U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

www.nhtsa.gov

DOT HS 811 060 December 2008

Commercial Medium Tire Debris Study

Final Report

This document is available to the public from the National Technical Information Service, Springfield, Virginia 22161

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT HS 811 060		

4. Title and Subtitle	5. Report Date
Commercial Medium Tire Debris Study	December 2008
	6. Performing Organization Code
7. Authors Woodrooffe, J.F., Page, O., Blower, D., & Green, P.E.	8. Performing Organization Report No. UMTRI-2008-34
9. Performing Organization Name and Address Virginia Polytechnic Institute and State University Collegiate Square 460 Turner Street, Suite 306 Blacksburg, VA 24060	10. Work Unit No. 11. Contract or Grant No. DTNH22-05-D-01019 Task Order # 0012
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration Office of Applied Vehicle Safety Research 1200 New Jersey Avenue SE. Washington, DC 20590	13. Type of Report and Period Covered July 2006 – June 2008 14. Sponsoring Agency Code NVS-322

15. Supplementary Notes

Contracting Officer’s Technical Representative (COTR): Stephanie Binder

Task Order Manager: Alrik L. Svenson

16. Abstract

Trucking fleets and owners of commercial vehicles utilize both new and retread tires on their vehicles in the United States. Retread tires are used primarily for the cost advantage they provide over a similar new tire. Despite the advantages that retreaded tires may bring, public perception is that retread tires are less safe than new tires as evidenced by the amount of tire debris frequently found on the sides of U.S. Interstate highways. During summer 2007, the University of Michigan Transportation Research Institute (UMTRI) under a subcontract from Virginia Tech Transportation Institute (VTTI) collected and studied truck tire debris and discarded tire casings from five sites in the United States. A random sample (totaling 1,496 items) of the tire debris/casings collected was analyzed to determine the probable cause of failure and its original equipment or retread status. This report presents the methodology and results from this investigation into the underlying causes of truck tire failures and gives an overview of the crash safety problem associated with heavy-truck tire failures. Also, background information on the manufacture of a truck tire, the truck tire retread industry, tire failure modes, industry stakeholder perspectives, an overview of other previous tire debris studies, conclusions, and recommendations for topics for further research are given.

17. Key Words	18. Distribution Statement
Tire, Retread, Tire Debris, Truck Tires	Unlimited

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	236	

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The following individuals are thanked for their advice, assistance, and insights shared in the execution of the Commercial Medium Tire Debris Study:

- Andrew Houff - GE Equipment Services
- Andy Canez - Arizona Department of Transportation
- Ben Chapman and staff - TravelCenters of America (Wytheville, VA)
- Bob Uteg and staff - Bell Tire Distributors
- Bob Watters and staff - Shrader Tire and Oil
- Cliff Riley - Arizona Department of Transportation
- Cory Beard and staff - TravelCenters of America (Lake Station, IN)
- Curtis Criswell - Florida Department of Transportation
- D. J. Wesie - J Rayl Transport Inc.
- David Laubie - Bridgestone Firestone
- David Schroeder - California Department of Transportation
- Diana Coles and staff - TravelCenters of America (Wheeler Ridge, CA)
- Eric Brooks and staff - TME Enterprises Inc.
- Greg H. Gentsch - Arizona Department of Transportation
- Guy Walenga - Bridgestone Firestone
- Harold Jones and staff - Flying J Inc. (Wytheville, VA)
- Harvey Brodsky - Tire Repair and Retread Information Bureau
- Jack Dowell and staff - Tucson Truck Terminal Inc. (Tucson, AZ)
- James Hannigan - Florida Department of Transportation
- James Patterson - Washtenaw County, MI
- Jennifer Maggon Judge - University of Michigan
- Steve Scanlan - Florida DOT
- Tim Cregger - Virginia Department of
- Jeremy Rayl - J Rayl Transport Inc.
- Jerry O'Connor - M&R Service
- Joel Martin - California Department of Transportation
- John Harris - TRC Inc.
- John Koch and staff - University of Michigan Transportation Research Institute
- John Wu - Rubber Manufacturers Association
- Katrina Newman Rogan - Indiana Department of Transportation
- Kevin Brennan - U.S. Department of Commerce
- Kristin McCray - Florida Department of Transportation
- Larry Evans - TRC Inc.
- Michael Bair and associates - Smithers Scientific Services Inc.
- Michael Dressler - University of Michigan
- Michael Hardiman - Indiana Department of Transportation
- Michael Shaffer - Liberty Tire Services of Ohio, LLC
- Mitch Burke - Bridgestone Firestone
- Mitch Windorff - Schneider International
- Myron Rolison - M&R Service
- Peggy Fisher - TireStamp Corp.
- Rick Denny - California Department of Transportation
- Ron Hutchison – Petro Shopping Centers (Reddick, FL)
- Steve Darmofal - GE Equipment Services
- Steve Fuller - California Department of Transportation
- Steven R. Bonham, Jr. and staff - VMS Inc.

Transportation

- Timothy R. Cullen - University of Michigan

Thanks also go out to several unnamed individuals who contributed to the success of this study.

GLOSSARY

Bead - A ring of steel wire that anchors the tire casing/carcass plies to the rim.

Belt - An assembly of plies extending from shoulder to shoulder of a tire and providing a reinforcing foundation for the tread. In radial-ply tires, the belts are typically reinforced with fine steel wire having high tensile strength.

Blowout - The rapid air loss or sudden deflation of a tire through an opening (i.e., hole) in the tire.

Casing - The tire structure, except tread and sidewall rubber, that bears the load when the tire is inflated.

Detachment - One or more of the tire's laminar components having become physically detached from adjacent components (e.g., the tread, or the tread and one or more steel belts, completely detaching from the casing).

Fatality - Any death resulting from a fatal injury at the time of the crash or within 30 days of the crash.

Fragment - Any portion of detached tread, or tread and belt(s), or belt(s) that is less than the total circumference.

Intact - Tires that have come out of service for some reason (road hazard, etc.), but have not sustained a detachment of any of the tire's laminar components.

Overinflation - A state when the cold inflation pressure in the tire exceeds what is needed for the tire to maintain an optimal footprint for the load it is carrying.

Ply - A sheet of rubber-coated parallel tire cords. Tire body plies are layered.

Retread Manufacturer - The business entity that provides the retread materials, equipment, and other items required in the retreading process. The retread manufacturer is most often NOT the entity that actually retreaded the tire.

Retreader - The business entity that actually retreads tires. Retreaders are very often independently-owned businesses that have made arrangements (franchise, dealer agreement, etc.) with a particular retread manufacturer to utilize its materials, equipment, and process. Some retread plant operations are owned and operated by the retread manufacturer.

Retreading - The process by which an additional tread is attached to a casing.

Rolling Resistance - The force at the axle in the direction of travel required to make a loaded tire roll.

Separation - One or more of a tire's laminar components having become separated from an adjacent component (or components) in the structure. The components, though separated, remain attached to the tire. The condition may be evidenced by polishing or other indications of relative motion of the separated layers.

Sidewall - The portion of the tire between the bead and the tread. The tire's name, safety codes, and size designation are molded on the sidewall.

Tire Scrub - A result of wheels that are rigidly secured together for rotation at the same speed but which must travel different distances at the inside and outside of the turning radii.

Tread - The peripheral portion of the tire designed to contact the road surface. The tread band consists of a pattern of protruding ribs and grooved channels on top of a base. Tread depth is measured on the basis of groove depth. Traction is provided by the tread.

Truck (Medium or Heavy) - A motor vehicle designed primarily for carrying property/cargo that has a gross vehicle weight rating of more than 10,000 pounds (or > 4,536 kilograms).

Vehicle Miles Traveled - The number of miles traveled by a vehicle for a period of one year. Vehicle miles traveled is either calculated by using two odometer readings or, for vehicles with less than two odometer readings, imputed using a regression estimate.

Sources: Deierlein, 2003; National Safety Council, 1996; Smithers Scientific Services Inc., 2008; and the Transportation Research Board, 2006.

ACRONYMS

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
AHAS	Advocates for Highway and Auto Safety
ASTM	American Society for Testing and Materials
ATA	America Trucking Associations
AZDOT	Arizona Department of Transportation
CALTRANS	California Department of Transportation
COE	Cab Over Engine
EDVSM	Engineering Dynamics Vehicle Simulation Model
EPA	Environmental Protection Agency
FDOT	Florida Department of Transportation
FMCSA	Federal Motor Carrier Safety Administration
FMVSS	Federal Motor Vehicle Safety Standards
INDOT	Indiana Department of Transportation
ISO	International Organization for Standardization
IVHS	Intelligent Vehicle Highway Systems
NAICS	North American Industry Code Classification System
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
OE	Original Equipment [Tire or Tread] Manufacturer
OSEH	Occupational Safety and Environmental Health Department of the University of Michigan
OTD	Original Tread Depth
P&D	Pick-up and Delivery
PSR	Passenger Vehicle Radial [Tire]
RMA	Rubber Manufacturers Association
RTD	Remaining Tread Depth
SAE	Society of Automotive Engineers
SIC	Standard Industrial Code Classification
SUV	Suburban Utility Vehicle
TBR	Truck or Bus Radial [Tire]
TIA	Tire Industry Association
TIN	Tire Identification Number
TMC	Technology & Maintenance Council
TPMS	Tire Pressure Monitoring System
TRIB	Tire Retread and Repair Information Bureau
USDOT	U.S. Department of Transportation
UTD	Useful Tread Depth
UTM	Useful Tread Mileage
VDOT	Virginia Department of Transportation
VLS	Visible Litter Survey

1 INTRODUCTION

1.1 Background

Trucking fleets and owners of commercial vehicles (heavy- and medium-duty trucks) use both new and retread tires on their vehicles in the United States. Retread tires are used primarily for the cost advantage and potential environmental benefit they provide over a similar new tire. “For most fleets, tires represent the second largest item in their operating budget, right after fuel costs” (Bandag, 2007). Savings in new tire purchase can significantly influence the bottom line for the trucking operator. Indeed, with the increase in the cost of crude oil and the need to engage alternative energy sources, retreads can and do make a positive environmental impact as “It takes approximately 22 gallons of oil to manufacture one new truck tire whereas it takes approximately seven gallons of oil to produce a retread” (Bandag, 2007).

A retread is essentially a used and remanufactured tire, where the old tread is buffed off and the tire casing is fitted with a new tread package through a mold-cure, pre-cure, or ring-tread process. According to 2002 U.S. Census figures, tire retreading is performed by approximately 600 establishments in the United States (U.S. Department of Commerce[a], 2004). The tire retread industry estimates there are 1,000 or more such establishments (Tire Retread and Repair Information Bureau, 2007). Several of the major tire manufacturers have a direct role in the retreading industry through franchised operations. However, the majority of these franchise operations are small businesses employing fewer than 100 employees.

