J. C., "Flow into Deflector Inlets," Journal of Sewage and Industrial Wastes, Vol. 26, No. 7 (July 1954).
4. LI, W. H., GOODELL, B. C., AND GEYER, J. C., "Flow into Depressed Combination Inlets," Journal of Sewage and Industrial Wastes, Vol. 26, No. 8 (August 1954).
5. "Storm Water Inlets," to be published shortly by Sanitary Engineering Department, The Johns Hopkins University, Baltimore, Md.

Relation between Automobile and Highway

K. A. STONEX, *Head, Technical Data Department*
General Motors Proving Ground

THE purpose of this paper is to review briefly the more-important characteristics of automotive vehicles with respect to the requirements they impose upon highway design and particularly upon the design of highway systems.

The motivating force behind the development of the automotive transportation system is a compelling urge within the individual for a high degree of flexible private mobility. As a result of this urge we now have approximately 45 million privately owned cars on the road, and the American public travels somewhat more than 500 billion miles each year. The significance of the automobile in modifying the American way of life during the past generation has not yet been generally appreciated, nor is the probable future effect generally understood.

A review of accident fatalities shows that there has been a consistent reduction in the mileage rate of fatal accidents; what is seldom emphasized is the more-important fact that the total number of fatalities has leveled off and remained nearly constant during the past 20 years in spite of the tremendous increase in total miles traveled. Much has been accomplished and much remains in highway layout and highway system design to further improve the fatal-accident picture. A major cause of accidents is inattention, and highway design should continue to eliminate obstacles, provide more maneuver room, separate traffic, segregate traffic types, and provide alternate and bypass routes to distribute rather than concentrate traffic flow.

It is shown that fuel consumption of automotive vehicles increases very sharply with curvature and gradient, and that the ideal design of highway systems from the standpoint of cost of fuel would be to build roads level and straight. This is consistent also with the best mobility of traffic and the greatest safety.

We accept the fact that the inadequacy of our present highway system has resulted from lack of funds and not lack of engineering competence on the part of highway designers. A significant increase in expenditure is required to bring the highway system capacity into balance with the demands of the public. For this reason highway policy must be to select the best uses for available funds to accomplish long range construction programs, rather than to move from one expedient to another, and to look with suspicion upon proposals which may divert funds from maintenance and construction.

● THE automobile industry and the highway designers and builders are partners in our great transportation system; highway transportation is more than a major industry, it is a sociological factor of such magnitude as to be a major component of the American way of life. The function of the automobile industry and the highway designers and builders is to provide the best possible tools to aid in the continued development of highway transportation. This paper discusses a few of the relationships between the automobile and the highway, with particular reference to those characteristics of automobiles which impose design characteristics upon highways and highway systems.

By reviewing the nature and behavior of automobiles we may be able to refresh our outlook on what should be the objectives of the design of highways and highway systems. This discussion will be confined to design aspects as a means of promoting effective use of the highway. It is a personal opinion and should not be interpreted as a statement of the policy of General Motors or the automobile industry.

SCOPE

The scope of the highway automobile system is that we now have on the road approximately 45 million automobiles, and with them the American public drives well over 500 billion miles each year. It is easily possible for the entire population of the country to travel in automobiles simultaneously. The estimated book value of the cars on the road is approximately $50 billion and the added annual investment in automobiles is at least $15 billion. I have no estimate of the book value of the existing highway system, but last year about $4 billion was available for highways, and authorities estimate that we will require an annual expenditure of at least $6 billion for the next ten years to expand and improve our highway system in line with current and foreseeable needs. In addition to the private transportation provided by the automobile, there is a tremendous trucking industry which is involved at some point in the movement of between 70 and 80 percent of the total volume of freight which is carried in this country.

There are very large and flourishing petroleum and rubber industries which draw their life from the highway transport system, so that all in all, a large proportion of the total business of the United States is associated with the highway-transportation system. In fact, it is estimated that one out of every seven people working in this country owes his job, directly or indirectly, to highway transportation.

In addition to these economic aspects is the important social fact that the automobile has enriched the lives of the American people to a degree not even dreamed of 50 years ago.

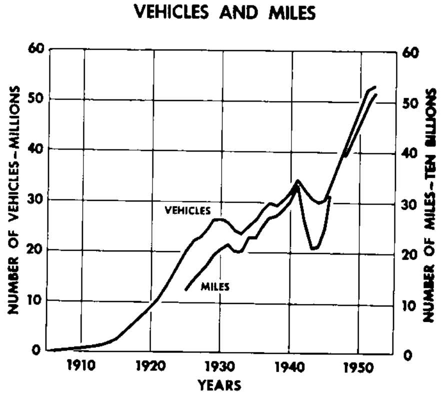

Figure 1. Number of vehicles registered each year and number of miles driven.

Maine and California and Yellowstone and Miami are within the reach of the average family. No longer is the separation permanent when the son or son-in-law takes a job in another state. The automobile has improved direct personal communication as much as rural mail delivery. Consolidated schools and suburban residences have been made possible. The standard of living of the American family is centered on the family car. The factories, tools, personnel, and technology of the automobile industry are a major part of our military defense.

Figure 1 shows the number of vehicles on the road since 1900 and the miles traveled by years since 1925; there has been a significant increase in the slope of these curves since the end of World War II. There is nothing in these trends to indicate that any saturation point will be approached in the forseeable future, and we can assume confidently that there will be more automobiles on the road and a greater total amount of travel each year for many years to come. For highway-design purposes we might assume that these rates will continue indefinitely.

