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Tire Use Survey The Physical Condition, Use, and Performance of Passenger Car Tires in the United States of America

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Tire Use Survey
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FOREWORD

There have been few systematic attempts to determine the way in which people maintain and use their tires; indeed, we believe this study reviews most of the available data. Because of this limited experience the art of deriving meaningful tire data through survey has not been fully developed. As a consequence, it must be pointed out that some of the conclusions and interpretations derived from the data in this study are suggested rather than proved.

As one of many examples illustrating the limitations of the survey material, the Texas Highway Department study shows that 50 percent of the tires on the rear axles of cars involved in wet weather accidents in certain areas of that state had bald or thin tires, as compared with only 25 percent of such tires on front axles. In order to conclude with certainty that it is safer to place the least worn pair of tires on the rear axle, we should ideally have comparable data on the incidence of bald and thin tires on front and rear axles of cars not involved in accidents in the same area.

In the absence of these data, the authors were forced to use the only tread depth data available on a general population; namely, the Davidson Laboratory summer survey, and to conclude that there is strong evidence that it is safest to have one's least worn tires on the rear axle. One can reason that loss of rear wheel traction on curves, and rear wheel lockup in panic stops are major contributors to accidents.

The authors frequently comment in the report on the inadequacy of available data. It is their hope that these comments will be beneficial to those planning surveys of tire condition and use in the future.

I. ABSTRACT

This review summarizes the results of two surveys of the physical condition and use of passenger car tires in the continental U.S.A., conducted under contract for the Office of Vehicle Systems Research (OVSR) of the National Bureau of Standards (NBS) during the period June 1967 through May 1968.

Data and results are compared with those in four related reports recently published by the Traffic Institute of Northwestern University. The latter reports cover studies on the use, condition, and performance of passenger car tires on the Illinois Tollway during the period September 1966 through August 1967. Pertinent information from various other sources is also included.

Based on the compiled evidence, some conclusions are drawn concerning the physical condition, use, and abuse of passenger car tires in service during these years, particularly with regard to tread depth, inflation pressures, and degree of overloading. The various estimates of tire disablement rates are compared, and contributions of tires to motor vehicle accidents explored.

The authors make several recommendations directed toward upgrading the level of quality of passenger car tires in service, and reducing their abuse, with the hope and expectation that service performance will be improved, and contributions of tires to highway accidents reduced.

Key words: Accident; review; survey; tread wear; tire disablement; tire inflation; tire loading; tire pressure gages; tire use.

II. HIGHLIGHTS

-- A greater percentage of severely worn tires were found on vehicles in accidents than in the general tire population.

-- Vehicles in accidents have a larger number of severely worn tires on their rear axles than on the front suggesting that it is safer to have newer or less worn tires on the rear axle (see Foreword).

-- There is a considerable body of evidence indicating that the risk of tire disablement and of loss of vehicle control rises sharply for tires having less than about 2/32-inch of tread depth remaining.

-- Air towers at service stations are generally not accurate. A motorist relying on a tower gage will have only about a 20 percent chance of getting within ± 1 psi of the inflation pressure he wants. A single point calibration of the tower gage could decrease the error substantially.

-- More than one out of four cars has at least one seriously underinflated tire (4 psi or more below the recommended normal inflation pressure for the vehicle).

-- About 2 percent of cars are overloaded by 10 percent or more; about 6 percent are overloaded to some extent. Most overloading occurs on station wagons and light trucks, and on passenger cars during vacation trips.

-- On the average most cars are loaded to about 80 percent of their allowable load (at the existing equivalent cold tire inflation pressure).

III. SUMMARY

Based on this review of available information on the physical condition of passenger car tires in service within the continental U.S.A. and of their use and performance primarily on throughways and interstate highways, we believe that the following conclusions may be drawn. We do not contend that the list is complete, nor do we lay claim to complete originality; such was not the purpose of this review. Indeed, the majority of the following conclusions are at most restatements of those drawn by the authors of the various papers reviewed. In many instances, we have been able to test their conclusions in the light of other information; that was one of the purposes of this review. Some of the following are conclusions drawn by the authors of this paper; for these they must and do accept full responsibility.

A. Sampling

1. Selection of sampling points and sampling periods has exceedingly important effects on the vehicle population sample and on the tire condition and use data obtained.

2. Use of service stations as sampling sites, while most convenient for the sampling team and causing the least interference with traffic, virtually excludes fleet and farm vehicles, and introduces a definite bias toward more heavily driven vehicles, particularly those on long trips away from home [6].

B. Effects of Car Size, Age, and Style (Section 3.1)

1. Car Size

Although the tires on small cars (less than 2000 lb) have less average tread depth remaining than those on larger cars [2], differences in tire disablement rates are not statistically significant (see table 12).

2. Vehicle Age

Vehicle age is a highly significant factor in the rate of tire disablements, other factors being equal. Baker and McIlraith report the following tire disablement indexes by vehicle age [2]:

Cars less than 2 years old	1.00
Cars 2 to 7 years old	1.73
Cars more than 7 years old	2.44

This significance is not surprising in view of their findings, confirmed by Automotive Crash Injury Research's North Dakota study [19], that average tread depth remaining decreases steadily with vehicle age. It is probable that a study of the data acquired in the three tire condition and use surveys would show that the major portion of bald and thin tires are to be found in older cars (see section III.F.3).

3. Vehicle Style

Rear tires on station wagons and front tires on light trucks appear to be the most frequently overloaded classes of passenger tire service. About 10 percent of rear tires on light trucks were also found to be overloaded in two surveys by the Davidson Laboratory of Stevens Institute of Technology. In the latter studies it was further observed that vehicles on vacation trips had overloaded tires more frequently than those being used for any other trip purpose. Rear tires were the more frequent offenders (see section 3.3.b(1).

C. Tire Types, Sizes, and Sources (Section 3.2)

1. Retreads

Some evidence was found in the work covered by this review indicating that retreaded tires are more prone to failure (see section 4.1.b(4)).

2. Two-Ply vs Four-Ply Tires

Based either on driver recollection or on the assumption that all 2-ply, 4-ply rated tires were original equipment, these were found to constitute 32, 35, and 43.5 percent of the sample populations in the respective physical condition and use surveys.

D. Tire Loading (Section 3.3.b)

1. Average Load

There is general agreement among the physical condition and use surveys that passenger car tires in service are, on the average, loaded to around 80 percent of allowable load at their equivalent cold pressures (Pc). About 6 percent are overloaded to some extent; roughly one-third of these or about 2 percent are overloaded by more than 10 percent of rated load at Pc or maximum Pc (see table 4).

2. Loading Tires for Test

Although some few tires in service do carry extreme overloads, this is frequently due to serious underinflation. It therefore appears unreasonable to test a tire at more than 10 percent overload plus a reasonable factor of safety--perhaps not to exceed 20 percent overload.

3. Small Diameter Tires

Evidence has been presented that 13-inch diameter tires on nominally six passenger cars (all manufactured prior to issuance of MVSS-110) are more frequently overloaded in service than the larger tire sizes, by a frequency of about 2 1/2 to 1 (see section 3.3.b(3)).

4. Need for Driver Education

MVSS-110, which became effective on January 1, 1968, will do much to alleviate tire overloading in the future. This standard specifies requirements for selection of tires by the vehicle manufacturer in terms of normal loading and maximum load conditions for a given vehicle. Nevertheless, car owners still must be educated; they must recognize that higher cold inflation pressures are required for maximum load conditions, and for high speed driving, and that failure to maintain proper inflation pressures will seriously shorten tread life and increase the risk of tire failure through overheating and overstressing.

E. Tire Inflation

Car owners need to have the importance of proper tire inflation impressed upon them. It is quite apparent from the work reviewed here that many car owners do not keep their tires properly inflated.

1. Underpressured Tires

Surveys indicate that a substanital number of tires in service are underinflated. Lepisto [7] reports that 11 1/2 percent of the "knowns" in the Southwest Research Institute (SWRI) tire population sample had corrected ambient pressures below the minimum inflation pressure for which a loading for the specific tire size is given in MVSS-109 (see section 3.3.b). Drs. Olson and Bauer in a General Motors survey [11] of inflation pressures in the tires of 405 cars in their company parking lots provide data indicating that some 10.9 percent of the tires had cold inflation pressures 4 psi or more below the vehicle manufacturer's recommended inflation pressure. A recent Uniroyal survey [12] has indicated that 28.4 percent of 1904 cars had one or more tires at 20 psi or less.

2. Overpressured Tires

Although perhaps less hazardous from a safety standpoint, seriously overinflated tires can also lead to vehicle handling problems particularly if only one or two of the tires on the vehicle are in such condition. Lepisto [7] reported 3.2 percent of the "knowns" in the SWRI survey as having Pc values above maximum Pc; Baker and McIlraith [2] reported finding 1.9 percent of such tires in their second Illinois Tollway study.

3. Air Tower and Hand Pressure Gages (Sections 3.4 and 3.5)

The car owner often does not have adequate means available to him to maintain his tires at correct inflation levels. Surveys indicate that many air towers at service stations are out of order, indicating poor maintenance; and that their pressure readings are frequently substantially incorrect. Moreover, hand tire gages of the type that the careful car owner might purchase for his own use are too often so inaccurate as to do more harm than good (see section 3.4.c).

F. Tread Depths, Tread Wear Patterns, and Tire Defects (Sections 3.6, 3.7, and 3.8)

1. Tire Position

Existing data on tire position (front or rear) vs tread depth are somewhat conflicting (see table 8). There is strong evidence that a significant number of car owners place least worn tires on the front wheels, whereas available accident experience indicates that the least worn tires should be placed on the rear (see sections 4.1.b, 4.2.b, and c).

2. Uneven Wear

A sizeable fraction (10 to 20 percent) of tires in service show sufficient variation in groove depth to suggest uneven wear as the result of either overinflation, underinflation, out of balance, or other mechanical problem (see section 3.7).

3. Vehicle Age

Tread depth remaining on tires decreases with vehicle age (see section 3.1). In their study of the condition and use of tires on the Illinois Tollway [2], Baker and McIlraith report finding the following average tread depths remaining:

Cars less than 2 years old	7.55 32nd of an inch
Cars 2 to 6 years old	7.30 32nd of an inch
Cars more than 6 years old	5.52 32nd of an inch

4. Bald Tires*

(a) There is evidence of significantly greater hazards of both tire failure and accidents with bald tires. The evidence is sufficient to justify further surveys leading, perhaps, to actions by appropriate authorities limiting the use of such tires.

(b) Baker and McIlraith have shown [3] that the likelihood of a tire disablement increases rapidly with decreasing tread depth. They have calculated that the risk of disablement for a tire having 2/32-inch of tread depth remaining is about 10 times that for a new tire (see section 4.1.b).

(c) Based on a sampling of the general population of such tires in the Eastern U.S.A. [6], it appears that about one-eighth of passenger car tires in service are bald (see table 8).

(d) Fortunately, there is also definite evidence that most drivers recognize that bald tires are unsafe for sustained high speed driving. Only 2 to 4 percent of bald tires were found in samplings of throughway and interstate highway traffic. It is possible that many drivers anticipating a long trip away from home at sustained high speeds replace marginal tires rather than risk a tire failure.

(e) A vehicle with one bald tire very likely has a second, and perhaps more. In their third study [3], Baker and McIlraith reported that "when the disabled tires were bald, 58 percent of the cars had one or more [other] tires in the same condition." In their second study [2] they pointed out that "approximately 2 out of 3 (415 of 607) cars with one bad tire also had a second" (see sections 3.7 and 4.1.b).

* Bald tires are those having less than 2/32-inch tread depth remaining.

5. Warranty Failure Experience

On the basis of evidence collected in the SWRI survey and the two DL surveys (summer and winter), it appears that warranty claims are made against 2.5 to 3 percent of new tires.

G. Tire Disablements (Section 4.1)

1. Tire Failures

Tire failure (including punctures) comprise 40 to 60 percent of all vehicle disablements (excluding "out of gas") on throughways and expressways (see table 10; also sections 4.1.b and 4.2). Experience indicates that about two-thirds of all drivers (mostly all male) change their own tires.

2. Effect of Temperature

According to Baker and McIlraith [1], the rate of tire failures rises quite rapidly with ambient temperature, other factors being equal (see section 4.1.a). They estimated the average year round rate of tire disablements on the Illinois Tollway to be about 50 per million vehicle miles (minimum). That for the general passenger car tire population in the Eastern U.S.A., based on driver recollections was reported [5] to be more than double this, reflecting the generally poorer condition of tires and the much higher incidence of bald and thin tires among the general population as compared to throughway (Tollway) traffic.

3. Rate of Tire Disablements

If one assumes a disablement rate of 50 per mvm as a reasonable estimate of actual experience, and an average tread life expectancy for new tires of 20,000 miles, one may calculate that one new tire in four experiences some form of disablement prior to discard for tread wearout.

H. Tire Disablements and Accidents (Section 4.2)

1. Need for Data

There is an urgent need for reliable data on the exact causes of motor vehicle accidents. Information presently available is scanty; moreover, much that is available is highly subjective and, therefore, suspect.

Needed are studies by competent and well-equipped accident investigation teams having both the opportunity and the authority to work, and a procedural rigor approaching that encountered in investigation of aircraft crashes. We understand that at least two such approaches to this task are in progress at this time [16, 21].

2. Bald and Thin Tires in Accidents

The incidence of bald and thin tires on accident vehicles in at least two of the four accident studies reviewed here is substantially higher than those found in samplings of comparable motor vehicle traffic populations. Moreover, by far the greater number of such tires are found on the rear wheels of the accident vehicles (see sections 4.2.c(1) & (2)).

3. Driver Age and Experience

Driver age and experience appear to be extremely significant factors in the ability to avoid an accident in the event of a sudden tire failure. In their study of accidents following tire disablement on the Illinois Tollway [4], Baker and McIlraith found that younger women and girls are especially prone to an accident in the event of tire failure (see section 4.2.a(3)). In tire disablements involving male drivers, those under twenty appear more than twice as prone to an accident as older men.

4. Power Steering

There is evidence that power steering is of some value in enabling a driver to maintain control of the vehicle in the event of a sudden tire failure (see section 4.2.a(3)).

5. Disablements and Accidents

Estimates of tire disablement per se as a major contributing cause of accidents involving four-wheel, four-tire vehicles lie in the range of 0.6 to 1.6 percent of such accidents in non-congested areas (see sections 4.2.a & c). However, such data do not take into account those accidents in which loss of road traction, or insufficient road traction, was the major contributing factor leading to the accident. It is evident, for example, from the Texas Highway Department's study (see section 4.2.c(2)) that poor tires are major factors in wet weather accident.

IV. RECOMMENDATIONS

A. Maintenance of Adequate Inflation Pressure

As pointed out in III.E.1 above, a substantial number of cars are operating with one or more tires at inflation pressures of 20 psi or less. This situation causes the tire to flex excessively in the sidewall region, enhancing the probability of a tire disablement.

The extensive development of high speed roads in and around cities makes it increasingly likely that these underinflated tires will be used at high speeds, thereby developing high temperatures which increase the danger of tire disablement. Needless to say, a tire failure in heavy traffic at the high speeds where such failure is more probable is more likely to produce severe bodily injury and greater property damage than at lower speeds.

In addition, underinflation reduces tread wear; affects the handling properties of the vehicle, thereby reducing its ability to respond safely; and reduces the feeling of stability which is a factor in riding comfort.

Higher than normal loads on vehicles without compensating higher inflation pressures also causes the tires to flex excessively, increasing the probability of tire failure. However, most such cases of tire overload would be corrected if the inflation pressure were increased within the permissible range (see table 3).

Since the evidence suggests that maintenance of proper inflation pressure in tires is of major importance in safeguarding the motorists' safety, pocketbook, and comfort; and since it is evident that the tires on many cars are not properly inflated, we recommend the following:

1. That a massive education program be undertaken to teach the public the importance of proper tire inflation, and how to achieve it.

2. That measures be adopted to ensure that every service station provides and maintains a source of compressed air equipped with a pressure gage regularly calibrated to within the accuracy of ± 1 psi recommended by recognized trade associations in the tire industry. Tower function and calibration of the pressure gage could, for example, be checked by the local weights and measures inspector on his regular rounds to inspect and certify the gas pumps.

3. That the gas and oil companies in cooperation with tire industry associations conduct campaigns to encourage service station personnel to foster better maintenance of tire inflation pressures in customers' vehicles. A major part of the campaign would be the training of service station attendents in the proper maintenance of tires, with special emphasis on proper inflation.

4. That manufacturers of hand tire pressure gages test, certify, and guarantee this same accuracy (± 1 psi) on each and every gage offered for sale.

We feel that if the above recommendations are implemented, the major responsibility for tire care and maintenance will rest on the driver--and that is where it belongs.

B. Prohibition of Use of Dangerous Tires

There is evidence of significantly greater hazards, not only of tire failure but of an accident, with bald tires. The evidence is sufficient to justify further studies leading, perhaps, to action by appropriate authorities limiting the use of such tires. Indeed it may be found desirable to establish 2/32-inch as the minimum average tread depth for acceptance in periodic inspections of cars in use. Tires with deep cuts and sidewall cracks should also be rejected.

Such cuts or sidewall cracks were found in over 4 percent of all tires examined in one survey [2]; in another study [3], 11.1 percent of disabled tires examined had either cracks or blisters, or both.

Other tire defects (such as fabric breaks) indicative of incipient or early failure should also be considered as adequate grounds for rejection.

C. Driver Education

Driver education courses with practical or simulated practical experience in handling sudden tire disablements, skidding, and other sudden emergencies, may be of value in reducing accident rates among inexperienced drivers.

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T I R E U S E S U R V E Y - -

THE PHYSICAL CONDITION, USE, AND PERFORMANCE OF PASSENGER CAR TIRES IN THE UNITED STATES OF AMERICA*

J. L. Harvey and F. C. Brenner

1. INTRODUCTION

1.1 Scope and Objective

This report summarizes the results of two surveys of the physical condition and use of passenger car tires in the continental U.S.A. These surveys were conducted for the Office of Vehicle Systems Research (OVSR)** of the National Bureau of Standards (NBS) during the period from June 1967 through May 1968.

The data and results obtained in the two surveys are compared with those of four related studies recently published by the Traffic Institute (TI) of Northwestern University. Other data obtained in the course of the OVSR's own studies on passenger car tires are also included, as well as pertinent information received from various sources.

1.2 Background

The National Traffic and Motor Vehicle Safety Act of 1966 (P.L. 89-563) provides for a ". . . a coordinated national safety program and establishment of safety standards for motor vehicles in interstate commerce. . ." Title II, "Tire Safety," of this Act provides that the Secretary of Transportation ". . . shall require that tires [for motor vehicles] . . . be permanently and conspicuously labeled with such safety information as he determines to be necessary to carry out the purposes of the Act."

Fulfillment of this responsibility placed on the Secretary by the Congress requires a knowledge of the general physical condition of tires in the hands of the motoring public, and of there use and performance in service.

