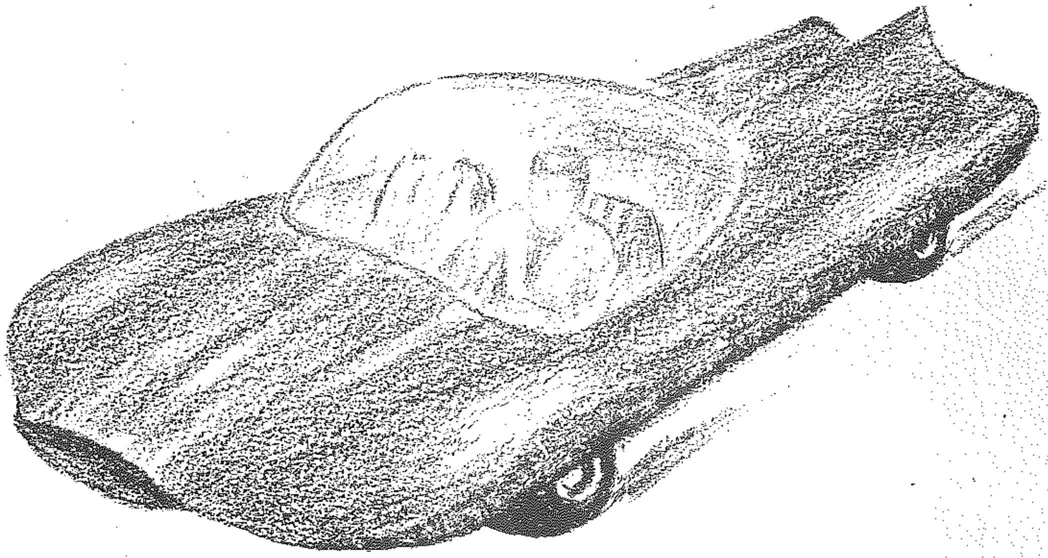
THE MOTOR VEHICLE OF THE FUTURE



MICHIGAN DEPARTMENT OF STATE HIGHWAYS

TECHNICAL REPORT NUMBER 2

APRIL 1966

STATE RESOURCE PLANNING PROGRAM
MICHIGAN DEPARTMENT OF COMMERCE

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This is one of a continuing series of working papers prepared as part of the State Resource Planning Program. This program is an interdepartmental planning function to assist the State of Michigan in taking advantage of the opportunities and meeting the needs arising from future growth.

GEORGE ROMNEY
Governor

ROBERT J. McINTOSH
Director

STATE OF MICHIGAN

DEPARTMENT OF COMMERCE

LANSING, MICHIGAN 48913

Direct Replys To:
OFFICE OF ECONOMIC EXPANSION

April 11, 1966

Hon. George Romney
Governor, State of Michigan
State Capitol
Lansing, Michigan

Dear Governor Romney:

We are pleased to transmit this report about "The Motor Vehicle of the Future". It represents another contribution to the State Resource Planning Program administered by our Department.

This project is a significant input to development of a statewide transportation plan which is a major element of the program. The study explores the probable change in the motor vehicle and assesses the impact which such modifications might have on our total transportation system.

The report will contribute to your Special Commission on Transportation, the Transportation and Land Use Study for the Detroit region, the various university studies and the local, regional and state agencies dealing with transportation.

Sincerely,

Robert J. McIntosh
Director

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March 15, 1966

Mr. Robert J. McIntosh, Director
Michigan Department of Commerce
Board of Water and Light Building
Lansing, Michigan 48913

Dear Mr. McIntosh:

Transmitted herewith is a Technical Report entitled, "The Motor Vehicle of the Future", developed and prepared in the Office of Planning by the Resource Transportation Planning Unit.

This technical study is forwarded to you as a contribution toward the development of procedures and supporting data to formulate a statewide Transportation Plan. This plan, is, in turn, an element of the Michigan State Resource Planning program being administered by your department.

Very truly yours,

Howard E Hill

HOWARD E. HILL
State Highway Director

MICHIGAN
WATER
WINTER
WONDERLAND

THE MOTOR VEHICLE
OF
THE FUTURE

Prepared By

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TECHNICAL REPORT NO. 2

STATE RESOURCE PLANNING PROGRAM

February 1966

Requests for copies of this paper should be addressed to:

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The preparation of this document was financially aided through a Federal grant from the Urban Renewal Administration of the Housing and Home Finance Agency, under the Urban Planning Assistance Program authorized by Section 701 of the Housing Act of 1954, as amended, and as authorized by the Governor's Interdepartmental Resource Development Committee of the State of Michigan, administered by the Michigan Department of Commerce, Office of Economic Expansion.

Preface

SEVENTY-THREE years ago, in 1893, Mr. Frank Duryea drove America's first successful gasoline automobile on the streets of Springfield, Massachusetts. A year later, Mr. Elwood Haynes' "horseless carriage" appeared on the streets of Kokomo, Indiana. In 1895, Mr. Alexander Winton's first car took to the road in Cleveland, Ohio.