AUTOMOBILE PERFORMANCE

It is common knowledge that the increasing traffic volumes are steadily reducing the effectiveness with which the highway system can carry the load upon it. In a paper before this conference last year, T. J. Carmichael (*1*) reviewed some of the fundamental performance characteristics of automobiles to show that the automotive industry is making a

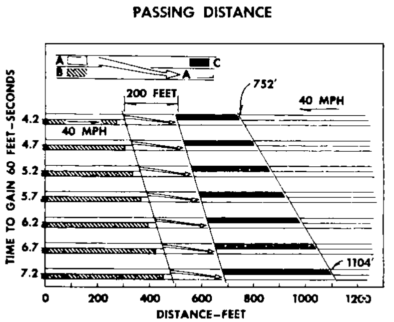

Figure 2. Passing distance as function of performance level on 1953 cars.

conscious effort to retard the effect of increasing congestion. I am going to repeat some of his data and extend it to include the 1953 cars.

Figure 2 shows how the distance and time to pass a car on the road is affected by accelerating ability.

The diagram at the top is a representation of a two-lane road with Car B traveling from left to right and Car A about to pass, with Car C approaching from the opposite direction. The assumption is made that Cars B and C are traveling at the uniform rate of 40 mph. In order for Car A to complete the passing maneuver it must accelerate to gain three car lengths or approximately 60 feet to clear Car B and then it must pull back into its own traffic lane before it meets Car C. We assume that it takes 200 feet to pull back into the traffic lane safely.

The system of bars in the lower part of the chart represents the distances required for Car A to complete this maneuver for several levels of performance exhibited by the 1953 cars. The car with the highest acceleration required 4.2 seconds to gain 60 feet on a car traveling at a constant rate of 40 mph. and the car with the lowest acceleration required 7.2 seconds. In all cases the transmission gear combination which gave the best performance was used. The crosshatched bar at the left represents the distances which will be traveled by Car B at 40 mph. during the time indicated in the scale at the left, which is the time required for Car A to gain 60 feet on Car B. The solid bars at the right central part of the chart show the distance which Car C will travel during this same period of time. The extreme right of each of the solid bars represents the

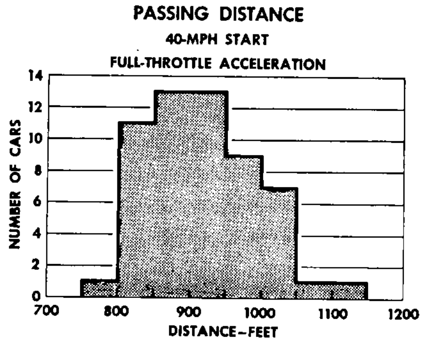

Figure 3. Frequency distribution of passing distance on 1953 cars.

closest point where Car C can be when the passing maneuver is initiated to permit Car A to complete it satisfactorily. The best car of the fleet takes 4.2 seconds and the minimum clearance with Car C is 752 feet. The poorest car takes 7.2 seconds, and Car C must be 1,104 feet away if Car A is to pass successfully.

Figure 3 is a frequency diagram showing the passing clearance distance required by the 1953 American cars. Most of the cars fall in the range of from 800 to 1,050 feet. It should be pointed out that these measurements were made on relatively new cars in the best mechanical condition, and that the required clearance will be increased greatly for older cars and for cars in poor mechanical condition. Figure 4 is a percentile distribution of the same data.

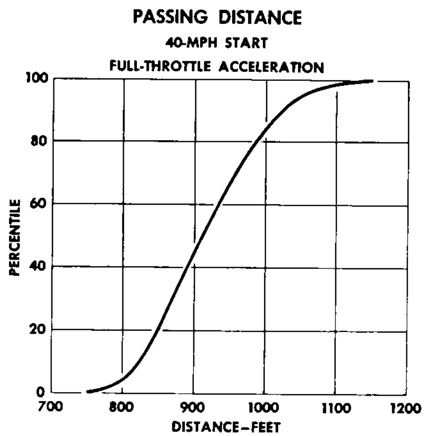

Figure 4. Percentile distribution of passing distance on 1953 cars.

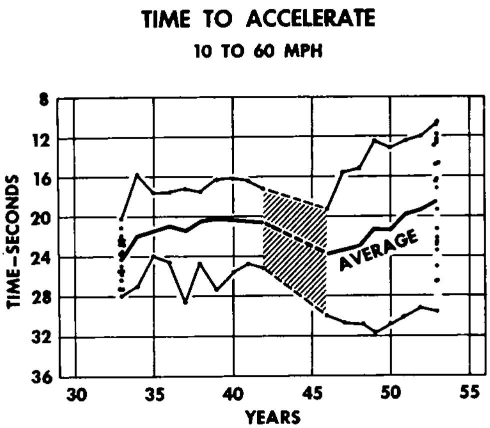

Figure 5. Trend of time to accelerate from 10 to 60 mph., 1933 to 1953.

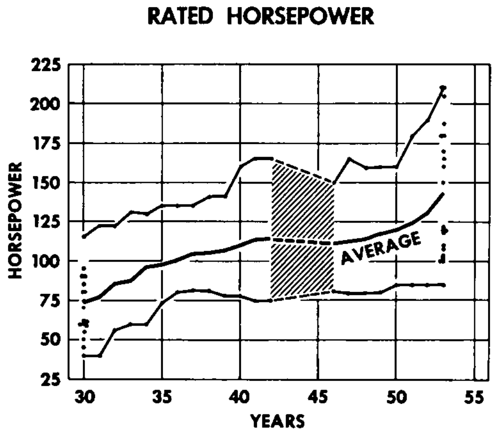

Figure 6. Trend of rated horsepower from 1930 to 1953.