In accordance with an agreement between the Departments of Commerce and of Transportation, the Office of Vehicle Systems Research of the National Bureau of Standards was assigned a responsibility for developing a technical background and expertise in three areas of auto safety, and for making recommendations to the National Highway Safety Bureau of the Department of Transportation (DOT) for motor vehicle safety standards in these three areas. One of these is tires.

A review of the literature on tires in 1966 disclosed little or no information on the general physical condition, use, and possible abuse of passenger car tires in service, or on the extent to which poor tire condition and actual tire failures may contribute to motor vehicle accidents. Recognizing the need for such basic information on the subject, the OVSR contracted in early 1967 for two surveys to be made of the physical condition and use of passenger car tires in service on roads and highways throughout the continental U.S.A. The Davidson Laboratory (DL) of the Stevens Institute of Technology, Hoboken, New Jersey, was commissioned to survey passenger cars' tires in that portion of the U.S.A. east of the Mississippi. The area west of the Mississippi, excluding Alaska and Hawaii, was assigned to the Southwest Research Institute (SWRI) of San Antonio, Texas.

*This work was carried out at the National Bureau of Standards under the sponsorship of the Department of Transportation, National Highway Safety Bureau (FH-11-6090). The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Safety Bureau.

**For brevity, initials in parentheses following an organization shall indicate its abbreviation for the rest of the report.

This paper summarizes the results of the two surveys; the data are also compared with those of similar or related studies that have recently appeared in the literature. Various data obtained in the course of studies by the OVSR and by others and pertinent to the discussions at hand are likewise included.

Most important among the other tire condition and use surveys covered herein is a series of studies conducted by the Traffic Institute of the Transportation Center at Northwestern University on the Illinois Tollway in 1966 and 1967. The results of these studies were published in 1968 as four reports [1, 2, 3, 4]*. This work was financially supported by the Rubber Manufacturers Association (RMA).

A report [5] summarizing the four TI studies was presented by J. Stannard Baker at the 48th Annual Meeting of the Highway Research Board. This abbreviated report emphasizes "results rather than methodology."

2. A BRIEF REVIEW OF THE AVAILABLE STUDIES

To make valid comparisons and draw reliable conclusions from related but not parallel studies in any broad and relatively unexplored area, one must first understand and evaluate the intents of the various observers. Their approaches, sample selection, instrumentation, methods of analysis, and other pertinent factors must be carefully examined and compared, one to another. In an attempt to provide the reader with sufficient background to permit him to exercise his own value judgments concerning the validity of the comparisons made and conclusions drawn in this review, we shall here briefly describe the available main surveys on the physical condition and use of passenger car tires in service. We shall attempt to summarize adequately their purposes, approaches to sampling, methods of sampling, instrumentation and measurement techniques, etc. However, it is neither possible nor desirable to explore fully every facet of these aspects in this review. Those readers desirous of more detailed information are urged to examine the basic documents.

2.1 Davidson Laboratory (DL) Studies [6]

The principal portion of the DL studies by I. R. Ehrlich and M. P. Jurkat summarizes the summer survey and conclusions drawn. A second covers a much more restricted winter survey, plus a comparison of the vehicle population stopping at service stations with the population passing by. A third section describes the survey teams, their assigned areas for sampling, equipment provided for field measurements, their preliminary training, a copy of the team leader's manual, and samples of the data sheets and handouts furnished for use in the field. Included also are brief reports by the leaders of three of the seven survey teams, describing some of their problems and experiences in carrying out the field surveys. The final section presents the procedure developed by Kamm and Parsons for converting field measurements on the tires to an equivalent cold inflation pressure, for use in determining inflation condition, manufacturer's load rating, and the ratio of actual measured load to allowable load carrying capacity (this subject is discussed further in section 2.6).

As previously stated, the DL was commissioned by OVSR "to conduct a survey of the actual conditions of passenger car tire usage on the highways of the United States east of the Mississippi River." The DL was further instructed to select a sample population that was insofar as possible representative of the general population of such tires in service in its assigned area.

After consideration of the various possibilities for obtaining such a representative sampling, the DL concluded that while somewhat imperfect, service stations as sampling sites offered the most practical means for obtaining a reasonably representative sampling of the general population of passenger car tires, while providing the minimum of inconvenience to the motorist and to the normal flow of traffic. It was recognized that use of gasoline stations probably introduces sample bias by the following:

a. Omitting many fleet-owned and farm-based vehicles (usually fueled and serviced through their own facilities).

*Figures in brackets indicate literature references at the end of this paper.

b. Placing greater emphasis on more frequently used vehicles (see introduction to section 3).

It was further recognized that to avoid the introduction of extraneous biases (local vs long trip, commuter vs pleasure driver, resident vs resort vacationer, etc.), sampling sites as well as sampling periods must be carefully selected and distributed.

The DL postulated that the population density of an area was an important indicator of individual driving habits, and chose counties as population density units for site selection, using a selected distribution of counties by population density roughly representative of the Eastern U.S.A. Counties within each of 10 arbitrarily chosen population density groups were randomly selected. In general, three service stations were chosen within each selected county, on the following basis:

a. A station selected at random from the telephone book in the county seat.

b. A service station on the largest highway passing through the county.

c. A station which local inquiry indicated as having a high stopping volume.

d. However, if the county contained a resort area, a fourth station within that area was also selected and used for sampling.

Both surveys were taken in 1967. The summer survey was made during the period July through September, the winter survey in late December. In the summer survey seven three-man teams, comprising primarily engineering students on summer vacation, surveyed 60 counties distributed throughout the Eastern U.S.A. Samplings were taken in all but seven of the 27 states (Delaware, Florida, Louisiana, Maine, New Hampshire, Vermont, and Wisconsin were omitted). The summer survey population comprises a total of 4502 vehicles sampled at 137 different sites.

The winter survey was much more limited. This task was performed by a single roving three-man team covering sampling sites in Maryland, Pennsylvania, New York, and Massachusetts. A total of 199 vehicles was measured at seven selected service stations. In these surveys, as in all other studies discussed in this review, attention was restricted to four-wheel, four-tired vehicles having passenger car tires as standard equipment; i.e., only passenger cars, station wagons, and some light trucks* were sampled and inspected.

Appendix A is a sample site data sheet, Appendix B is a sample copy of the three-page vehicle and tire inspection form used in the field.

2.2 Southwest Research Institute Study (SWRI) [7]

The SWRI study had the following three primary goals:

(1) Determination of the physical condition and usage of passenger car tires on U.S. highways in the Western States.

(2) Analysis of the nature and frequency of manufacturing defects in new or slightly used tires (as reported by motorists).

(3) Examination of tire tread rubber and other sections discarded along main highways.

In contrast to the Davidson Laboratory, which was directed to select a population sample representative of the general (total) population of passenger car tires in service in its designated survey area, the SWRI was instructed to restrict its attention to the long distance traveler. It was thought that a comparison of this group with the general population of Eastern motorists would lead to some interesting and informative conclusions with respect to the general physical condition, age, remaining tread depth, and relative loading of tires by the two populations.

*SWRI only excluded light trucks.

This difference in intent of the two surveys is an important one, and does reveal some important differences in tire condition and use. Additional information has been obtained by selecting out of the DL summer survey population a portion (approximately 4 percent) that is also representative of high speed through traffic, and comparing these data with that of the total DL population and with the other two related surveys [2, 7].

a. Sampling Sites

The desired deliberate bias of the SWRI sample somewhat simplified the selection of sampling sites, as such a population is relatively easy to obtain on turnpikes and on the Federal Interstate Highway System. Sampling sites were distributed roughly in accordance with population concentrations in basic areas (geographic divisions) of the Western U.S.A. as follows:

Southwestern States	- 3 sites
Rocky Mountain States	- 2 sites
Pacific Coast States	- 4 sites
Upper Plains States	- 1 site
Middle West States	- 1 site
TOTAL	11 sites

The following specific areas were then selected for the survey:

Texarkana, Texas
Van Horn, Texas
Needles, California
Grand Junction, Colorado
Wendover, Utah
Fresno, California
Burns, Oregon
Murdo, South Dakota
Emporia, Kansas
Rolla, Missouri

Either two or four service stations were chosen at each sampling point in the above 10 specific areas. On turnpikes (limited-access highways) only two service stations were used: at other locations (state highways or Federal Interstate Highways) four service stations were selected, with due consideration to the proximity of other gas stations and their number in relation to the local population. Every effort was made to select sampling sites located about 2 to 4 hours travel time from large population centers. About 40 service stations in all were selected and used for sampling.

b. Sampling Period, Sampling Times, and Survey Teams

Sampling days were distributed throughout the year on the following basis:

Month	Sampling Days
July '67	4
August '67	4
September '67	3
November '67	2
January '68	2
March '68	2
May '68	3
TOTAL	20

On sampling days at each of the selected sites sampling was performed only during the period from 10 am to 4 pm, thus covering the period of highest traffic volume while excluding the major portion of any localized commuter traffic.

Survey teams were recruited locally in each of the 10 selected specific areas. Resident high school and college science teachers were favored as team leaders, with interested students as members. Team leaders were depended upon for selection, training, and supervision during the survey. (Special training for the team leaders, if any, has not been disclosed in the final report.) Samples of the data sheets and questionnaires used by the SWRI teams in their survey are presented in Appendix C.

The SWRI survey is summarized in a final report [7] by Paul R. Lepisto dated September 30, 1968.

The report contains considerable information from the motorist (such as the source of purchase of new and retread replacement tires) which may be of interest to those concerned with the distribution and marketing of passenger car tires.

2.3 Studies by the Traffic Institute of Northwestern University [1, 2, 3, 4]

The Traffic Institute (TI) of the Transportation Center at Northwestern University, Evanston, Illinois, has recently published a set of four papers [1, 2, 3, 4] by J. Stannard Baker and G. Delan McIlraith on the condition and use of passenger car tires in service. The four papers cover a series of surveys conducted on the Illinois Tollway, a network of approximately 190 miles of divided, limited-access highway around and radiating from Chicago. These surveys, which began in September 1966 and extended over a period of about one year, were conducted in cooperation with the Illinois Toll Highway Commission and the Illinois State Police. As stated earlier, the work was financially supported by the Rubber Manufacturers Association (RMA).

The first paper discusses a set of three surveys concerned with the frequency of tire disablements, as reported by motorists traveling on the tollway. The second is a use and condition study comparable to those conducted by the DL and SWRI for the OVSR. The third and fourth are concerned with tire disablements and their relation to actual motor vehicle accidents.

We shall explore the background for the second report in some detail here, and reserve the other three for discussion later on in this review (section 4.)

a. Sampling Sites

Field data for Tire Study No. 2 were collected by members of the Tollway Battalion of the Illinois State Police, under the supervision of Robert Witt of the Field division of the Traffic Institute, at all five service areas of the Tollway during October, November, and December of 1966. Tires of 1746 four-wheel, four-tired vehicles were examined; as in the other surveys, additional information was recorded on the car, driver, and nature of the trip (see Appendix D).

Baker and McIlraith state that their objective in Tire Study No. 2 was "to obtain data on ordinary tire use and condition [on the Illinois Tollway] to compare with similar data obtained in connection with tire disablements; that is, to serve as a "control' to judge what factors contribute to tire disablement."

b. Sampling Times and Survey Teams

As in the DL survey, survey crews consisted of three men, one interviewing the driver while the other two made measurements. Sampling was scheduled from 7 am to 11 pm including weekends. Cars traveling in both directions were surveyed at different times at all five service areas on the Tollway.

c. Evaluation of Sample Population

It is apparent that the population sample of passenger car tires in this TI study, representative as it is of the general population of motorists using the Illinois Tollway, should be comparable to that of the SWRI survey. It is, however, probably less purely representative of vehicles being used on long trips at sustained high speeds. As evidenced by the third survey in TI Study No. 1, there is considerable local short-haul traffic on certain portions of the Tollway.

Baker and McIlraith state that the "data obtained probably represent tires in better than usual condition because people who pay tolls probably have good tires and motorists on long trips are less likely than others to be using old tires." (See section 3.6 for further evidence of the latter.)

In the third survey referenced above, we shall find that older cars with poorer tires comprised a significantly larger portion of the population than in the other two surveys of long-haul traffic reported in TI Study No. 1. It would appear that the long trip at sustained high speed is the more important factor leading to an upgrading of tire quality on tollways and on the interstate highway system. Again, an economic factor may be important. In addition to the desire to avoid the hazards and delay of a tire failure, many motorists faced with a long trip probably choose to replace marginal tires at their regular dealer, before starting out.

2.4 Data Collection

In all three surveys, the teams collected data on the vehicle and obtained information by questioning the driver, in addition to measuring and examining the vehicle's four tires. The Traffic Institute survey sheet (Appendix D) represents perhaps the minimum information necessary for a meaningful survey of tire condition and use. In both the DL and SWRI surveys, additional information was sought from the driver, principally with regard to the sources and ages of the vehicle tires, whether he had experienced any tire defects or failures in the previous 2 years, and the extent of care normally given the tires on the vehicle. Such information is highly subjective and frequently quite inaccurate. As pointed out by Ehrlich and Jurkat [6], "many of the items. . . were pure guesses of the driver, especially those given by a non-owner." Psychological factors also may have influenced the responses elicited (by the form, tone of voice, and sequencing of some of the questions asked). Some examples of these effects are discussed section III of [6].

We are concerned that in none of the surveys was a systematic record kept of the number of motorists refusing to participate and the suspected reasons therefore. One suspects that most refusals are made by motorists unwilling to be bothered or to spare any time. On the other hand, how many refused to participate because they were aware of and embarassed by the poor condition of their tires?* Only a few such motorists could significantly bias some of the surveys reported here.

2.5 Instrumentation

Survey teams in each of the studies were provided with dial-type tire pressure gages, tread depth gages, and tire load scales. Teams in the DL study were in addition provided with Alnor Pyrocon Model 4000a pyrometers for measurement of tire sidewall temperatures.

In our opinion, none of the reports provides sufficient information on the precision and accuracy of the instrumentation used or the field measurements made with the equipment. Nor is there complete assurance that adequate calibration checks were made in the field by all of the survey teams. Indeed, the DL reports lead one to doubt that calibration of the instruments was adequately maintained in the field at all times during their surveys; one team leader mentions [6] resetting the needle on the tire pressure gage "to zero as it had been the day before." The TI and SWRI reports state that all pressure gages were periodically compared with Marsh master gages.

In view of the range of loads to be measured (500-2000 lb per wheel), the capacity (20,000 lb) of the General Electrodynamics Corporation MD-400 loading scale used in the DL survey seems inordinately high. However, if comparable to the Black and Decker Loadometer used by the Illinois State Police in the TI survey and by OVSR in some recent work, it can be read to ± 5 lb and is capable of accuracy to ± 10 lb within the range used. The SWRI, on the other hand, used a hydraulic tire load measuring device of their own design. In view of the precision available in the scales used in the TI study, this SWRI "Ground Load Indicator" appears to have an unacceptably high measurement error. Lepisto states that "the minimum accuracy of the instrument was within 10 percent of the true weight."

*The DL had some data on refusals encountered. M. P. Jurkat reported the following experience at three of the sampling sites in their summer survey [6]: 1 out of 20, 5 out of 41, and 13 out of 100.

2.6 Ambient (Cold) Tire Inflation Pressure Correction

Tire design, construction and, most important, inflation pressure, have significant effects on the steering, handling, and ride characteristics of passenger vehicles. Car and tire manufacturers devote considerable attention to proper matching of tires to the vehicle, and tire inflation pressures are always carefully specified by the vehicle manufacturer. Too often, however, such recommendations are unknown to garage and service station personnel and are likewise blithely ignored by car owners. We shall discuss the available information on tire inflation pressure and the problems of maintaining correct pressures later (section 3.3).

Tire inflation pressure not only affects vehicle ride and handling characteristics, but also determines the load which a given size and type of tire may safely carry. Both the tire load rating pressure and the vehicle manufacturer's recommended tire inflation pressures are given as ambient (or cold) pressures. Now it is well-known (among technically oriented individuals at least) that tires heat up in use and inflation pressures rise. The RMA's "Consumer Guide to Tire Care and Safety" [8] states that "it is normal for inflation pressure to increase up to 6 pounds or more above the cold pressure levels shown in the table."

Tire pressures measured in field surveys must necessarily be taken "hot." Detailed information on the extent of this pressure rise, and on the effects of tire size, design or construction, number of plies, ambient temperature, road conditions (wet, dry, snow, icy), vehicle speed, travel time, cooling rates on standing, and possibly other factors, is not available in the literature. Each group of investigators therefore conducted enough experiments to satisfy themselves as to the extent of correction needed to obtain the equivalent cold inflation pressue (Pc) from the hot tire pressure measured in the field.

a. Traffic Institute Studies [1, 2, 3, 4]

Baker and McIlraith assumed that all their cars would have traveled "some distance at steady speeds of about 60 mph." The TI staff therefore conducted a series of 100-mile trips on the Tollway at a steady 60 mph, using the project's Chevrolet station wagon equipped with standard 4-ply, 8.25-14 tires. Runs were made starting with the tires at ambient (cold) pressures of 15, 19, 24, 28, and 32 psi. The car was stopped after 5, 10, 20, 40, and 80 minutes at 60 mph, and tire pressures quickly measured. At the end of each 100-mile trip, pressure cooling curves were taken by measuring the tire pressures at approximately the same intervals. The results of these experiments are shown in figure 1.

Allowances were made in correcting the hot pressures on cars which had traveled only short distances before examination. Baker and McIlraith state [2] that "for the 15 percent with less than 20 miles since last long stop, less correction for hot pressure was required." The authors further state that "the refinement of making tests on various sizes of tires with various tread depth was not considered worthwhile for the purpose although it would have been an interesting experiment."

b. Davidson Laboratory Surveys [6]

In the DL survey measured hot tire inflation pressure was transformed to the equivalent ambient (cold) pressure (Pc) using a correction based on simultaneous measurement of the tire sidewall temperature by an Alnor Pyrocon Model 4000a contact pyrometer. Kamm and Parsons discuss the correction procedure in a report dated February 1968 (Section IV, [6]). In a laboratory test program a tire was equipped with various thermocouples, two of which were placed in the tire air chamber. The instrumented tire was then mounted on the rear wheel of a test vehicle and driven on a chassis dynamometer. The authors report finding a linear correlation of chamber temperature vs tire sidewall temperature for the instrumented tire.

Using the instrumented tire and the Alnor pyrometer in road tests, a linear correlation between tire sidewall temperature minus ambient and chamber temperature minus ambient was developed for a range of ambient temperature (70° to 100°F). A number of other tire sizes, with varying tread depths, were road tested also, and from these data a secondary correction was developed as a function of tread depth and tire cross section.

