Narrative form of the substance of Mr. MacDonald's testimony given a
the hearing held on March 5, 1931. I.C.C.

Prepared for Mr. Leo J. Flynn, Attorney-Examiner, I.C.C. Oct. 16,

The Substance of
Testimony of
Thomas H. MacDonald, Chief
U. S. Bureau of Public Roads
Before
Interstate Commerce Commission

Washington, D. C.,

March 5, 1931.

Mr. Commissioner, my appearance before you is in response to the invitation addressed to the Secretary of Agriculture by yourself to present through any of the Bureaus any material which would have a bearing upon the present inquiry of the Commission. My testimony is not given for or against any particular proposition or any carrier or agency, but, rather, is intended to present the latest scientific data we have bearing upon the subject of the use of the highways and the relationship of the motor vehicle to the highways. I intend to present the evidence without statement of opinion except as justified by the facts.

The design of the standard paved highways, which are now being largely built on the main thoroughfares of the nation, consists either of a rigid concrete base with a top of bituminous mixture or brick or stone block or a concrete slab without other covering. The thickness of the concrete slab, which determines its strength, whether it be the base or the surface itself, must be sufficient to resist not only the static load on the wheels of vehicles, but also the impact forces applied through the wheels. That is, the design must be based not upon the static wheel load but upon the blow which the wheel delivers in passing over the surface.

I have here a chart which shows the relation between static wheel load and corresponding impact delivered to a fair sheet asphalt surface (taken as a standard of normal smoothness) when the vehicle is operated at various speeds and equipped with pneumatic, cushion and new and worn solid tires.

The chart shows that when a vehicle, having a wheel load of 9,000 pounds, is equipped with pneumatic tires and operated at 30 miles per hour over a pavement of smoothness equal to that represented by the chart, the resulting normal impact will be about 12,500 pounds.

For the sake of comparison, if the same vehicle of 9,000 pounds static wheel load, were operated over the same pavement at 20 miles an hour, equipped with worn solid tires it would deliver a normal impact well above 21,000 pounds, or practically twice the impact delivered by the same wheel equipped with pneumatic tire.

Although these impacts correspond to 30 and 20 miles per hour respectively, our studies indicate that there would not be much difference if the speed were greater so long as it did not exceed about 45 miles per hour. I can explain that in this way. When the wheel of a vehicle strikes an obstruction or irregularity in the road surface it applies to the road surface at the instant of striking the obstruction or irregularity an impact force which is known as the shock impact. The wheel is then thrown either partly or wholly into the air and when it drops again to the road it delivers another blow which is known as the drop impact. The magnitude of these two kinds of impact is affected differently by variation in speed. Thus, we find that with high-pressure pneumatic tires the drop impact increases with speed up to a speed of about 30 miles per hour and then becomes practically constant. The shock impact, on the other hand, increases with practical uniformity but more slowly up to the point where its magnitude overtakes and passes that of the drop impact at a speed of about 45 miles an hour. Thus, between about 30 miles an hour and 45 miles an hour, with pneumatic tires, there is very little change in the magnitude of the impact for which the road must be designed. With balloon tires the maximum drop impact is reached at about 25 miles per hour and above that speed drops away, so that if you go faster it is really easier on the road.

It is the impact forces, however, and not the static loads on the wheels for which roads must be designed.

The design formula involves, in addition to the applied load, (1) the safe unit stress, which for concrete pavements we have taken as 350 pounds per square inch or about half of the designed modulus of rupture, (2) a factor expressive of the support afforded by the subgrade, and called the modulus of subgrade reaction, and (3) the area of contact of the wheel with the surface of the road, expressed by the radius of an equivalent circular area. With these quantities known or assumed, the formula may be solved for the depth of concrete slab required to support the load.

Of the assumptions we make in applying the formula it is desirable to point out that the unit stress, assumed as 350 pounds per square inch involves a factor of safety of 2, since the probable breaking stress is 600 to 700 pounds per square inch; and that the modulus of subgrade reaction, taken as 50, represents a very low subgrade support. Consequently, the design based upon these assumptions is believed to be safe and conservative.

The area of contact of the tire with the pavement we have determined experimentally for various sizes of tires under various loads, and I show you here reproductions of impressions made by the tires, from which we have determined the areas.

