrial safety standards to our operation on our road system, we became properly concerned about the hazards which were involved.

Our primary road system was designed more than 30 years ago and much of our operation is conducted on that part of the system. The design provided one-way operation, controlled access, elimination of grade crossings, and most of the other concepts which are part of the standards of the Interstate System and the major toll roads. The primary concern of all safety engineers is to eliminate accidents. The next important concern of the industrial safety engineer is to minimize the effect of any accident which may occur. While our road system had been designed to obviate the accidents which occur most frequently on the public highway system, too few precautions had been taken to minimize the effect of accidents resulting from the vehicle leaving the roadway.

A review of our accident statistics during the six calendar years, 1953-1958 inclusive, covering approximately 65 million test miles, revealed a total of 236 accidents, of which 72 per cent were off-the-road.

In spite of careful selection of driver personnel, the application of the best training programs we can evolve, and operation on a closed road system under adequate supervision, evidence shows that we cannot keep our drivers on the roadway all the time. Drivers on the public highways cannot be kept on the road all the time either, as the statistics bear out.

The National Safety Council statistics show year after year that from 30 per cent to 35 per cent of the fatalities are incurred in off-the-road accidents—the one-vehicle, non-collision type. (Figure 7)

We found that our roadsides presented numerous hazards. In an attempt to apply the second precept of safety engineering rapidly—to minimize the effect of accidents—we looked at the roadsides on adjacent public highways in the hope of finding ready-made solutions. We found that these roads were designed according to the same standards as ours. We looked at the roadsides of most of the turnpikes and free-ways in the north central and the northeastern parts of the country and found none of these facilities are free from roadside hazards. (2) (Figures 8, 9, 10)

Fig. 7. Significance of off-the-road accidents.

Fig. 8. Examples of roadside hazards—lamp posts, unprotected bridge abutments and piers—on controlled access highway.

Fig. 9. Trees in median on controlled access road.

Fig. 10. Sharp V-ditch on modern super highway.

As we travel any road we see many hazards which become involved when a driver leaves the travelled surface; typical are trees, ditches, lamp posts, bridge abutments, and traffic signs. (Figures 11, 12, 13)

Fig. 11. Tree-lined arterial road.

When our safety engineer looked at our Proving Ground road system in his study of accident potential he saw these same problems. (Figures 14, 15)

In the early days trees were planted beside roads (Figure 16) to provide shelter from rain and sun. They are beautiful. However, if an automobile runs directly into a tree very serious damage is inevitable. (Figure 17) To the safety engineer trees must be removed from the immediate roadside on all major highways. (Figure 18) In parks or residential areas, where speed regulations are observed, trees do not present a comparable hazard. (Figure 19) In areas where it is desirable to retain trees appropriate speed controls must be imposed.

On rural roads where ditches and steep embankments occur immediately adjacent to the gravel road surface, speed control is imperative. (Figure 20)

In areas where lamp posts are erected adjacent to the highway, speed regulations should be imposed or a safe design of the lamp post, as suggested in Figure 21, should be developed.

Fig. 12. Ditch-lines county arterial road.

Fig. 13. Roadside sign with heavy supports on concrete base.

Fig. 14. Proving Ground Test Track—1926 design standard.

Fig. 15. Proving Ground roadside—Hill Route—1926 standard.

Fig. 16. Tree-lined rural highway.

Fig. 17. Proving Ground car-tree accident.

Fig. 18. Removal of roadside trees.

Fig. 19. Example of conservative speed regulation on Parkway Drive.

Fig. 20. County road with hazardous ditch bank adjacent to paved surface.

The standard installation of ordinary traffic signs is in itself a hazard on highways where free traffic flow occurs. Figure 22 shows that at normal traffic speeds a collision with a standard traffic sign may result in a serious or fatal injury to the driver or passengers.

GUARDRAILS

In many cases guardrails are used to protect against obstacles or unfavorable terrain conditions. The safety of guardrail design and installation and the protection afforded to travellers had not been evaluated in full-scale tests since the middle 1930s. At the General Motors Proving Ground we became concerned about this problem because we had approximately 14 miles of guardrails. Tests (Figure 23) showed that much of our installation was ineffective except for purposes of delineation. We made a series of tests to determine whether the material in the guardrail installations on our road system could be salvaged and, following that, to determine the best type of installation where guardrail could not be eliminated.