These earliest cars, and their immediate successors, pioneered many of the mechanical features which are still to be found in the basic design of today's sophisticated vehicles, such as: the four-stroke cycle, water-cooled, front-mounted gasoline engine; spark ignition; geared transmission driving through a clutch to the rear wheels; steering-wheel control; and pneumatic tires. This basic design has competed with the vogues of steam and electricity, and outlived them; it has been refined with overhead-valve engines, automatic transmissions, power steering and independent suspension; but fundamentally it has persisted without radical alteration by innovation or discovery.

Will this continue to be true in the next seventy years, or the next fifty, or even the next twenty? If not, what will be the directions which innovation and invention are likely to take, and what will be the impacts on the vehicle, the driver, the transportation system and the economy in general?

It is the purpose of this technical report to explore the probabilities for change in the motor vehicle, its use and control in the next few decades, and to assess the impact of change. Such a forecast is vital in the establishment of a long-term overall transportation plan, as a part of the State Resource Planning Program now in progress.

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Introduction

TRANSPORTATION is one of the major program elements of the State Resource Planning Program, because it is a key factor in the state's future development of industry, tourism and economic well-being. Its importance can hardly be overemphasized.

It is not coincidence that the world's most highly developed nations have the most modern and extensive transportation systems. Nor is it coincidence that the most backward areas of the globe still struggle along with only the most primitive transport facilities, such as pack-mule and camel.

In Michigan the automotive vehicle and the paved highway constitute the dominant form of transportation, both public and private. The highway system and its development are of the utmost importance in the projection of future transportation needs and the means of meeting these needs to the best interests of the economy. These future requirements will be based on a broad study of all forms of transportation through cooperative effort by the state agencies most directly concerned.

In particular, future highway needs - for 1980, the target year of the state comprehensive plan - will be determined primarily on the basis of a projection of probable volumes and distributions of traffic, derived from a mathematical model which can be updated periodically in the light of new traffic and economic data.

Of perhaps equal importance to the overall picture is the development and future form of the automotive vehicle itself, and the environment in which it operates. What kinds of vehicles will we have; what new driver aid devices will be developed; what new roadway geometrics and materials may we expect; and, finally, what will be done to improve vehicle operation under the various hazards of the physical and climatic environment?

It is the purpose of this paper to examine the probabilities for change and improvement in the highway vehicle itself, and the possibilities for improving the safety and efficiency of driver control. Other papers are planned, hopefully, to complete a review and projection of the entire highway transportation complex in relation to other aspects of transportation and the entire state comprehensive plan.

The highway vehicle will be analyzed in terms of (1) support and directional control, (2) dimensions, and (3) motive power. Vehicle operation and driver control will be considered in terms of the possible benefits to be derived from the field of electronics, first in providing visual and aural aids to the driver, and ultimately in taking over all or many of the functions of vehicle operation.

* * * * *

Summary and Projection

1. THE MOTOR VEHICLE of the future, 1980 and beyond, will continue to roll on pneumatic-tired wheels. Automotive engineers and other experts recognize that the rubber tire possesses the fundamental and unique property of providing precise directional control by its resistance to displacement from its normal rolling path. This property, called cornering force, is the one thing which makes the motor vehicle so much simpler to control and operate than any other of the many mechanized transportation vehicles, land, air or water.

2. Tomorrow's passenger cars will not differ materially from the current models in size and passenger accommodations. They will be lighter, with better performance and economy, better suspension and brakes. They will be safer, with devices and construction features to protect driver and passengers, and to provide for better control.

3. Trucks and buses will show the greatest changes in the field of long-distance freeway transport. They will be much larger, both to meet the demands of the growing economy and to take full advantage of the efficiencies of the freeway system. Double-bottom freight transports will be common, with gross combination weights of well over 170,000 pounds and lengths in excess of 100 feet. The cabs will be fitted for the utmost driver efficiency and comfort, with air conditioning, eating and sleeping facilities, and the latest in communication devices. Highway buses may well be of the articulated type, of course with air conditioning and toilet facilities, and possibly with sleeping berths on an upper level, hostesses, hot meals and television.

4. *Motive power for passenger cars is expected to be a greatly improved spark-ignition gasoline engine, with the possibility that the gas turbine may make an appearance in some numbers.* There also is an outside chance that a breakthrough in fuel cell chemistry, if coupled with a drastic worsening of the air-pollution situation, could bring about electric propulsion, especially for urban and commuting usages - in spite of the cost and weight disadvantages.

5. *New regenerative gas turbines may challenge the diesel engine in heavy truck transport.* These turbines will be competitive in fuel economy and production cost, and superior in specific weight per horsepower and in torque output. The facts that the turbines need no cooling system, produce little noise and vibration, and above all that their exhaust is relatively free of pollutants, will make them a very real threat to the presently used prime movers.

6. *Electronic controls and automated highways are "just around the corner".* They will be a reality within the next two decades, on selected freeways. However, there are many problems to be resolved before they will be extended to the complete interstate and freeway network. One problem is the question of component reliability and "fail safe" operation; another is the handling of both manually and electronically controlled vehicles in the same traffic stream; a third is the question of cost and economic advantage.