The public perception is that retread tires are less safe than new tires and are responsible for the tire scraps found on the sides of most U.S. interstates. This negative attitude towards tire debris is confirmed by Phelan (2007) when he states that because “tire debris on roadsides is so visible compared to other forms of litter, some individuals and environmentalists have called for a ban on the use of retread tires.” In recent years, several U.S. States − Maine (1995), Pennsylvania (1995), Texas (1995), Tennessee (2001), and Florida (2007) – introduced legislation related to retread tires. However, all these attempts to legislate retreads have been defeated. Currently, there are no nationally mandated manufacturing or performance standards for medium- or heavy-duty tire retreads. Recognizing this situation, the general public may perceive that the lack of standards may result in no or weak standards or ineffective enforcement of standards. However, there are manufacturing standards governing retread quality that are industry-driven and that significantly improved the manufacturing quality of retread tires in recent years.

The Tire Retread and Repair Information Bureau (TRIB) and Technology and Maintenance Council (TMC) of the American Trucking Associations (ATA) contend that retreads are just as safe as new tires and that tire failures occur mostly due to lack of maintenance of the tire or through road hazard injury. The tire industry blames poor inflation pressure maintenance, overloading, mismatched tires, and steel belts failing for the majority of tire failures. Using this reasoning, most truck tire failures are thought to involve a failure of the casing rather than the retread product or interface. It has been proposed that tire pressure monitoring systems (TPMS) may directly target this cause and subsequently reduce tire road debris. In addition, some highway safety advocate organizations perceive retread tire failures as a significant problem and have called for the regulation of retread tires and/or the oversight of the retread process. Advocates for Highway and Auto Safety (AHAS) based in Washington, DC, made such a call in October 1998. Currently, there are no Federal Motor Vehicle Safety Standards (FMVSS) governing retreaded commercial (i.e., medium- or wide-base) truck tires.

Previous studies on tire debris were conducted by TMC in 1995 and 1998, the Commonwealth of Virginia Department of State Police in 1999, and the Arizona Department of Transportation in 1999. In all of these studies, retread tires were overrepresented in terms of their proportion of all tire debris items collected/surveyed. In the TMC studies, retreads averaged 86 percent of all the tire debris collected. Even though the conclusion of these studies was that specific manufacturing defects due to retreading were not responsible for most of the tire failures, it is evident in the data presented that retreads failed with greater frequency for all other types of tire failures including the maintenance and road hazard categories. The Arizona study categorized 72 percent of the medium- and heavy-truck tire samples collected as retreads. This same study estimated that in 1998, 63 percent of medium- and heavy-truck tires sold in the United States were retreaded (8.5% of the total for all tire sales).

1.2 Study Objectives

An article by Galligan (1999) noted that there is "a lack of industrywide, scientific data about what causes tire debris and a lack of consensus on how to improve it." Since that time, several tire debris studies have been conducted around the Nation. Each of these studies has sought to bring closure to the causes and impacts of tire debris on the Nation's highways. Although the implementation of recommendations from these studies may have improved individual fleet tire operations and management, the tire debris problem still remains. Adopting a scientific approach to determine the causes, extent, and impacts of tire debris, the study objectives were to:

1. Investigate the underlying causes of tire failures in heavy- and medium-duty trucks through an analysis of tire debris samples collected on interstate highways in five regions of the United States;
2. Determine the extent of truck tire failures for retread tires; and
3. Determine the crash safety problem associated with tire failures for large trucks.

In achieving these three objectives, this study has sought to contribute to scientific knowledge and close the gap in our understanding of tire debris on the Nation's highways.

1.3 Project Scope and Approach

There are millions of medium- and wide-base truck tires (the tire types of interest in this study) in use on the Nation's highways at any point in time. A medium truck tire is defined as a tire with "a rim diameter of 18-24.5" and cross section 11.50 or smaller, metric sizes with rim diameters from 19.5 up to and including 24.5, low platform trailer tire sizes 7.50 and larger, tube type tire sizes with a cross section of 11.50 or smaller and a rim diameter of 18" up to and including 25", and tubeless tires with a cross section of 12.75 or smaller and a rim diameter 19.50 up to 24.50". A wide-base truck tire is one which can replace two regular medium truck tires" (Rubber Manufacturers Association, 2006). The majority of these tires, whether retreads or new, are well maintained.

However, any tire has the potential to fail during service if it is damaged or its capabilities have been exceeded. As a first step in understanding the tire debris issue, existing literature and scientific studies post-1990 were consulted. The year 1990 was used as the cut-off year in this exercise as tire design and construction technologies have improved significantly post-1990. Additionally, the extent of the research presented in this report focuses on the United States only. This is partly due to the uniqueness of the U.S. trucking and highway environment in terms of the vehicle population and mix, highway extent, and miles driven, all of which are important factors influencing tire debris research.

The scientific method used in this project is designed to provide empirical information supporting or disproving several tire debris hypotheses. Gathering the required information and executing this research project took several months and involved the execution of a number of subtasks, each of which is described in a subsequent chapter.

A literature synthesis commences this study (Chapter 2) with an overview of the construction, manufacture, and structure of a new tire. The retread tire manufacturing process is also described. Statistics are presented for the new and retread tire industry with respect to production, sales, and manufacturing plants. The legal requirements of tire production are also described. The overview presented in Chapter 2 will enable the reader to put into context the manufacture and operation of a tire and whether these processes may influence its subsequent failure.

The ongoing debate over the incidence and traffic safety impacts of tire debris on the Nation's highways has influenced the continued study of this issue since 1990. Some of these studies have been regionally or nationally focused in their scope but all have had the primary objective of validating or disproving whether the retread tire is a contributing factor in the formation of tire debris on the Nation's highways. A review of these studies is presented in Chapter 3.

Chapter 4 presents an overview of commercial medium- or wide-base truck tire failure. There have been relatively few empirical studies about this issue, which in the past was due to the difficulty of following a tire from the "cradle to the grave." However, recent advances in tire technology have enabled tire life, distance traveled, and usage to be tracked by way of microchip/wireless technologies.

In recent years, several research projects have been conducted to assist in clarifying the concept of tire failure. However, the role of the initial cause precipitating tire failure and subsequent impacts on vehicle or highway safety is still unclear. Chapter 5 reviews commercial medium- and wide-base tire safety and durability issues with particular reference to retread tires. Methods for estimating the amount of tire debris on the Nation's highways and determining the extent of overrepresentation of debris generated by new or retread tires are also presented.

Stakeholder perspectives on the retread issue were sought from several organizations. Interviews were conducted with representatives from a brand-name truck tire manufacturer, a line-haul truck operator, and several members of a tire industry association. Their perspectives on new versus retread tire issues are presented in Chapter 6.

In recent years several advocates have called for greater oversight of the trucking industry in order to enhance the highway safety environment. Furthermore, these advocates have argued that the presence of tire shreds on the Nation's highways posed a safety hazard to road users, despite the lack of empirical data to validate their claim. Chapter 7 discusses the highway safety environment through the analysis of traffic crash injury and fatality statistics. The analyses presented in this chapter focus on traffic crashes involving trucks or roadside debris.

During the summer of 2007, a tire debris and casings collection exercise was conducted by the University of Michigan Transportation research Institute (UMTRI). The objective of this exercise was to collect a representative sample of tire fragments and casings for subsequent analysis to determine their status (new or retread) and their probable cause of failure. Chapter 8 describes the survey methodology followed in this tire debris collection exercise.

Chapter 9 presents the results of the tire casings and debris collected during summer 2007. The tire failure analysis methodology engaged in the testing of collected tire casings and fragments is also described. Overall, more than 86,000 tons of tire/rubber casings and debris were collected, of which 1,496 items were assessed to determine their probable cause of failure. The chapter concludes with a comparison of these results with previous tire debris surveys.

Chapter 10 summarizes this report and provides conclusions of the research.

2 THE ANATOMY OF A TIRE, TIRE MANUFACTURE, AND THE U.S. TIRE INDUSTRY

2.1 Introduction

The literature review commences with an overview of the concept of a new tire with respect to its structure and manufacture, as well as the associated U.S. manufacturing industry. The retread tire manufacturing process is then described. The overview presented in the following sections puts into context the manufacture and operation of a tire and whether these processes may influence its subsequent failure.

2.2 The Process of Tire Manufacture

A variety of chemicals are used in tire manufacture. Tire plants may produce and store some of these chemical ingredients on site or have them brought in from several suppliers. Typical chemicals used in tire manufacture include carbon black, silica, and sulfur.

Compounding and Mixing
At this stage of the process, all the required ingredients in the manufacture of a tire are brought together and mixed to form a homogenous “hot, black, and gummy” compound. Different sections of the tire require different compound mixtures. Heat is generated during the mixing process which is performed using a Banbury® Mixer. The mixing temperature is a critical element in ensuring the quality and integrity of the rubber compound produced.

Processing
The processing step involves:

Milling: The cooled rubber (in the form of thick slabs) is continuously fed between pairs of rollers that feed, mix, and blend the compound.

Extruding: The rubber compound is forced through a die (mold or template) that creates different tire components (e.g., sidewall or tread) for future tire building.

Calendaring: The rubber compound is coated with fabrics (e.g., polyester, rayon, steel, or nylon) that will be used in the construction of the tire with the rubber compound.

Cooling and Cutting
Water is used to cool the rubber compound which is subsequently cut to the required lengths and weights for the tires being built.

Tire Building
A tire building machine is used to preshape the various components (e.g., sidewalls, bead assemblies, etc.) into a shape that is very close to the tire’s final dimensions. Subsequently, a second machine is used to apply other components (e.g., belts and tread) on top of the first stage. At this point in the process, the tire does not have any tread pattern.

Vulcanizing
Vulcanizing or tire curing is the stage where the uncured tire is placed in a mold where high temperatures and pressure are applied to the uncured tire. The curing process converts and bonds the various components of the uncured tire into a highly elastic product. Here the tire mold is engraved with its tread pattern, the sidewall markings, and other marks as required by law.

Finishing
At this final stage of the tire manufacture process, the tire is inflated, trimmed, and balanced. This procedure is then followed by visual and x-ray inspections performed simultaneously with painting and marking of the tire as required. Figure 2.1 presents the tire manufacturing process.