It is obvious that the best-performing cars provide a significant margin of safety, because the exposure during passing is materially reduced, and that their flexibility in traffic will contribute to the reduction of traffic congestion on the rural highways.

We do not have data in these terms for more than 3 years, but in Figure 5 we have summarized the trend of performance in terms of the time to accelerate from 10 to 60 mph. for the period from 1933 to 1953. This value is a reasonably good representation of performance in traffic. The scale at the left has been arranged to show the best performance at the top; it shows that there has been a small but genéral increase in performance throughout the period, except in the immediate post-war years because of a combination of conditions. The better cars have reduced the acceleration time from 16 to approximately 11 seconds during the past seven model years. It may also be noted that even the poorest-performing cars in the fleet are beginning to show a rather sizeable improvement. The so-called average curve represents an average of accelerating ability by makes and is not a representative average of the performance of all cars on the road.

This improvement in performance has come about in part by an increase in horsepower, achieved in many instances by higher compression ratios. Figure 6 shows the trend in rated horsepower over the period of 1930 to 1953. It may be noted here that the average curve shown is the average by makes and does not take into account differences in production volume. The best engines have increased their rated horsepower since the war from about 160 to well over 200 in 1953; of the number of automobiles in service only a small percentage is in the group with 180 hp. and up.

Associated with rated horsepower in the minds of many people is maximum speed. The trend for representative American cars is shown in Figure 7. The average maximum speed by makes in 1930 was about 66 mph. and in 1953 it was about 94 mph. The fastest car in 1930 was about 74 mph. and in 1953 it was about 106 mph. There has been a steady increase in maximum speed since the war, but the rate is considerably less than during the period from 1930 to 1935. The number of automobiles capable of 100 mph. comprises only a small percentage of the cars on the

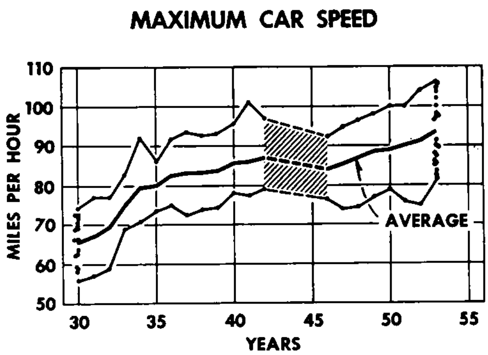

Figure 7. Trend of maximum car speed from 1930 to 1953.

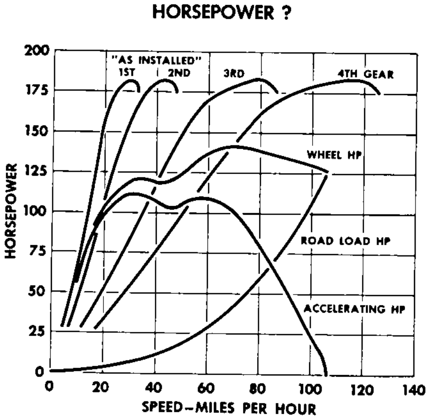

Figure 8. Comparison of "as installed," road wheel, acceleration, and road load.

highway, and even these have to be in top mechanical condition to be capable of operating at this speed.

The need for sizable engines to develop passing performance in the middle range is indicated on the next several charts. Figure 8 shows several aspects of horsepower. This is of a modern, high-performing engine having a rated horsepower somewhat above any of the values shown on the chart. It should be understood that the values of rated horsepower published by the manufacturers are determined under specific test conditions; in general, these conditions do not include several accessories essential to the installation in the automobile, nor are the temperature standards necessarily the same as in normal operation. These values are basically bare engine values, and they are perfectly good for comparison of engine designs.

On test dynamometers with standard accessories and induction and exhaust systems and at normal temperatures, this engine develops an "as-installed" horsepower indicated by the four curves labeled first, second, third, and fourth; these are plotted against road speed in miles per hour, and the horizontal distances between these curves are proportional to the overall gear ratios for the several gears.

When a car is accelerated on the road, the engine and other rotating parts in the power train have to be accelerated also, so that the power transmitted to the rear axle is considerably less than that developed at constant speed on the test stand. The second curve from the top shows the horsepower actually transmitted to the rear wheels of this particular car during acceleration. It is determined by measuring the acceleration of the car, expressing this in equivalent power units, and adding it to the horsepower used to overcome wind and rolling resistances.

The wind-and-rolling-resistance horsepower is shown by the curve which starts at zero at the left side of the sheet and rises with an increasing slope toward the right. This curve intersects the wheel horsepower curve at 106 mph., which was the observed maximum speed of this car.

The horsepower available to accelerate the car reaches a maximum of about 112 at 30 mph and falls very rapidly from 110 hp. at 60 mph. to zero at the maximum speed point at 106 mph. This chart suggests that there are four kinds of horsepowers which are significant, the rated horsepower, the as-installed horsepower, the horsepower transmitted to the rear wheels, and the horsepower which is available for acceleration. Thus this car which has a rated horsepower of something over 200 actually has a maximum of about 112 hp., or a little more than 50 percent available for acceleration at any point in the speed range.

Acceleration is produced by a reaction on the road developed by rear wheel torque, and torque is probably what we should talk about in relation to performance in traffic. Figure 9

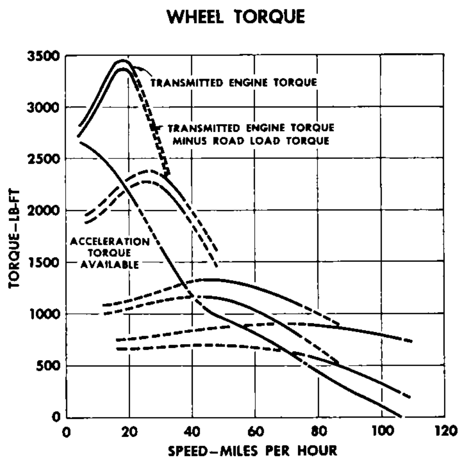

Figure 9. Comparison of engine torque transmitted to rear wheels and torque available for acceleration.