7. *Meanwhile, the driver will have other, though less dramatic, electronic aids to safe operation at his command.* There are devices in

experimental use today for driver aid and information through radio communication, and there will be others - more or less sophisticated - providing driver information and possibly such aids as vehicle detection, road edge delineation, and hazard warning. These devices will need to be adaptable to, and compatible with, a future fully automated highway, particularly with regard to the vehicle-mounted equipment.

* * * * *

CHAPTER I

Support and Directional Control

THE WHEELS of today's vehicles provide three essential functions: (1) support and cushioning of the vehicle and its load, (2) application of the motive power to produce movement, and (3) directional control by the operator. Of these functions the third, as we shall see, is uniquely a property of the pneumatic tire.

> "There is no foreseeable substitute for the pneumatic tire. In the early days of motoring, when its unreliability forced designers to consider substitutes, there were many devices to carry the load, maintain level motion and cushion the vehicle against the effects of uneven road surfaces and obstacles. When the allied governments became worried about the shortage of rubber during World War II, searches were made among the old ideas on sprung wheels; the conclusion was that with modern technical knowledge all the required properties could be obtained - except one.
>
> This was the fundamental property of the pneumatic tire in 'persuading' or guiding the vehicle on a chosen course. To quote Gough, 'the ability of a tire to produce a general lateral force with only a relatively small angle of drift from the course it would take if rolled freely without a side force, is fundamental to the production of a practical vehicle which must be maneuvered on land. The progressive relationship between drift, or slip angle, and lateral force obtained with a tire is also of fundamental importance.'" (1)

* * * * *

> "Without the pneumatic tire automobile controllability as we know it today could not exist at the speeds we enjoy driving. The tire historically was invented as a partial solution to the problems of rough riding over the very bad roads in existence at the time of the earliest automobiles. Those who participated in the invention and development of the tire achieved

something which they did not at first realize.

They were attempting to cushion the ride, and accomplished this in some measure. The really important thing they gained though, was the development of a device which enables the driver of an automobile to have a measure of control over his car which could not be realized without the pneumatic tire." (2)

* * * * *

"Directionally stable maneuvering of self propelled vehicles presupposes the ability of the tire to support side forces developed by centrifugal effects, side winds and road bank elevations. Research in the mechanics of tire cornering is of relatively recent date, and advanced development is still in progress. The unusual complexity of the subject permits treatment here of only basic principles . . .

Rigid wheels give sufficient stability to a low-speed vehicle steered by outside forces. The horse and carriage is an example. An automotive vehicle steered from within, on the other hand, maintains directional stability at high speeds only by utilizing the much higher side-thrust capacity of a rubber tire.

Rolling motion of a wheel is obviously possible only in its longitudinal plane. If by any action of external side forces, the travel direction of a wheel is forced to deviate from true rolling direction, the rubber tire counteracts with a frictional resistance or cornering force. Condition for its existence is an area ground contact, which contrasts with the linear contact of a rigid wheel. The tire cornering force originates in the elastic forces of rubber particles which, as they pass the ground-contact area, are forced to travel sideways in addition to their rolling progression. Conversely, the tire will develop a cornering force only if its path of travel deviates from the true direction of rolling. Cornering force is in fact, proportional to the angle of deviation, or slip angle." (3)

* * * * *

"Any discussion of the mechanics of vehicle directional control must start with the fundamental cornering characteristics of the pneumatic tire - i.e., the way in which it develops lateral or side thrust and how this force varies with the load, inflation pressure, and speed. Primarily, the tire develops lateral thrust by running at an angle of inclination between the plane of rotation and the direction of travel of the wheel. This is known as the slip angle . . .

The aerodynamic stability characteristics of a vehicle are very closely associated with its cornering stability. This is true fundamentally because side-wind forces as well as centrifugal forces can be reacted only by tire side thrust, as a function of side slip." (4)

* * * * *

". . . the automobile has evolved to its present-day form without possessing any fundamental deficiencies in lateral stability or control. This result has come about neither by happenstance nor by the determined efforts of technologists, but merely because the mechanics of motor vehicles (of the conventional form) cause this to be so.

Thus we find that automobiles are ever so much easier for man to control than, for example, airplanes, helicopters, submarines, ground-effect machines, and the like. For reasons of perspective, we thus emphasize that the automobile is a vehicle which has lateral stability and control characteristics sufficiently well matched to man's needs so that he easily learns to drive a car . . .

In the early period of the automobile, efforts to improve or understand stability and maneuverability, both in this country and abroad, were largely empirical. As has been reviewed elsewhere, theories of handling could not be advanced until investigators first demonstrated the process whereby a pneumatic tire can sideslip and thus produce side forces proportional to the lateral distortion of the tire contact print." (5)

* * * * *

> "It might be permitted to interject here some comments on the ground effect vehicle or 'air car' which has had considerable publicity lately. With modern road materials and modern tires _it is the very high 'cornering force' available in the conventional car which makes it such a precision transportation instrument_. Think of the innumerable times each of us, in complete confidence, passes within three or four feet of sudden death going in the opposite direction. This is possible only because of the high control forces available. In the air car such control forces are essentially zero. Without adequate control forces such air cars cannot become an essential part of a complex transportation system and must be looked upon as special purpose devices." (6)

* * * * *

In summary, it is concluded that the highway vehicle of the future (as opposed to off-the-road and over-the-water vehicles, where the ground effect machine may reign supreme) will continue to roll on pneumatic-tired wheels. The tires themselves doubtless will be greatly improved as to cord body, tread configuration and rubber compounding, to provide an even greater measure of that precise control over the vehicle and its path which cannot be achieved by any substitute yet devised or imagined.