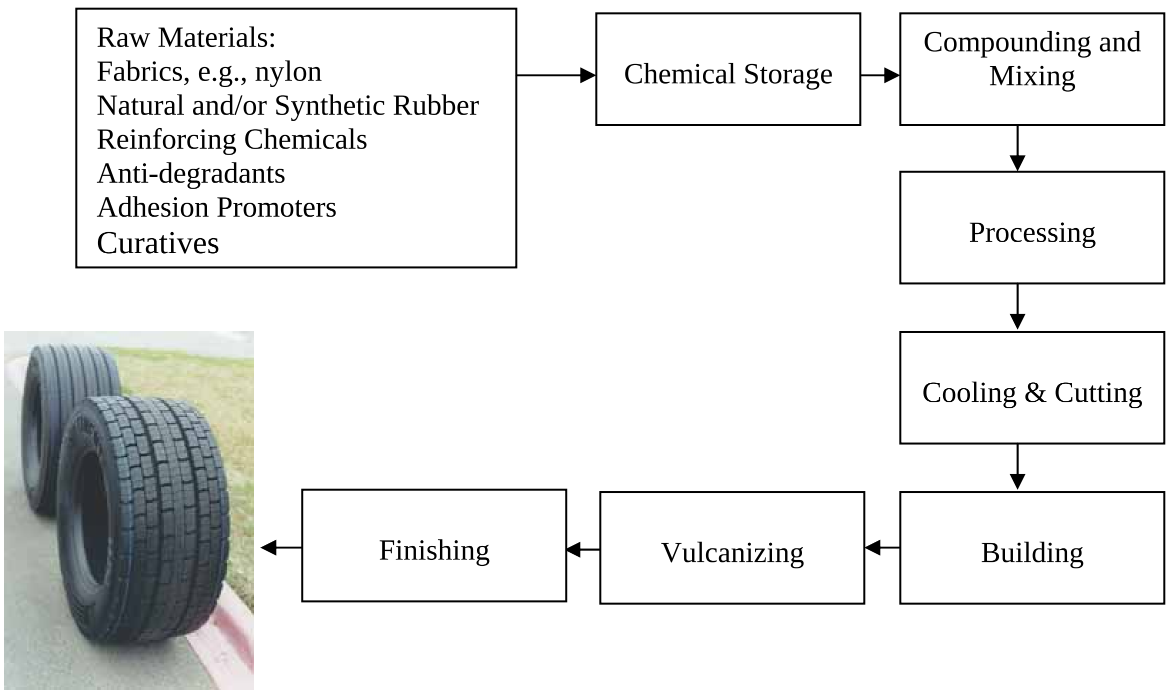


Figure 2.1 - The Tire Manufacturing Process

2.3 The Structure of a Tire

Figure 2.2 (Goodyear, 2003) presents a cross-sectional view of a typical tire illustrating the various components (e.g., bead core) and specific areas (e.g., sidewalls) that make up the tire structure. A brief explanation of these various components and areas follows (overleaf).

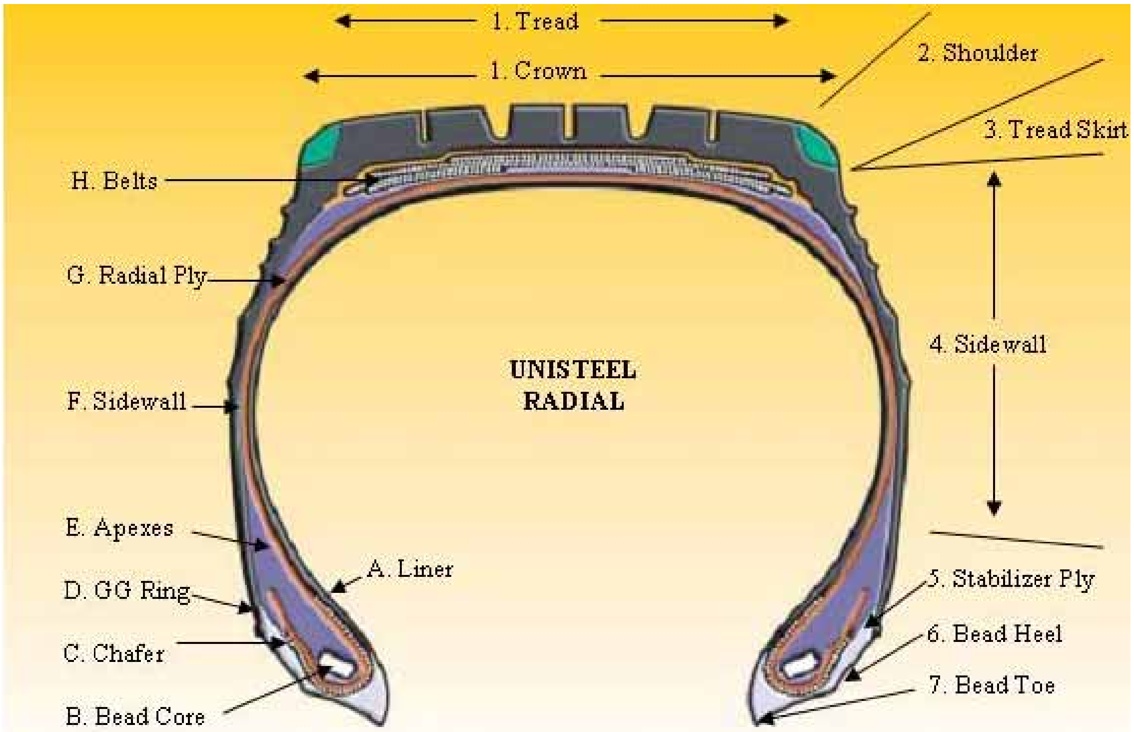


Figure 2.2 – Tire Structure
Source: Goodyear, 2003

Tire Components

A. Liner

A layer or layers of rubber in tubeless tires that resists air diffusion. The liner in the tubeless tire replaces the inner tube of the tube-type tire.

B. Bead Core

The major structural element in the plane of tire rotation that maintains the required tire diameter on the rim. The bead core is made of a continuous high-tensile wire wound to form a high-strength unit.

C. Chafer

A layer of hard rubber that resists rim chafing.

D. GG Ring

Used as reference for proper seating of the bead area on the rim.

E. Apexes

Rubber pieces with selected characteristics used to fill in the bead and lower sidewall areas and to provide a smooth transition from the stiff bead area to the flexible sidewall.

F. Sidewall
Withstands flexing and weathering and provides protection for the ply.

G. Radial Ply
Together with the belt plies, withstands the loads of the tire under operating pressure. The plies must transmit all load, driving, braking, and steering forces between the wheel and the tire tread.

H. Belts
Steel cord belt plies provide strength, stabilize the tread, and protect the air chamber from punctures.

I. Tread
This rubber provides the interface between the tire and the road. Its primary purpose is to provide traction and wear.

Tire Areas

1. **Crown**
   Area of the tire that contacts the road surface.
2. **Shoulder**
   Transition area between the crown and tread skirt.
3. **Tread Skirt**
   Intersection of tread and sidewall.
4. **Sidewall**
   Area from top of the bead to the bottom of the tread skirt.
5. **Stabilizer Ply**
   A ply laid over the radial ply turn up outside of the bead and under the rubber chafer that reinforces and stabilizes the bead-to-sidewall transition zone.
6. **Bead Heel**
   Area of bead that contacts the rim flange, the "sealing point" of the tire/rim.
7. **Bead Toe**
   The inner end of the bead area.

2.4 Tire Design – Bias- or Radial-Ply

There are two basic types of tire design, bias- and radial-ply. In section 2.18, statistics are presented that show the dominance of radial tire production and use in the United States. However, an overview about the differences between the two designs is given here. A bias-ply tire (enhanced by the vulcanization process developed by Charles Goodyear in the late 1800s) is constructed with the cross plies running in a diagonal direction, anywhere between +60 to -60 degrees, from tire bead to tire bead. Radial-ply tires on the other hand (introduced and patented by Michelin in 1946) are constructed where the cross plies run at 90 degrees from tire bead to tire bead, in addition to tire belts (steel or nylon) wrapped around the tire in the direction of travel. The differences in cross ply alignment according to tire type are illustrated in Figure 2.3.

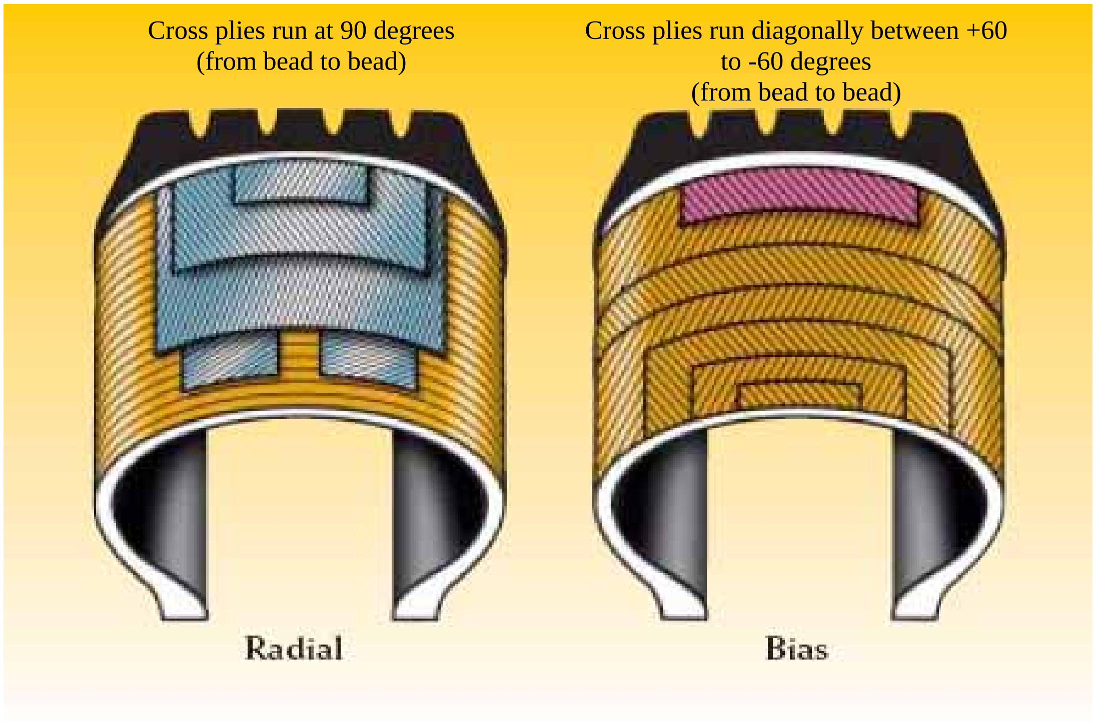


Figure 2.3 – Radial versus Bias-Ply Tire Structures

Source: Goodyear, 2003

A listing of the strengths and weaknesses of bias versus radial-ply tires is presented in Table 2.1.

Table 2.1 – Tire Design Strengths and Weaknesses

Tire Design	Strengths	Weaknesses
Bias Ply	• Stiffer sidewalls give better driver handling/feel • Lower susceptibility to sidewall snags, hazards, and rusting • Load-carrying capability in relation to tire size • Lower initial tire purchase price	• Increasing the strength of bias-ply tires through increasing the number of plies increases heat retention, which in turn reduces tire life. • Deflection of the sidewalls squeezes and distorts the tread, which in turn decreases traction and operator control and accelerates tread wear and fuel consumption.
Radial Ply	• Better treadwear performance (i.e., traction and longevity) • Higher potential for retreading • More fuel-efficient • Lower susceptibility to tread punctures • Better traction characteristics (i.e., less distortion of the contact patch surface) • Reduction in plies rubbing up against each other decreases rolling friction while improving fuel economy	• "Low on air" bulging look of the tire sidewalls • Greater knowledge required for proper set-up and maintenance • Tubeless technology more difficult to fit/repair in field

Sources: Goodyear, 2003

2.5 The Retread Tire Process

The tire retread process (i.e., pre-cure or ring-tread) is described is this section. In some cases there are slight differences in the techniques used according to the retread process adopted by each retread plant. However, all retread processes strive for the same end result, a tire that "meets the same quality standards as an original equipment tire."

Step 1 - Casing Receiving

Casings are received at the retread plant (Figure 2.4). Each casing is marked (or given a unique bar code) with basic information that will enable easy identification and tracking during the retread process.