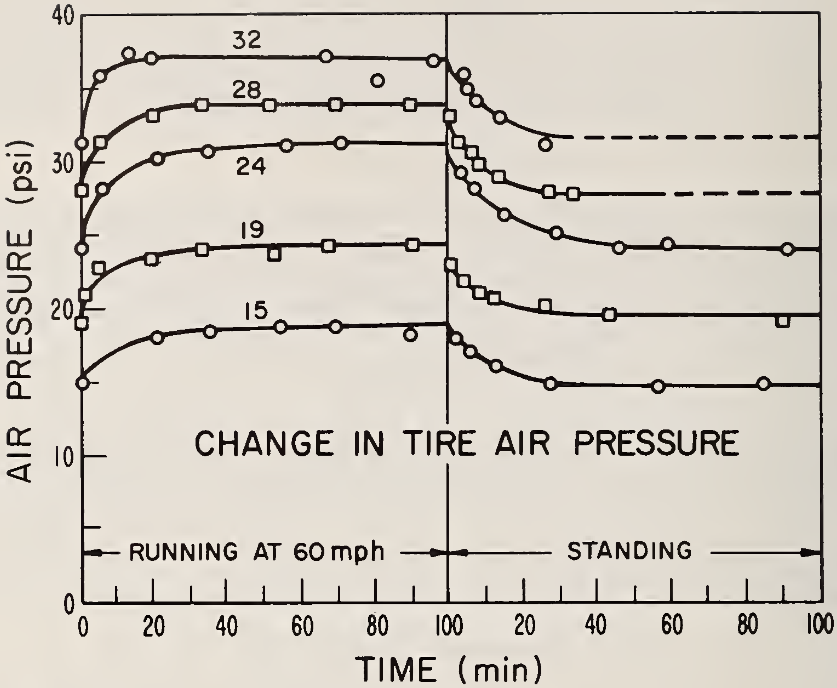


Figure 1. Changes in tire pressure with steady 60 mph driving. (Ref. 2, Exhibit 7, p.14)

To obtain the Pc of a tire, the sidewall temperature as measured in the field was first corrected for the cross-section and tread depth effects; the final pressure correction was made by applying the ideal gas law and assuming a constant volume change to ambient temperature:

$$(Pc + 14.7) = (Ph + 14.7) \frac{Tc}{Th}$$

where

Pc = equivalent ambient (cold) tire inflation presssure, psi gage. (The Tire and Rim Association tables of allowable load are given in terms of gage pressure.)

Ph = measured hot inflation pressure, psi gage

Tc = ambient temperature, K

Th = corrected hot tire chamber temperature, K

Kamm and Parsons do not present any data showing comparisons of actual hot tire chamber temperatures vs values calculated from the measured sidewall temperatures, nor do they present comparisons of calculated equivalent cold pressures vs actual measured values obtained by allowing test tires to cool. In the final report (Section I, [6]), Ehrlich and Jurkat present a table showing the average computed pressure rise of tires surveyed due to increase in operating temperature above ambient as a function of tire load ratios. It is reproduced below as table 1.

Table 1. Average computed pressure rise (psi) and standard deviation of examined tires due to increase in operating temperature above ambient (From Ref. 6, Section I, R-1336, Table XV, p. 20)

LOAD RATIO GE but	LT[a]	FRONT TIRE No. of Tires	FRONT TIRE Average Inflation Rise	FRONT TIRE SD[b]	REAR TIRE No. of Tires	REAR TIRE Average Inflation Rise	REAR TIRE SD[b]	BOTH TIRES No. of Tires	BOTH TIRES Average Inflation Rise	BOTH TIRES SD[b]
-	1.0	4848	1.4	0.97	4528	1.5	1.04	9376	1.5	1.00
1.0	1.1	282	1.5	0.98	176	2.1	1.30	458	1.7	1.15
1.1	1.2	84	1.5	1.00	57	2.4	1.24	141	1.9	1.18
1.2	1.3	8	1.3	0.88	33	2.8	1.22	41	2.5	1.30
1.3	1.4	6	1.7	0.91	4	1.3	0.94	10	1.5	0.90
1.4	1.5	0	-	-	2	1.8	1.99	2	1.8	1.99
1.5	-	2	2.3	0.15	2	0.9	1.07	4	1.6	1.03
Undetermined		3097			3636			6733		

[a]Equal to or Greater Than (GE) but Less Than (LT)) Footnotes added by Harvey
[b]Standard deviation) and Brenner

With exception of those tires overloaded 20 percent or more, the average computed pressure rises are of the order of 1.5 to 1.9 psi. This is substantially less than the 5-6 psi found by both the TI and SWRI for extended running at highway speeds and generally accepted as the norm. It may be argued that the DL summer survey population contained a considerable number of short trip traffic (60.8 percent were less than 5 miles), thus leading to the small average pressure rise. In a study of tire inflation pressures, the OVSR found that the inflation pressure of a radial ply tire at approximately 100 percent rated load increased 1.7 psi in 2 miles of travel in city traffic (maximum speed 30 mph) and 2.9 psi at the end of 5 miles. A bias ply tire should develop a somewhat greater pressure rise under the same circumstances [9].

c. Southwest Research Institute Survey [7]

The method used by the SWRI for calculating Pc from the actual measured hot tire inflation pressure was based on that used by the Traffic Institute.

The latter's experimental results were confirmed by SWRI in a series of test runs on three sizes of tires (6.50-13, 7.75-14, and 8.45-15), using a fleet of 24 cars. All tires were 4-ply rated, but whether actually 4-ply is not stated in their report;* all were "inflated to 24 psi cold."

The SWRI obtained results quite similar to those reported by Baker and McIlraith (see figure 1), but noted a one psi greater rise in the rear (driving) tires than in the front (driven) tires. Assuming that the TI's curves were based on the overall mean pressure rises, the SWRI allowed for this observed difference by subtracting 0.5 psi from the TI's correction on a front tire, and adding 0.5 psi for a rear tire. The following correction factors were thus calculated for times of 10, 20, 30, and 40 or more minutes of driving (at sustained highway speed) since the last stop:

Table 2. Psi rise as related to period driven (From [7], Exhibit 3, p. 12)

Minutes	Mean psi Rise	Correction Front Tires	Correction Rear Tires	Rounded Correction Front Tires	Rounded Correction Rear Tires
10	3.5	3.0	4.0	3	4
20	4.5	4.0	5.0	4	5
30	4.9	4.4	5.4	4	5
40	5.2	4.7	5.7	5	6
100	5.4	4.9	5.9	5	6

*It may be assumed, with negligible error, that all OE tires were 2-ply, 4-ply rated, and all bias replacement tires 4-ply in both construction and rating.

d. NBS/OVSR Tire Inflation Pressure Studies [9]

OVSR has measured the change in pressure in a 2-ply, 4-ply rated 7.35-14 bias ply tire with different initial cold inflation pressures. The pressure was continuously monitored by means of a rotary pressure union installed on the right rear wheel of the test car and connected to a precision pressure gage in the vehicle. The vehicle was driven at a steady 60 mph on an interstate highway for 50 miles and then allowed to cool until a steady pressure was obtained. The results corrected to an ambient temperature of 60°F (15.5°C) are reported in figure 2 and agree in general with those reported by SWRI and TI. Within the range of cold inflation pressures studied, as a rule of thumb, the steady state inflation pressure at 60 mph rises about 6.5 psi. Note that the tires cool quite rapidly on standing; measured hot inflation pressures decrease quite rapidly during the first 10 minutes. Unfortunately, none of the reports assures the reader that adequate consideration was given to this factor. One wonders whether all cars were checked promptly or after standing a bit, and how much time was normally consumed in making the four hot inflation pressure measurements.

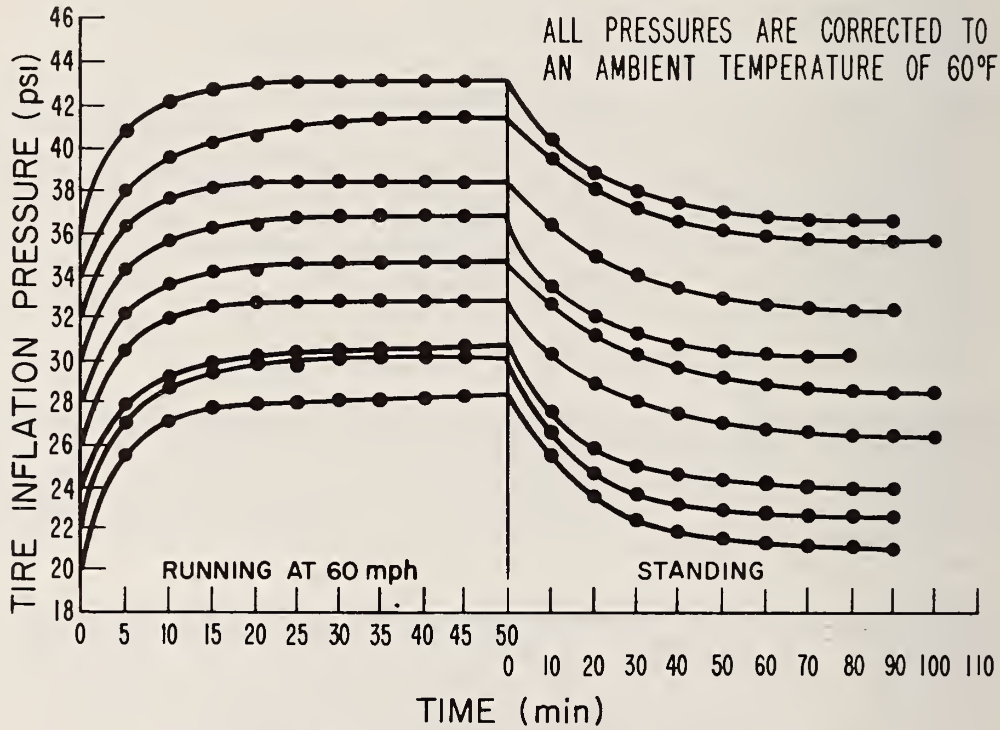


Figure 2. Change in inflation pressure, bias ply tire.

3. RESULTS AND CONCLUSIONS, PHYSICAL CONDITION AND USE STUDIES

As we have seen, it was the intent of the Davidson Laboratory in their summer survey to select and examine a sample that would be fully representative of the general population of passenger car tires in use in the Eastern half of the U.S.A. It is our opinion that the DL achieved its purpose in sample selection quite well. With due consideration for economics and practicality, we doubt that a more representative sampling of the general population of passenger car tires could be obtained. While the DL have themselves demonstrated in their station-road comparison [6] that use of service stations as sampling sites places "greater emphasis on more frequently used vehicles," it may be argued that such vehicles wear out proportionally more tires, and that for this reason any tire condition and use study perhaps should be somewhat biased toward such vehicles. However, the size of the sample in this DL summer survey

(4502 vehicles examined at a total of 137 different gasoline stations) was dictated solely by an availability of time and manpower. We have no real measure of its adequacy in representing the general population of passenger car tires in the Eastern United States.

In the small winter survey conducted by the DL in the last 2 weeks of December 1967, "a heavy emphasis" (72 out of a total of 199 vehicles examined) was placed on turnpike driving. Ehrlich and Jurkat point out that this bias "was somewhat deliberate, since the summer survey showed a concentration of tire abuses by people on vacation." Again, sample size was dictated by the limitations of time and manpower. The sampling is so small, and so limited geographically, that it can probably do no more than provide an indication of the true winter picture in similar areas.

The SWRI survey, as we have observed earlier, was directed entirely toward the high speed, long distance, through traveler portion of the vehicle population. The much simpler task of obtaining this population sample was accomplished by appropriate selection of sampling sites on or near interstate highway systems, and by selecting sampling times deliberately to exclude most of any local commuter traffic. The SWRI survey covered some 11,385 vehicles (passenger vehicles only; no trucks) for a total of 45,540 tires examined.

The TI Study No. 2 as we have noted earlier, was made on a population considered to be representative of general traffic on the Illinois Tollway. This population is similar to that of the SWRI survey, but contains a larger fraction of commuter and other short haul traffic. To obtain some feel for this, we have taken exhibit 10 (Distance Driven Since Last Hour Long Stop) from the TI Study No. 2 and table 2 (Duration of Driving Since Last Stop) from the SWRI final report [7], made some simplifying assumptions and rearranged the data as follows:

Minutes Since Last Stop	Percent of Sample	
	SWRI[a]	TI#2[b]
0-20	12.4	14.9
20-49	12.5	26.2
50-119	29.3	42.7
120-199	34.3	8.6
200-300	5.7	5.3
300 or more	5.8	2.3
	100.0	100.0

[a]Assumes last stop was for one hour or more

[b]Assumes average speed of 60 mph

In the TI Study No. 2, a total of 1746 vehicles were inspected, equivalent to 6984 passenger car tires examined. Baker and McIlraith state in their report as follows:

> As the survey progressed, data collected were examined. Size of sample was considered adequate when additional batches of data had almost no effect on the averages and ratios established for data items of particular interest.

While perhaps not statistically sound, such an empirical approach certainly presents a very strong practical appeal.

As the actual sampling and examination of vehicles in all of these surveys were performed at gasoline stations or service areas, it may be assumed that all are more or less equally biased toward the more frequently used vehicles in the general population.

Keeping always in mind the different aims and sample populations of these various tire use and condition studies, as well as their relative successes in achieving their selected goals, we shall attempt to analyze and compare their various findings. Hopefully, we shall produce a more meaningful picture of the physical condition and use of passenger car tires in the United States than any of the single studies alone can provide. Using such information as we have on the incidence of tire disabilities and of tire failures, we may then explore the relative importance of tires as contributors to motor vehicle accidents.

3.1 Car Styles, Sizes, and Age Distributions

The make, model, body style, and year were recorded in all three of the tire use surveys. The TI and DL studies included some light trucks in their sampling though neither explicitly defines the classification; presumably it covers any four-wheel, four-tire vehicle designed primarily for carrying materials, equipment, and supplies but having passenger car tires as standard equipment. However, the SWRI restricted its attention solely to passenger cars and station wagons.

In the first three TI reports, the vehicles surveyed are divided into three classes according to size as follows:

Standard--more than 3000 lb;
Compact--2000 to 3000 lb;
Small--less than 2000 lb.

The vehicles were likewise divided into three categories by age as follows:

	TI Study No. 1	2	3	4
Survey Period	Apr, May, Jul 67	Oct-Nov 66	9/1/66-8/31/67	9/1/66-8/31/67
New	66-67	65-66	65-66	
Medium	60-65	60-64	60-64	
Old	59 or older	59 or older	59 or older	

TI Study No. 1, to be discussed in greater detail in section 4.1.a, indicates that the likelihood of tire disablement increases with vehicle age. We shall see that this is attributable to the presence of older and more worn tires. McIlraith and Baker comment [1] that "compared to cars less than 2 years old, those 2 to 7 years old had 1.7 times as many [tire] disablements per million vehicle miles; those more than 7 years old had 2.4 times as many. This difference is believed actually to be due much less to vehicle age than [to] tire age."

In their second study [2], Baker and McIlraith reported finding average groove depths (in 1/32-inch) by car size as follows:

Standards	7.45
Compacts	7.36
Small	6.76

They attribute the lower average groove depth on the small cars at least partially to the possibility of less groove depth to begin with on the smaller tires for these cars. Despite the lower average groove depth, their Study No. 1 indicated that car size is not a significant factor in the frequency of tire disablements; nor was car size found to be significant in their second study of tire disablements [3]. Both findings lend credence to their explanation for the lower groove depth.

Data comparing the distributions of bald* and thin** tires with vehicle age would be of interest, but unfortunately none of the three TI tire use and condition surveys present such data.

In section 3.3.b we shall discuss some observations of tire loading as a function of vehicle type.

*Bald: 2/32-inch or less of tread depth remaining.
**Thin; tread greater than 2/32-inch but less than or equal to 4/32-inch.

3.2 Tire Types, Sizes, and Sources

All three surveys attempted to obtain considerable information on the types, sizes, sources, and construction of the passenger car tires on the vehicle (see Appendixes B, C, and D). Much desirable information, such as the type of fiber in the cords and even the actual number of plies, was not always available on a reliable basis. Frequently sidewall information was abraded away to such an extent as to be illegible. Some of the problems encountered in obtaining these data are discussed by one of the DL survey team leaders in his final report [6]. Indeed the TI, apparently recognizing the improbabilities of obtaining reliable data, made no attempt to ascertain tire source or fiber type.

Comparing the questionnaires used in the three surveys, we find the following:

	TI	DL	SWRI
1. Tire Make, Model, Size	Yes	Yes	Yes
2. Ply and Ply Rating	Yes	Yes	a
3. Cord Type	No	b	Yes
4. Source (OE, Replacement, Recap)	c	Yes	Yes
5. Tube?	Yes	No	No
6. Snowtire?	No	Yes	No

[a]No indication of possible difference between ply rating and actual plies

[b]Nylon or rayon only

[c]Recap? (Yes or No)

The SWRI in its survey sought to obtain considerable additional information from the driver of the vehicle, such as the precise sources of purchase of the tires and their ages in months, his usual highway driving speed, and questions concerning this normal care of the tires. Analyses of the data obtained in response to these inquiries, for such value as they may have, are to be found in the SWRI final report. In particular, comparisons of tire purchase sources are made with those reported in an earlier economic study by the Federal Trade Commission on the manufacture and distribution of automotive tires [10].

a. Original Equipment and Retreads

Excluding unknowns (5 1/2 percent of total), the SWRI reports finding [7] about 32 percent original equipment tires, vs DL's finding of slightly over 35 percent in its summer survey [6] and 25 percent in its small winter survey. Again excluding unknowns, the following percentages of recaps were reported.

Survey	Reference	Percent Retreads[a]	Percent Unknown[b]
DL--Summer	6 Table VI	6.1	8.3
Winter	6 Table XXII	0.0	3.2
SWRI	7 Table 5	5.7	8.1
TI Study 2	2 Exhibit 14	0.26	29.1

[a]Excluding unknowns

[b]Of total sample

The number of recaps found in these surveys is perhaps considerably less than one might expect, in view of the extent of retreading done annually in the U.S.A. However, one must remember that much of the retread work is done on truck and bus tires, and for taxi cabs and other fleet cars, none of which were included in any of these surveys. Moreover, doubtful casings would be classed as unknowns.

b. Tire Styles, Sizes, and Plies

Of the three surveys, only the SWRI has provided a tabulation of the tires examined in its study according to style and size. Of a total of 45,540 tires, only about one percent were radials. Not unexpectedly, the majority (56.37 percent) fell into the 14-inch diameter, standard low section category.

Of the three tire condition and use surveys, only the TI has reported a distribution by ply count. Ply counts were available on 4949 (70.8 percent) of the 6984 tires examined in their survey; the TI reported the following ply count distribution for these tires [2].