The series of tests is reported in the Highway Research Board literature. (3) Suffice it to say that we found that a collision with a

Fig. 21. Comparison of experimental low impact tripod lamp post and conventional lamp post installation.

guardrail at angles of impact and speeds normal to the freeway system was a very serious accident. (Figure 24) We made tests to evaluate various types of guardrail construction, including post design and spacing and end treatment; we came to the conclusion that guardrails should be eliminated wherever possible. Thus, in the reconstruction of our 30-year-old highway system we are building flat, gentle slopes wherever possible and removing guardrails. Where this is economically im-

Fig. 22. Damage from collision at 40 mph with traffic sign mounted at 42 inches.

Fig. 23. Test of 10-year-old Proving Ground guardrail.

Fig. 24. Experimental collision with guardrail at 65 mph.

Fig. 25. Results of experimental collision with guardrail standard end installation.

practical we are using the relatively stiff modern W-beam type of guardrail installed on posts at a spacing of six feet three inches, which is half the spacing used in normal standards.

The end of the guardrail installed according to normal highway standards provides a serious and hazardous obstacle. (Figure 25) Because we still require some guardrails on the road system, we have made considerable effort to modify the end treatment to eliminate these hazards. One suggestion tried out was to ramp the end of the rail down to the ground. (Figure 26) This type of installation was

Fig. 26. Experimental guardrail ramped end installation.

not entirely satisfactory; in the designs evaluated the ramp was short and the car was pitched into the air too far. A longer ramp would be required to control this pitching.

Concern about this subject has been expressed by highway authorities, and we tested one installation suggested by the Michigan State Highway Department. This consisted of using an end section bent to a radius of 50 feet. Tests showed that this was not a complete answer to the problem (Figure 27) because relatively high deceleration rates persisting for 0.1 to 0.2 seconds occurred.

Fig. 27. Test of guardrail end section bent to 50-ft. radius.

One of the best solutions we have found is shown in Figure 28. Near the logical beginning of the guardrail installation there was a shallow ditch with a backslope about 30 inches high. It was simple to bury the end of the rail in the backslope and obviate the end problem. Figure 29 is an artist's concept of how the guardrail ends may be covered by constructing long, low mounds of earth.

DITCH SECTION

When the guardrail and other obstacles are eliminated, the drainage becomes of primary importance in roadside safety. We could find no information in the literature which would give criteria for rational design of ditch cross sections. In the concept of roadside safety it is implicit that the roadside be developed so that the driver can traverse it without damage to the vehicle, or injury, or extreme shock, so that he can recover control and return to the road without incident.

In the absence of data, we made tests from which we developed the criteria to establish a rational system for road ditch cross section design. (4)

Fig. 28. Guardrail installation with end buried in ditch backslope.

Fig. 29. Artist's concept of method of concealing guardrail end by building long, low mound of earth.

To do this we made a simple analysis of the problem and computed the severity of passage through a group of ditches with different cross sections over a range of speeds and angles of attack.

Then we built a series of ditches with different cross sections and drove cars through them at increasing speed increments over a range of angles of attack up to the limit of driver tolerance.

"Vertical" accelerations normal to the car axis were measured as an index of severity so the analysis could be verified and a value of limiting driver tolerances established. Figure 30 shows a typical test scene.

Fig. 30. Test of experimental ditch section.

Figures 31 and 32 show the basis of analysis and Figure 33 shows the comparison of the results computed and observed; under the more severe conditions the observed values were approximately twice the computed values. The tolerable limit which an experienced test engineer would sustain was about 1 g observed; this occurred under conditions where the computed value was about 0.5 g. The difference between the computed and the observed results is attributed to the fact that discontinuities occur when the suspension system bottoms. It was concluded, therefore, that a rational criterion for ditch cross

DITCH CROSS SECTION

Fig. 31. Analysis of passage through ditch.

SIDE SLOPE AND CIRCULAR DITCH BOTTOM

Fig. 32. Projection of ditch section on path of car.