The actual area is expressed in the design formula by the radius of the equivalent circular area and it has a very important effect upon the stress in the road slab. Thus, if the radius were assumed to be zero, as it would be if the load were concentrated upon a point, the stress, corresponding to a load of 10,000 pounds applied at the edge of the slab and a modulus of subgrade reaction of 50, would be 833 pounds; whereas, if the same load in the same position and with the same subgrade support were applied through a circular area of 8-inch radius, the stress would be reduced to 453 pounds per square inch. This effect of the area of tire contact is very important and it has previously been entirely overlooked in comparing the relative effects of the automobile, the truck, and the bus upon our highways.

That there is a very considerable difference in area of tire contact between automobiles and the larger vehicles is indicated by the fact the contact area of a 7½-inch balloon tire on a seven-passenger car with a wheel load of 1,750 pounds is only 35 square inches, whereas the gross contact area of a 6-inch dual, high-pressure pneumatic tire on a 2-ton truck of which the wheel load is 4,400 pounds is 106 square inches. A dual 10½-inch high pressure pneumatic tire on a 7½-ton truck with wheel load of 11,000 pounds would have a gross contact area of 210 square inches; but the same wheel load if applied through a new solid tire would fall upon a gross area of only 121 inches. I give these examples simply to show how greatly the area of tire contact varies.

The actual areas of tire contact, determined experimentally for each of several sizes of vehicle and kinds of tire equipment, are given in the table which I now submit; and the same table gives the edge and center thickness of concrete slab required to support the several sizes of vehicles. (Exhibit 494, Witness MacDonald)

Thus it will be seen that the 7-passenger car has a rear wheel load of 1,750 pounds. Operated at 30 miles an hour over a pavement of smoothness equal to that described and equipped with a single $7\frac{1}{2}$-inch balloon tire the wheel thus loaded would apply to the pavement an impact force of 5,100 pounds. The area of tire contact is 35 square inches and this is considered as applied in the form of a semi-circle at the edge of the pavement and a full circle in the center of the slab, the resulting radii being 4.7 and 3.3 inches respectively. Under these conditions, the table shows that there would be produced in a concrete slab of edge thickness 7 inches and center thickness 6 inches, stresses of 226 pounds at the edge and 218 pounds at the center.

Although these stresses are less than the assumed safe stress of 350 pounds per square inch, we believe the above dimensions to be the practicable minima. We would not build roads much less than 7 inches thick at the edge and 6 inches thick in the center no matter what loads they were required to carry.

For a 2-ton truck with wheel load of 4,400 pounds and impact of 7,900 pounds the table shows that a road slab of the same dimensions would have a stress at the edge of 280 pounds and at the center 290 pounds; and the same road would carry a 3-ton truck with edge stress of 320 pounds and center stress of 332 pounds, both well within the working limits of the material, which we have taken at 350 pounds per square inch.

It is not until we get to the 5-ton truck that it is necessary to increase the thickness of the road and then only by one-half inch. To support a 7½-ton truck, the rear wheel load of which is 11,000 pounds, another increase of a half inch in both edge and center thicknesses would be required, bringing the former to 8 inches and the latter to 7 inches.

Thus, if we express by the index 1.000 the average thickness of road slab required to carry passenger cars and the lighter trucks such as are used by farmers, if you please, the thickness required to support a 5-ton truck would have an index of only 1.077 and that required for 7½-ton trucks only 1.154. In other words a pavement slab capable of supporting 7½-ton trucks, assuming the use of pneumatic tires, would need to be only 15.4 per cent thicker than the slab which we would build if there were only passenger cars and light trucks to be accommodated.

I wish to emphasize that these conclusions are based upon the use of pneumatic tires. Balloon tires would apply to the road slightly lower impact forces, but cushion and solid tires would apply greater forces. Thus, the table shows that to support 5-ton trucks equipped with new cushion tires the pavement would require a thickness represented by the index 1.231 and if solid tires were used the same size of vehicle would require a pavement of thickness represented by the index 1.423.

In other words, it is not until we have to deal with 7½-ton trucks operated on solid rubber tires that we have to increase by as much as four tenths the thickness of pavement that would be provided if there were no traffic other than passenger automobiles and the lightest trucks.

We find, however, that the laws of the States, the practice of manufacturers and, apparently, the desires of the public, are all turning toward the use of pneumatic tires. It is my judgment that within the next two or three years we shall see solid tires prohibited by State law and motor vehicles permitted to operate on pneumatic tires only.