	Percent
2-ply	43.5
4-ply	55.4
6-ply	0.8
8-ply	0.3
	100.0

All the 2-ply tires were 4-ply rated and are presumably OE. Tube type tires (that is, tires actually designed for inner tubes and excluding tubeless tires in which tubes were being used) were reported as a rather surprising 6.2 percent of the total.

c. Regular vs Snow Tires

In a classification of tires as either "regular" or "snow tires," the DL reported finding [6] exactly 4 percent snow tires in its summer survey. Here again, a significant fraction (11.6 percent) of the total sample was unknown (not typed). In their winter survey, of a total of 796 tires examined on the 199 vehicles in the sample, the DL found 301 snow tires (39 percent) with only 24 tires not classified either way.

While it is undoubtedly true that when their tread is worn down past the point of usefulness as snow tires, they are worn out as regular tires, the authors wonder if it would not be wise to separate out snow tires in any tire condition and use study, and examine their tread depth distribution separately (particularly during the winter). In the annex to their main report, Ehrlich and Jurkat note the definite skewing toward deeper tread depth occasioned by the presence of the large proportion of rear snow tires in the winter survey. The authors comment: "Apparently, many car owners check the tread of their snow tires more closely than that of their regular ones."

It is viewed as unfortunate that no record of snow tires vs regular tires was made in either of the other two condition and use surveys reviewed here.

3.3 Tire Loading and Tire Inflation

As we have noted earlier, tire loadings and inflation pressures are critical factors in determining the steering and handling characteristics, tire traction, and response of a motor vehicle on the road. Moreover, proper inflation of the vehicle tires, according to the load being carried and the distribution of that load, is of critical importance in terms of tread wear and tire life. We therefore want to know how well car owners are aware of these factors, how they load their tires in service, how well they maintain correct inflation pressures--and otherwise care for their tires. We also need information on the general quality of facilities and service available to the motoring public for maintaining the correct inflation pressure in automobile tires. We shall explore these factors here using such information as we have found available to date.

a. Classifying a Tire Population

In all three tire condition and use studies, the authors consider the effects of proper tire inflation on tire load distribution, and provide comparisons with the distribution as actually found in the sampling. Much of this information is given in table 3 following.

Baker and McIlraith present an interesting discussion of the terms "underinflation," "overinflation," and "overloading" in their Tire Study 2. In reviewing the three studies, it was our strong feeling that a general agreement on the use of these terms would have been extremely helpful. Such agreement, accompanied by analyses of the sample populations both as actually found and as they would have been had recommended tire inflation practices been fully utilized, would have added much more to our rather limited knowledge of the use of passenger car tires, we beieve. We offer the following thoughts for consideration.

Overloading. A tire carrying more than the allowable (rated) load for its equivalent cold inflation pressure (Pc) is certainly overloaded under existing conditions of use. Such a condition is unsafe; it shortens the life of a tire and may lead to sudden failure. However, as Baker and McIlraith point out, unless the actual loading exceeds the allowable load for the tire's maximum permissible inflation pressure, we may just as correctly describe such a tire as underinflated.

Overinflation. A tire having a Pc value in excess of its maximum permissible (cold) inflation pressure (32 psi for a 4-ply tire) is unquestionably overinflated and is in an unsafe condition. We might also use the term "overpressured" to designate such tires.

Underinflation. A tire may be described as underinflated if it has a Pc less than that required for the actual load on the tire, as stated earlier. However, the term "underinflated" should be limited to those tires carrying less than their maximum load ratings.* Any tire loaded beyond its maximum load rating must be recognized as "overloaded" under any inflation condition.

Underinflation also constitutes an unsafe operating condition. Seriously underinflated tires heat up rapidly sometimes to higher than normal operating temperatures, and may fail catastrophically at sustained high speeds.

Analysis of a Sample Population. With the above ideas in mind, a sampling of an existing population of tires in service with respect to loading and inflation pressures can be divided into five regions. See the diagram of tire loading vs cold inflation pressure which illustrates the following thoughts.

Safe Operating Pressure Region. This is the operating range and includes all combinations of actual loadings and inflation pressures not definitely considered as unsafe. Except for the bounding lines on left and above, tires in this region have a "pressure reserve" in the sense that they provide reserve load carrying capacity for the actual tire loading under normal driving conditions. The boundary on the left is the Vehicle Design Pressure (VDP), the manufacturer's recommended normal inflation pressure; on the right the Maximum Permissible Pressure, the maximum cold inflation pressure to which the tire may be inflated.

Underinflated for Actual Load. This region includes all tires which are underinflated for the actual tire loading, but which condition can be corrected, i.e., brought into the safe operating region merely by adding air. The dividing line between these regions is the line representing the minimum acceptable inflation pressure for the actual load on the tire and for normal driving conditions.

Underpressured. Tires in this region are underpressured and probably also overloaded. However, the condition is also correctable by adding sufficient air to the tire to bring the cold inflation pressure into the operating range.

Overpressured. Tires in this region are overpressured, but the condition can be corrected merely by letting air out of the tire.

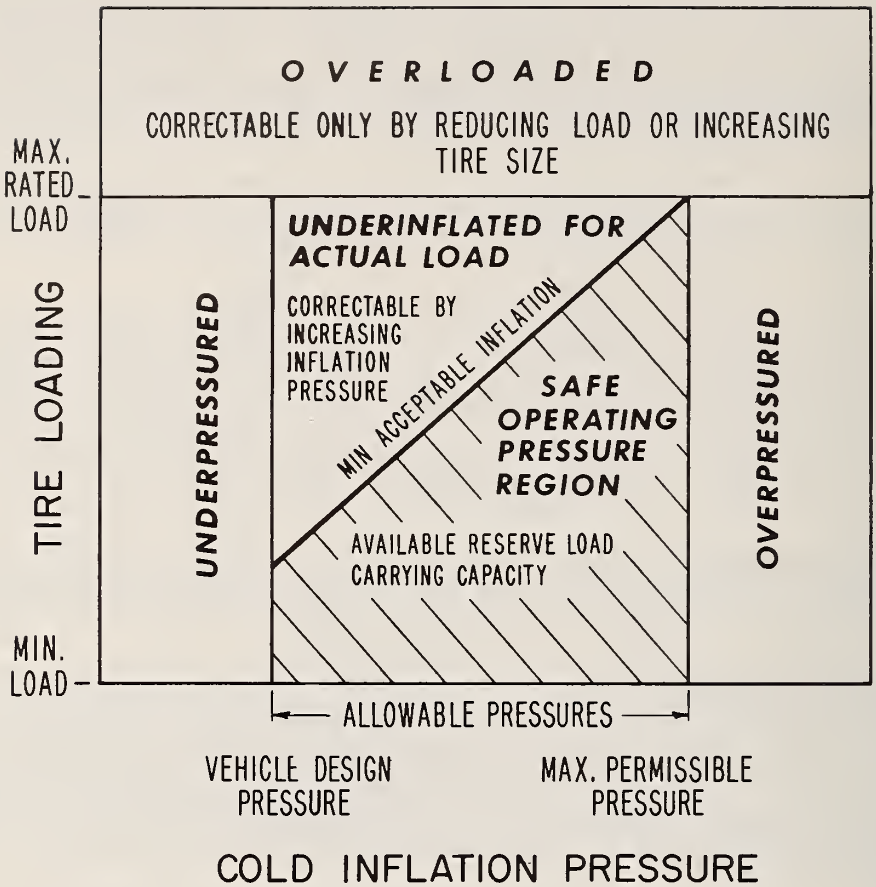
Overloaded. Tires in this region are overloaded, and this condition cannot be corrected except by reducing load or appropriately increasing tire size.

By appropriate theoretical adjustments of Pc to meet the actual measured loadings, the sample population could then be reduced to the following two categories:

-- Properly inflated

-- Overloaded at max Pc

*Load rating at maximum permissible inflation pressure for the tire (MVSS-109).



b. Tire Loading

Although the necessary basic information was acquired in each of the three tire condition and use studies, none of the reports presented an analysis as described above. Moreover, the three presentations of tire loading vs inflation pressures are each so different that it is difficult to compare them on any common basis.

For example, in analyzing the tire load distribution among its survey population, the SWRI excluded from consideration those tires for which the corrected Pc values (Baker and McIlraith method) were outside "the allowable limits as specified by the Federal Motor Vehicle Safety Standard, Title 23; Part 225, Standard 109, as amended February 1, 1968." In the SWRI report, Mr. Lepisto states:

> When a tire exceeded the maximum allowable inflation pressure after adjustment, it was placed in the "Overinflated" category. When a tire was below the minimum allowable inflation pressure, it was placed in the "Underinflated" category.

In table 12 of his report we find that "Underinflated" tires comprised 11.5 percent of the known population, and "Overinflated" tires 3.2 percent. For the standard low section bias ply tires comprising the preponderant majority (89 percent) of the SWRI survey sample population, the minimum inflation pressure for which a load is given in MVSS-109 is 20 psi. Our reaction is that the SWRI reports finding a substantial number of tires in its survey that are seriously underinflated and therefore a potential safety hazard.

In their analyses of tire load distributions, neither the DL nor the TI setup such categories. In calculating the load ratio for overpressured tires, each divided the actual load by the rated load for the maximum permissible pressure. Neither of their final reports makes any mention of seriously underinflated tires, nor is it stated how either calculated the tire load ratios for such tires, if found.

Baker and McIlraith in Exhibit 19 of TI's Tire Study 2 report finding 87.5 percent of their sample "at or below design load pressure." They define design load on a wheel as "the weight on that wheel of the car with passengers in every seat, a certain amount of luggage, and any special accessories," and state that this pressure is ordinarily 24 psi. We shall discuss the occurrence of serious underinflation further in section 3.3.c.

It is with some misgivings, therefore, that we offer in table 3 tire loading data from the three tire condition and use studies for comparison. The data in the table are based on expressing the actual measured load on the tire to allowable load based on tire size, ply rating, and inflation pressure using either MVSS-109 (by SWRI), RMA (by TI), or Tire and Rim Association (T&RA) (by DL) tables. The data are based on all the tires in each survey for which the necessary information was available except as stated in our footnotes.

Table 3. A comparison of tire load findings in the tire use and condition studies

	TI #2	Davidson Lab Summer	Davidson Lab Winter	SWRI[a]
1. Av percent of rated load at equivalent cold pressures	80.4	77.6	79.6	80[b]
2. Percent overloaded at equiv. cold pressure	5.9	6.5	9.3	6.2
3. Percent overloaded by more than 10 percent of rated load at equiv. cold pressure	1.8	2.0	2.0	2.1
4. Percent remaining overloaded at max allowable inflation pressure	2.4	0.5[c]	---	0.9

[a]These data exclude tires for which the equivalent cold pressure was outside the allowable limits as specified in MVSS-109 (as amended February 1, 1968).

[b]Approximate modal value, [7], figure 1.

[c]Percent overloaded at 32 psi.

(1) Overloading by Vehicle Type and Trip Purpose. Though lacking ease of comparability, one with another, each of the studies presents aspects of the passenger car tire loading picture that are in themselves interesting and enlightening. In the DL reports, for example, we find analyses of tire load distributions by vehicle type (sedan, coupe, convertible, station wagon, light truck, or other) and also by stated trip purpose [6, Tables X, XXV, XI, & XXVI]. The former disclose that rear tires on station wagons and both front and rear tires on light trucks appear to be the principal offenders with respect to overloading of tires. The latter tables indicate, not unexpectedly, that rear tires are overloaded substantially more frequently on vacation trips than for any other trip purpose. Pertinent data from the four tables are presented in table 4.

In the SWRI report, Mr. Lepisto presents similar but more limited data on load distributions for front and rear tires by vehicle body style (two door, four door, or station wagon). These data have been recast to eliminate "Underinflated" and "Overinflated" categories. They are also presented in table 4.

Table 4. Overloaded tires, percent of total

Survey	Body Style	No. of Vehicles	100-110 Percent		More than 110 Percent		Total Overloaded		All Tires
			Front	Rear	Front	Rear	Front	Rear	
Davidson Laboratory Summer	Station Wagon	300	5.1	9.9	2.1	9.1	7.2	19.0	
	Light Trucks	75	10.5	7.7	4.6	4.2	15.1	11.9	
	Vacation	460					5.2	10.6	
	All Vehicles	2800					7.2	5.7	6.5
Winter	Vacation	56					1.8	17.0	
	All Vehicles	125					10.1	8.3	9.3
Southwest Research Institute	Two Door		3.8	4.7	1.6	2.3	5.4	7.0	6.2
	Four Door		3.6	3.9	1.2	2.0	4.8	5.9	5.4
	Station Wagon		2.7	6.9	0.9	4.7	3.6	11.6	7.6
Traffic Institute	Station Wagon	58			1.4	3.6	3.2	8.4	5.8
	Other Cars	356			2.1	1.3	7.9	6.1	6.0

These data confirm the DL findings that rear tires on station wagons are more frequently overloaded than either set on any passenger type vehicle (the SWRI survey, contrary to the other two, excluded light trucks).

In the report on TI Study #2 Baker and McIlraith present an even more limited breakdown by body type. They describe their sample population as follows:

> Of the 1,746 four-tired vehicles surveyed, 250 (14.3 percent) were station wagons; the remainder, with the exception of a few small trucks, were ordinary passenger cars.

Their Exhibit 25 provides a comparison of tire loadings for station wagons and for passenger cars. Contrary to the other two surveys, the data indicate about the same overall extent of overloading of tires for station wagons as for cars (5.8 percent vs 6.0 percent): Rear tires of station wagons were found to be more frequently overloaded than front tires (as in the other two surveys) but not to a much greater extent than overloading of front tires on cars. Pertinent data excerpted from Exhibit 25 are also presented in table 4.

(2) Overloading, Front vs Rear Tires: We have seen in table 4 that the SWRI confirmed the DL finding that rear tires on station wagons are more frequently overloaded than either set on any other passenger vehicle. However, these SWRI data indicate that rear tires are overall, the more frequently overloaded set. This finding is contrary to those of both the TI and DL surveys. In Exhibit 22 of the TI Tire Study 2, we find that about 7.1 percent of front tires are reported as overloaded at their equivalent cold pressures (Pc) vs about 4.8 percent of rear tires. The DL data summer survey [6] show 7.2 percent of all front tires overloaded to some degree vs only 5.7 percent for rear tires. It is true that the SWRI survey did not include any light trucks, whereas these vehicles were included in the other two surveys. Nevertheless, the presence of 153 light trucks out of a total of 4502 vehicles in the DL survey (less than 3.4 percent) with 15.7 percent of their front tires overloaded to some degree vs 9.8 percent of their rear tires, does not appear sufficient to account for the difference. (The separate contributions of trucks in the TI study is not reported.)

With regard to overloading of rear tires on station wagons, one is led to wonder how much of the problem is genuinely overloading (i.e., actual tire loading in excess of rated load at maximum permissible inflation pressure) and how much is actually underinflation. Most car manufacturers recommend a 4 psi higher inflation pressure for rear tires on a station wagon. A GM study [11] leads one to suspect that more station wagons are inflated to "the same pressure all around" than not. Without presenting any evidence, Baker and McIlraith state in TI Study 2 that "wagons have more rear tires underinflated whereas cars have more front tires underinflated."

(3) Tire Loading vs Tire Size. In the SWRI report [7], Lepisto presents an analysis of tire load distributions by tire sizes and construction styles; the data are summarized in their table 16. Again recasting the SWRI data to exclude the "Underinflated" and "Overinflated" categories for which load conditions were not reported, we obtain the data shown in table 5.

Table 5. Tire load distribution by tire size and style

Size	Style	100 Percent or less	100-110 Percent	More than 110 Percent	Total Overloaded
13"	Standard	83.2	9.1	7.7	16.8
	Radial	84.8	10.2	5.0	15.2
14"	Standard	94.8	3.8	1.4	5.2
	Series 70	93.5	5.2	1.3	6.5
	Radial	92.9	1.1	6.0	7.1
15"	Standard	94.4	3.8	1.8	5.6
	Series 70	93.6	6.4	0.0	6.4
	Radial	95.6	3.5	0.9	4.4

The data indicate that 13-inch diameter tires, comprising some 6.5 percent of the SWRI population, were more frequently overloaded than the larger sizes by a factor of about 2 1/2 to 1. These 13-inch tire sizes are found on nominally six passenger cars. It is apparent that many of these vehicle/tire combinations do not provide a reserve tire load capacity sufficient to handle the number of passengers and accompanying impedimenta that the motoring public expects of a six passenger vehicle. Presumably MVSS-110, which became effective on January 1, 1968, will do much to alleviate tire overloading in the future. This standard specifies requirements for selection of tires by the vehicle manufacturer in terms of both normal loading for the vehicle and maximum load conditions. Nevertheless, car owners still must recognize that higher cold inflation pressures are required for maximum load conditions and for high speed driving, and that failure to maintain adequate inflation will seriously shorten tire life and greatly increase the risk of tire failure through overheating and overstressing.

c. Underpressured Tires

We have mentioned earlier that the SWRI reported finding 11.5 percent of its sample population having a Pc not only below VDP, but even below the minimum allowable inflation pressure as specified by MVSS-109. There is no confirmatory information available in the other two reports. However, Drs. Paul L. Olson and Herbert J. Bauer, in reporting a survey of inflation pressures in the tires of 405 cars in company parking lots [11], provide data that sheds some additional light on the frequency of underpressured tires in service. The histogram of their data is shown in figure 3.

It appears that some 120 tires out of the total of 1620 tires examined, or about 7.5 percent, had cold inflation pressures 5 psi or more below the car manufacturer's recommended pressure. If we assume that this recommended pressure is 24 psi or less, such tires are seriously underinflated (underpressured); the SWRI's finding of 11.5 percent of such tires in their population sample does not appear unreasonable.