Step 2 - Initial Inspection

The initial inspection is performed visually and is often hands-on (Figure 2.5). This process determines whether the casing is retreadable according to accepted industry standards. Marks are made on the casing to identify any visible defects (e.g., a cut, bruise, or puncture). Casings that do not meet the required retread standards, due to factors such as extensive sidewall damage, are rejected at this stage. Industry practices promote that "a tire must be less than five years of age to be retread" (Day, 2007).

Step 3 - Secondary Inspection

A variety of noninvasive or nondestructive devices, such as florescent light probes, are used at this step of the process (Figures 2.6 and 2.7) to identify internal casing defects that are invisible to the naked eye. A typical technique used is shearography, which is a nondestructive testing procedure that can detect casing defects (within the casing) using laser technology. Different original equipment [tire/tread] manufacturers (OEs) have adapted the shearography testing procedure to give them a competitive edge. For example, Goodyear uses ultrasound (i.e., high-energy sound waves), while Michelin uses a combination of shearography and fluoroscopic X-rays (Bearth, 2007). Casings that do not meet the required retread standards at this stage of the process are rejected.

Step 4 - Buffing

A buffing machine is used to remove the tread (i.e., the old, worn tread design) from the casing (Figure 2.8) to prepare it to receive the new tread. The casing is buffed to a specified crown width, profile, and radius.

Step 5 - Casing Preparation and Repair

Removal of the old tread may expose minor defects which are then repaired (Figures 2.9 and 2.10). Any injuries identified are determined repairable or nonrepairable. Casings that do not meet the required retread standards (after any attempted repair) at this stage of the process are rejected.

Figure 2.4 – Casings Received for Retreading

Figure 2.5 – Hands-On Inspection of Casing

Figure 2.6 - Shearographer

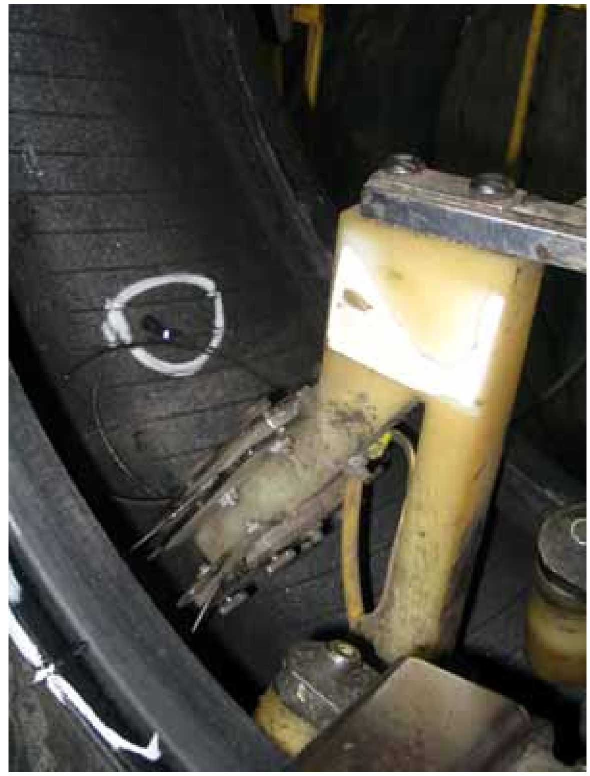


Figure 2.7 – Shearographer at Work

Figure 2.8 – A Buffing Machine

Figure 2.9 – A Buffed Casing Showing Area in Need of Repair

Figure 2.10 – A Buffed Casing After Required Repair

Step 6 - Application of New Tread (or Building)
A thin strip of rubber (the uncured bonding layer) is then applied to the casing to enable the new tread to bond to the casing (Figures 2.11 and 2.12). The new tread is then centered and aligned to the casing. Three methods of new tread application are available in the retread process: mold-cure, pre-cure, and ringtread (discussed in section 2.5).

Step 7 - Enveloping
A reusable rubber envelope is wrapped around the uncured casing (Figure 2.13) and a vacuum is created.

Step 8 - Vulcanizing (or Curing)
The enveloped casing is placed in a curing chamber (Figure 2.14) where the new tread is bonded with the casing through the vulcanization process. The objective of this process is to increase the cross-linking of the rubber polymer chains, the greater the cross-linking, the greater the strength of the finished product. Time, heat, and pressure combine during the vulcanization process. The amount of heat that is applied is critical, as too much heat may "cause the original tire to deteriorate faster" (Waytiuk, 2008). The following account aptly describes the process. "One way to visualize this (i.e., vulcanization) is to think of a bundle of wiggling snakes in constant motion. If the bundle is pulled at both ends and the snakes are not entangled, then the bundle comes apart. The more entangled the snakes are (like the rubber matrix after vulcanization), the greater the tendency for the bundle to bounce back to its original shape" (Environmental Protection Office, 2005). During the vulcanization process, "the separate tire layers and components do not mix or become homogenous. Rather, the materials chemically bond together" (Gardner & Queiser, 2005).

Step 9 - Final Inspection
The retread tire is inspected to ensure that all industry standards are met. "A warm tire can reveal anomalies and separation more readily because it is swollen by the heat" (Terry Westhafer quoted in Commercial Tire Systems, 2001). Casings that do not meet the required retread standards at this stage of the process are rejected.

Step 10 - Preparation for Shipping
The retread tire is then painted, marked (with required industry and federal identification marks as discussed in section 2.10), and made ready for delivery to the customer (Figures 2.15 and 2.16).

2.5.1 Mold-Cure, Pre-Cure, and Ring-Tread Retread Processes
Currently in the U.S. retread industry, there are three retread manufacturing processes: mold-cure, pre-cure, and ring-tread. Usually, a particular retread franchise adopts in one of these processes.

- In the mold-cure process (Figures 2.17 to 2.19), unvulcanized (i.e., uncured) rubber is strip-wound to the buffed casing. The casing and unvulcanized rubber are subsequently placed into an individual rigid mold where the tread design is molded in and the tread rubber is cured. Since this curing process requires temperatures in the range of 300º F, many in the industry refer to a mold-cure retread as a "hot cap."

Figure 2.11 – Application of New Tread (Precure Process)

Figure 2.12 – Application of New Tread (Ringtread Process)

Figure 2.13 – Pre-Cured Retread Casings Enveloped

Figure 2.14 – Inside Vulcanization Chamber

Figure 2.15 – Painted New Retread Casings

Figure 2.16 – New Retread Casings With Ringtread Identification Markings

Figure 2.17 – Uncured Rubber (Mold-Cure Process)
Courtesy of Bridgestone Firestone

Figure 2.18 – Uncured Rubber Wrapped Around Casing (Mold-Cure Process)
Courtesy of Bridgestone Firestone

Figure 2.19 – Removing Casing from Retread Mold (Mold Cure Process)
Courtesy of Bridgestone Firestone

- In the pre-cure process (Figures 2.20 and 2.21), previously cured tread rubber stock, which contains a tread pattern, is applied to the buffed tire casing. The new tread is spliced onto the buffed casing in the pre-cure system. Splicing enables the pre-cured tread to correctly fit the circumference of the buffed casing. A thin layer of uncured rubber and cement is placed between the casing and the bottom of the new tread and that thin layer is cured, resulting in the bond between the new tread and the casing. Some in the industry refer to this curing process as "cold cap," even though this process requires temperatures in the range of 200º F.
- The ring-tread process (Figures 2.22 to 2.24) involves the pre-cured and non-spliced tread (with tread pattern) being wrapped (i.e., stretched) around the buffed casing. A thin layer of uncured rubber and cement is placed between the casing and bottom of the new tread and that thin layer is cured, resulting in the bond between the new tread and the casing.

2.6 Retread Costs and Benefits

Tire industry advocates state that seven gallons of oil are required to make a retread, compared to 22 gallons to make a new tire. This cost differential enables savings to U.S. truck operators of approximately $2 billion per year (Condra, 2007). Apart from direct operating costs savings, there are other benefits cited such as:

- A reduction in the dependence on and use of fossil-based fuels (e.g., oil); and
- Reduction in the volume of tire scrap. The growth in scrap tire generation from all vehicle types has been balanced by the increasingly environmentally friendly uses developed for scrap tires to reduce the numbers of tires that may end up in landfills or stockpiles. RMA statistics also

Figure 2.20 – Precured Rubber Tread (Precure Process)

Figure 2.21 – Precured Rubber Tread Wrapped Around Casing (Precure Process)
(Note: Tread splice is clearly seen)

Figure 2.22 – Precured Tread (Unbroken) Stretched to Receive Casing (Ringtread process)

Figure 2.23 – Precured Tread (Unbroken) Brought Into Place around Casing (Ring-Tread Process)

Figure 2.24 – Precured Tread (Unbroken) Positioned Into Place Around Casing (Ring-Tread Process)

indicate that an environmentally friendly use was found for 86 percent of the scrap tires generated in 2005.

2.7 Regrooving

Regrooving is the process of extending the mileage of a casing by renewing the tread pattern by carving out a new or similar tread pattern. Regrooving is permissible where there is sufficient undertread depth (the thickness from the bottom of the original tread to the top of the uppermost belt). An indication of whether a casing can be regrooved is branded on the casing sidewalls at the time of original manufacture. According to industry practices, regrooving is more common with bus fleets than in trucking fleets. Regrooving is performed subject to prevailing regulatory guidelines (currently Chapter 49 Code of Federal Regulations 569.3) and requires a skilled operator with appropriate tools. Regrooving of tires to be used in a steer position is prohibited as defined in Title 49 CFR Section 393.75 Tires which states that: (d)"No bus shall be operated with regrooved, recapped or retreaded tires on the front wheels," and (e)"A regrooved tire with a load-carrying capacity equal to or greater than 2,232 kg (4,920 pounds) shall not be used on the front wheels of any truck or truck tractor." Figure 2.25 illustrates the tread pattern of a regrooved tire collected as part of this study.

2.8 The U.S. Commercial (Medium- and Wide-Base) Truck Tire Industry

2.8.1 Standard Industrial Code Classification

The Standard Industrial Code (SIC) classification system established in the 1930s classified (by way of a four-digit code) products produced in the United States into various industry groups and subgroups. For example, SIC code #3011 represents the tire and inner tube industry, and SIC #7534 is used for the retread or recapping tire industry. The first two digits of the SIC code designate the broad industrial group or process. Thus, SIC code 30XX included establishments that manufacture products from plastic resins, natural and synthetic rubber, reclaimed rubber, etc., of which tire manufactures are a subgroup (Environmental Protection Office, 2005). Codification of industrial products and processes allows the tracking of flows (i.e., financial or units of production) of goods and services in an economy, an invaluable tool in macroeconomics.

2.8.2 North American Industry Classification System

During 1997, the North American Industry Classification System (NAICS) superseded the SIC system. NAICS classifies industry groups or industrial processes according to a six-digit code and is used primarily in the United States, Canada, and Mexico. Thus, the four-digit SIC code migrated to a six-digit NAICS code. For example, SIC code #3011 designating tire manufacturing (pneumatic, semi-pneumatic, and solid rubber) became NAICS code #326211, and SIC #7534 (tire retreading, recapping, or rebuilding) became NAICS code #326212. For the purposes of the economic overview of the tire industry presented in this section, the NAICS codes and associated industrial and financial outputs will be used.