Also, we believe that the maximum wheel load should be limited to about 9,000 pounds, and the gross load to that which would cause no more than a 9,000-pound wheel load. If it is desired to move heavier loads than can be carried on four wheels with a maximum wheel load of 9,000 pounds, then, we believe, the number of wheels should be increased, retaining the 9,000-pound maximum wheel concentration.

Our tests show that so long as adjacent axles are not closer together than 3 feet, the maximum stress in the road structure is no greater than would be caused by the single wheel loads. If, then, it is necessary to carry a load greater than can be carried on a 4-wheel vehicle with a maximum rear-axle load of 18,000 pounds the single rear axle should be replaced by two separated by at least 3 feet. On these two axles there could then be carried 36,000 pounds without causing greater stress in the road surface than would be caused by 18,000 pounds on one rear axle.

If only pneumatic tires are permitted to be used and if the wheel load is restricted to 9,000 pounds the table submitted shows that the heaviest vehicle could be carried on a concrete pavement only about 8 per cent thicker than would be built for the accommodation of the lightest vehicles.

Considering the loads actually applied to roads and the kinds of tires actually used it is my judgment that the heavier trucks and busses, by the higher taxes they are paying - both license fees and gasoline taxes - are fully meeting all excess cost resulting from the increased thickness required for their support.

In the foregoing no distinction has been made between vehicles as to character of usage, whether as common carriers, contract haulers, or private operation. Only physical characteristics have been considered and particularly the effects of load and tire equipment on the road structure. Whether it be used as a common carrier, a contract hauler, or, let us say, by a farmer for hauling his own produce, a vehicle of given maximum wheel load and given tire equipment will have exactly the same effect upon the road.

The second part of my testimony concerns the relative utilization of roads by various classes of operators; specifically, common carriers, contract haulers, and those operating vehicles for their own private purposes.

We have obtained information of this character in a traffic survey conducted in cooperation with the State highway departments of eleven Western States in 1939 and 1930. At key points on the Federal-aid road system in these States traffic counting stations were established and field parties operated at those stations according to a carefully planned schedule designed to furnish representative data with respect to the various characteristics of the traffic under study. The survey was continued for a period of a year; and while the counting of traffic at each of the stations was not continuous for this period, the scheduling of the counts was so arranged as to obtain fair and representative samples of the traffic operating over the roads during the entire period.

The States in which the survey was conducted were Arizona, California, Colorado, Idaho, Nebraska, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming.

In the studies designed particularly to determine the relative proportions of common-carrier, contract and private operations, observations were made and data obtained on 180,000 separate trucks. Wherever necessary to establish the fact as to the character of usage of vehicles the vehicles were stopped and the drivers questioned.

Certain results of these studies are presented in a folder which is submitted in evidence.

[Note: The folder submitted is attached hereto. It is entitled "Evidence Presented by Mr. Thomas H. MacDonald, Chief, Bureau of Public Roads, at the Interstate Commerce Commission Hearings, March 5, 1931." The folder was submitted and received in evidence; but the transcript does not clearly indicate that it was so received and does not clearly assign it an exhibit number.]

The first chart of this exhibit shows by the total length of the bars for each State the amount of all truck traffic as a percentage of the total traffic. By the subdivisions of the bars the total truck movement is broken down into the portions which consist of interstate common carriers, intrastate common carriers, contract haulers, and so-called owner-operated vehicles, respectively. The term "owner-operated" as here used means a truck operated by its owner for the transportation of his own goods.

It will be seen that the truck traffic as a whole does not in any State exceed 16 per cent of the total traffic, and the entire common-carrier truck movement does not exceed in these States 1½ per cent of the total traffic. The interstate common-carrier movement, shown by the solid black section at the top of each column, is a small part of one per cent in every case.

The information presented graphically in this first chart is also given in the table which follows immediately after the chart in the folder.

On the next sheet, under the heading "Common Carrier Truck Registration Compared with Common Carrier Truck Traffic", evidence is presented tending to show that common-carrier trucks are operated more than 3½ times as intensively as other trucks. This is indicated by the fact that, whereas common-carrier trucks made up 1.4 per cent of all trucks registered in the States of Arizona, California, Idaho, Nevada, New Mexico, Oregon, Utah, and Washington, the common-carrier vehicles observed on the roads in these eight States constituted 4.95 per cent of the total truck traffic during 1930. This would indicate that the gasoline taxes and other fees based upon mileage are correspondingly high for common carriers.