The Uniroyal Tire Company measured tire inflation pressures on 1904 parked cars during the spring and summer of 1969. The study [12] did not include vehicles having VDP's below 24 psi. One survey covered 25 cities, and three others were area studies. The number of cars examined at each location is shown in the following list:

Location	Cars
Atlanta	72
Baltimore	30
Boston	24
Buffalo	24
Charlotte	24
Chicago	48
Dallas	73
Allen Park	48

Location	Cars
Houston	24
Los Angeles	72
Memphis	48
Miami	24
Philadelphia	24
St. Louis	24
Salt Lake City	24
San Antonio	48
San Francisco	48
Cincinnati	24
Kansas City	72
New York City	48
Phoenix	24
McKee's Rocks	24
Denver	26
Minneapolis	24
Seattle	24
Los Angeles Area	507
Minnesota Area	247
Texas Area	205
Total	1904

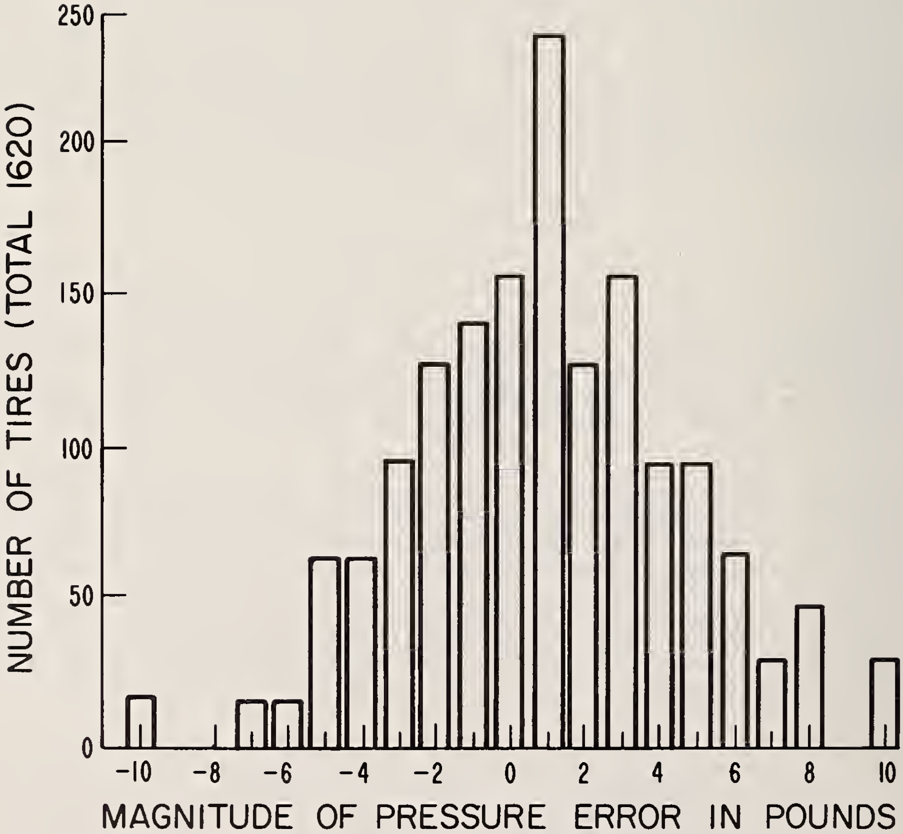


Figure 3. Distribution of pressure error measured on 405 cars (Ref. 11, p. 5)

Each survey classified the data by number of cars having one, two, three, or four tires at or below a given inflation pressure. All the data related to underinflated tires at cold pressures of 20 psi or less. The data in each survey for cars with three and four underinflated tires was combined and a Chi-square test made to determine if any of the several populations was significantly different at the 95 percent confidence level; none was. The data were therefore combined and are shown in table 6. The table indicates that 541 of 1904 cars (28.4 percent) had one or more tires at 20 psi or lower (cold) inflation pressure. The last two columns on the right indicate the total number and percent of cars with one or more tires at or below the specified inflation pressure. The data are cumulative; that is, the cars and tires at a higher inflation pressure include those below.

Table 6. Number and percent of cars classified by number of underinflated tires at or below specified pressures

Total Number of Cars Examined = 1904

	Tires per Car and Percent of Population								Total	
Inflation Pressure	1 Tire	Per-cent	2 Tires	Per-cent	3 Tires	Per-cent	4 Tires	Per-cent	Cars[a]	Per-cent
20	316	16.6	126	6.6	65	3.4	34	1.8	541	28.4
18	170	8.9	48	2.5	21	1.1	7	0.4	246	12.9
16	79	4.1	16	0.8	3	0.2	1	0.1	94	5.2
14	40	2.1	4	0.2	2	0.1	1	0.1	47	2.5
12	20	1.1	3	0.2	0	0	0	0	23	1.2

[a]With one or more underinflated tires

Based on the data in table 6, the total number of tires with 20 psi or less inflation pressure is 899* or 11.8 percent of the total tire population. This agrees with the approximate 10.9 percent that can be derived from the GM data [11], graphically shown in figure 3, and the 11.5 percent obtained by SWRI after estimating the cold inflation pressures by the B-M method (see section 3.3.b).

The agreement lends credence to the B-M method and consequently to the estimates of the frequency of tire overloading based on these estimated cold inflation pressures.

If it is assumed that underinflated tires occur 11.8 percent of the time with equal probability in every tire position on a vehicle, we would expect 60.5 percent ($0.882^4 \times 100$) of the cars to have no tires at 20 psi or under, and 32.4 percent ($4 \times 0.882^3 \times 0.118$) with only one tire so underpressured.

The Uniroyal data indicate that 71.6 percent of the cars have no tires at or below 20 psi and that only 16.6 percent have one such tire. It is apparent that the occurrence of two (or more) underinflated tires on any given car in an actual population substantially exceeds that from a random distribution. It may be inferred that this difference reflects a greater concern on the part of some drivers for maintaining proper tire inflation pressure; and on the other hand, a greater carelessness on the part of others.

3.4 Air Tower Pressure Gage Accuracies

In the GM survey described above, Olson and Bauer report that "about 80 percent of the vehicles checked had tires that were underinflated or overinflated by 2 psi or more," and that "the correct pressure differentials were found on less than 10 percent of those cars on which differential pressure are specified for front and rear tires." Later on they make the following comment:

> Most serious from the standpoint of handling, however, were the variations in air pressure on individual cars. About 60 percent of the cars checked had one or more tires that were at least 5 psi above or below specifications.

* (1 x 316) + (2 x 126) + (3 x 65) + (4 x 34) = 899

The authors conclude that "the results of surveys made by the GM Research Laboratories indicate that little or no attention is paid to tire pressure by the majority of motorists," and add that "the situation is further complicated by the fact that service station attendants are, in general, poorly informed in this area, and dispense a good deal of misinformation concerning tire pressure specifications."

Let us consider now the motorist who reads his car owner's manual and is concerned about maintaining proper inflation in his tires. Relying on service station air towers and attendant's hand tire gages, what are his chances of getting his tires properly inflated? Assuming that he has a car manufactured after January 1, 1968, MVSS-110 requires that the following information about his car be made available to him:

-- Designated seating capacity (total number and seat locations)

-- Vehicle capacity weight (i.e., rated cargo and luggage load plus 150 lb times the vehicles designated seating capacity)

-- Recommended tire size

-- Recommended cold tire inflation pressure for maximum loading, and (presumably) the recommended cold inflation pressure for normal driving conditions (as defined by the manufacturer)

Although he does not have access to a highway load scale, the intelligent motorist who is willing to take the trouble to do so with the above information available to him should be able to estimate the proper cold inflation pressures for his tires fairly closely. After all, for most common tires sizes, the difference in load carrying capacity in going from 24 psi to 32 psi is only about 17 percent. But how accurately will his tires be inflated to the pressures he requests?

Let us ignore the problem of tire temperature and consider only gage accuracies. In the GM survey, Olson and Bauer report that of service station gages checked at a dozen gasoline stations, all but one were "accurate within 2 psi throughout the test range." However, the RMA recommends a tolerance of ± 1 psi. Moreover, the authors themselves do not seem to consider an error of ± 2 psi in tire inflation entirely acceptable. The results of other surveys are distinctly less heartening.

a. NBS/OVSR Air Tower Study

The OVSR has recently reported the results of a study of the accuracy of air tower pressure gages sampled in the Washington, D.C., metropolitan area [13]. Fifty service stations were chosen at random from a population of some 200 in selected nearby suburban areas. Using a test gage ± 0.15 psi accuracy) connected to the spare tire of the survey vehicle, the air tower gage at each of the 50 stations was tested at settings of 20, 24, 28, 32, and 36 psi. The sequence of pressure settings was randomized for each tower. At each setting, the spare tire was pumped up until the tower bell ceased ringing; the pressure was then read with the test gage. The latter was calibrated against a master gage (accuracy ± 0.10 psi) at the beginning and end of each day to assure reliability of the data. Histograms of the results for three tower settings are presented in figure 4.

Statistical analysis provided the following information:

1. A motorist using an air tower in the suburbs described has only a 20 percent chance of obtaining an inflation pressure within ± 1 psi of the setting he selects on the air tower.

2. The probabilities for larger pressure deviations are as follows:

Deviation from Tower Setting	Probability Percent
± 2 psi (or greater)	62
± 3 psi (or greater)	45
± 4 psi (or greater)	32

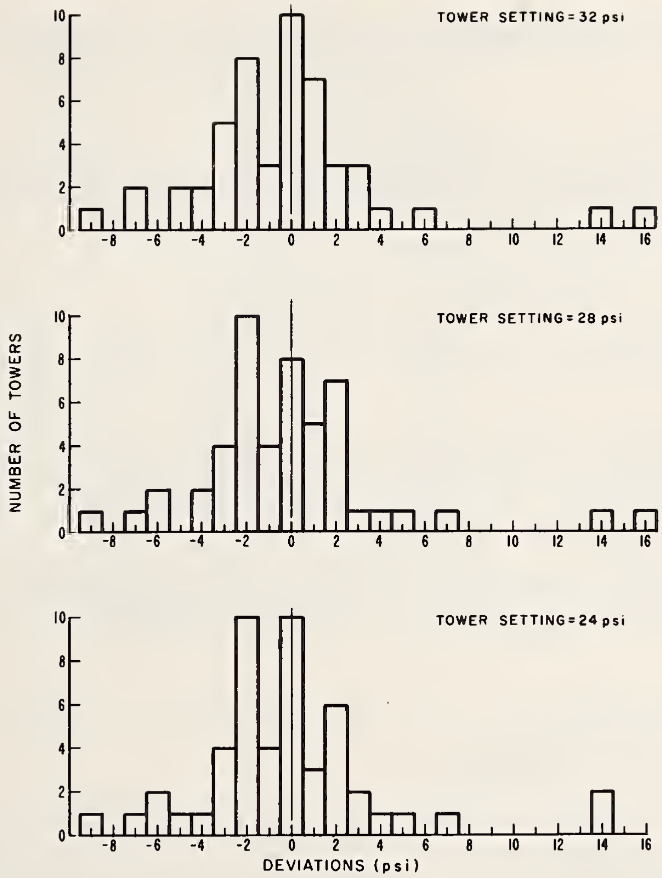


Figure 4. Inflation pressure deviations between air tower and test gage (Ref. 13, p. 8).

The results also showed that air towers incorrect at one setting were in error on the other four settings by about the same amount. It appears that a simple periodic calibration to ± 1 psi at one tower setting would be sufficient to provide corresponding accuracy throughout the range normally used.

b. Davidson Laboratory Surveys [6]

The DL Survey teams checked air towers at the 137 sampling sites in its summer survey, also at the seven Chicago area service stations used for the winter survey. Of the latter, only one had a functioning air tower, and towers at the six others were either frozen or broken. In the summer survey about 47 percent of the 137 service stations either had no air supply or required an auxiliary tire gage for checking tire inflation pressure. Similar to the OVSR survey, their data indicate that "if a tower delivered a low reading at one pressure, the measurements were low throughout the range examined." Their results are given in table 7.

3.5 Hand Automobile Tire Pressure Gages

The OVSR has recently conducted a study of the accuracy of hand tire pressure gages. The gages tested can not be assumed to be a random sample of hand gages in service; all gages tested were the property of NBS employees who submitted them voluntarily.

Each hand gage was tested at 24, 28, and 32 psi against a master gage accurate to 0.10 psi. The hand gage was read to the nearest 1 psi. The population consisted of 251 pencil and 23 dial types; the two populations were not analyzed separately.

Table 7. Measured pressure deviations from tower indicated pressures (Number of Stations)

Measured Tire Pressure Deviations (psi)	Tower Pressure Setting 20 psi No.	Percent	25 psi No.	Percent	30 psi No.	Percent	35 psi No.	Percent	40 psi No.	Percent
No Answer*	64	47.1	62	45.6	63	46.3	65	47.8	70	51.5
-8									1	.7
-7			1	.7			1	.7		
-6					1	.7				
-5	3	2.2	1	.7	1	.7	2	1.5		
-4	2	1.5	3	2.2	4	2.9	3	2.2	5	3.7
-3	3	2.2	5	3.7	5	3.7	3	2.2	4	2.9
-2	5	3.7	8	5.9	7	5.1	5	3.7	6	4.4
-1	10	7.4	9	6.6	10	7.4	13	9.6	9	6.6
0	36	26.5	33	24.3	35	25.7	33	24.3	32	23.5
+1	10	7.4	9	6.6	6	4.4	5	3.7	4	2.9
+2	1	.7	2	1.5	3	2.2	4	2.9	2	1.5
+3	2	1.5	3	2.2	1	.7	1	.7	3	2.2
+4										
+5										
Total Stations	136	100.2	136	100.0	136	99.8	135	99.3	136	99.9
Av Error (psi)	-.48		-.57		-.70		-.64		-.85	
Std Deviation	1.60		1.76		1.65		1.73		1.76	

*Including those stations with

a. No integral gage with air supply
b. Broken pressure control or indicator
c. No air supply

There was no significant variation in the distribution of differences between the master gage and the hand gages at the three pressures. The results were as follows:

35 percent differed by less than ± 0.5 psi
75 " " " " " ± 1.5 "
90 " " " " " ± 2.5 "
97 " " " " " ± 3.5 "

Consumers Research, Inc. [14] reported 6 of 12 brands of new gages tested in 1955 were accurate to within 1 psi, whereas in 1962 only one of 13 brands was that accurate.

Consumers Union [15] in 1968 tested 35 pencil and 4 dial type gages. Six samples of each of the 39 models were tested at 10°, 70°, and 110°F. Only 10 models were within 1 psi at all temperatures.

3.6 Tread Depths

In all three major studies, tread depths were measured using commercially available gages designed for the purpose. Tread wear patterns were examined also.

Baker and McIlraith [2] describe the method used for measuring tread depth in the Traffic Institute surveys as follows:

> Groove depth of each tire was measured at three points: inside, middle, and outside. All measurements were made in 1/32 in. The minimum remaining groove depth and the maximum variance of groove depth from minimum were tabulated for each tire. . . . These two figures give a measurement of the wear on a tire and also of the uneveness of the wear.

The DL reports [6] do not describe how the tread depths were taken in their survey except to state "The tread depth recorded was the minimum of approximately five readings taken around the tire at each position." The Team Supervisor's Manual provides a brief instruction on manipulation of the tread depth gage. However, it appears from Table XIII (Tire Wear Patterns) in their final report that the DL survey teams may also have measured inside, center, and outside grooves on each tire. In any event, the values given in Table VIII (Measured Tread Depth) are described as "Minimum Measured Tread Depth to Nearest 1/32-inch."

Lepisto, in the SWRI report [7] states that "Three tread depth measurements were taken on each tire across the tread surface and the total was averaged." None of the reports state, even approximately, what fraction of the tire circumference was gaged, nor again is there much similiarity in the analyses and presentations of the data.

Baker and McIlraith in their Tire Study No. 2 present a distribution by tire position that is quite informative. The data show little difference by tire position either in tread depth distribution or in average tread depth remaining: right front, 7.50; left front, 7.66; right rear, 7.46; and left rear, 7.51 (all in 32nds of an inch). The authors conclude that: "The small differences between the average groove depths of the four tire positions suggest that wear is relatively even on all tires or that people rotate their tires, or both. . . ."

In the DL reports separate distributions are provided for front and rear tires. In addition, Ehrlich and Jurkat have broken out snow tires and report them separately, providing tread depth distribution for (1) regular tires, (2) snow tires, (3) not typed, and (4) all. Thirty-nine percent of the 772 typed tires examined in their winter survey (late December in Maryland, Pennsylvania, New York, and Massachusetts) were classified as snow tires vs only 4 percent of the 15,912 typed tires in the summer survey. The authors state that "In contrast to the summer survey, which showed a relative uniform distribution of minimum tread depth, the winter survey is skewed toward deeper depth by the presence of a large proportion of rear snow tires at 11/32 inches."

With respect to tread depth distributions at least, it would appear desirable to treat snow tires separately, particularly during the winter months of any tire condition and use survey in areas where snow tires are common.

Let us now examine and compare, as best we can, the tread depth findings in the three condition and use studies. In doing so we shall take special note of the percentages of tires in each survey having less than 2/32-inch of minimum tread depth remaining.

The Rubber Manufacturers Association's Tire Inspection Guide lists the following condition as a cause for rejection of passenger car tires without tread wear indicators:

> Any tire worn to the point where less than 2/32nds of an inch of tread design depth remains in any two adjacent tread grooves, exclusive of tire bars, at three equally spaced intervals around the circumference of the tire, or where any part of the ply or cords is exposed.

In section 4.2 of this report we shall learn that in 57 percent of tire failures in an investigation of some 60,000 accidents, the California State Highway Patrol reports finding that tread depths were less than 2/32-inch [16]. Moreover, we shall there have cause to return to examine bald and thin tires, wherein we shall define bald tires as those having a minimum remaining tread depth less than 2/32-inch, and thin tires as those having a minimum tread depth remaining that is equal to or greater than 2/32-inch, but not more than 4/32-inch. We shall review in section 4.2 a report by the Texas Highway Department [17] on the condition of the tires on some 240 wet weather accident vehicles, disclosing that the incidence of bald and thin tires (as defined above) on the rear wheels of these vehicles is about 40 percent higher than that found in the general population as represented by the DL summer survey, and about 3 times as large as the percentage found in samplings on interstate highways (SWRI survey) or tollway systems (TI Study No. 2).

Comparative data on average minimum tread depths remaining and on the fractions of the sample populations having minimum tread depths of 2/32-inch or less are presented in table 8. Note the lower tread depths found in both the DL surveys, also that the percentages rejectable by the RMA standards is about 3 times those of the SWRI and TI surveys. It is evident that many drivers using the turnpikes for long trips at high speeds replace marginal tires rather than risk a possible tire failure. A breakout of 183 vehicles from the total population of the DL summer survey, representing high speed, throughway traffic only confirms this conclusion. We shall see further evidence that tire quality in the general population is significantly poorer than that among high speed through travelers when we consider TI Study No. 1 under section 4.1.

Table 8. Tread depths, physical condition and use surveys

	Total Tires in Sample	Tire Position LF	RF	LR	RR	All
TI STUDY NO. 2	6,984					
Tread depth < 2/32", percent[a]		3.5	3.7	5.2	4.6	4.2
Av min tread depth, 32nd-inch		7.7	7.5	7.5	7.5	7.5
SWRI SURVEY	45,053					
Tread depth < 2/32", percent[a]						1.7
Av min tread depth, 32nd-inch						7.2
		Both Fronts		Both Rears		All
DL SURVEYS						
Summer	17,948					
Tread depth < 2/32", percent[a]		11.3[b]		12.3[c]		11.8[d]
Av min tread depth, 32nd-inch		6.4[b]		5.8[c]		6.1[d]
Thruway Vehicles Summer Survey	728					
Tread depth < 2/32", percent[a]		2.2		4.4		3.3
Av min tread depth, 32nd-inch		7.5		6.6		7.0
Winter	796					
Tread depth < 2/32", percent[a]		18.9[e]		7.0[f]		12.9
Av min tread depth, 32nd-inch		5.5[e]		7.6[f]		6.6

[a]Percent of known population

[b]Snow tires 0.6 percent of population

[c]Snow tires 6.5 percent of population

[d]Snow tires 3.5 percent of population

[e]Snow tires 1.8 percent of population

[f]Snow tires 73.9 percent of population

3.7 Tread Wear Patterns

Baker and McIlraith examined the variance of tire groove depth in their population sample of 6984 tires [2]. They report finding 3.6 percent as having differences of more than 4/32-inch groove depth (inside, middle, and outside). Somewhat surprisingly, there were more such tires on the rear wheels than on the front: LF, 1.9 percent; RF, 2.6 percent; LR 4.4 percent; and RR, 5.6 percent. Almost 10 percent of the tires had more than 3/32-inch variance in groove depth, "enough to suggest definitely uneven wear caused by overinflation, underinflation, or improper mechanical adjustment." The authors examined for other tire ailments as well; these will be discussed in section 3.8.a following.