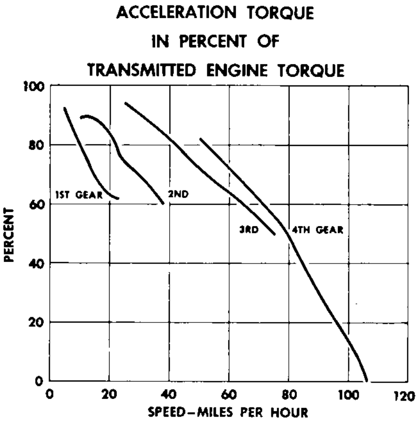

Figure 10. Acceleration torque in percent of transmitted engine torque for each gear ratio.

shows the various torques through the gears and speed range which are related to this performance comparison. The upper curve in each pair shows engine torque transmitted to the rear axle. They are derived from the torque observed on the test stand with the engine in the as-installed condition and operating at constant speed, by adjusting for the four gear ratios of the transmission.

The continuous curve is the rear axle torque computed from the observed acceleration; it is the torque remaining after all losses, including wind and rolling resistances, have been subtracted. The lower curve in each pair shows the residual transmitted torque after the torque required to overcome wind and rolling resistances is subtracted. The difference between the continuous curve and the lower of each pair is the torque absorbed in accelerating the engine and power train rotating parts.

It is clear that only part of the engine torque is available to accelerate the car. Figure 10 shows the percentage of the transmitted engine torque available for acceleration for the four transmission gears as a function of road speed. In third gear, for example, 80 percent of the transmitted torque was available for acceleration at 40 mph. and only 64 percent at 60 mph. In top gear, 80 percent was available at 50 mph. and none at all of the maximum speed.

This chart shows that, wherever two gears overlap, the most-nearly direct drive provides a significantly greater proportion of the engine torque available for acceleration, because the effect of the inertia of the rotating parts is proportional to the square of the gear ratios.

It is clear, therefore, that even the highest increases in torque and horsepower output actually provide only relatively small improvement in actual traffic and highway performances. Considering that some of the horsepower ratings exceed 200, the gain in performance is much less than persons not closely familiar with horsepower requirement in relation to vehicle performance would suppose.

FUEL ECONOMY

We have just shown that the more-nearly direct-drive gear ratios provide a greater proportion of the transmitted torque for acceleration. Figure 11, which is reproduced from Carmichael's paper, is a plot of the specific fuel consumption against engine speed for two values of horsepower. The road-load horsepower required to maintain a constant speed of 40 mph. is about 10 brake horsepower and that required to maintain a speed of 55 mph. is about 20 brake horsepower. Specific fuel consumption is expressed in terms of the pounds of fuel per brake horsepower-hour; it is a standard term used to express the efficiency of an engine.

This chart shows that if the engine size is such that it has to turn 1,800 rpm. to give 10 hp., the specific fuel consumption would be 1 lb. of fuel per brake horsepower-hour, while if the engine is large enough to give 10 hp. at 600 rpm., the specific fuel consumption would be only 0.52 lb. of fuel. This general relationship holds for all values of horsepower. It is ob-

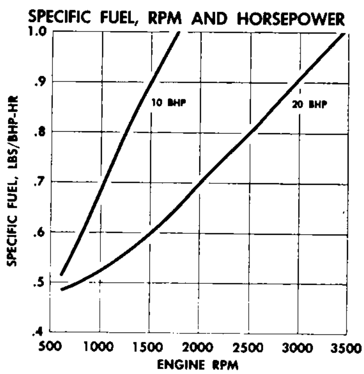

Figure 11. Relationship of specific fuel consumption and engine speed at constant outputs in brake horsepower.

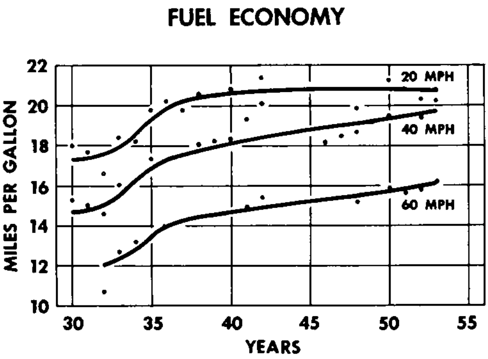

Figure 12. Trend of fuel economy at 20, 40, and 60 mph., 1930 to 1953.

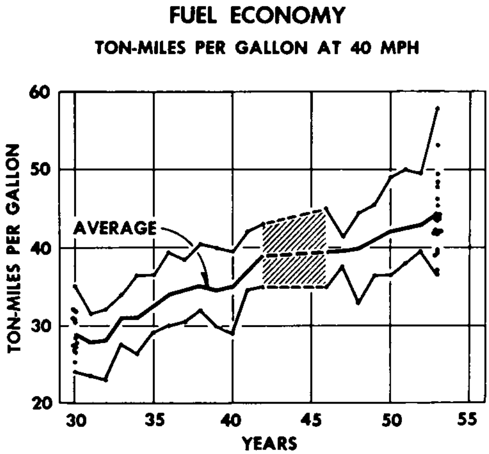

Figure 13. Trend of fuel economy at 40 mph., 1930 to 1953.

vious that substantial improvements in specific fuel consumption are achieved by keeping the engine speed as low as possible. It follows from this that engines must be selected which will deliver the required horsepower at low speeds in order to give reasonable values in fuel economy. The combination of engines with more piston displacement and higher compression ratios which give suitable torque and performance characteristics with gear ratios to give the desirable fuel-economy characteristics usually adds a few miles to the maximum speed. The slight increase in top speed, in a sense, can be considered a byproduct of the engineering effort to increase economy and acceleration.