* * * * *

CHAPTER II

Dimensions of Motor Vehicles

THE PASSENGER CAR in its present stage of evolution is a structure with, generally, three separated compartments for (1) motive power, (2) driver and passengers, and (3) luggage and spare tire. All three compartments vary somewhat in size according to the power, passenger capacity and general purpose of the vehicle. Most sports cars have seating for only two persons and minimal luggage space; the station wagon is a hybrid which provides one relatively large compartment for six to nine persons as well as the luggage or cargo.

Thus, passenger cars on the road today range in overall length from about twelve to about nineteen feet. It is unlikely that future cars will be built substantially smaller, because the lower limit represents just about the minimal accommodation for two persons; or substantially larger, because the present largest vehicles are limousines seating eight people in the most luxurious comfort.

The proportion of cars of various sizes within the traffic stream may vary with economic conditions or with the public taste of the moment; the past decade has witnessed a swing to the compact car, followed by a reverse trend toward the medium size car or "large compact". Such changes in choice doubtless will continue to occur in the future, but there are no grounds for projecting any radical change in the upper and lower limits of passenger car size.

> "Therefore, let a good look be taken at the automobile, the most influential consumer product of the twentieth century, as it is today and as it might be many years hence. . .

> . . . the car of the 1970's might be only seven-tenths as heavy as the comparably dimensioned car in its category in 1962. As for dimensions, all extrapolations of past trends show that cars ten or twenty years hence should be almost the same as cars of 1962 in each comparable category as to width and length . . .
>
> . . . compounding all the improvements in cars gives a picture of this future vehicle as being thirty percent lighter and far more efficient in performance and economy." (7)

In contrast to the single people-carrying function of the passenger car, the truck has dozens of uses, for each of which there is a best size, shape and weight - from the half-ton pickup to the two-cargo-body combinations or "double bottoms", with up to thirteen axles and as many as fifty tires. The only significant effect on the transportation picture would stem from an extension of the present upper size limit, and therefore the attempt at projection will be confined to the "big jobs" of the future.

Undoubtedly there will be a growing economic pressure aimed at liberalizing the dimensions of the large vehicle combinations, both to reap the full advantages of our modern highways, of which the Interstate System is an example, and to offset the increasing competition of the railroads with their trailer-trains and auto-carriers. (According to the Association of American Railroads, 2,000,000 trailer-on-flat-car movements and 3,000,000 new automobile deliveries were handled in 1964.)

Historically, regulation of truck weights and axle loadings has been necessary to protect the public investment in roadways and bridges against the damaging effects of uncontrolled loading. By inference, regulation of truck dimensions has been based on the need for operational safety; height as related to overhead clearances at structures; width as related to lane and pavement widths; length as related to safe passing distances on rural two-lane, two-way roads and to maneuverability at intersections and on urban streets.

Section 127 of Title 23, United States Code, specifies the maximum axle weights, gross weights and widths of vehicles which the States shall permit to use the Interstate System. There is no limitation specified on length of vehicles or vehicle combinations.

A report of the U. S. Department of Commerce, Bureau of Public Roads, has recommended that Section 127 be amended to provide for such limitations; the upper limit would be sixty-five feet for any combination of vehicles. The report says, in part:

> ". . . there is a point where increases in vehicle length create serious safety problems: in passing operations, particularly on two-lane highways; in the time required to clear at-grade intersections; and in negotiating turning movements, especially in urban areas." (8)

None of these hazards applies on the Interstate System, and none would have any validity whatever if marshalling yards were available at the interchanges so that larger trains could be broken up for operation within the safety limits of the local roads and streets.

This is exactly what has been done on the New York Thruway. In 1959, six trucking companies began operating 98-foot, 65-ton combinations with the permission of the Thruway Authority. During test runs aggregating 350,000 miles there were no operational problems, no serious accidents and no adverse public reaction. The big rigs were broken up for travel on the regular highways at marshalling yards maintained at the thruway exits.

In regard to trailer-on-flat-car service by the railroads and its effect on line-haul highway trucking, the report of the Department of

Commerce concludes that regardless of the ultimate growth of such service, there will always exist some break-even point below which it will be cheaper to utilize highway transportation. Therefore, with the continuing growth of the economy and its transportation demands, and in the absence of radical and presently unforeseeable technical advances, it is unlikely that the growth of trailer-on-flat-car service will substantially affect the future numbers of large vehicle combinations on rural freeways.

In a section devoted to "Vehicle Length Limitations", the report goes on as follows:

> "A length up to 75 feet would not have a significant effect upon the safety potential of the usual passing operations on a two-lane facility. Observations of the operation of 100-foot-long trailer combinations on toll highways, built to interstate standards, has indicated that the normal behavior of other traffic <u>was not significantly affected</u>.
>
> The use of double-trailer (tractor, semi-trailer and full trailer) combinations is permitted on several toll facilities. These units, usually made up of two 40-foot trailers drawn by a tractor, measure from 97 to 105 feet in overall length. Both trailers are generally of the same length and axle arrangement, with the second trailer assembled from a semitrailer with an appropriate trailer converter dolly . . . The individual trailers are hauled singly with smaller tractors at either end of the line haul . . ."