Ehrlich and Jurkat present a tabulation of tread wear patterns in their main report [6]. Of the 18,008 tires examined in their summer survey, they report 27.8 percent of front tires and 17.8 percent of rear tires as showing some unusual tread wear pattern.* Their tabluation shows 22.2 percent of front tires and 21.8 percent of rear tires as having differences in groove depth (inside, middle, and outside); however, the minimum difference established as their criterion is not stated.

3.8 Tire Defects

a. Tires in Service

Baker and McIlraith in their report on the use and condition of tires on the Illinois Tollway present an interesting and informative discussion of various tire defects found in their survey. As the authors describe their summary of tire ailments [2],

*Inside, outside, both sides, center, bald, waves, feathered, flat spot, or step wear, as defined by MIL-STD-1224, "Visual Inspection Guide for Pneumatic Tires (Non-Aircraft)."

it "aims to point out conditions about which a car owner or driver should do something or of which he should at least be aware."

In table 9 we have attempted to assemble comparable information on these conditions, insofar as such information is available in the final reports of the three studies.

Table 9. Summary of tire defects found in condition and use surveys

	Percent of Tires Examined[a]			
			DL Surveys	
	TI No. 2	SWRI	Summer	Winter
Overloading				
1. As Found	5.9	6.2[b]	6.2	9.3
2. Not correctable by inflation[c]	2.4	0.9	0.5	-
Not enough tread left[d]	4.2	1.7	11.8	12.9
Sidewall cracks[e]	4.2	-	-	-
Uneven wear	3.6[f]	-	22.0	-
Overpressured				
1. As found	1.9	3.25	-	-
2. Not correctable by deflation[c]	0.1	0.9	-	-
Bulges or blisters[g]	0.17	-	-	-
Underpressured	-	11.5[h]	-	-

[a]Excluding "unknowns" or "No Response"

[b]Does not include the 11.5 percent of underpressured tires reported for which load conditions were not given

[c]Require larger tire or removal of some load

[d]Minimum groove depth less than 3/32-inch

[e]One or more cracks in outside wall large enough to be probed by fingernail

[f]More than 4/32 inch differences in depth remaining in different grooves

[g]Any lump or swelling on visible part of tire

[h]ECP below permissible range for specific tire

(1) Percentages of Tires and Cars Examined. Excluding uneven wear, Baker and McIlraith reported finding 1022 of the total of 6984 tires examined, or 14.7 percent, with one or more deficiencies serious enough to warrant correction. There were a total of 1117 ailments found, or 1.09 per defective tire. These 1022 tires were on only 607, or 34.7 percent, of the 1746 vehicles examined. As the authors point out, "approximately two out of three (415 out of 607) cars with one bad tire also had a second bad tire."

Ehrlich and Jurkat reported 77.2 percent of the 18,008 tires in their summer survey as having none of the tire wear patterns for which they made observations (see section 3.7 above). They too found that some tires had more than one defect.

(2) Tread Rubber on Roadsides. The tread rubber strewn along roadsides is taken as evidence of tire failure. This kind of failure has been attributed to the attainment of high temperatures in the tire caused by sustained high speed, overloading, high pavement and ambient temperatures, either single or in combination. An attempt was made by SWRI [7] and DL [18] to determine the source and frequency of this type of failure by examining the rubber collected along the roadsides.

Both groups found that the amount of large truck tire rubber exceeded the passenger car tire rubber. However, they were not able to draw conclusions about the frequency of the event or otherwise interpret their findings in a useful way. We may explain this if we compare the practices of commercial truckers with what is likely to be the reaction of the driver of a passenger car or small truck when a tire throws tread rubber.

The long haul truckers do not stop to remove a tire if it is possible to continue. Consider a case in which one tire of a dual pair has a blowout or throws a piece of tread. The truck continues to roll (the cost of the tire is less than the cost of the delay), and the tire may be completely destroyed leaving a trail of rubber along the road.

If a passenger car tire experiences a tread separation, the driver will stop to find the cause of the noise. In any event he will probably be forced to remove the failed tire before continuing; little or no rubber will appear on the road from this source. Therefore, a single truck tire failure may produce a large number of pieces of rubber whereas a single passenger car tire may produce none.

b. Failure Experience, New Tires

In both the SWRI and the DL summer survey, drivers were asked about tire problems or failures experienced in the previous 2 years. We must recognize the fallibility of such information; nevertheless, it is of interest to examine and compare their data.

Of the 4502 drivers interviewed in the DL summer survey, 1195 answered "Yes" to the question, "Have you had a tire problem in the last 2 years?" Of these, 366 said the failure was covered by warranty with 213 "not sure;" 2194 drivers reported no failures, while 1113 did not know.

Of the 11,385 drivers interviewed in the SWRI survey, 1462 responded "Yes" to the question, "Any defects in newly purchased tires within the last 2 years?" In the SWRI report, Lepisto concludes that "Almost one-half (42.7 percent) of the original equipment tires required some kind of warranty claim within the last 2 years."

These authors cannot agree with this conclusion. It appears to them that Lepisto has assumed that all of the reported tire warranty failures (1462) were OE failures, for with the "approximately 30 percent (3415) of the cars in the sample. . . equipped with OE tires" (see page 41 of his report), we have

$$\frac{1462}{3415} \times 100 = 42.8 \text{ percent of new cars having a tire warranty failure.}$$

The above calculation also ignores the fact that each new car comes equipped with five new tires.

Assuming that on the average about two new tires are purchased for each vehicle every year (20,000 miles average tread wear per tire prior to discard; average of 10,000 miles driven per vehicle per year), we can arrive at some estimates of warranty failures on new tires as percentages of all new tires purchased (including OE) for both the SWRI and DL (summer) surveys:

<u>Tire Defects or Failures under Warranty as Percent of All New Tires Purchased</u>

<u>DL Summer Survey</u>:

Assuming that half of the "not sure" category were actually failures under warranty, we have

$$100 \; \frac{366 + \frac{213}{2}}{4502 \times 2 \times 2} = 2.6 \text{ percent}$$

<u>SWRI Survey</u>: Assuming that each of the "yes" responses represented only one tire defect or failure, we have

$$100 \; \frac{1462}{11{,}385 \times 2 \times 2} = 3.2 \text{ percent}$$

However, the above calculations ignore the fact that each car in a survey that was purchased new actually brought five new tires into the survey. The above calculations therefore somewhat over estimate the percentages of warranty claims on new tires. Using the reported data on OE tires in each survey, we can recalculate as follows:

DL Summer Survey: 35.5 percent of tires surveyed reported as OE [6]

$$100 \frac{366 + \frac{213}{2}}{4502\ (0.354 \times 5 + 0.646 \times 2 \times 2)} = 100 \frac{472.5}{4502 \times 4.35} = 2.4 \text{ percent}$$

SWRI Survey: 31.8 percent of tires surveyed reported as OE [7]

$$100 \frac{1462}{11{,}385\ (0.318 \times 5 + 0.682 \times 2 \times 2)} = 100 \frac{1462}{11{,}385 \times 4.32} = 3.0 \text{ percent}$$

As the DL summer survey asked for all tire problems rather than just those on newly purchased tires, as in the SWRI survey, we can make some further estimates. Again we shall assume that half of the "not sure" category were actually under warranty:

Warranty claims as percent of all tire failures reported for the previous 2 year period in the DL summer survey:

$$100 \frac{366 + \frac{213}{2}}{1195} = 40 \text{ percent}$$

Tire failures in previous 2 years as percent of total tire positions:

$$100 \frac{1195}{4502 \times 4} = 6.6 \text{ percent}$$

The DL summer survey questionnaire also asked each driver to estimate the number of miles the car was driven each year. Using this information and the reported tire failures, Ehrlich and Jurkat calculated a tire failure rate of 113 per million vehicle miles. In section 4.1.a, we shall observe that this failure rate is almost 2 1/2 times that found in the Traffic Institute studies. The major part of this difference can probably be ascribed to the difference in the two populations sampled.

4. TIRE DISABLEMENTS AND VEHICLE ACCIDENTS

Most of the information presently available on tire disablements and their relation to motor vehicle accidents is that which was obtained during the series of studies by the Traffic Institute of Northwestern University on the Illinois Tollway during the period September 1966 through August 1967 [1, 3, 4]. As in the tire condition and use studies, we shall briefly review each of the three reports by Baker and McIlraith in an attempt to provide the reader with sufficient background to exercise his own value judgments, then compare their findings with such other information as we have available to us.

As in the tire condition and use studies, many interesting details will necessarily be omitted in this review. The reader who wants the full picture is urged to consult the original reports.

4.1 Tire Disablements Not Followed by Accidents

a. Frequency of Tire Disablements

In their introduction to TI Study No. 1, Baker and McIlraith present an excellent discussion of the factors and problems involved in obtaining reliable data for a tire disablement study. The authors point out that the principal factors affecting tire disablement rates are the following:

--Vehicle speed
--Condition of tires, including inflation pressures and loading
--How the vehicle is driven
--Type and condition of highway
--Weather conditions, principally temperature.

With regard to sample size, the authors state that it was arbitrarily decided to continue a survey "until about 50 disablements had been recorded, but not for more than 3 weeks."

(1) Number and Purposes of Surveys. Three tire disablement surveys were taken, all by interviewing drivers at selected toll booths on the Illinois Tollway. As in all of the studies included in this review, only four-wheel, four-tired vehicles equipped with passenger car tires were considered.

The first survey was taken at South Beloit, the farthermost exit on the Tollway, in April and early May 1967. The second, designed to evaluate the effect of temperature, was also conducted at South Beloit, in July of the same year. It was recognized that the second survey would probably include a higher percentage of long-distance, through-traffic (vacationers), and we shall see evidence that this was so. Nevertheless, it was felt that the principal factor difference would be that of temperature.

The third survey was made in such fashion as to emphasize the effects of different driver populations. Carried out at the same time as the second survey, and therefore at the same ambient temperature, the third was taken at a toll booth near the intown Kennedy Expressway, to include a maximum percentage of short-trip commuter traffic to and from downtown Chicago, in contrast to the preponderance of long-distance travelers at South Beloit.

(2) Data and Results. In the surveys, each driver was asked two questions: (a) Where did you enter the Tollway? and (b) Since entering the Tollway, did you experience a tire disablement or other vehicle trouble?

Drivers reporting a difficulty were questioned further. However, the interview was designed to delay such drivers no more than 30 seconds. All replies were accepted without question. Results of the three surveys are presented in table 10.

Table 10. Frequency of tire disablements on the Illinois Tollway

			Total Vehicle Disablements[a]							
Survey	Period	No. of Drivers	Tire Failures	Other	Percent Tire Failures	Av Miles Driven on Thruway[b]	Ambient Temp, °F Range	Ambient Temp, °F Av	Av Miles per Tire Failure	Tire Failures per mvm[c]
1	4/24-5/11/67	32,034	56	33	63	60	35-63	48	34,322	29
2	7/10-7/25/67	23,332	67	37	64	64	60-75	69	22,287	45
3	7/10-7/28/67	29,792	38	53	42[d]	18	60-75	69	14,112	71

[a]Excluding "out of gas" category

[b]Based on random sampling of about 6000 cars in each survey

[c]Per million vehicle miles

[d]Vehicle overheating comprised 30 percent of total in this survey vs less than 8 percent in each of first two surveys

In their report Baker and McIlraith demonstrate that for each of the surveys there is no reason to reject their preliminary hypothesis that the observed incidence of tire disablements would follow a Poisson distribution. As in their tire condition and use survey, cars surveyed were classified by size and by age (see section 3.1). Based on a sampling of 3000 cars from each survey, distributions by vehicle size and age were as shown in table 11.

Table 11. Distributions (percent) by size and age of cars surveyed

(Based on the 3000 car samplings from each survey)

Vehicle	Standard			Compact			Small			Totals		
	Survey			Survey			Survey			Survey		
Age	1	2	3	1	2	3	1	2	3	1	2	3
Old	6.0	4.3	8.9	0.9	0.2	0.9	0.6	0.0	0.6	7.5	4.5	10.4
Medium	33.2	34.0	42.2	7.5	6.7	8.1	1.8	0.9	3.5	42.5	41.6	53.8
New	42.7	47.1	31.6	6.6	5.9	3.0	0.7	0.9	1.2	50.0	53.9	35.8
	81.9	85.4	82.7	15.0	12.8	12.0	3.1	1.8	5.3	100.0	100.0	100.0
Av		83.3			13.3			3.4				

Comparing the distribution matrix by size and age for the vehicles experiencing tire disablements with the corresponding matrix (table 11) based on the sampling of 3000 cars, Baker and McIlraith found for each survey that there was no statistically significant difference between the two matrices for either size or age using a Chi-square test at the 95 percent confidence level. Later in their report, the authors combine the three pairs of distributions into one by weighting "to take account of different vehicle mileages." Using the resultant pair of matrices for all vehicle surveys and for all vehicles experiencing a tire disablement in Chi-square tests at the 95 percent confidence level, Baker and McIlraith then found that although again classification by vehicle size was not statistically significant, vehicle age very definitely was (Chi-square value 19.5 vs the critical value of 5.99).

Using the distributions by vehicle size and age of the tire failures reported in each survey and the corresponding survey distribution (based on the 3000 car samplings from each survey population), the authors calculated disablement indexes. Establishing those for the standard size and for the new cars in each survey as 1.00, reduced disablement indexes were calculated. Those by size are presented in table 12 and by age in table 13.

Table 12. Tire disablement indexes by vehicle size

Vehicle Size	Survey 1	Survey 2	Survey 3
Standard (3,000 lb)	1.00	1.00	1.00
Compact (2,000 to 3,000 lb)	0.80	1.45	1.32
Small (2,000 lb)	0.53	--[a]	1.79

[a]No tire failures reported

Table 13. Tire disablement indexes by vehicle age

Vehicle Age	Survey 1	Survey 2	Survey 3	Overall (combined)
New (1966-67)	1.00	1.00	1.00	1.00
Middle (1960-65)	1.38	1.89	1.98	1.73
Old (1959 or older)	1.76	3.96	2.94	2.44

Minor findings in the surveys included the following:

--Neither driver sexnor age appeared to be significant.
--About two-thirds of all drivers changed their own tires.
--Women constituted about 9 percent of the driver population surveyed.
--About 3 1/2 percent of the disabled vehicles had no spare.

In presenting the results of these three surveys, Baker and McIlraith present some interesting conjectures regarding the affect of ambient temperature on the frequency of tire disablement. To this we should like to add that there were 40 percent fewer old cars in the second survey (more new cars on vacation trips in July). The temperature effect is therefore probably even more significant than the data show, as it is apparent from this review that the tires on older cars are in poorer condition and have less tread remaining.

The highest disablement rate occurred in the third survey, which emphasized commuter traffic. In similar fashion, it may be argued that the higher disablement rate is attributable principally to the much higher incidence of old and medium age cars in the third survey. It is also true that vacationers and other long-distance, through-travelers have tires in better condition than those of the general population (see table 8).

In closing their report Baker and McIlraith use a combination of reasonable assumptions and estimates to arrive at an overall annual rate of about 46 tire disablements per million vehicle miles (mvm) or one for every 22,000 miles of vehicle travel. The authors emphasize that this figure is "only a rough estimate for four-tired vehicles on limited access roads" comparable to the Illinois Tollway with respect to mean annual temperature, road surface, quality of maintenance, and traffic mix. The authors cite (but do not reference) a 1962 Eisenhower Surveillance Project, "a three-day continuous surveillance study of a 4.5 mile length of the Expressway in 1962." The findings of this project were that: 1) of a total of 122 vehicle stoppages on the 4.5-mile length of Expressway, 64 (or 52.5 percent) were tire disablements, "almost exactly the same as that obtained in this study;" 2) 69 percent of the drivers changed their own tires; and 3) the estimated disablement rate was 42 per mvm.

Assuming that 50 tire disablements per mvm is a reasonable estimate, and that average tread wear (i.e., useful life) for a new tire is 20,000 miles, we may calculate* that about one new tire out of every four experiences some form of disablement prior to wear out.

b. Disablements Not Followed by Accidents

In the third of their series of four reports, Baker and McIlraith consider a total of 407 special reports on tire disablements collected by state highway patrolmen on the Illinois Tollway during the 12 month period September 1, 1966, through August 31, 1967. As stated by the authors, the purpose of the Tire Study No. 3 was "to discover 1) circumstances of tire disablements which were not followed by accidents to compare with those which are followed by accidents [see their Tire Study No. 4], and 2) conditions of disabled tires to compare with tires in general use."

(1) Sample Size. Based on annual reports of the Illinois Tollway police battalion, the 407 special reports on disabled tires constituted about 15 percent of the approximately 2800 annual cases of "Assistance Rendered, Tire Trouble." Based on the 60,000 annual tire disablements on the Tollway estimated in Tire Study No. 1, the special reports amounted to about 0.75 percent of all tire disablements.

(2) Information and Measurements. The four page tire disablement report used is presented by the authors in their report. Tread depth measurements were made on all tires on the disabled vehicle, as were inflation pressures on the nondisabled tires. Loads on the tires were estimated using the curb weight of the vehicle from published

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* $\frac{10^6 x4}{2x10^4}$ = 200 new tires per mvm

50/200 = 1/4

data assuming standard accessories and a full fuel tank, plus the patrolman's estimates of occupant and cargo weights. Weight distribution between front and rear tires was also based on published data for each vehicle.

It was most unfortunate that as emphasized by the authors, "There was no question listed on the report form to ascertain time between the car stopping and the tire inflation pressure being taken by the patrolman." As a consequence, estimates of actual equivalent cold pressures (Pc) become extremely doubtful.

(3) Vehicles and Drivers. A comparison of the 407 disabled vehicles in Tire Study 3 by size and by age with similar classifications for the population samples of the Traffic Institute Studies 1 and 2 is presented in table 14.