The achievements of automobile designers in terms of improved fuel economy during the past 20 years have been significant. Figure 12 shows the average of fuel economy in miles per gallon for the representative American cars at speeds of 20, 40, and 60 mph. At 40 mph., for example, the average of all American cars has improved approximately 30 percent, from about 14.5 to 19.5 mpg.

Figure 13, which takes weight into consideration, shows ton-miles per gallon at 40 mph. for representative American cars through the period of 1930 to 1953. Improvement in the average car here has been well over 50 percent.

In a paper before the American Petroleum Institute in 1951 (*2*), C. L. McCuen, vice president in charge of General Motors Research Laboratories, showed that if all the nearly 50 million vehicles then on the road were of 1950 design, the savings on fuel per year compared with that consumed by 50 million vehicles of 1930 design would amount to the tremendous total of 10.5 billion gallons.

The possibilities of further improvement in fuel economy are encouraging. In the same paper, McCuen gave data which indicated how much-more gain could be realized as soon as fuels are available. Four Cadillacs were used on these tests, one was a 1915 model, the second a 1935, and the third a 1951, all production cars. A new engine of advanced design was installed in a 1951 car; this engine was developed to provide performance equivalent to that of the 1951 car.

Figure 14 shows a comparison of full-throttle accelerating ability of the four cars from a standing start. The scale at the left shows the distance traveled in comparison with the 1951 production car which was taken as the standard. After 25 seconds the 1915 car was about 850 feet behind the 1951 car, the 1935 car was about 350 feet behind it, and the 19XX car of the future was only a few feet behind at 25 seconds and equal to or above the 1951 from then on. This test is a sensitive indicator of small performance differences, so that the 1951 and the 19XX cars may be regarded as substantially equal in performance.

Figure 15 shows the constant-speed, level-road fuel economy of these four cars. At 50 mph. the 1915 car ran about 7.5 mpg, the 1935 car ran approximately 12 mpg., the 1951 car about 18.5 mpg, and the 19XX car somewhat more than 25 mpg.

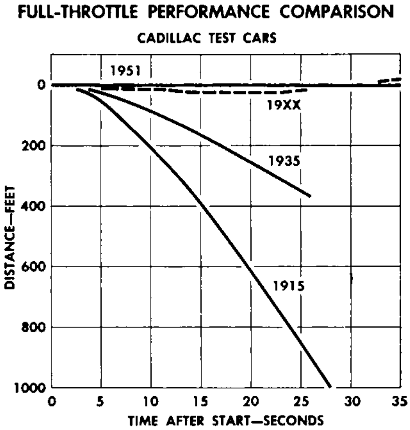

Figure 14. Full-throttle performance comparison of 1915, 1935, and 19XX Cadillacs with respect to the 1951 Cadillac.

Figure 16. New designs will save 10.5 billion gallons of fuel annually.

This shows that when the required fuel becomes available, it will be possible to build engines which will provide the automobile with present-day top performance but with fuel economy increased well over 35 percent. In terms of the national economy, this improvement is equal to that which has been achieved during the past 20 years (*2*); on the basis of the nearly 50 million vehicles designed in accordance with the 19XX engine, the total saving of fuel compared with 50 million vehicles of 1951 standard would amount to about another 10.5 billion gallons of gasoline per year. This quantity, as shown in Figure 16, represents approximately the present annual fuel consumption of the motor vehicles in the 17 western-most states.

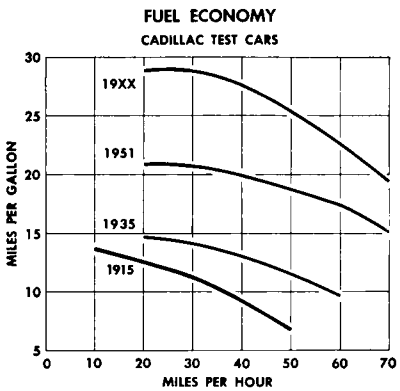

Figure 15. Constant-speed level fuel economy on four Cadillacs.

HILL-CLIMBING AND BRAKING ABILITIES

The two other factors most predominant in providing mobility on the road for passenger cars are hill-climbing capacity and braking ability. Hill-climbing capacity is closely related to acceleration, and without going into detail, it may be stated that there has been a substantial improvement during the past 20 years to the point where grades commonly encountered on primary or even secondary roads do not seriously restrict passenger-car speeds, except where congestion or sight distance are involved.

The performance of brakes has been improved materially in the last 30 years by the general introduction of four-wheel and hydraulic brakes and improvements in lining materials which provide both more-nearly constant braking performance and materially longer brake-lining life.

Braking capacity required at high speeds is greater than at low speeds because the kinetic energy of the vehicle is much greater. Figure 17 shows the kinetic energy of the 1953 heaviest and lightest cars, and their average, as a function of speed. At 30 mph. the average is slightly over 100,000 ft.-lb., and at 60 mph. it is nearly 450,000 ft.-lb. Intensive development work is in progress to improve the capacity of brakes to absorb the higher energy developed at the higher highway traffic speeds. The development problems are basically those of

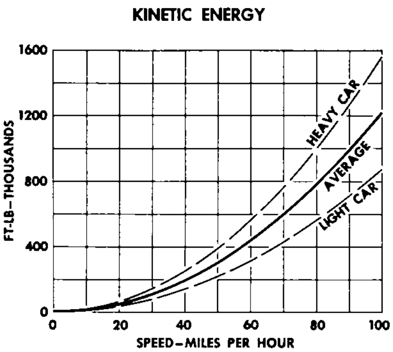

Figure 17. Kinetic energy as a function of speed for the average car, a heavy car, and a light car.

more rapid transfer of the kinetic energy in the form of heat.