An exciting glimpse of truck transportation in the future is provided by the Ford Motor Company's experimental Gas Turbine Superhighway Truck, which was exhibited at many major cities during a 5,500-mile national tour in the fall of 1964, and is now (1965) on display at the New York World's Fair. It is 96 feet in overall length, 13 feet high and 8 feet wide, and consists of two 40-foot trailers and a tractor powered by a 600-horsepower gas turbine. The gross combination weight is 170,000 pounds.

Full details of this vehicle and its design concepts have been made available through the courtesy of the Public and Professional Relations Engineering and Research Staff of the Ford Motor Company. (9) A few of the more interesting highlights are quoted or paraphrased herewith:

> ". . . as population figures mounted and the trucking industry was called upon to increase its service and to keep pace with this growth, the 'double bottom' appeared in the West - a tractor pulling two trailers each about 25 to 27 feet in length. In addition to their greatly increased capacity the doubles offered incomparable flexibility. Furthermore, the fact that they tracked as well as a city bus added more safety to trucking operations.
>
> Now we are in the midst of a new era in the technology of highway building . . . If past history provides any indication of what will happen in the future, we can look forward to a new vehicle that will match the interstate system. The interstate system is a high speed facility and to derive full use of it, experts believe, trucks should travel at speeds consistent with the rest of the traffic on the level and even climb the grades at performance rates greatly in excess of what they have been accustomed to in the past. Both of these concepts coupled with heavier combinations, mean increased power.
>
> The trend is well underway. The advent of the great superhighways in the East and Midwest opened the way for the larger, Eastern version of the double bottom . . . Though their operation is still restricted to a limited number of toll roads in the East and Midwest, double bottom mileage has shown a strong and steady increase. For example, double bottoms rolled up 6.5 million trailer miles the first year on the New York State Thruway, and now the figure runs better than 16 million a year.
>
> The Interstate and Defense Highway System is now more than 41 percent built. When completed, this 41,000-mile system will link 90 percent of U. S. cities of over 50,000 population, and will bring new development potential to countless small towns and rural areas.

> When the full 41,000-mile network is in operation, new types of trucks will be called for. It will be possible for the first time in the nation's history to plan on truly long-distance non-stop hauling. The road system will have the capacity to accommodate trucks making maximum use of the potential of double-bottom operation, pulling the trailers at passenger car speed, making use of terminals near exits to uncouple a trailer for local delivery and to pick up another for hauling along the super-highway."

In 1962, research engineers of the Ford Motor Company began to examine the implications of the new interstate and freeway systems on the future of truck transportation. Their development program was based on these concepts:

"1. Design to the maximum weight and cargo capacity within limits of the legislative restrictions and available power plant capacities expected in the 1970-1980 decade.

2. Design for economical operation and equipment use, and take advantage of aerodynamic treatments of the tractor-trailer complex.

3. Incorporate all possible safety features to permit high speed operation while sharing the superhighways with other traffic. This involves visibility, optimum brake control, light precise steering control, and provision of driving efficiency features including a heating, ventilating and air conditioning system and good ride quality.

4. Provide improved crew accommodations to permit long-range, non-stop hauling for maximum revenue-returning operation.

5. Optimize all design features for exclusive operation on the turnpikes and freeways of the new interstate road system."

Briefly, the resulting super transport truck is capable of level road cruising at 70 m.p.h. and can maintain a minimum speed of 30 m.p.h. on a sustained three percent grade. It is designed around a 600-horsepower gas turbine engine and five-speed automatic transmission with retarder. The suspension consists of air springs, leveling valves and radius rods supporting the axles.

The cab interior is arranged for two-man operation, with sleeping accommodations, walk-around headroom, washroom conveniences and food facilities - fold-away table, lavatory, toilet, oven, refrigerator, heating, air conditioning and co-driver television. With these facilities, it would be practical for the truck to operate non-stop for up to 20 hours, with periodic alternation of the driving duty.

The present fuel-tank capacity limits non-stop operation to about nine hours, but even this could represent 600 miles under ideal freeway and weather conditions.

* * * * *

If, as it seems, the trend toward larger and more efficient commercial vehicle combinations is inevitable, and if 85-ton gross combination weights and 600-horsepower prime movers are seen as feasible, not to say common, by the year 1980, what then are the probable needs and solutions after another twenty years of economic growth? Evidently the controlling factors are legislative restrictions, based on the strength and durability of the highways and their structures, and power plant capacities, which are restricted only by technological progress.

It can be assumed that the latter will not stop with the achievement of a 600-horsepower package. Even modest progress (between one and two percent a year) would produce a package of 800 horsepower by the end of the century, and this without any new breakthrough in design, metallurgy or fuel sources.