Figure 2.25 – Tread Pattern on a Regrooved Tire
(Note: Amateurish Tread Pattern Design)
Source: Smithers Scientific Service Inc.

2.8.3 Tire Original Equipment Manufacturers

In 2005 there were approximately 18 U.S. tire OEs (Rubber Manufacturers Association Factbook, 2006; Tire Business, 2006). However, of these 18 OEs, only seven were involved in the manufacture of truck and bus tires (a full listing of OE manufacturers is found in Appendix A). These 18 tire manufacturers operated approximately 48 tire plants in 17 States across the United States. In 2005, Ohio had the highest number of tire manufacturing plants at six. Figure 2.26 presents the geographical distribution by State location of the 48 original equipment tire manufacturing plants. It is apparent that the geographical location of these tire plants is skewed towards the midwest, northeast, central, and southeastern regions of the United States.

2.8.4 Retread Tire Manufacturers

Estimates of the number of retread tire manufacturers/plants can be obtained from various sources. The 2002 Economic Census for the Tire Retreading Industry estimated that there were 597 U.S.-based establishments involved in tire retreading (U.S. Department of Commerce[a], 2004). However, not all tire retread plants by State location are identified in the census data. An additional source for data on the number of tire retread plants (and establishments that transact business in retread tires) is TRIB. TRIB is a tire retread and repair industry association, retread industry advocate, and information bureau based in California. Lastly, NHTSA is another source for estimating the number of retread tire plants in the United States.

Figure 2.26 Geographic Distribution of the Tire Industry (2005)
Source: Rubber Manufacturers Association, 2005

It is required that any establishment that intends to manufacture retread tires (which are to be sold to a third party in the United States) obtain a three-letter authorization code from NHTSA. This three-letter code is a unique identifier for each retread plant. Summary statistics by State indicating the numbers of U.S.-based retread plants from each of the three sources are presented in Table 2.2.

Table 2.2: Retread Establishment (i.e., Plant) Statistics 2005

State	**# of Retread Establishments[1]**	**# of Retread Establishments and/or Vendors[2]**	**# of Retread Establishment Codes Issued[3]**
Alabama	20	25	208
Alaska	*	4	12
Arizona	8	18	57
Arkansas	10	31	113
California	52	85	502
Colorado	10	35	97
Connecticut	*	8	64
Delaware	*	0	8
District of Columbia	*	0	1
Florida	40	53	227
Georgia	20	31	271
Hawaii	*	1	33
Idaho	*	0	45
Illinois	19	44	105

Table 2.2: Retread Establishment (i.e., Plant) Statistics 2005 (continued)

State	# of Retread Establishments[1]	# of Retread Establishments and/or Vendors[2]	# of Retread Establishment Codes Issued[3]
Indiana	15	20	113
Iowa	11	28	47
Kansas	*	20	58
Kentucky	10	15	115
Louisiana	10	25	66
Maine	*	9	26
Maryland	*	18	53
Massachusetts	*	9	48
Michigan	21	26	104
Minnesota	7	30	73
Mississippi	9	17	102
Missouri	18	38	125
Montana	*	4	42
Nebraska	7	10	35
Nevada	*	9	21
New Hampshire	*	6	21
New Jersey	8	6	60
New Mexico	*	12	29
New York	20	22	158
North Carolina	25	52	583
North Dakota	*	9	19
Ohio	28	24	242
Oklahoma	*	14	88
Oregon	12	7	102
Pennsylvania	32	76	323
Rhode Island	*	0	13
South Carolina	9	15	174
South Dakota	*	12	23
Tennessee	21	17	179
Texas	50	98	284
Utah	*	11	69
Vermont	*	1	14
Virginia	11	27	252
Washington	*	2	93
West Virginia	*	7	97
Wisconsin	7	54	65
Wyoming	*	9	20
Total	**595**	**1,094**	**5,679**

Notes for Table 2.2: Retread Establishment (i.e., Plant) Statistics 2005 (continued)
* There may be retread facilities in these States, but actual numbers are low and have been suppressed by the U.S. Census Bureau to protect privacy/confidentiality (personal communication with Kevin Brennan of the U.S. Census Bureau).
Sources:
1. 2002 Economic Census U.S. Census Bureau
2. Tire Retread and Repair Information Bureau (downloaded State-by-State vendor statistics 08/10/2007)
3. U.S. Department of Transportation (downloaded 08/10/2007) (authors' analysis of the dataset)

Table 2.2 indicates a wide disparity among the numbers of retread establishments derived from the three sources presented. Statistics from the 2002 Economic Census can be taken to represent the base case, as the census is developed from a sample of retread tire plants. The statistics from TRIB represent manufacturers and vendors of tire retread products and it was not possible from an analysis of the data to differentiate manufacturers from vendors. Caution is warranted in estimating the number of retread plants using the NHTSA codes, as possession of a code does not imply that the plant is still operational today.

2.9 Tire Identification Numbers and Authorization

Enterprises involved in the manufacture and sale (to third parties) of OE (i.e., new) or retread tires in the United States are issued with a unique two- or three-letter code by NHTSA on behalf of the U.S. Department of Transportation (U.S. DOT). The tire identification number (TIN) was instituted as a method by which new tire manufacturers, tire brand-name owners, tire distributors, retreaders, and retread tire brand-name owners can identify and record any tire used on a motor vehicle. The issue of the TIN is subject to a written application made to NHTSA by the prospective pneumatic and non-pneumatic tire manufacturers or retreaders. The legislation states (Code of Federal Regulations [CFR] part 574.5 [Office of the Federal Register, 2007]) with respect to OEs:

"Each tire manufacturer shall conspicuously label on one sidewall of each tire it manufactures, except tires manufactured exclusively for mileage contract purchasers, or non-pneumatic tires or non-pneumatic tire assemblies, by permanently molding into or onto the sidewall…a tire identification number."

And with respect to retreaders:

"Each tire retreader, except tire retreaders who retread tires solely for their own use, shall conspicuously label one sidewall of each tire it retreads by permanently molding or branding into or onto the sidewall…a tire identification number."

The TIN permits the notification by OE manufacturers or retreaders (in the interest of motor vehicle safety) of purchasers of OE and retreaded tires should such items be defective or nonconforming. The TIN is comprised of four groups of symbols, letters and, numbers (illustrated in Figure 2.7) as follows:

Group 1 - Two or three symbols represent the manufacturer's assigned identification mark.
Group 2 - Two symbols (for OEs) represent tire size.

Two symbols (for retread tires) represent retread processing matrix or tire size (if no matrix was used).

Group 3 - Four symbols (maximum) represent a descriptive code for the purpose of identifying significant characteristics of the tire. (Note: this code is optional.)

Group 4 - The first two symbols represent the week of manufacture (i.e., 01 to 52) and the third and fourth symbols represent the year of manufacture (i.e., 00 to 99). (Note: this arrangement applies to tires manufactured after July 2, 2000).

Figure 2.27 – Tire Identification Marks on a Casing

Key:

1. DOT required symbol (i.e., "DOT" for new or "DOT-R" for retread tires)
2. Manufacturer's Identification Mark (MC = The Goodyear Tire & Rubber Company, Danville, VA)
3. Tire Size (manufacturer specified)
4. Tire Type Code (optional)
5. Date of Manufacture 4600 = Week 46 of 2000 (i.e., 12 to 18 November, 2000)

Original Casing #1 to #5

6. R = Retread (1R could indicate 1st retread)
7. Retreader's Identification Mark (BRR = Southern Tire Mart LLC, Dallas, TX)
8. Tire Type Code (optional)
9. Date of Retread 0506 = Week 5 of 2006 (i.e., 30 January to 5 February, 2006)

First Retread #6 to #9

2.10 Passenger-Car Tire Retread Standards

Passenger car tire retread standards are governed by CFR 571 Section 117. The purpose of this standard is to "require retreaded pneumatic passenger car tires to meet safety criteria similar to those for new pneumatic passenger car tires" (Office of the Federal Register, 2007). The standards mandate that a retreaded passenger car tire must:

- At minimum meet applicable performance standards of the original casing;
- Be manufactured on a casing that is of good quality (i.e., without exposed cord fabrics, and with intact and original belts and plys). Replacement of the original belts or plys or the need for substantive repairs may render rejection of the passenger-car tire casing; and
- Be manufactured on a casing that displays the required DOT sidewall marks and branding (see section 2.10)

No guidance given as to the wheel placement of retread passenger-car tires or their preferred operating regime. Thus, it is assumed that retread passenger-car tires can be used on any wheel and operate in a similar fashion as an OE.

2.11 Commercial (Medium- or Wide-Base) Retread Tire Standards

Currently, there are no legislated standards for commercial (i.e., medium- or wide-base) retread tires. Standards can relate to manufacturing or testing. Discussions with industry representatives revealed that the various OE manufacturers do apply their own standards for retread tires, but there are no uniform manufacturing or performance standards applied throughout the retread tire industry.

One of the challenges in adopting a unified standard for commercial retreaded tires is recognizing that the retread is being used on a casing that has already passed applicable U.S. DOT standards (i.e., Federal Motor Vehicle Safety Standard [FMVSS] part 571 section119). Any casing that does not have its original tread and is subsequently retread does not require U.S. DOT markings. The only marks required are the retreader's DOT (i.e., TIN, see section 2.10) and if the retreader uses these retreaded tires in-house even these marks are not required (see section 2.10). To some industry stakeholders this situation is seen as a flaw in the current regulatory environment. A retreader can import casings from overseas without U.S. DOT markings and retread these same casings for use in their own fleets without ever needing to show U.S. DOT markings. Currently, the numbers and proportion of commercial tires in the United States that lack U.S. DOT markings are unknown.

2.12 Tire Plant Identity Code and Authorization

Enterprises involved in the manufacture and sale (to third parties) of OEs in the United States are issued with a unique two-alphanumeric-character code by NHTSA (on behalf of the U.S. DOT). It is therefore possible through analysis of these codes to estimate the number of manufacturing plants (domestic and international) that supply tires to the U.S. passenger and commercial motor-vehicle market. According to the 2005 Global Tire Report (Tire Business, 2006), 791 codes had been issued by the U.S. DOT at the time of the survey. Furthermore, 110 of the codes issued were for "closed" plants and at least 30 were for factories that did not make tires or manufactured bicycle tires and/or tubes. Numbers of tire manufacturing plant identity codes issued by NHTSA according to country are presented in Table 2.3.