CALCULATED VS MEASURED ACCELERATIONS

DITCH SECTION 3-6:1; 8 FT BOTTOM

Fig. 33. Comparison of observed and computed ditch test results.

section design would be to provide that the maximum computed acceleration normal to the axis of the car would be 0.5 g. Under these conditions the driver would experience a deceleration of about 1 g and this would be about the limit which he would consider tolerable without severe psychological or physical consequences.

From these data we have developed a ditch cross section considered appropriate for a speed of 65 mph. At an angle of attack of 15° the ditch will be traversable without undue shock or alarm to a driver with normal physical qualities. Figure 34 shows the elements which must be specified and Figure 35 shows the significant relation between severity and length of the vertical curve.

ROADSIDE SLOPE

An element of considerable importance in the roadside hazard problem is the relation of the slope of the bank and the stability of the car. (Figure 36)

DITCH CROSS SECTION

Fig. 34. Elements of ditch cross section significant in design.

Fig. 35. Severity in terms of normal acceleration during passage through a ditch as a function of vertical curve length.

Fig. 36. Car on test at 65 mph rolls over at the toe of 4:1 slope.

A mathematical analysis of the car stability problem (Figure 37) shows that when a car is at a point of equilibrium of overturning on a roadside slope, the ground reaction force, F , is given by

$$F = \frac{T}{2H} W \cos \theta$$

where T = car tread

H = center of gravity height

W = weight

θ = angle of inclination of slope

By dividing through by W , we get an expression

$$f = \frac{F}{W} = \frac{T}{2H} \cos \theta$$

where f is equivalent to a coefficient of friction or "coefficient of ground reaction."

This concept suggests that we may measure the "coefficient of ground reaction" as a characteristic of the material on the roadside slope surface and it provides a means of specifying the performance of the roadside

FORCE AND MOMENT RELATION

Fig. 37. Force and moment relations of car on side slope balanced over the lower wheel.

material if we should want to refine our construction procedures in this respect.

The factor $\frac{T}{2H}$ is a stability characteristic of the car. Since the car stability factor, $\frac{T}{2H}$ averages about 1.4 for current vehicles, with

some variation due to design considerations, it is interesting to compare this stability factor with some observations of the coefficient of ground reaction. We made some measurements on sod by the method indicated in Figure 38 and on some other types of surfaces and found typical results as indicated in Figure 39. This shows that the sod surfaces had coefficient of ground reaction of approximately 1.2, either wet or dry, and it appears, thus, that there is a narrow margin between the stability factor of the car and the "frictional" characteristics of a typical roadside. This margin is so small that the importance of smooth, firm roadside slopes can hardly be ignored.

Fig. 38. Measurement of coefficient of ground reaction.

Fig. 39. Comparison of coefficient of ground reaction on several types of surfaces.

Since the car sliding down the roadside slope will be decelerated by the ground reaction force, it is of some interest to compute the deceleration rate at which the car will trip and overturn.

It can be shown that this deceleration is given by the following expression:

$$\frac{a}{g} = \frac{T}{2H} \cos\theta - \sin\theta$$

where a = deceleration in ft/sec/sec
 g = acceleration due to gravity

The effect of the roadside slope on the stability is shown in Figure 40 where the per cent of decrease in the deceleration required to trip the car is shown as a function of the side slope. This shows, for example, that on an 8:1 slope, which is quite flat, six per cent less deceleration is required to trip the car than on a level road. On a steep slope the car can be tripped much more easily. The deceleration required to overturn the car on a 2:1 slope is twenty-three per cent less than that required to tip it over on a level road.

The stability factor shows by direct inspection that the value is increased as the tread is increased and as the center of gravity height is lowered. If we take derivatives to find the rate of change, we find

Fig. 40. Influence of roadside slope on reduction of "tripping" deceleration.

that the rate of change of the stability factor is negative and inversely proportional to the square of H , the center of gravity height; that is, the contribution of the center of gravity height to the stability factor varies as the negative reciprocal of H^2 . Thus, the automobile designers who have progressively made lower and lower cars with lower and lower heights of center of gravity have increased the stability by significant amounts, and the fact that we have some margin over the coefficient of ground reaction of the normal roadside slope is undoubtedly due to the trend toward lower and wider cars.