The next table shows that of the 180,000 motor trucks observed in the eleven States, only 5.5 per cent were common carriers, 8.7 per cent were contract operated trucks and the balance of 85.8 per cent were operated by their owners for shipment of their own goods.

This table also shows that of the total of 16,535 busses observed 36.8 per cent were engaged in interstate service.

The next chart in the folder shows the relation between taxes paid by common carriers and intrastate common-carrier usage. In general where common-carrier taxes are high common carrier usage is shown to be low. In every case where the fee is above average, usage is below average. The table following immediately after this chart gives in figures the same information plotted in the graph.

In the next table contained in the folder comparison is made of the taxes that would be paid in each of the eleven States by a 3-ton truck described in detail in the note which accompanies the table, when operated, (1) by the owner for transportation of his own goods, (2) as a contract hauler, and (3) as a common carrier. In this comparison the assumption is made that the vehicle is driven 10,000 miles per year in each class of usage. On this assumption it is shown that the owner-operated truck would pay $108.70 per year, the contract-operated vehicle $132.98, and the common carrier $195.66. It appears from these figures, which are the averages of taxes paid in the eleven States, that on the basis assumed - 10,000 miles of operation annually by each class of vehicle - the common carrier truck pays 80 per cent more tax than the privately operated truck and the contract operated truck pays 22 per cent more than the privately operated truck.

But the best available information indicates that the average annual travel by vehicles of the three classes is not the same, as assumed in the foregoing analysis. Instead it is estimated that the average annual travel by common-carrier trucks is 20,000 miles, by contract operated trucks 15,000 miles, and by privately operated trucks 5,000 miles. On this basis - all other assumptions remaining the same as in the foregoing analysis - the taxes that would be paid by 3-ton vehicles of each class in each of the eleven States are shown in the next table in the folder.

This table indicates that the average tax paid by the owner-operated truck on the assumed basis would be $83.99, as compared with $173.31 by the contract-operated truck and $308.95 by the common-carrier truck. In other words, the 3-ton common-carrier truck pays, on this basis over 3½ times as much in motor vehicle taxes as the privately-operated truck and the contract-operator pays more than double the tax paid by the private operator.

The last two charts in the folder and the associated tables show the distribution by capacity of the trucks observed in the survey and their classification according to trip mileage. Over two-thirds of all trucks observed were under 2-tons capacity, which is in line with the observations made in surveys in eastern States since 1922. All our observations over this period have pointed to a tendency toward the use of lighter and faster trucks rather than toward the heavier units, although there now appears to be a tendency toward the use of trailers with the lighter trucks, so that the gross load is much larger.

The average daily trip mileage of all trucks observed was approximately 100 miles.

I think it is a fair conclusion to say that, so far as the main State roads are concerned, the relatively small amount of common-carrier truck usage or even the operation of busses makes very little difference in the building of the roads. We would be building the roads just as wide and just as thick as we now are if there were no common-carrier trucks at all - so small relatively is the usage of the roads by such vehicles in comparison with the usage by private vehicles.

I would not confine that observation to any section of the country. Whenever there is a heavy utilization of the roads by common-carrier vehicles there is a concentration of population which causes a heavy traffic of private vehicles which without the operation of a single common carrier would require the construction of the same type of road that the common-carrier operation requires.

My observation is that motor transport of all kinds, both passenger and freight, fits into a very definite field that can not be filled by the railroads or waterways, or airplanes, and that it is so flexible that any uneconomical regulation only succeeds in denting it at one point and bulging it at another. I say uneconomical regulation; it is that that I believe will be ineffective. I would say that there should be the closest possible regulation to secure the rights of the public and particularly to protect the public in its use of the highways.

There is one further exhibit [Exhibit 495, Witness MacDonald] I think should go in the record. It is a statement of road revenues, divided between State and local revenues by percentages. The State highways, for which the funds shown in this table are used, constitute all of the main roads of the nation and comprise in the neighborhood of 300,000 miles. The table shows that the percentage of highway income from road users - motor vehicle fees and gasoline taxes - has been growing very rapidly from 1921 to 1929. In the latter year, of the total income collected for State highway purposes motor vehicle fees were 31.3 per cent and gasoline taxes 32.4 per cent. An additional 18.2 per cent was from bond issues which were almost wholly supported on the income from gas and motor vehicle taxes. These three sources together total 81.9 per cent, practically all of which was supported by road users. In addition, motor vehicle fees constituted 6.8 per cent and gasoline taxes 9.3 per cent of the income for local roads.