Table 2.3 - U.S. DOT Tire Manufacturing Plant Identity Codes (By Country of Company Headquarters) as of November 2007

Country	# Manufacturing Plant Codes Issued	Rank
China	247	1
United States	129	2
India	38	3
Japan	29	4
Germany	28	5
Thailand	26	6
France	25	7
Canada	22	8
Brazil	18	9
Mexico	18	10
Subtotal	580 (69%)	
Other	261 (31%)	
Grand Total	841 (100%)	

Source: US Department of Transportation (downloaded 11/01/2007) (authors' analysis of the dataset)

Table 2.3 presents the top 10 countries ranked according to the number of tire manufacturing codes issued by NHTSA. It is evident that the 10 countries in Table 2.3 account for nearly 70 percent of all permits issued, and China alone accounts for nearly 30 percent. It can also be inferred from the data that a significant proportion of new tires sold in the United States are manufactured abroad. In the three years between 2005 and 2007, the number of tire manufacturing plant permits issued has grown by 50 (791 to 841) or 6 percent. Again, caution is warranted in estimating the number of tire manufacturing plants using the U.S. DOT codes, as this dataset represents codes issued to each plant (at some point in time from the conception of the database) and possession of a code does not imply that the plant is still operational (i.e., at the time of writing). In addition, the purging of tire manufacturing plant codes has not been undertaken for some time. A full listing of tire manufacturing permits issued by NHTSA according to country appears in Appendix B.

2.13 New Equipment and Retread Tire Manufacturing Statistics

The OE and retread tire manufacturing industries are highly competitive and proprietary, which has resulted in the lack of detailed sales statistics (e.g., manufacturer sales or units of production statistics by State) made available for public consumption. However, two sources are available to access tire sales statistics, though they are presented in aggregate format: the Rubber Manufacturers Association (RMA) and *Tire Business* (a tire industry news source). The RMA collects tire production statistics from its members and presents them annually in its *U.S. Rubber Industry Factbook* (at the time of writing, the latest edition was for the year 2006 representing calendar year 2005). *Tire Business* presents an exhaustive global review of the tire industry in its annual *Global Tire Report*. (August 2007 saw the publication of the 2007 Global Tire Report representing the calendar year 2006).

2.14 Original Equipment Tire Sales Statistics

According to figures obtained from *Tire Business* for the year 2004 (the most complete year for which data was available), North American tire sales approximated $27.3 billion. Four tire manufacturers were responsible for 75 percent of tire sales (by dollar value), namely Goodyear Tire and Rubber, Michelin North America, Bridgestone Firestone, and Cooper Tire and Rubber Company. Table 2.4 presents statistics for the top 10 tire manufacturers based on 2004 tire sales.

Table 2.4 – North American Tire Sales (2004)

Manufacturer	Tire Sales ($ millions)	Percent	Rank
Goodyear Tire & Rubber	7,900	28.9%	1
Michelin North America	6,300	23.0%	2
Bridgestone Firestone	4,500	16.4%	3
Cooper Tire & Rubber Co.	1,875	6.9%	4
Continental Tire North America	1,730	6.3%	5
Yokohama Tire Corp.	650	2.4%	6
Toyo Tire (USA) Corp.	500	1.8%	7
Kumho Tire USA	400	1.5%	8
Hankook Tire America Corp.	325	1.2%	9
Pirelli North American Tire	325	1.2%	10
Other	2,867	10.5%	na
Total	27,372	100%	

Source: Personal communication with Tire Business official

Table 2.5 presents OE data by number of units produced for the period 2001 to 2005, showing consistent growth in the number of OE and replacement tires produced. Estimates for retread tires have fluctuated during the same period. It is evident from Table 2.5 that OE truck tire production (by RMA members only) accounted for 25 to 35 percent of the replacement (aftermarket) medium-truck tire production. However, this disparity is to be expected, as OE truck tire production is directly linked to new truck and trailer production rather than to the overall demand for medium-truck tires. Figure 2.28 presents the tire production data in Table 2.5 graphically.

Table 2.5 – Tire Production Statistics (2001 to 2005) (in Thousands)

Year	Original Equipment (RMA members only)	Total Industry Replacement (Aftermarket)	Retread Tires (Estimate)
2001	3,441	13,572	15,560
2002	3,862	14,721	15,560
2003	4,160	15,516	15,463
2004	5,742	16,288	15,061
2005	6,238	17,523	15,249

Source: RMA Factbook 2006

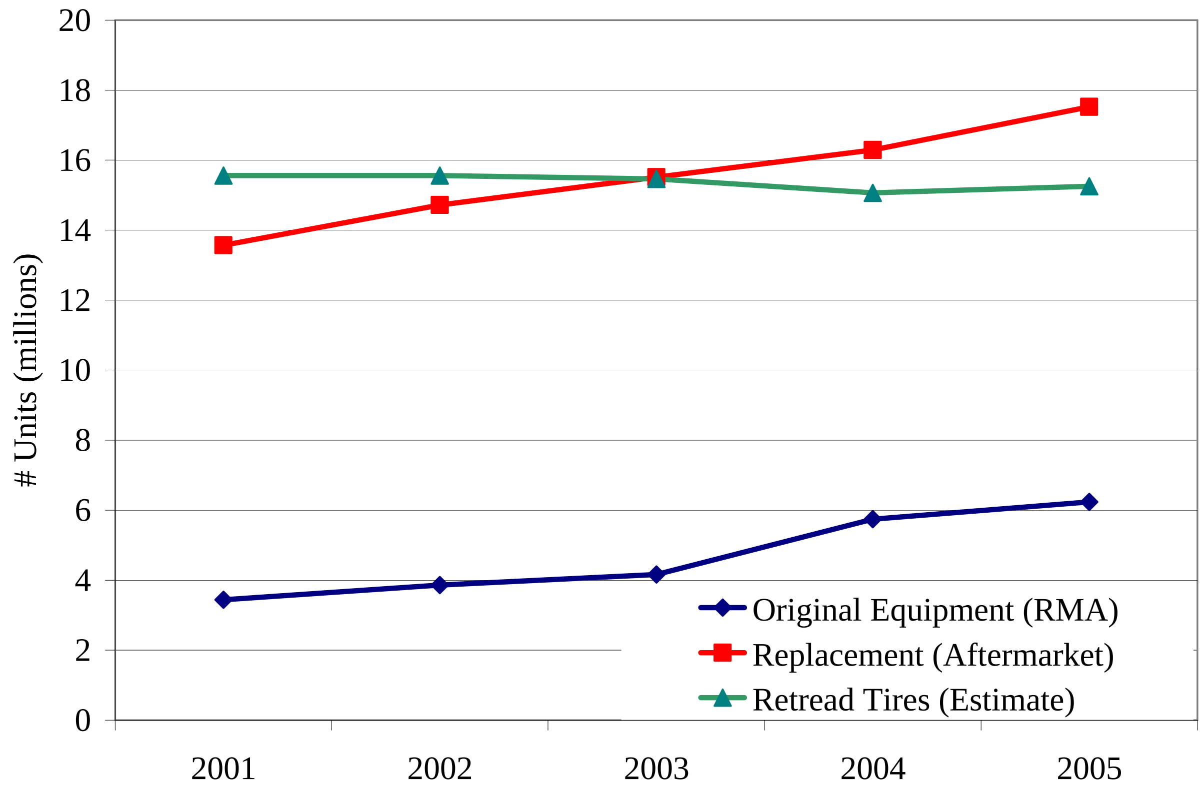


Figure 2.28 - Tire Production Statistics (2005)
Source: RMA, 2006

2.15 Retread Tire Manufacturer Production Statistics

Each year the publication *Modern Tire Dealer* produces a ranking of the 100 top retread plants in the United States, based on the average amount of tread rubber used to retread different types of tires. In order to retread a commercial medium- or heavy-duty truck tire, it is assumed that on average 24 pounds of rubber is required. Information gained from the individual companies with respect to the volume of rubber supplied is then approximated into the number of retread tires manufactured. The 2005 rankings for medium- and heavy-truck retread tires are presented in Table 2.6.

Table 2.6 – The Top 10 Medium Truck Tire Retreaders in the United States (2005)

Rank	Company	# Truck Tire Retreads/Day	Retread Method	Retread Process Franchisor
1.	Wingfooot Commercial Tire Systems LLC	6,610	Precure & Mold Cure	Goodyear
2.	Tire Centers LLC	3,000	Precure & Mold Cure	Michelin
3.	Best One Group	2,145	Precure	Bandag
4.	BFS Retail & Commercial Operations LLC	1,955	Precure & Mold Cure	Oliver, Bandag, Oncor
5.	Chicago Bandag	1,600	Precure	Bandag

Table 2.6 – The Top 10 Medium Truck Tire Retreaders in the United States (2005) (continued)

Rank	Company	# Truck Tire Retreads/Day	Retread Method	Retread Process Franchisor
6.	Les Schwab Tire Centers	1,502	Precure, Mold Cure & Sculpture	Marangoni, Other
7.	Pomp's Tire Service	1,352	Precure	Bandag
8.	Snider Tire Inc	1,300	Precure	Bandag
9.	Purcell Tire & Rubber Co	1,000	Precure, Mold Cure, Flexcure, Unicircle	Goodyear
10.	Tire Distribution Systems Inc	979	Precure	Bandag

Source: Modern Tire Dealer, April 2006

2.16 Demand for Tires

According to the *RMA Factbook 2006*, the most popular size of OE commercial tire (i.e., medium- and wide-base) demanded in 2005 was 295/75R22.5. This size was also the most popular medium- and wide-base tire demanded for replacement shipments (see Figure 2.29). Demand for the top five truck tire sizes accounted for approximately 80 percent of the OE market when compared to the replacement market at 60 percent. The tire demand statistics presented here are for RMA members only and do not give the complete tire market picture. However, as RMA members make up the majority of the 18 OE manufacturers in the United States (see section 2.9); it can be assumed that these figures represent a significant share of the total market.

2.17 Radial Tire Production

Over the years, the popularity of radial tires has substantially surpassed that of bias-ply tires. Section 2.4 briefly described the two tire designs and Figure 2.30 illustrates the proportion of radial tires (medium- and wide-base) produced to total tire production. It can be seen that in most years, OE radial tire production has approximated 100 percent of total tire production by RMA members.

2.18 Number of Employees

Employment statistics obtained from the 2002 Economic Census indicated that 63,000 persons were employed in the OE manufacturing industry compared to 8,000 in the tire retread industry (U.S. Department of Commerce, 2004[a&b]). The distribution of these employees by employment size class is indicated in Table 2.7. It is evident from Table 2.7 that retread plant by employment size class is skewed towards plants with fewer than 50 employees. Approximately 80 percent of retread plants had 19 or fewer employees. On the other hand, OE manufacturers are skewed towards plants employing large numbers of people. According to the 2002 Economic Census, approximately 50 percent of OE plants had 50 or more employees.