Even assuming no further progress in pavement and bridge design and the maintenance indefinitely of present axle load restrictions, the fact remains that truck chassis designers are becoming more knowledgeable and adept in designing suspensions and linkages to equalize the transfer of both weight and driving torque over three and even four axles, so that gross combination weights also can increase as much as a third.

The largest highway transport vehicle in use as the year 2000 dawns might be a combination with a gross combination weight in the range of 225,000 - 250,000 pounds, perhaps 135 feet or more in length, powered by a gas turbine or other prime mover developing 800 horsepower, and with over-the-road performance at least as good as that of the prototype Super Transport Truck developed by the Ford Motor Company.

These developments will of course necessitate changes in legislation and highway design policy, at both State and Federal levels, so timed and executed as neither to force premature obsolescence of existing highways and structures, nor to delay the advent of the larger, more efficient vehicles to the detriment of the economy. This might mean, for instance, that legal axle loads would not be increased materially during the expected life of existing pavements; vehicle heights would not be increased during the expected life of existing structures. Design policy, however, will immediately be concerned in two areas: (1) upward revision of structure and pavement designs to meet the distant-future requirements as based on firm and acceptable projections, and (2) revision of major interchanges to meet the near-future needs as evidenced by current trends.

Many existing major interchanges, and some of those being planned under present geometric standards, will require upward changes in ramp pavement widths and turning radii to accommodate the increased off-tracking of the larger vehicle combinations. (In fact, some existing interchanges are inadequate in these respects even for present vehicle sizes). It also will be necessary to plan for, and to provide, marshalling yards in the immediate vicinity of the major interchanges for the exchange of terminating and originating trailer loads, and for the breaking up of trailer trains into units which will be legal and maneuverable on non-arterial highways and urban streets.

These areas would be analogous to railroad freight classification yards, or even to division points, and could include fuel, service, restaurant and sleeping facilities; weigh scales for regulatory purposes could be incorporated in the terminal areas or maintained on adjacent state-owned right-of-way.

* * * * *

CHAPTER III

Motive Power: Engines and Fuels

THE TYPE of motive power and fuel used in the vehicles of fifteen and twenty-five years hence will have little impact upon the volumes and speeds of future traffic, or on the appropriate geometric design of the highways. However, they will be important in establishing the probable needs in the ancillary services such as service stations, fuel depots and terminal facilities. If petroleum fuels continue to predominate, and it is most probable that they will, then the familiar service station will remain and flourish; but should a practical commercial stage be reached in the development of the fuel cell for electric propulsion, or in the even more exotic power of the atom, then the roadside and terminal requirements would change radically, with far-reaching effects on transportation, and indeed, on the entire economy.

Obviously, any practical substitute for the spark-ignition gasoline engine must be competitive in production cost, operating cost, reliability, power-weight ratio, fuel consumption, fuel availability, operating range and performance. There is no present threat to its supremacy in the passenger car field, despite the existence of a small number of diesel-powered cars, a few experimental turbine-powered cars and, now being imported from Europe, a small car powered with the "Wankel" engine which features an eccentrically rotating three-lobed element which replaces the pistons of a conventional engine. All of these, however, are fueled with petroleum products.

As for trucks, the diesel engine has become the dominant motive power in the heavyweight division (as well as in intercity and transit buses). It may be challenged and eventually superseded in the long-distance hauling field by a supercharged, regenerative turbine of the type recently developed for a prototype super transport truck. (10) This engine was designed to compete with current diesel engines in both fuel consumption and production cost; in addition it offers less weight per horsepower and excellent torque characteristics. It needs no liquid cooling system and no circulating oil supply; has low noise and vibration levels, relatively clean exhaust products, wide tolerance in fuels, and very good cold starting ability.

Although this engine is interesting both technically and as a preview of things to come in the heavy truck field, the fact remains that the transportation economy would not be upset by changes in the relative popularity of the petroleum fueled prime movers. And the petroleum internal combustion engine - whether spark or compression ignition, whether reciprocating or rotating - is very likely to continue for many years as the dominant power source in highway transportation.

Some rather radical changes would be triggered, however, by a technological breakthrough leading to the practical application of electric or nuclear power, or both. The new fuels and prime movers would require new and entirely different motorist service facilities, both in roadside service stations and dealer or repair establishments, to mention only one of the economic effects.

The potential for future electric propulsion has been recognized, as a possibility rather than a probability, by experts such as L. R. Hafstad, General Motors Research Laboratories, and G. A. Hoffman of the RAND Corporation. Mr. Hafstad says:

> "The only really promising 'dark horse' in the picture at the present time seems to be the fuel cell as a source of power for an all-electric car.
>
> . . . the present versions are much too bulky and heavy, and at the moment also too expensive, for automobile use. The fuel cell has another potential advantage, however, which may prove decisive in certain situations. In some of its many versions the only gaseous end products of the chemical reactions are water or carbon dioxide. The significance lies in the fact that neither of these would be considered to be an atmospheric pollutant.
>
> In summary, then, no significant change is foreseen in power plants in conventional cars in the next decade or two. The one big unknown is the smog situation. If and when a compact high-efficiency fuel cell is developed, its potentially smog-free characteristics may enable it to overcome what would otherwise be an insurmountable cost disadvantage." (11)