1960 DESIGN STANDARD

From our consideration of our roadside hazard problems we have developed design standards identified in Figure 41 as the General

1960 STANDARD CROSS-SECTION

Fig. 41. Proving Ground 1960 road cross section standard.

Motors Proving Ground 1960 Road Section Design Standards. Among the elements are :

1. Where reasonably high speed may be anticipated, above 35 to 40 mph, the roadside will be clear of obstacles, including drainage structures for 100 feet from the edge of the road.
2. Ditch cross section design to provide a maximum calculated severity of 0.5 g, normal acceleration at 65 mph at 15° angle of attack, will be provided.

3. No guardrail will be installed unless extreme terrain requires it.
4. Where terrain considerations require, a guardrail will be of the beam type with posts at six feet three inches spacing where speeds of about 35 mph may be anticipated.

Several roads representing this design concept have been constructed (Figures 42 and 43), and we have a current program at the Proving Ground whereby the earlier roads having substantial traffic volumes

Fig. 42. Test road at the Proving Ground constructed according to the 1960 standard.

are being reconstructed according to this concept. (Figures 44, 45, 46, and 47)

This material has been presented in other forms to numerous highway groups including national and regional meetings of the American Association of State Highway Officials and to conferences of several of the state highway organizations, specifically Maine, New Jersey, Texas, Oregon, Michigan, and Ohio, and to the staffs of several of the turnpike authorities.

One of the questions arising immediately is the relative cost of construction.

Proving Ground roads constructed or reconstructed according to this standard, have included those on flat and rugged terrain. Con-

Fig. 43. Test road at the Proving Ground with roadside trees set back to give an unobstructed roadside up to 100 feet from the pavement edge.

Fig. 44. Proving Ground Test Track after modernization of roadside.

Fig. 45. Typical scene of the Proving Ground Test Track after reconstruction to bring the roadside up to the 1960 standard.

Fig. 46. Track access road during modernization. The steepest grade in the central portion of the picture is 14 per cent. This is a one-way downhill road.

Fig. 47. Proving Ground gravel road after modernization of the roadside.

struction costs vary widely depending upon the terrain. On one road built on nearly level terrain the cost of construction according to the 1960 Standard was only about \$9,500 per mile more than it would have been if conventional standards employing steeper slopes, deeper ditches, and clearance of obstacles only to the toe of the slope or top of cuts had been used. The most expensive reconstruction was on a long, steep hill, part of which is a 14 per cent grade and the remainder approximately 10 per cent. This reconstruction involved an expensive drainage system, and the cost of reconstruction above the elementary 1926 Standard was about \$75,000 per mile. On our Test Track, reconstruction of the inside edge only was \$47,000 per mile, but on our gravel Hill Road, which has many sharp curves and steep grades, the cost of reconstruction was about \$26,000 per mile.

This investment in safety in the Proving Ground road system is a good one. We have had 14 minor accidents in areas where the roadside has been reconstructed. Without reconstruction any one or all of them could have been fatal. We think the public highway construction standards should be raised to meet the 1960 Standard wherever the terrain permits and that this would be an equally good investment.

Some meaningful data are being accumulated on the costs of accidents. Possibly the best are from the Massachusetts Study, one result of which is reproduced in Figure 48. (5) This shows not only that

Fig. 48. Yearly accident cost on roads with controlled access and no control of access—Massachusetts Study.

roads with controlled access have a substantially lower cost of accidents per mile but also that a very significant sum of money is being wasted each year per mile of highway in highway accidents. This figure shows that on controlled access roads the yearly accident cost per mile is approximately linear with respect to traffic volume and that the cost of accidents is about 67 cents per vehicle for each mile of road. On roads without control of access, after the volume reaches about 7,000 vehicles per day, the cost of accidents is approximately \$4 per vehicle for each mile of roadway. For example, on a road of this type carrying a traffic volume of 15,000 vehicles per day the cost of the accidents each year is about \$45,000. When we look at accident costs of \$20,000 and \$30,000 per mile per year, an investment of from \$30,000 to \$50,000 per mile in original construction for safety, or reconstruction for safety, appears to be small.