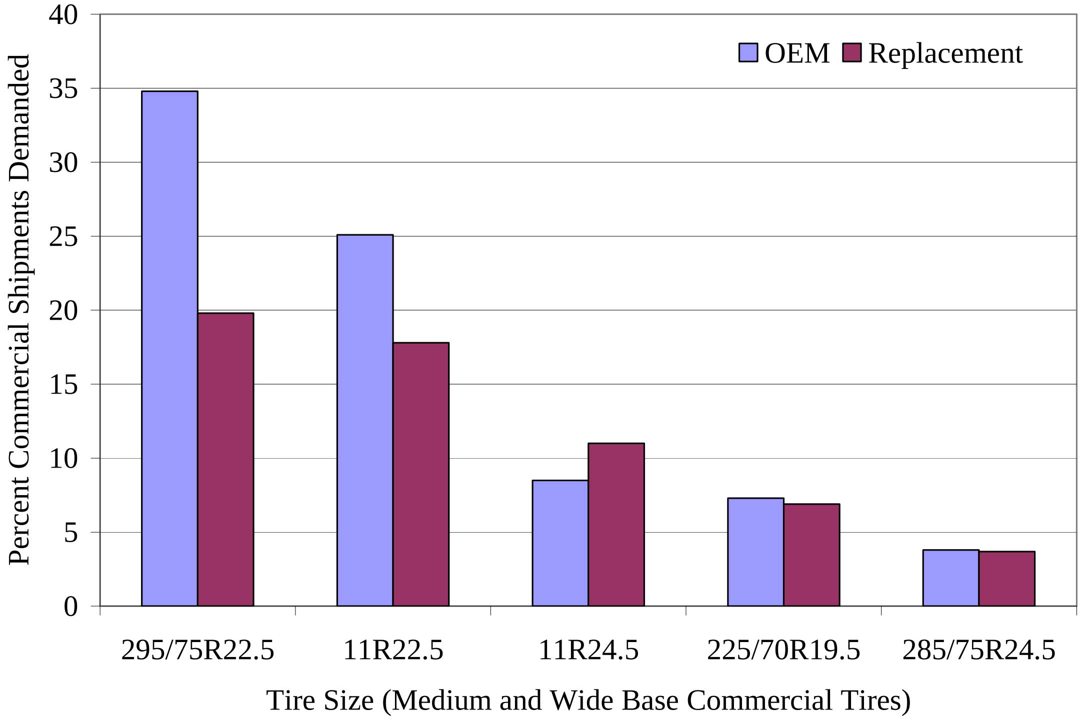


Figure 2.29 – 2005 Commercial (Medium- and Wide-Base) Truck Tire Popularity
Source: RMA, 2006

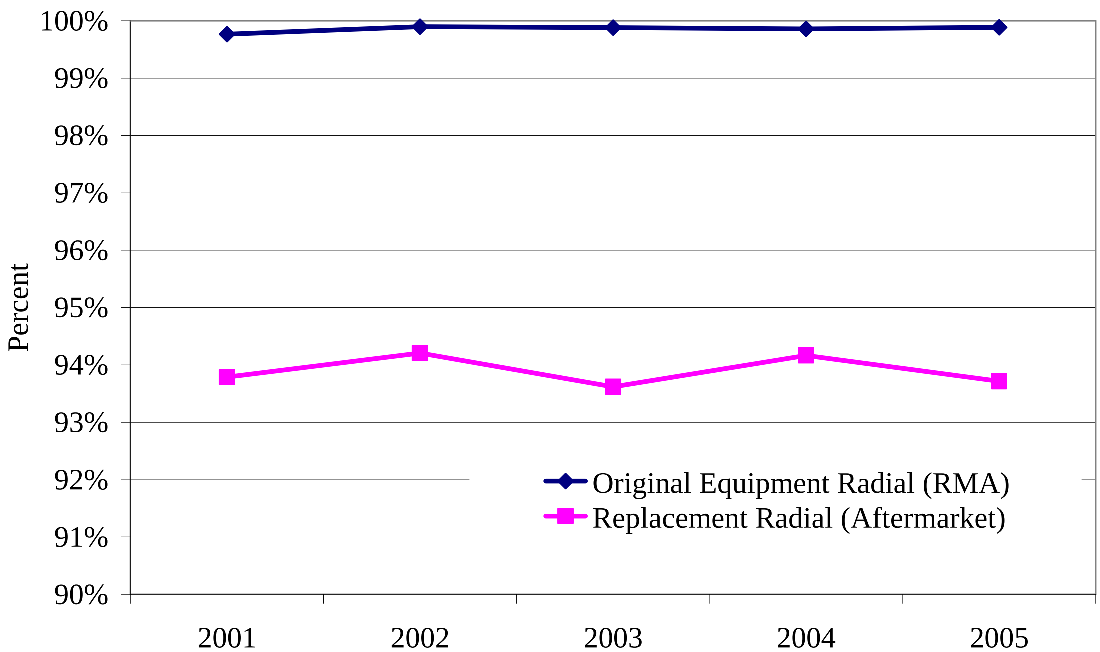


Figure 2.30 – Radial Tire Production Percentage
Source: RMA 2006

Table 2.7 - Tire Industry Statistics by Employment Size Class

Employment Size Class	# OE Manufacture Establishments	Percent	# Retread Tire Manufacture Establishments	Percent
1 to 4	43	27.2%	219	36.7%
5 to 9	18	11.4%	110	18.4%
10 to 19	11	7.0%	140	23.5%
20 to 49	10	6.3%	110	18.4%
50 to 99	12	7.6%	13	2.2%
100 to 249	17	10.8%	5	0.8%
250 to 499	12	7.6%	0	0.0%
500 to 999	5	3.2%	0	0.0%
1,000 to 2,499	26	16.5%	0	0.0%
> 2,500	4	2.5%	0	0.0%
Total	158	100.0%	597	100.0%

Source: 2002 Economic Census US Census Bureau

2.19 Summary

This chapter highlighted the steps involved in the manufacture of OE and retread tires. The three different types of retread processes, namely mold-cure, pre-cure, and ringtread, each require the buffing of the old casing and the application of a new tread. Tire manufacturing statistics revealed that in 2005 there were approximately 18 U.S. tire OEs, compared to more than 5,000 retread tire manufacturing plants/vendors. Nevertheless, each OE or retread manufacturer has a unique tire identification number (TIN) that must be shown on all tire products. It is therefore possible on inspection of the casing to acquire information as to the casing's origin, plant of manufacture, or retread status. In excess of 32 million aftermarket and retread tires were produced in 2005 with the greatest demand for tire size 295/75R22.5.

3 REVIEW OF TIRE DEBRIS STUDIES

3.1 Introduction

The ongoing debate over the incidence and traffic safety impacts of tire debris on the Nation's highways has influenced the study of this issue since 1990. The studies have been regionally or nationally focused in their scope and have had the primary objective of validating or disproving whether the retread tire is a contributing factor in the formation of tire debris on the Nation's highways. A review of these studies is provided in the following sections.

3.2 Technology & Maintenance Council Studies

The TMC of the ATA conducted two national surveys of truck tire debris in 1995 and 1998 respectively. It is tasked with addressing the operational and technological needs of the truck industry through the provision of technical, information technology, and logistical expertise. In 1995, the Tire Debris Prevention Task Force (a sub-unit of the TMC) was formed and tasked with carrying out the proposed Rubber on the Road tire debris studies.

3.2.1 Study Objective

The primary objective of the TMC studies in 1995 and 1998 was to determine the probable cause of tire failure and in so doing ascertain factors contributing to tire debris on the Nation's interstates.

3.2.2 Composition of Study Team

The TMC study team in 1998 (and presumably in 1995) consisted primarily of representatives and experts from the U.S. tire industry. The organizations providing members to the study teams were:

- Bandag Inc.
- Bridgestone Firestone Inc.
- Continental General Tire Inc.
- Eaton Corporation
- Goodyear Tire & Rubber Company
- Hawkinson Companies
- Hercules Tire & Rubber Company
- Michelin North America Inc.
- Oliver Rubber Company
- Pressure Systems International
- Teknor Apex Company
- The Tire Retread Information Bureau
- Yokohama Tire Corporation

3.2.3 Study Period

The tire debris surveys were conducted during the summer months of 1995 and 1998. It is generally accepted that heat is a key factor affecting tire longevity and degradation. Conducting a tire debris survey during the summer months will therefore offer the worst case scenario in witnessing the accumulation and subsequent highway safety impacts of tire debris on the Nation's highways.

3.2.4 Locations

The 1995 and 1998 tire debris surveys conducted by TMC were national surveys. The survey sites selected (State highway maintenance yards and truck stops) in 1995 were visited again in 1998. Figure 3.1 indicates the locations of the TMC 1995 and 1998 survey sites.

3.2.5 Methods

In both TMC surveys, members of the study team (tire forensic scientists and others) visited each site and performed visual and tactile inspections of the tire debris collected. In each State in the United States, highway maintenance teams are tasked with maintaining highway cleanliness (i.e., keeping them free of trash and other objects that may endanger highway users) within their jurisdictions. Roadside debris including tires (further discussed in Chapter 5) collected by these teams is deposited at State maintenance yards before collection and ultimate disposal by waste management agents. TMC survey staff members were able to perform the majority of their tire debris inspections at such State highway maintenance yards and, in several cases; surveys were also conducted at truck stops.

3.2.6 Results

The TMC study teams were able to assess a total of 3,920 tire pieces, of which 1,720 were inspected in 1995 and the balance (2,200) in 1998. The survey site breakdown of the pieces inspected is presented in Table 3.1. It was not possible to determine from the literature review the rationale used to determine the collection sites for the TMC studies. However, the following may be postulated:

- Time period of survey execution was summer. Conducting a tire debris survey during this period affords the opportunity to witness the greatest volume of tire debris generated by vehicles and its subsequent collection from the Nation's interstates and truck stops.
- Collection sites were situated close to freeways to take advantage of the high truck traffic flows.
- Representative collection sites in all five U.S. regions (e.g., northwest, southwest, midwest, northeast, and southeast) were surveyed to enable regional comparison of the tire debris volume generated and its subsequent collection and analysis.

Table 3.1 – TMC Studies (1995 and 1998) Tire Debris Inspected by Location

Survey Site/State	1998	1995	% Change
TravelCenters of America - Kenly, NC	41	33	+24
TR Stop - Columbia, SC	45	27	+67
Ohio Turnpike, OH	46	96	-52
DOT – Mobile, AL	68	118	-42
TravelCenters of America, Raleigh, NC	71	99	-28
DOT - Pendleton, OR	90	327	-74
DOT - Columbia, SC	91	110	-17
DOT - Raleigh, NC	105	67	+43
New Jersey Turnpike – Milltown Mile, NJ	137	37	+270
New Jersey Turnpike – Crosswicks, NJ	147	100	+47
Las Vegas, NV	261	68	+283
Dallas, TX	385	87	+466
Tucson, AZ	713	531	+34
Total	2,200	1,720	+28

Source: Laubie, 1999

Figure 3.1 – TMC Tire Debris Studies Survey Locations

✦ TMC Tire Debris Collection Sites (1995 & 1998)

x2 Two collection sites at particular location

Table 3.2 and Figure 3.2 present information on the types of tire inspected by the TMC study teams with respect to a variety of characteristics (i.e., OE versus retread or passenger/commercial vehicle usage). It is evident that over half of the debris collected (in 1995 or 1998) originated from retread truck/trailer tires. If we include OE debris from trucks and/or trailers, more than 60 percent of the debris inspected originated from these vehicle types. Tire debris originating from passenger cars accounted for no more than 28 percent of the debris inspected in both survey years. Without detailed information on the TMC survey methodology, it was not possible to deduce factors that may have influenced the changes in tire debris proportions deposited and inspected from one survey year to the next. However, analysis of axle/vehicle counts could have provided an estimate of the number of wheels (i.e., tires) that passed over a given stretch of freeway (i.e., the collection area from which the tire debris originated). These results may have provided further insight into whether the types of tire debris deposited bore any relationship to the proportions and type of wheels/tires that traversed the given stretch of freeway. (Note: Tire debris estimation techniques are discussed in Chapter 5.)