TRUCK PERFORMANCE

Road performance of trucks depends upon torque output of the engine, vehicle weight and payload, and highway grades. Because of the great variations in engine sizes and individual loads, it does not seem practical to present performance data. There is no question that the acceleration of trucks is much poorer than that of passenger cars, and it seems improbable that economics will ever permit providing trucks with passenger-car performance.

EFFECT OF HIGHWAY-DESIGN FEATURES ON ECONOMY

There are highway-design features which have significant effect on traffic-mobility characteristics. It is generally agreed that curves and hills restrict mobility, primarily because short sight distance reduces the opportunity to pass to the extent that even relatively light traffic can add to the apparent congestion. There are few data to show the restrictions of curves and hills quantitatively, but the means to obtain such data are available in the statistical instrumentation developed by the Vehicle Characteristics Committee of the Highway Research Board.

It is not generally appreciated that alignment and gradient also have an important effect on the operating economy of the automobile. Figure 18 shows the relative fuel economy of a typical car over a speed range under various conditions of operation. The top curve shows the fuel economy with the

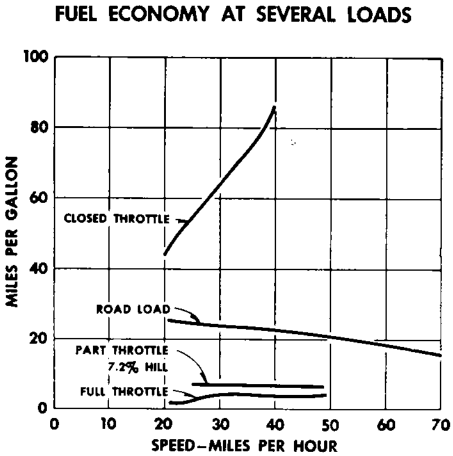

Figure 18. Fuel economy at constant speed with several loads.

throttle closed, which is equivalent to coasting at constant speed down hill; this car will give about 44 mpg. at 20 mph. and about 85 mpg. at 40 mph.

The road-load test was run at constant speed on a level pavement. Fuel economy decreases from about 25 mpg. at 20 mph. to slightly less than 16 mpg. at 70 mph.

The part-throttle test was run at constant speed on a hill of 7.2-percent grade. Here the fuel economy is practically constant at about 6.5 mpg. from 25 to 50 mph.

On the full-throttle test the car was run on a level pavement and restrained by a towed load so that full-throttle measurements could be made. Fuel economy averages about 4 mpg. in the speed range between 30 and 50 mph.

There is a serious loss in economy caused by the increase in load from the normal wind-and-rolling resistance on the level highway to that on the 7.2-percent hill. The increase in road power required on the 7.2-percent grade is 56 percent of the difference between road load and full throttle, while the decrease in fuel economy is 84 percent of the difference. Grades of less than 7 percent would produce curves which fall somewhere between and probably much closer to that of the 7-percent grade than of the road-load curve.

We ran a series of tests on another car under several conditions of gradient and cornering to develop more information about such operations. Figure 19 shows the road horse-

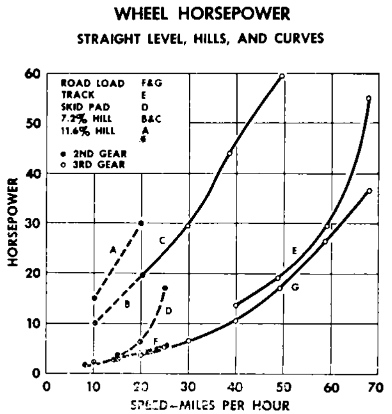

Figure 19. Comparison of rear wheel horsepower on level straight road, hills, and curves.

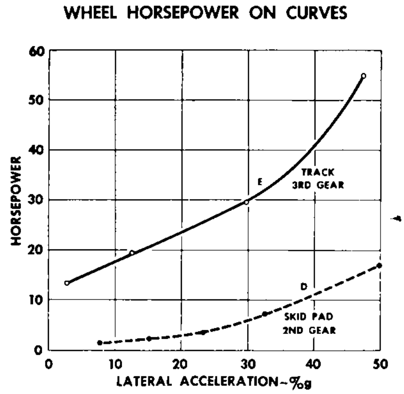

Figure 21. Wheel horsepower as function of lateral acceleration.

power as a function of speed for the following conditions.

Curve

- A Climbing 11.6% Grade, 2nd gear
- B Climbing 7.2% Grade, 2nd gear
- C Climbing 7.2% Grade, 3rd gear
- D Cornering on 108-ft radius curve, 2nd gear
- E Cornering on test track, 3rd gear
- F Road Load, 2nd gear
- G Road Load, 3rd gear

Figure 20 shows fuel economy in miles per gallon under these conditions. The difference between Curves A and B reflect the difference between climbing the 7.2-percent and 11.6-percent hills. The difference between Curves B and C reflect the difference in engine speeds in second and third gears. The effect of increased power required to go around curves is reflected in the differences between Curves D and F and between E and G.

Figure 21 relates the total power required under Conditions D and E to the value of lateral, or radial, acceleration, and Figure 22 relates the fuel economy to lateral acceleration under these conditions.