To relate these traffic volumes to highways upon which the traffic situation is familiar to residents of Detroit, the current average daily traffic volumes for a number of arterial highways in the Detroit area are listed; these data are provided through the courtesy of the Michigan State Highway Department.

AVERAGE DAILY TRAFFIC VOLUMES HIGHWAYS IN DETROIT AREA

US 25—

- 18,000 at Allen Park, south city limit
- 53,000 at north Detroit city limit
- 15,000 at Mt. Clemens, north city limit
- 7,000 at Marysville, west city limit

M 53 (Van Dyke)—

- 55,000 at Detroit city limit
- 14,000 at Utica, north city limits
- 5,000 at Romeo, north city limits

M 150 (Rochester Rd)—

- 10,000 from north limit Clawson to north limit Rochester

US 10 (Woodward)

- 61,000 at north Detroit limit
- 36,000 at north Birmingham limits

US 24 (Telegraph)—

- 22,000 south Dearborn limit
- 25,000 at intersection Grand River
- 19,000 at intersection 14 Mile Road

US 16 (Grand River)—

- 36,000 at intersection McNichols
- 27,000 at intersection 8 Mile Road
- 16,000 at intersection 10 Mile Road
- 12,000 at intersection US 23
- 10,000-11,000 Brighton to Williamston
- 7,000 at Portland

M 14 (Plymouth Road)—

- 23,000 at intersection with Telegraph
- 7,500 at Plymouth east limit
- 5,000-7,000 Plymouth to Ann Arbor

US 112—

- 36,000 at intersection of US 24
- 15,000-12,000 Wayne to Ypsilanti
- 6,500 at intersection of US 23
- 6,000-4,000 Saline to Sturgis

US 12—

- 32,000 west of intersection with US 24
- 24,000-19,100 from US 24 to Willow Run area
- 9,000 Ann Arbor to Jackson
- 5,000-7,000 west to Kalamazoo

US 27—

6,000-7,000 Lansing to Alma

5,000-3,000 Alma to Houghton Lake

4,000-3,000 Houghton Lake to Indian River

Edsel Ford X-Way—

124,000 at intersection of US 16

This shows that most of the arterial roads in the metropolitan area carry traffic volumes in excess of 10,000 vehicles per day and that several of them have volumes from 30,000 to 50,000. It should be clear, then, that the accident costs reflected in this Massachusetts Study can be taken as representative of the accident costs on the metropolitan district arterial highways which we travel every day. It seems clear that the yearly cost of the accidents on these roads would pay much of the cost of modernization even at costs reflecting urban and suburban property values.

It is estimated reliably that, nationwide, the cost of accidents is the equivalent to a tax of 12.5 cents per gallon of fuel. (6) While this may not be distributed in exactly those terms, a good portion of it is distributed in the cost of insurance, and it is fair to say that the cost of accidents to us as individuals approaches the cost of gasoline tax.

SUMMARY

Application of high design standards in the construction of toll facilities and comparable highways in the United States results in an accident death rate less than half of that for the country as a whole. Several of the newest and best-designed and operated of these facilities have an accident death rate much lower than the average. With the application of the highest design standards in current use, it is evidently possible to achieve accident rates as low as one-fifth that of the present national average.

We have called attention to some concepts of roadside design and elimination of roadside obstacles which are a refinement of the standards of even the newest of the modern highway facilities. We believe that the applications of these concepts would achieve a further significant reduction in accident death rates on even the best of our present roads.

We believe that the applications of these concepts of safe roadside design to the remainder of the public highway system, even without changes in alignment or grade of the road, would contribute very significant reductions in the total number of road accident fatalities and

injuries. This belief is confirmed by experience on our own road system where, during the past two years, modernization of the roadside has made only minor incidents out of several accidents which could have been fatal.

We believe there is need for better public understanding of the potential gains in highway safety which may be achieved by scientific design and a need for better public support of the highway program. Even if the gains in public safety are not sufficient motivation, the cost of accidents should be.

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