Mr. Hoffman used systems analysis to project the vehicle of the future. In regard to the electric power potential, he says, in part:

> ". . . a complete systems analysis of the electric motor car - battery or fuel cell operated - shows that this is indeed an excellent possibility for future passenger cars, but it is not discussed here because it requires some rather drastic changes in the other components of the car, and a comparably drastic change in the attitudes of the motoring public . . .
>
> Surprisingly, future piston engines still look the best and cost the least all around, with the only close competitor being the rotating combustion (Wankel) engine. The extensive analysis of electric motor cars alluded to earlier shows at this point that battery-operated cars are also very attractive for limited-range urban travel." (12)

Neither of the above-quoted writers, nor any of the source material listed in their papers, makes any reference to nuclear power and its potential. As Mr. Hoffman says in reference to electricity, nuclear power would require "some rather drastic changes in the other components of the car, and a comparably drastic change in the attitudes of the motoring public." It is evident that atomic power is still in the realm of imaginative thinking so far as any automotive application is concerned, and that any real progress in this field must depend on the solution of at least three presently forbidding problems:

(1) The excessive weight resulting from the necessity of shielding with lead or other dense material.

(2) The safe disposal of the spent fuel element, with its residual radioactivity.

(3) Overcoming public fear of rupture of the nuclear package in an accident, and distrust of being in close and prolonged contact with a radiation source.

* * * * *

CHAPTER IV

Vehicle Operation and Driver Aids

Vehicle operation is a fertile field for speculation, innovation and improvement. There is a pressing need to improve both the safety and the precision of driver actions; to improve his ability to control his vehicle, to comprehend and react to his environment, and to drive safely under the most adverse conditions.

It is now technically possible, and soon may be economically feasible, to relieve the driver of much of the control responsibilty and to alert him to environmental changes and hazards through the use of more or less sophisticated electronic devices. There is even some prospect of a breakthrough in dispelling fog by sonic devices and reducing the hazards of darkness by radar or infra-red sensors.

Although the ultimate objective of current research and experiment is to devise a system for completely automated vehicle guidance and control, there also is an immediate interest in developing practical means to alert and inform drivers of road and traffic conditions by less sophisticated devices.

One such device, already on the market, is called "Drive-A-Lert". Its operation is based on the fact that even on a straight road, the driver must make a certain number of steering wheel corrections to maintain a stable path positioned within the driving lane. When these minute corrections are not being made because of driver inattention or dozing, the Drive-A-Lert sets off a warning alarm loud enough to restore him to the proper state of alertness.

The Ford Motor Company has tested an electronic system which uses the car radio for warning of roadway or traffic hazards. Pre-programmed roadside transmitters operate through magnetic type cartridges in the car trunks to activate the radios whether or not they are turned on. Emergency messages other than the pre-taped ones also can be transmitted.

General Motors has experimented with a somewhat similar system called "Hy-Com", which transmits voice messages of warning or information through the car radio from low-frequency roadside transmitters. They also have developed an edge-of-road detector (Electro Lane) which signals by buzzer or flashing light when a car strays too far off course.

These devices all may be said to have two purposes; (1) to provide immediately some tangible assistance to the safety and efficiency of vehicle operation, and (2) to serve as compatible transitional elements of a future automated system.

About four years ago the Radio Corporation of America submitted to the Department of Commerce, "A Proposal for Improving Safety and Efficiency on the Nation's Highways", in which they laid down these guidelines:

1. The highway system must be immediately useful to all drivers, whether their vehicles are electronically equipped or not.
2. It must provide additional benefits and assistance to drivers of equipped cars.
3. It must be applicable to existing roads.
4. It must permit expansion, without premature obsolescence, into the "fully-automated" highway.

Very briefly, their system begins with a vehicle detector consisting of a wire loop embedded in the road surface and a detector circuit at the road edge. These detectors can be used singly or in series, and can be used to activate warning lights at the side of the road or to transmit to audio, video or servo mechanisms in the vehicle, if and when installed. Using these detectors, it would seem feasible to progress from individual installations for specific locations and purposes, through any number of intermediate steps, to a final extensive automated system without obsoleting the highway elements or subjecting the driving public to the necessity of purchasing all of the vehicle equipment at one time.

* * * * *

Although the devices and systems above described indicate considerable progress in electronic guidance and control, there are major problems to be resolved before the practical application to any extensive and connected mileage of highways is possible.

The first problem has to do with the mechanics of electronic control, and the fundamental question of reliability and "fail safe" design. It is axiomatic that no mechanical system, however sophisticated, is immune from failure; it remains to define an acceptable level of reliability and to determine the probability - and the cost - of being able to achieve it.

According to one published series of calculations (13) it would require that triple roadway elements be installed to insure a degree of reliability which would keep fatalities below a rate of three per 100,000,000 miles - about the present rate on modern freeways. Even with this degree of redundancy, the probability still would exist of a need for emergency takeover of manual control about once in three hundred miles of travel. Since this represents no increase in safety over existing freeway operation, it is questionable whether it could be considered acceptable or even tolerable, considering the costs of installation and maintenance, even though traffic volumes and efficiency of movement might be improved.

A second problem, of course, is the simple question of practicality.