Figure 23 shows fuel economy as a function of horsepower required under the third-gear Conditions C, E, and G; points of equal speed are connected.

Figure 24 shows the percentage change in fuel economy and road power for the third-gear Conditions C, E, and G, and the second-gear Condition D. Fuel economy falls approximately 50 percent for an increase of about

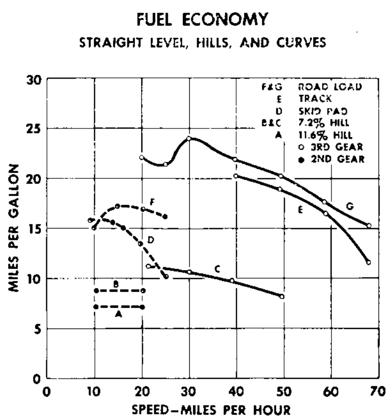

Figure 20. Comparison of constant-speed fuel economy on level straight road, hills, and curves.

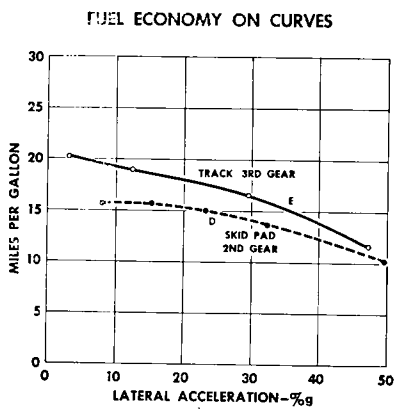

Figure 22. Fuel economy as function of lateral acceleration.

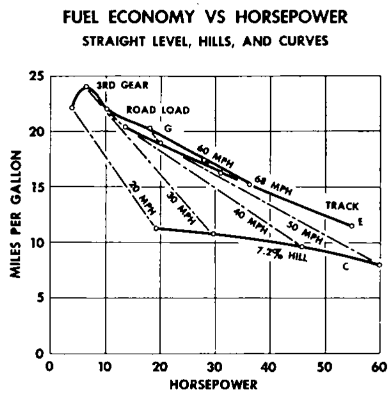

Figure 23. Effect of hill climbing and cornering loads on fuel economy.

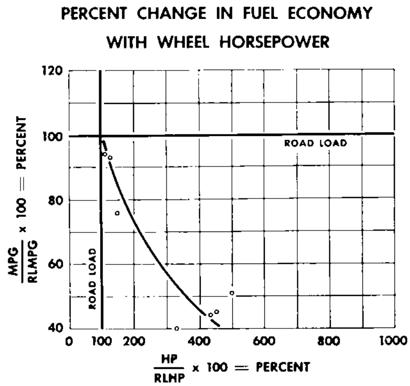

Figure 24. Percentage change of fuel economy with wheel horsepower on hills and curves.

400 percent in road power; at 40 mph. this corresponds with the increase from 11 hp. road load to about 45 hp. on the 7.2-percent grade. On corners with a radial acceleration of 0.12 to 0.15 g., equivalent to friction factors of 0.12 and 0.15, the fuel economy falls about 7 percent.

HIGHWAY CAPACITY

Highway capacity is a feature significant to the free flow of traffic. From the design standpoint we can improve the situation only by increasing the capacity by adding lanes and by eliminating curves, hills, and other bottlenecks. In rural areas the construction of alternate routes to distribute the traffic volume on two or more highways rather than concentrating it on one appears to have been a feasible solution in many cases.

TRAFFIC ACCIDENTS

A primary objective in vehicle or highway design is to eliminate, as far as possible, the hazards of traffic operation to reduce accicents. It is perhaps worthwhile to review the traffic-fatality trends for the last 50 years or so in order to see what has happened and then to decide whether we might be able to contribute to increased safety by additional highway design or highway policy factors. Figure 25 shows the mileage and the vehicle-fatality rates by year. The mileage rate is available from 1925, and this shows a steady reduction from about 18 deaths per 100 million vehicle miles to approximately 7. The fatality rate per 10,000 motor vehicles has decreased from nearly 50 in 1907 to approximately 7 in 1953 (*3*).

Figure 26 is a plot of the total traffic-accident fatalities since the automobile became

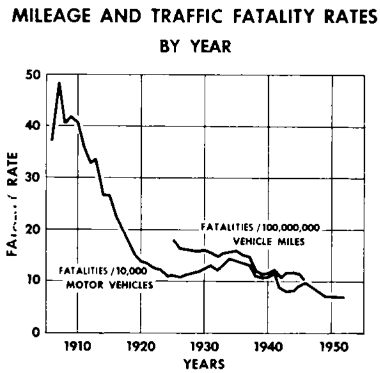

Figure 25. Trend of mileage and accident-fatality rates.

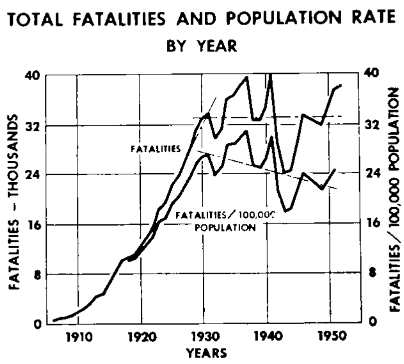

Figure 26. Trend of total accident fatalities and population rate.

a part of our transportation system. There was a steady and rapid increase in the total number of fatalities until 1930. From 1930 to 1952 the average has remained constant. If the slope of this curve had continued at the rate in the middle 20's there would now be about 80,000 traffic fatalities a year instead of 38,000.