Table 14. Size and age of cars

Car Size	STANDARD			COMPACT			SMALL			TOTALS		
Car Age	Study 1[a]	Study 2	Study 3	Study 1[a]	Study 2	Study 3	Study 1[a]	Study 2	Study 3	Study 1[a]	Study 2	Study 3
Old	6.4	3.6	10.8	0.7	0.3	1.0	0.4	0.1	0.2	7.5	4.0	12.0
Medium	36.4	23.0	44.5	7.4	2.5	6.9	2.1	0.5	1.0	45.9	26.0	52.4
New	40.5	63.0	29.7	5.2	5.5	5.2	0.9	1.5	0.7	46.6	70.0	35.6
TOTALS	83.3	89.6	85.0	13.3	8.3	13.1	3.4	2.1	1.9	100.0	100.0	100.0

[a]Average of the three surveys, each weighed equally

It is apparent that vehicle size has no significance in the disablements. Vehicle age is another question. In both Studies 1 and 3, more old and medium age cars experienced tire disablements than were found in the Tollway physical condition and use study. The distribution by vehicle age in Study 3 is roughly the same as that found in the third survey (this one included the maximum of short-haul commuter traffic and yielded the high failure rate) on frequency of tire disablements in Study No. 1 (see section 4.1.a).

About 70 percent of the 407 vehicles had power steering, about the same as the percentage (73 percent) found in Study No. 2. Not surprisingly, women drivers constituted a much larger percentage than in the general population. However, neither sex nor driver age were significant with respect to the occurrence of a tire disablement.

(4) Tire Types and Sources. Of the 407 disabled tires, 44.5 percent were 2-ply construction vs 43.5 percent of the population in the TI's condition and use survey [2]. Although 6- and 8-ply tires amounted to 1.1 percent of that population, none was found among the disabled tires.

With respect to retreaded tires, only 0.26 percent of the population sample in the TI Study No. 2 for which definite information on retreading was available were retreads. In contrast, 11 of the 407 disabled tires, or 2.71 percent, were retreads. Baker and McIlraith report that the difference is statistically significant "at the 0.01 level of confidence."

(5) Inflation Pressures and Loading. Baker and McIlraith assumed "in all cases that the [tire inflation] pressure was taken 'hot,' that is, fairly soon after the vehicle had come to rest." As only 10 minutes standing after stopping reduces the necessary correction by about half (see figure 1), this procedure may have resulted in Pc values substantially below their true values. The authors acknowledged this.

A pressure distribution is given for the nondisabled tires, showing 95.3 percent at or below design pressure, 1.2 percent overpressured, and the remaining 3.5 percent somewhere between design and permissible. As estimates, the resultant tire load distributions and average loading (79 percent of rated load) for the accompanying non-disabled tires on the 407 vehicles are quite similar to those found in all four of the condition and use surveys covered by this review (see table 3 and section 3.8.a). One may conclude that neither underpressured nor overloaded tires were especially significant factors in these 407 tire disablements. Of the nondisabled tires, only 72 (6 percent) appeared to have been overloaded; of these, 52, or 72 percent, could have been inflated sufficiently to carry the loading without exceeding the maximum permissible pressure.

(6) Difficulties Reported by Drivers. Baker and McIlraith explore the kinds of difficulties reported by the drivers and their various reactions and responses to the tire disablement. However, our reaction is that it is exceedingly doubtful that uniformed highway patrolmen will receive frank, honest responses to questions of this type from the average motorist. The authors themselves recognize this problem later in the report, and point out that the motorist grossly underestimated vehicle speeds and stopping distances. Moreover, "All but a very few [of these] tire disablements occurred on virtually straight road."

We consider it significant that 38 of 326 drivers (11.6 percent) expressed concern about possible loss of control, and that three reported actual loss of control (none resulting in an accident).

(7) Physical Condition of the Tires. As indicated earlier, minimum groove depth and maximum variance in groove depth were measured on all four tires; in addition, all were examined carefully for cracks and blisters. The average minimum remaining groove depth for the disabled tires was 4.44 32nds of an inch, and for the nondisabled, 4.89 32nds. These values are very much lower than the averages found in both the TI and SWRI physical condition and use surveys on limited access highways, and are even substantially lower than those found by the DL in samplings more representative of the general population of passenger car tires in service (see table 8).

Of the disabled tires, 28.0 percent were rejectable by the RMA criterion for remaining tread depth (see section 3.6), as were 21.3 percent of the nondisabled. Compare these figures with the 6.9 percent of such tires found in the TI's Tire Study No. 2 on the Tollway, and the 4.8 percent found by SWRI in a similar condition and use survey of long-distance travelers on high-speed, limited access highways. These percentages are even higher than the 17.7 percent with tread depths of 2/32-inch or less found by the Davidson Laboratory in their two surveys more representative of the general population of passenger car tires in use. Baker and McIlraith report [3] that:

> When the disabled tires were bald, 58 percent of the cars had one or more [other] tires in the same condition. When the disabled tires were not bald, only 24 percent of the other tires on the same cars were bald.

It is also of interest to note that 18 drivers among the 407 claimed to have suffered a previous tire disablement on the same trip.

(a) Cracks and Blisters. Cracks and/or blisters were present on 11.1 percent of the disabled tires; the corresponding figure for the nondisabled tires was not given. This value is about 2 1/2 times the 4.4 percent reported by Baker and McIlraith in their physical condition and use survey [2].

(b) Risk Indexes. In their evaluation of the accumulated data, Baker and McIlraith calculated a "'risk index'. . . obtained by dividing the percent of disabled tires with a . . . [minimum] remaining groove depth by the percent of tires in use with the same remaining groove depth." They then multiply these risk indexes by the average number of disablements per mvm, to arrive at estimates of the number of disablements per mvm to be expected for any given tread depth remaining. The very striking results are tabulated in their report [3] and graphically represented in figure 5.

We believe it to be quite apparent from this and other information (see 4.2.c) that bald tires (i.e., those having a minimum remaining tread depth of 2/32-inch or less) should be either recapped or replaced. The likelihood of a disablement for such tires appears to be about 10 times that for a new tire, according to TI Study 2.

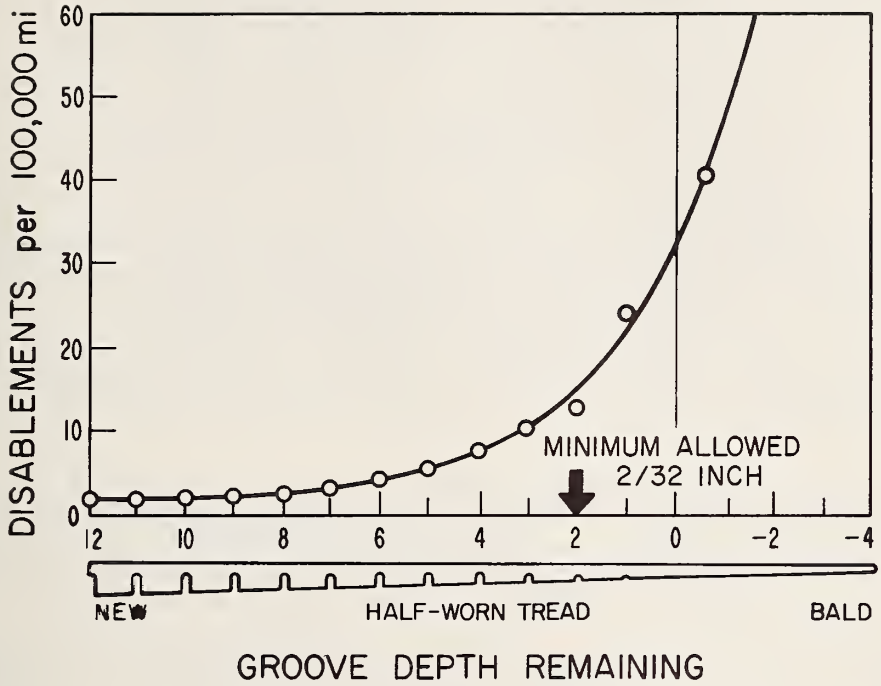

Figure 5. Tire disablement rate related to tire wear (Ref. 3, Exhibit 29, p. 43).

(8) Tire Position Effects. Among the 407 disabled tires, the front tires had less tread depth remaining (LF, 3.40; RF, 4.24; LR, 4.99; RR, 4.67 minimum average groove depth remaining, in 32nds of an inch). Among the nondisableds, rear tires had slightly less tread depth remaining (LF, 4.99; RF, 4.95; LR, 4.75; RR 4.71). Except for the disabled left front tires, however, differences among all the tires on the 407 vehicles were slight. Despite this absence of any substantial differences in tread depth remaining (disabled LF's excepted), 64 percent of the disablements were rear tires and 38 percent of all tire failures occurred on the right rear. We shall again take note of this high incidence of rear tire failures when we consider the Texas Highway Department information on wet weather accidents in section 4.2.c.

4.2 Tire Disablements Followed by or Found in Accidents

In this section we shall consider tire disablements found in or followed by accidents. We shall find the available information much more limited than that on any of the other areas of passenger tire service experience already discussed; and this despite an importance that, to our minds at least, outweighs all the rest.

We have two reports to consider, with additional pieces of information from various other sources. As in the previous section on tire disablements, the major work available is a Traffic Institute study [4]. The other report is a study of some 378 accident vehicles in rural areas of North Dakota [19].

a. Disablements Followed by Accidents on the Illinois Tollway

In their Tire Study No. 4, Baker and McIlraith report on the incidence of tire disablements followed by accidents on the Illinois Tollway. Data for this report were collected during the calendar year period September 1, 1966, through August 31, 1967. This was the same period during which data for their third tire study was taken. For the investigation, Tollway police were asked to fill out a special supplementary tire report in addition to their regular accident report whenever a passenger car or light truck was involved and had a "flat tire," regardless of how or why the flat had occurred. The investigators also obtained the disabled tire and rim for detailed examination whenever possible.

In the introduction to TI Study 4, the authors point out that "Tires may contribute to accidents in two ways: first, by the extent to which their road traction may be limited; and second, by their disablement, which may affect control of the vehicle."

Baker and McIlraith correctly point out that their study was directed only toward the second effect. As we shall see in section 4.2.c, the importance of the first factor is much too great to be ignored. Unfortunately, the Texas Highway Department's wet weather accident data is all that was available to us for this review.

(1) Efficiency of Data Collection. During the period, 1432 accidents involving a total of 2196 four-wheel, four-tire vehicles were reported on the Tollway. Supplementary reports of tire disablements were received on only 80 (3.6 percent) of these vehicles; 39 of the disabled tires and rims were obtained. Regular police accident reports indicated that an additional 32 supplementary tire reports should have been turned in. Based on a telephone sample,* it was further estimated that "there may have been as many as 123 additional vehicles with tire disablements following accidents, making a possible total of 235 or 10.7 percent of all four-tired vehicles in accidents" during the 1 year period. The estimated 123 additional vehicles amounted to 6 percent of the 2051 vehicles for which specific tire disablement information was not available.

(2) Incidence of Tire Disablements in Accidents. As stated above, Baker and McIlraith estimated that about 11 percent of the accident vehicles had a flat tire, incurred either before or during the accident. This percentage compares favorably with similar figures quoted in their Tire Study No. 1**. However, it is about 10 times higher than the figure reported by the State of California Highway Patrol for a 6-month study of tire failures on similar accident vehicles (see section 4.2.c).

Based on a close study of all available information on each of the 112 vehicles positively known to have had a disabled tire on examination after the accident (i.e., so stated in police reports), Baker and McIlraith classified the tire disablements as follows:

	Number	Percent
Accident followed disablement	13	11.6
Questionable	20	17.8
Disablement followed accident	79	70.6
Total	112	100.0

Using a series of arguments, the authors conclude that among these the maximum number of tire disablements causing accidents could only have been 17 (or 15 percent of 112). Applying this percentage to the 123 possible undiscovered tire disablements, they conclude that the minimum number of tire disablements resulting in accidents was 13, and the maximum number 17, plus 15 percent of the 123, or a total of 36. This is 0.59-1.64 percent of the 2196 four-tired accident vehicles, or 0.91-2.58 percent of the 1432 accidents involving such vehicles during the period. Using their own estimate of 60,000 tire disablements experienced annually on the Tollway by four-wheel, four-tired vehicles [1], they conclude further that between 0.022 and 0.060 percent of tire disablements on the Tollway result in accidents.

(3) Other Results and Conclusions. Among other interesting aspects of these accident data, Baker and McIlraith consider the effects of power steering, tire type and condition, age and sex of driver, and type of tire failure as related factors in tire disablements leading to accidents. We shall summmarize these very briefy.

(a) Power Steering. In their Tire Studies 2, 3, and 4, Baker and McIlraith listed power steering among the survey questions. In Studies 2 and 3, they found that 73 percent and 70 percent of the vehicle population samples were so equipped. Interestingly enough, of the 21 accidents definitely or possibly following a tire disablement

*Two of a selected 35 of the motorists living in the Chicago area reported disablements that did not appear in the accident reports.

**Ohio Turnpike figures of 12, 11, and 10 percent for years 1964, 1965, and 1966, respectively; 6.5, 6.5, and 6.4 percent reported by the New York Thruway Authority for years 1966, 1967, and 1968. However, the latter figures imply that the tire disablement was the cause of the accident (see section 4.2.c).

for which information was available, only 10 (48 percent) of the vehicles has power steering. The authors state that "There is less than one chance in 20 that the differences in percentages is due to chance." An analysis of accident data in the 1968 Annual Report of the New York State Thruway Authority [20] confirms this finding (see section 4.2.c).

(b) Tire Type and Condition. The percentage of 2-ply tires was nearly the same in disablements not followed by accidents as in those followed by accidents. Data on retreads and tube type tires was insufficient to draw any inferences.

(c) Age and Sex of Drivers. Baker and McIlraith also analyze the data on age and sex of the drivers in the 33 accidents definitely or possibly following tire disablements for which information was available. Fourteen of these (42 percent) were women, compared with the following percentages found in other studies:

Study	Women Drivers Percent of Sample
TI No. 1	10.9[a]
TI No. 2	8.8
TI No. 3	29.7[b]
DL Survey	--c
SWRI Survey	--d

[a]Percent of drivers experiencing tire disablement

[b]More women than men wait for assistance in changing a tire

[c]Taken but not reported

[d]Data not taken

The authors compare the driver age-sex distribution matrix [4] with that presented in their Tire Study No. 1 for motorists experiencing a tire disablement without having an accident. Dividing the percentage of drivers in each category for disablements followed by accidents by the percentage in the corresponding category for disablements not followed by accidents, they arrive at risk indexes for the various classes of drivers. These are compared in table 15.

It appears that driver experience plays an important role in the ability to cope with a tire disablement. Girls and younger women appear especially prone to accidents in event of tire failure, probably owing principally to the more limited amount of driving done by them.

Table 15. Age and sex risk indexes following tire disablements based on Tire Study No. 1 [4, Exhibit 34]

Age	Men	Women	Both
Less than 20	1.8	21.6[a]	5.17[a]
20 to 35	.49	5.4[a]	.95
35 to 50	.70	1.30	.77
50 to 65	.78	----	.70
More than 65	---	----	---
All	.657	3.89[a]	1.00

[a]Significant at the 0.01 level [of confidence]

(d) Type of Tire Failure. Of 17 disablements followed by accidents, four drivers (24 percent) reported a blowout vs 47 blowouts in 321 tire failures reported in the TI's Tire Study No. 3. Baker and McIlraith state that the difference is not significant at the 5 percent level of confidence, but does suggest that as one might reasonably expect, it is more difficult to avoid an accident in the event of a sudden and unexpected tire failure. However, they point out that in their Tire Study No. 1, 52 percent of the tire disablements were classed as "sudden" by the motorist.

b. Condition of Tires After Automobile Accidents in North Dakota

Data on the condition of tires on 378 automobiles involved in rural accidents in North Dakota that resulted in one or more injuries are analyzed in a report by J. K. Kihlberg and Arthur Stern of the Automotive Crash Injury Research (ACIR) Center of Cornell Aeronautical Laboratories, Inc. [19]. The authors state that "the purpose of the study has simply been to test a new method of data collection and to take a first look at the potential usability of tire condition data."

(1) Data Collection. Data were collected for ACIR over a 13-month period beginning in July 1964. Investigating police offficers measured tread depth, taking the apparent minimum point at the center line of the tire. General tire condition, evenness of wear, and any damage were reported. Pressures were estimated by inspection rather than by actual measurement. All four tires were so evaluated whenever possible. Summer accidents numbered nearly twice as many as winter ones. Of the 378 vehicles, 290 had four standard tires (regular tread), 58 had standards front, snow tires rear, and 30 had various other combinations. Of the 1470 tires on which information was available, 91 percent were regular tread; all but three snow tires were on the rear wheels.

(2) Findings. Some results of this study considered pertinent to this review are summarized below:

(a) About 10 percent of the tires had less than 2/32-inch tread depth remaining (see also table 8).

(b) Vehicles with higher mileage had less tread depth remaining on the tires (confirms other studies).

(c) No tire failure was reported as a contributing cause of an accident. (However, investigating officers were not requested to evaluate the cause of the accident.)

(d) Uneven wear was reported on 3.5 percent of the tires, and twice as frequently for front tires. (Compare 3.6 percent found in TI Study No. 2--but more rears than fronts. See section 3.7.)

(e) No left side vs right side effects were apparent. (Compare 55 percent failures on right side in TI Study No. 3--also not significant.)

(f) Some evidence found that a fair number of car owners seem to keep their best tires on the front of the car. Of 282 vehicles with all standard tires, 189 had no significant difference in tread depth, front to rear. Of the remaining 93, 67 had deeper tread on the front tires. Using a Chi-square test, Kihlberg and Stern found the difference to be significant at the 0.5 percent level.

(g) Rear tires were generally more worn than front tires, as indicated by (f) above. About 14 percent of all rear tires were bald (i.e., rejectable by RMA criterion) vs only about 6.5 percent of all front tires. Confirming the DL summer vs winter surveys, Kihlberg and Stern found that "use of snow tires in the rear is strongly associated with poor front tires." (See table 8 and section 4.2.c(1) and (2).)

c. Other Information

(1) California State Highway Patrol. In commenting on proposed Federal standards for passenger car tires in December 1966, the California State Highway Patrol [16] presented highlights of a 6-month study of tire failures in accidents undertaken by them in 1965. The survey covered some 60,000 accidents involving four-wheel, four-tire vehicles (i.e., passenger cars, station wagons, and light trucks), and occurring principally on freeways and in rural areas. The following information was reported:

(a) Five hundred forty-five tire failures were reported or 0.91 percent of the 60,000 fatal injury and property damage accidents investigated (whether these were all tire disablements or only those leading to accidents is not stated).

(b) Seventy-four percent occurred on straight roads.

(c) Sixty percent occurred on freeways.

(d) Fifty-eight percent involved the vehicle running off the road.

(e) Sixteen percent involved another vehicle.

(f) Fourteen percent occurred on station wagons (about the same as registration percentage).