> "Because of the complexity of the sensing systems required in general vehicular traffic, most proposals for automatic control of vehicles have been considered to be applicable only to some type of specially equipped controlled-access highways. This restriction immediately reduces the utility of automatic control systems since even with the completion of the Interstate System, only about ten percent of highways, or just over <u>one percent of total road mileage</u>, will be in this category. It is therefore clear that a relatively small proportion of the total vehicle mileage will be accumulated on this type of road, even taking into account the generally higher speeds and longer trips for which they usually are employed." (14)

It also may be inferred that only a small percentage of the registered vehicles of a state or region are driven regularly on long trips on the freeway system. Since it would be completely impractical to factory-equip all vehicles with the necessary sensing devices, the question remains as to how many drivers would be willing to invest in the devices as extra-cost options which would be usable only for freeway driving, and how much they would willingly pay for such equipment.

> "One of the most difficult problems with regard to automatic vehicle control is that associated

> with the transition from our present day manual system. This is a particularly difficult problem if it is necessary to provide some of the control equipment in both the highway and the vehicle. It is clearly not economically feasible either to produce vehicles with automatic control systems or to provide roads equipped for this type of operation unless the other is also available. (15)

* * * * *

It must be assumed that the roadway elements for automatic control would be limited to freeways, which even in 1980 or 2000 still will account for but a small percentage of the total road and street mileage. These elements will be installed and financed as a part of the freeway construction programs, but they will constitute only one part of the complete guidance system. The other part is the sensing and servo mechanisms which must be installed in, or attached to, the vehicles and which must be paid for by the individual owners.

The economic question which arises is: What must be the ratio between cost of equipment and frequency of use, in terms of time or percentage of annual mileage driven, in order to induce people to have their vehicles equipped for automatic guidance? Commercial trucking companies operating regularly over freeway routes doubtless would take advantage of the efficiencies inherent in an electronic system, and perhaps this factor alone might justify the expense of installing roadway elements in the outer lanes of those freeways with a heavy concentration of long-haul trucking in the traffic stream. But before overall automating of the freeways could be considered, it would be necessary to have some basic and accurate information on many other social and economic factors such as: the travel habits of people, the usage of freeways, the lengths and frequencies of trips involved, the minimum length of trip and the minimum frequency which would make electronic guidance attractive or worthwhile, the possibility of renting "bolt-on" equipment for freeway travel, and so forth.

There is no question but that some electronic highways of a prototype nature will be built in the near future, perhaps within the current decade. There may be many such highways throughout the nation within the forecast period, but it is considered unlikely that there will be complete automation of the freeway systems, even by the year 2000. The whole process is more apt to be a gradual evolution, progressing from radio driver aids through road-edge detectors and vehicle-spacing sensors, and finally to a complete control and guidance system.

> "In summary, all indications are that passenger cars of 1980 will still be recognizable as descendants of current models. Wheels and tires will probably continue to provide support, tractive force, and directional control. Highly refined spark-ignition engines will serve as prime movers, propelling the car through transmissions designed to provide improved part-load economy and optimum performance. The major revolutionary changes will result from increased attention to driver-vehicle-highway relations and will include new types of driver control elements, and simplified instrumentation. Dynamic properties of vehicles will be improved by new steering and suspension systems to increase convenience, safety and comfort. Better road information and communication, and completely automatic control for highway operation will be here in 1980." (16)

* * * * *

Conclusion

ACCORDING to the purpose as stated in the Introduction, this paper has been an examination and assessment of the probabilities for change in the highway vehicle, and the possibilities for improvement in its operation. It is intended as a contribution to the Transportation Element of the State Resource Development Planning Program.

Research of available published material on the subjects dealt with in these pages and on related subjects in the general domain of the automobile, has revealed a consistency of opinion and prognosis amounting almost to unanimity.

This consensus may be expressed as a conviction that the pneumatic tire is essential to the control and maneuverability of highway vehicles, and a prediction that progress in the design and operation of these vehicles will be in the nature of evolution and refinement of existing forms, accelerated by the practical application of mechanisms and devices already existing in prototype or model. The prognosis does not include, nor does it specifically exclude, the possibility of a nuclear-powered era of highway transport in the nebulous future.

The projection date for the State Resource Development Planning Program is the year 1980, but consideration has been given to possibilities up to the year 2000. Within the projection period we may anticipate that the highways and streets of the state and nation will be carrying passenger cars much like those of today, but more efficient and much safer - and of course far more numerous. On the freeways which by that time should span and criss-cross the country traffic will move faster, trucks will be much larger and more efficient, and the operators of both private and commercial vehicles will be relieved of much of the effort and concentration of the driving task by electronic aids of ever-increasing adaptability and sophistication.

The speed with which these developments come to pass will depend on many factors other than the technologies involved. The growth - and particularly the distribution - of population of course will be a factor; so will the growth of disposable income and multiple-car ownership - the demands of industry - the expansion of the general economy - the proliferation of goods and services to meet the demands of a rising standard of living and a great increase in leisure time. The most potent factors, and those most apt to spur action and progress in this field, will be the increasing traffic volumes, the growing traffic congestion, and above all <u>the critical need for solutions to the highway safety problem</u>.

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