While it is not possible to establish definitely the specific reasons for the change in shape of this curve in about 1930, it is undoubtedly due to the combined efforts of highway designers, the automobile industry, and the traffic-safety programs which have made the motoring and pedestrian public aware of the highway-fatality picture.

RELATION OF HIGHWAY DESIGN AND ACCIDENTS

We should take a realistic view of hazards of highway transportation. While we all concede that there is a certain degree of hazard involved in taking a car out on the highway, no highway designer feels that he is designing a death trap, nor does any automobile manufacturer consider that he is building a lethal weapon. It seems obvious that the motoring public thinks likewise, or no one would ever take his family out for a ride on Sunday. On the other hand, 38,000 people were killed needlessly in traffic accidents last year; substantial progress in fatality reduction has already been made, particularly since 1930, and by proper design and design policies even more progress may be made.

In this discussion of highway safety we are fortunate in being able to confine ourselves to design aspects, and we can exclude as extraneous such factors as driver-licensing requirements, enforcement, vehicle inspection, and other contributing factors unrelated to highway and vehicle design. There can be no doubt that a major cause of traffic accidents is driver inattention, and as designers, our proper objective is to build both the cars and the roads in such a way that momentary inattention on the part of the driver will have the least probability of involving him in an accident.

In passing, we may note that the automobile industry has made substantial progress (*4*) by providing greater flexibility of the car in acceleration, easier and quicker braking, easier steering, better vision, improved headlighting, and more-nearly constant response to the controls. Year by year we are making cars easier to drive, so that more and more we control the car with our fingers, wrists, toes and ankles, rather than with shoulder and thigh muscles. This gives more-rapid and more-precise control and less effort so that fatigue on long trips, which contributes to highway accidents, is reduced greatly.

Turn indicators and automatic transmissions let the driver keep his hands on the wheel and his attention on the road ahead.

The story is told of the small boy who fell out of a tree. His mother rushed up and said, "Did the fall hurt you?", and he replied, "No, but the sudden stop did." Many fatal accidents are the result of a too-sudden stop. As highway designers, your concern is with the obstacle that caused the sudden stop and not with the obvious fact that the driver was driving too fast for conditions. As long as obstacles exist, some drivers will hit them, and the safety of a design should be in direct proportion to the time the driver has available between making his error and striking the obstacle.

We have adopted higher design standards for all components of the highway, longer curves, greater sight distances, wider pavement lanes and divided highways, better warning signs, wider shoulders, and elimination of more obstacles at the roadside. However, we still have hundreds of thousands of miles of two-lane highways where opposing traffic streams of units with hundreds of thousands of foot-pounds of kinetic energy pass within a few inches of each other. We have shoulders which are narrow, rough, soft when wet, obstructed by culvert head walls, stones, trees; we have highways where the curves are short and sharp, sight distances so short that almost no opportunity for safe passing is provided, traffic lanes which are very narrow, deep roadside ditches, traffic types mixed from transport vehicles to pedestrians, and far too few roads to carry the traffic volume. It is no wonder that the accident record is as bad as it is.

FINANCE

All reasonable people concede freely that the deficiencies in the highway system are chiefly the result of not having made enough money available to the highway builders to make it possible to meet the demands forced upon them. Because the amount available is so pitifully inadequate, it is of paramount importance that maximum effort be made to invest such funds in the wisest manner possible. This has always been the case, and we have too often done our construction in terms of expedients rather than as well coördinated long-range programs. This is the principle reason why alignments and grades are obsolete and streets and bridges too narrow.

The present status of the highway program should be regarded as encouraging. Innumerable studies of specific needs have been made, many projects have been completed, many more are under way, and designs are well advanced on a great many others. Planning groups are probably better organized and coördinated than ever before. What is needed, and the order in which it needs to be done, are fairly well known.

There is a growing movement among business and civic leaders in all fields in support of the necessary expansion of the highway system. There is, I believe, a slowly growing understanding by the general public that funds must be provided to expand the highway system to raise our standard of living even higher. The essential step remaining is the development of this understanding to the point that the funds are provided in the amount required.

REFERENCES

1. T. J. Carmichael, "Motor-Vehicle Performance and Highway Safety." Highway Research Board, 1953.
2. C. L. McCuen, "Economic Relationship of Engine-Fuel Research." Division of Refining, American Petroleum Institute, May 3, 1951.
3. D. M. Baldwin, "Traffic Accident Trends." Highway Research Board, 1953.
4. K. A. Stonex, "Trends in Automobile Design Related to Traffic Engineering." Sixth Annual Illinois Traffic Engineering Conference, November 4, 1953.

Vibratory Median Delineators of Bituminous Material

R. J. Furbeck, *Highway Engineer*
Illinois Division of Highways

The rehabilitation of multilane pavements having a narrow, flush median by resurfacing with a bituminous hot-mix material has created the problem of redelineation of the median area. This problem has raised the question as to the desirability of replacing this flush-median area with some type of raised-median section which, by its cross-sectional characteristics, would give both visual and physical warning of encroachment on the median area and yet would permit safe transverse crossing in case of inadvertent physical contact or deliberate crossings at drives and private entrances. A possible solution is the disregard of visual contrast as such and the employment of an intermittent raised bituminous section which would give a physical warning of encroachment and which could be placed on the bituminous resurfacing material either during or after resurfacing operations.

This paper reports results of the physical sensations of the riding qualities of test sections of varying combinations of design elements at speeds of 35, 50, 70, and 80 mph. The design elements considered were spacing of units, height of section, face slope, length of section, placement of section in relation to direction of travel and the shaping of the noses.

The tests established an acceptable combination of the variable design elements based upon physical sensations and their effectiveness as a warning of encroachment