(g) Seventy-two percent of the tire failures were rear tires, evenly divided between left and right.

(h) Fifty-seven percent of the disabled tires had less than 2/32-inch of tread depth remaining (i.e., were bald).

(i) Eighty percent were reported as blowouts.

We must recognize that the above data are based on accidents occurring only in relatively noncongested areas. As such, the information probably represents the minimum contribution of tire disablements to accidents. The California State Highway Patrol stated that a repeat of the survey, in greater detail and with better control, was planned.

(2) Texas Highway Department. The Texas Highway Department examined the tread depths of all tires on some 240 four-wheel, four-tire vehicles involved in wet weather accidents [17]. We think that a comparison of their findings with those of the three tire condition and use studies is of considerable interest. We shall again define bald tires as those having a minimum remaining tread depth less than 2/32-inch, and "thin" tires as those having a minimum tread depth remaining equal to or greater than 2/32-inch but not greater than 4/32-inch. A comparison of these two classes for the four studies is presented in table 16.

Table 16. Bald[a] and thin[b] tires in wet weather accidents relative to those found in condition and use surveys

		Percent of Total Population Sample				
		LF	RF	LR	RR	All
Wet Weather Accidents in Texas	Bald Tires	8.6	7.0	21.8	21.4	14.8
	Thin Tires	14.3	19.2	27.7	28.1	23.7
	Total	22.9	26.2	49.5	49.5	38.5
TI Tire Study No. 2	Bald Tires	3.5	3.7	5.2	4.6	4.2
	Thin Tires	10.7	11.2	13.6	14.7	12.5
	Total	14.2	14.9	18.8	19.3	16.8
DL Summer Survey		Both Fronts		Both Rears		All
Total Sample	Bald Tires	11.3		12.3		11.8
	Thin Tires	19.1		23.4		21.2
	Total	30.4		35.7		33.0
Thruway Vehicles Only (183 cars)	Bald Tires	2.2		4.4		3.3
	Thin Tires	14.3		20.5		17.3
	Total	16.5		24.9		20.6
SWRI Survey	Bald Tires					1.7[c]
	Thin Tires					12.8[c]
	Total					14.5[c]

[a]Minimum tread depth less than 2/32-inch

[b]Minimum tread depth equal to or greater than 2/32-inch, but not more than 4/32-inch

[c]Percent of all tires, excluding unknowns

These wet weather accident data show a much higher incidence of bald and thin tires than either the TI or SWRI physical condition and use surveys. If we may assume that the average condition of tires in the Western U.S.A. is not substantially different from that of the general population in the Eastern half (as represented by the DL survey), the incidence of bald and thin tires in wet weather accidents is, overall, higher than that in the general population, especially for rear tires.

Moreover, note the significantly higher percentages of bald and thin tires on the rear wheels of the wet weather accident vehicles. We have observed in previous studies (TI Study No. 2, DL survey, and North Dakota accident data) that all four tires on most cars are about equally worn. Yet on these some 240 vehicles there were almost 3 times as many bald tires on the rear wheels as on the front, and about two-thirds more thin tires. As also evidenced in the ACIR study [19] (see 4.2.b), it would appear that some car owners place their best tires on the front wheels, possibly expecting to maintain better control in the event of a blowout or skid. Analyses of accident data, on the other hand, indicate that a vehicle's best tires should be placed on the rear wheels.

(3) New York State Thruway Authority 19th Annual Report, 1968 [20]. In view of Baker and McIlraith's brief citations of tire disablement and accident data taken from various annual reports for the Ohio Turnpike and New York Thruway, we believe that a more detailed examination of the pertinent data in at least one of the more recent annual reports is in order. We shall assume that the vehicle disablement and accident experience on any one of these throughways is probably more or less representative of all, and will take a close look at that reported by the New York State Thruway Authority in its 19th Annual Report for the year 1968 [20].

The report states that of 5031 accidents reported on the Thruway in 1968, "the major vehicular cause was tire blowouts - 232, with an additional 92 mishaps attributed to worn or defective tires."

From the data on "Accident Analyses" in the report, we have constructed table 17.

Table 17. Tires and brakes as causes of accidents on the New York State Thruway

	1968	1967
Total Accidents Reported	5031	4822
Blowouts Reported as Cause	232	222
Vehicles Having Power Steering, percent	54	41
Defective or Worn Tires as Cause	92	92
Total, All Tires Reported as Cause	324	314
All Tires as Cause of Accident, percent	6.4	6.5
Blowouts as Cause of Accident, percent	4.6	4.6
Defective Brakes Reported as Cause	119	70
Percent of All Accidents Reported	2.4	1.5

As Baker and McIlraith have emphasized however [1], it is by no means certain that in all of the above accidents was the tire disablement actually the cause and not a result of the accident.

(a) Blowouts and Power Steering. It is interesting to note that over the 2 year period, 48 percent of the accident vehicles for which a blowout was reported as the cause were equipped with power steering. This percentage is exactly that reported by Baker and McIlraith in their fourth study [4] for vehicles in accidents following a tire disablement. If we can assume, as seems quite reasonable, that the New York State Thruway traffic population had percentages of vehicles with power steering similar to those found by Baker and McIlraith on the Illinois Tollway (73 percent in Study 2, 70 percent in Study 3), the difference is again significant at the 95 percent level. We may therefore conclude with greater certainty that vehicles equipped with power steering are less prone to accidents following a tire disablement, even a blowout.

It is also of interest to observe that defective tires are reported about 3 times as often as defective brakes as the cause of accidents on the New State Thruway.

(b) Tires vs All Vehicle Disablements. Using the "Emergency Service" data of the report, it is possible to estimate tire disablements as a percentage of all vehicle disablements on the Thruway, for comparison with the findings of Baker and McIlraith for the Illinois Tollway:

	1968	1967
Total Service Calls (excluding "Out of Fuel")	84,887	77,834
Tire Trouble	14,794	14,675

Assuming that, as on the Illinois Tollway [1], roughly two-thirds of all drivers change their own tires, we have the following:

All Tire Disablements (estimate)	44,000	44,000
All Vehicle Disablements (estimate)	114,000	107,000
Tire Trouble, percent	39	41

These percentages are considerably smaller than the Illinois Tollway experience reported (see table 10).

(c) Other Information from New York State Thruway Authority. We were interested to learn that the Thruway authority has vehicle inspection teams operating at selected interchanges at varying times. In 1968 these teams checked over 31,000 vehicles for condition of tires, lights, horn, and windshield wipers, and the use of seat belts. This amounted to only 0.023 percent of the some 134,600,000 individual trips on the Thruway for the year. Of the vehicles checked, "a total of 869, or 2.80 percent [of those examined], was refused entry to the Thruway because of serious [safety] defects. An additional 2,204, or 7.10 percent, were warned to have minor deficiencies corrected promptly."

Also reported by the New York State Police patrolling the Thruway system were 6345 arrests during the year for vehicle inspection violations, 4085 arrests for unsafe tires, and 132 for inadequate brakes.

5. ACKNOWLEDGMENTS

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To Miss Elaine Beale and Mr. James Payne our thanks for their many helpful editorial suggestions and careful preparation of the paper for publication.

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APPENDIX A. DAVIDSON LABORATORY SITE DATA SHEET

KEY SHEET

Date	1st Sample No.	Last Sample No.
______	______	______
______	______	______
______	______	______

TEST LOCATION

Name: ____________________ Route: ____________________

Address: ____________________ or Miles to nearest town or city:

City: ____________________ ____________________

County: __________ State ______ Direction: ____________________

Approval from: ____________________ Position: ____________________

Time/date of request for approval: ____________ Gal/month: ____________________

Class of Road: __________ ______ Area: Residential ______
surface no. lanes Commercial ______
Industrial ______

AIR PUMP CHECK AT STATION

Setting on pump	20	25	30	35	40
Reading in tire					

WEATHER INFORMATION

Date	Time	Weather information	Sample no. at time of reading

APPENDIX B. DAVIDSON LABORATORY VEHICLE AND TIRE INSPECTION FORM (3-PART)

NATIONAL BUREAU OF STANDARDS TIRE SURVEY 1967

TIRE SURVEY RESULTS

LEFT FRONT
MAKE ____ MODEL ____
SIZE ____ X ____ REGULAR SNOW
PLY ____ PLY RATING ____ NYLON RAYON
PRESSURE ____ p.s.i.
APPEARANCE: CUT BRUISE BULGE SEPAR. CRACKS
MISSING VALVE CAP OTHER
WEAR PATTERN: INSIDE OUTSIDE IN & OUT CENTER FLAT SPOT
WAVES BALD FAB.SHOW FEATH'D STEP WEAR

LEFT REAR
MAKE ____ MODEL ____
SIZE ____ X ____ REGULAR SNOW
PLY ____ PLY RATING ____ NYLON RAYON
PRESSURE ____ p.s.i.
APPEARANCE: CUT BRUISE BULGE SEPAR. CRACKS
MISSING VALVE CAP OTHER
WEAR PATTERN: INSIDE OUTSIDE IN & OUT CENTER FLAT SPOT
WAVES BALD FAB.SHOW FEATH'D STEP WEAR

RIGHT REAR
MAKE ____ MODEL ____
SIZE ____ X ____ REGULAR SNOW
PLY ____ PLY RATING ____ NYLON RAYON
PRESSURE ____ p.s.i.
APPEARANCE: CUT BRUISE BULGE SEPAR. CRACKS
MISSING VALVE CAP OTHER
WEAR PATTERN: INSIDE OUTSIDE IN & OUT CENTER FLAT SPOT
WAVES BALD FAB.SHOW FEATH'D STEP WEAR

RIGHT FRONT
MAKE ____ MODEL ____
SIZE ____ X ____ REGULAR SNOW
PLY ____ PLY RATING ____ NYLON RAYON
PRESSURE ____ p.s.i.
APPEARANCE: CUT BRUISE BULGE SEPAR. CRACKS
MISSING VALVE CAP OTHER
WEAR PATTERN: INSIDE OUTSIDE IN & OUT CENTER FLAT SPOT
WAVES BALD FAB.SHOW FEATH'D STEP WEAR

Bureau of the Budget Form No. 41567062 Exp. June 1968 — Sheet 1 of 3

SAMPLE No. 42052

NATIONAL BUREAU OF STANDARDS TIRE SURVEY 1967

TIRE TEST RESULTS — AMBIENT TEMP. - PYROC. ____ °F.

RIGHT FRONT
TREAD DEPTH ____/32" ____/32" ____/32"
INSIDE CENTER OUTSIDE
TEMPERATURE ____ °F LOAD ____ 0 lbs.

LEFT FRONT
TREAD DEPTH ____/32" ____/32" ____/32"
INSIDE CENTER OUTSIDE
TEMPERATURE ____ °F LOAD ____ 0 lbs.

LEFT REAR
TREAD DEPTH ____/32" ____/32" ____/32"
INSIDE CENTER OUTSIDE
TEMPERATURE ____ °F LOAD ____ 0 lbs.

RIGHT REAR
TREAD DEPTH ____/32" ____/32" ____/32"
INSIDE CENTER OUTSIDE
TEMPERATURE ____ °F LOAD ____ 0 lbs.

NUMBER OCCUPANTS IN ____ GAS IN YES NO

Bureau of the Budget Form No. 41567062 Exp. June 1968 — Sheet 2 of 3

SAMPLE No. 42052

NATIONAL BUREAU OF STANDARDS TIRE SURVEY 1967

OBSERVATIONS — TIME: ____ M

STATE OF REG. ____ AMBIENT TEMPERATURE ____ °F
MAKE ____ MODEL ____
STYLE: SEDAN COUPE CONVERT. WAGON LT.TRK. SPORTCAR OTH
GALLONS GAS RC'D ____ NO. OCCUPANTS ____ TRAILER ATTACHED
DRIVER: M F AGE: UNDER 26 26-45 46-60 OVER 60
SEAT BELTS INSTALLED YES NO IN USE BY DRIVER? YES NO OTHERS? YES NO

— INQUIRE OF DRIVER —

YEAR: ____ NO. CYL. ____ MILEAGE ____ 000
TIRE: LF ____ LR ____ RF ____ RR ____ O-ORIG. R-REPLAC. T-RETREAD U-UNKN.
ARE YOU THE OWNER? YES IF NO: RENTAL FAMILY COMPANY OTHER
WAS CAR PURCHASED NEW? USED? DK
HOW MUCH PUBLIC LIABILITY INSURANCE CARRIED? $ ____ DK
DRIVER EDUCATIONAL LEVEL: GRADE HIGH SCHOOL COLLEGE
DO YOU USE SNOW TIRES? YES NO DK
DO YOU ROTATE? IF SO HOW OFTEN? ____ 000 MILES

HAVE YOU HAD A TIRE PROBLEM IN THE LAST TWO YEARS? YES NO DK
TYPE OF PROBLEM: BLOW LUMP CUT PUNCTURE OTHER UNKN.
WAS IT COVERED BY WARRANTY? YES NO DK
MANUFACTURER'S RECOMMENDED PRESSURE? FRONT ____ REAR ____
WHAT PRESSURE DO YOU TRY TO KEEP? FRONT ____ REAR ____
HOW OFTEN DO YOU CHECK TIRE PRESSURE? ____ WEEKS
HOW LONG SINCE YOU CHECKED TIRE PRESSURE? ____ WEEKS
HAVE ANY OF YOUR TIRES BEEN REPAIRED?
PLUG BOOT VULCANIZED SEALANT OTHER

LOCAL LONG DISTANCE WHAT WILL TOTAL TRIP MILEAGE BE? ____ MILES
TIME SINCE LAST STOP ____ HRS.
PURPOSE? SHOPPING BUSINESS COMMUTING VACATION PLEASURE OTHER
NO. OF MILES DRIVEN PER YEAR (This Car) ____ 000 MILES
DRIVER'S OCCUPATION: ____ OWNER'S OCCUPATION: ____

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SAMPLE No. 42052

APPENDIX C. SOUTHWEST RESEARCH INSTITUTE VEHICLE AND TIRE INSPECTION FORM (3-PART)

Time: ______ a.m. ______ p.m.   Car No. ______

TIRE USAGE SURVEY QUESTIONNAIRE

1. Location ______
2. Station ______
3. Car No. ______
4. Date ______
5. Ambient temp. ______
6. Road temp. ______
7. Car make, model & cylinders: ______
8. Body style ______
9. Year ______
10. State of registration ______
11. Towing a trailer? No ______
    If yes, type: Boat ______ Box ______
    Horse ______ Camper ______
    Other ______
12. No. of passengers ______
13. Inflation pressure: Right front ______ Left rear ______
    Right rear ______ Left front ______

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Location ______ Station ______ Car No. ______

14. Period of travel since last stop (minutes) ______
15. Any tire defects in newly purchased tires within last two years?
    No ______ Yes ______
    If yes, type of defect:
    Tread separation ______ Crack or split ______
    Bulge ______ Not able to balance ______
    Sidewall defect ______ Blowout ______
    Other ______

	Right Front	Right Rear	Left Rear	Left Front
16. Tire age in months:				
17. How were tires obtained?				
Original equipment				
With used car				
Replacement, service store				
Replacement, tire store				
Replacement, dept. store				
Replacement, discount store				
Replacement, mail order				
Replacement, auto supply				
Retread, original				
Retread, other				

18. Are your tires rotated? Yes ______ No ______
19. What is normal inflation pressure carried: Front ______ Rear ______
20. How long has it been since inflation pressure was measured? (Weeks) ______
21. What is your usual speed of highway travel? ______ mph
22. Tire load (pounds): Right front ______ Left front ______
    Right rear ______ Left rear ______

2

Location ______ Station ______ Car No. ______

	Right Front	Right Rear	Left Rear	Left Front
23. Tread depth:				
Inside				
Center				
Outside				
Inside				
Center				
Outside				
24. Condition of tread wear:				
Even				
Inside worn				
Outside worn				
Flat spots				
Chunks out				
Separation				
Under-inflated				
Over-inflated				
Other (specify)				
25. Number of wheel weights:				
26. Obvious tire defects:				
Bulge				
Sidewall cracks				
Boot (patch)				
Misalignment				
Cuts				
Bruise				
Other (specify)				

27. Brand name, grade and cord: ______ Size and # ply
    Right front ______ ______
    Right rear ______ ______
    Left rear ______ ______
    Left front ______ ______

3

APPENDIX D. TRAFFIC INSTITUTE TIRE USE AND CONDITION DATA COLLECTION FORM

TIRE USE AND CONDITION

If accident, give number only. Otherwise complete identifying data below.

LOCATION (tollway, oasis, plaza)	MILEPOST	HOUR	DATE	MONTH	OCCUPANTS	☒ Dry ☐ Wet ☐ Snow ☐ Ice	ACCIDENT NUMBER
HINSDALE N.-B.	25	9:00A	11	OCT.	1		
VEHICLE-TYPE	**STATE**	**MAKE**	**YEAR MODEL**	**DRIVER AGE**	**SEX**		
4DR. DYNAMIC 88	ILL.	OLDS	66	42	M		

"Where did you get on the Illinois Tollway?"	ILL. 120	AIR TEMPERATURE 50
"From there did you have tire trouble before you got here?"	☐ Yes ☒ No	"Does this car have power steering?" ☒ Yes ☐ No
(If yes) "Did a police officer ask details about it?"	☐ Yes ☐ No	
"How far has the car been driven since it was stopped for an hour or more?"	77 miles	
"On this trip on the Illinois Tollway, before you got here, was the car parked in a parking space at a service area?"	☐ Yes ☒ No	
"Where do you intend to leave the Illinois Tollway?"	MIDWEST RD. E-W TOLL	

DATA		RIGHT Front	RIGHT Rear	LEFT Rear	LEFT Front
RECAP?		☐ Yes ☒ No	☐ Yes ☒ No	☐ Yes ☒ No	☐ Yes ☒ No
BRAND		GOODYEAR	"	"	"
TIRE NAME		POLICE SPECIAL	"	"	"
SIZE		8:45-15	"	"	"
PLY AND PLY RATING		UNKN	"	"	"
SIDEWALL CRACKS		NO	"	"	"
BULGES, BLISTERS		NO	"	"	"
PRESSURE		27	29	27	29
TUBE?		☐ Yes ☒ No	☐ Yes ☒ No	☐ Yes ☒ No	☐ Yes ☒ No
GROOVE DEPTH	Inside	11	9	9	10
	Middle	10	9	10	10
	Outside	11	10	11	11
Describe UNEVEN WEAR		NO	NO	NO	NO
WEIGHT ON TIRE (If weighed)		1200 lb.	1130 lb.	1220 lb.	1320 lb.

Estimated WEIGHT OF OCCUPANTS

FRONT SEAT	205 lb.	— lb.	— lb.
REAR SEATS	— lb.	— lb.	— lb.

Estimated WEIGHT OF CARGO

TRUNK 200 lb.	CAR TOP — lb.
TRAILER--Type —	TRAILER WEIGHT ON CAR — lb.

Comments:

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