Table 3.2 – TMC Tire Samples by Type of Tire, 1995 and 1998

Product Group	**1995**		**1998**	
	#	**Percent (%)**	**#**	**Percent (%)**
Passenger auto OE	472	27.4%	551	25.0%
Light truck OE	146	8.5%	242	11.0%
Medium truck/trailer/bus OE	139	8.1%	220	10.0%
Medium truck/trailer/bus Retread	963	56.0%	1,186	54.0%
Total	1,720	100.0%	2,200	100.0%

Source: Laubie, 1999

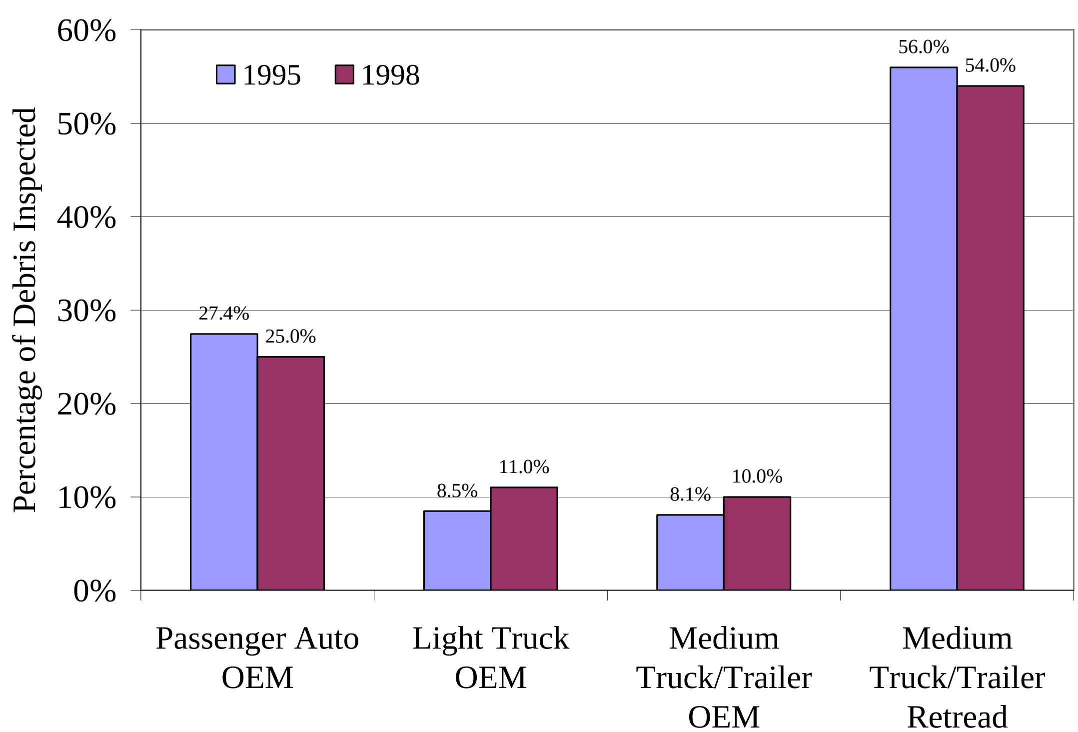


Figure 3.2 – TMC Tire Samples by Type of Tire, 1995 & 1998
Source: Laubie, 1999

Figures 3.3 and 3.4 summarize results from the failure analysis (i.e., to determine the probable cause) of the tire debris inspected in the TMC studies in 1995 and 1998. Six probable cause of failure categories were designated as (Carey, 1999):

- **Belt separations**
  The unraveling or separation of tire belt materials due to excessive flexing of the casing
- **Road hazard**
  Stress resulting from road hazards (e.g., nails, potholes, etc.)
- **Manufacturer issues**
  Poor quality control in the tire/retread manufacturing process
- **Repair failure**
  Inappropriate/poor quality tire repairs
- **Maintenance issues**
  Inadequate fleet maintenance (e.g., allowing tires to run on insufficient tread depth)
- **Other**
  All other probable causes not defined above

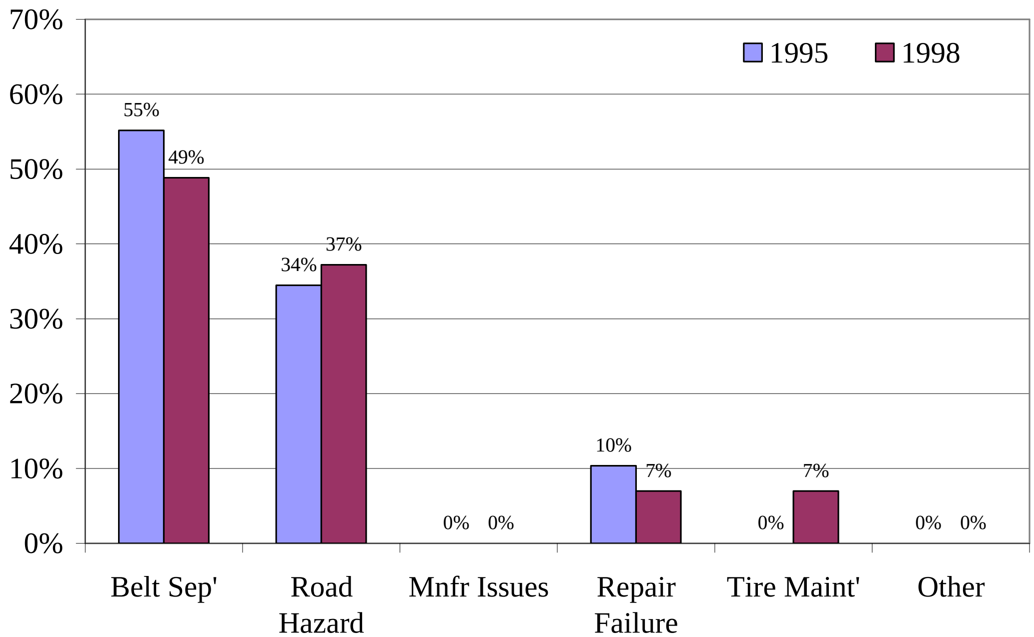


Figure 3.3 – Probable Failure Reasons New Tires TMC Study, 1995 & 1998
Source: Laubie, 1999

Figure 3.3 illustrates the probable failure reasons for new tires. Belt separation was the probable cause of failure for more than 50 percent of new tires analyzed in both survey years. Failure due to road hazards accounted for more than a third of the new tires assessed in both survey years. None of the new tires analyzed failed due to manufacturer/manufacturing issues and similarly, when the probable cause of failure could not be classified (i.e., other). Belt separation is a result of excessive flexing of the casing usually precipitated by underinflation. The excessive stresses placed on the tire will cause the tire structure to break down and separate (i.e., unravel). (Note: A tire is constructed in layers. See Chapter 2 for more information on tire structure). No matter how well a tire is constructed, underinflation creates excessive heat that will lead to a premature failure of the casing.

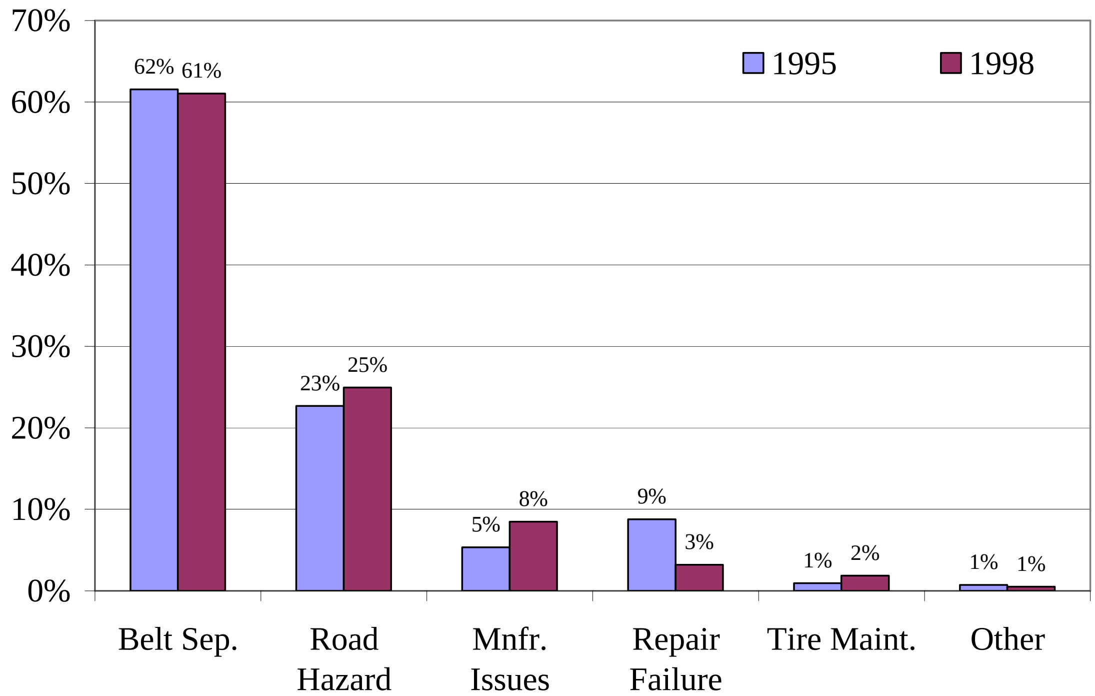


Figure 3.4 – Probable Failure Reasons Retread Tires TMC Study, 1995 & 1998
Source: Laubie, 1999

The proportions of probable failure causes for retread tires showed a similarity to the failure proportions for OEs. Figure 3.4 presents these results as assessed in the TMC studies of 1995 and 1998. Similar to OEs, belt separations took the majority share (approximately 60% for retread tires compared to 50% for OEs) of probable failure causes in both survey years. As the retreading process adds a new tread to the original casing (as well as repairing any defects as necessary), it may be argued that a retread tire can never be the same in every aspect as an OE tire.

Continuing with the retread tire analysis, failure due to road hazard was the next largest category of retread tires assessed, accounting for approximately 23 and 25 percent, in the years 1995 and 1998, respectively. Probable failure due to manufacturing issues was evident in several of the retread tires inspected. It is possible that retread tire failures in this category may have been due to lack of quality controls in the retread manufacturing process rather than the OE manufacturing process. Retread tires failing due to repair failure accounted for 9 and 3 percent, respectively, in each of the TMC survey years – 1 and 4 percentage points less, respectively, than the corresponding categories for new tires (see Figure 3.4). Though marginally less, these results are not surprising as an integral part of the retread manufacturing process involves a thorough inspection of each casing to identify any visible and internal defects. Repairable defects are repaired and casings with defects beyond repair are discarded. In Figure 3.4, tire maintenance and other probable failure reasons (e.g., not categorized) for the retread tires assessed accounted for 1 to 2 percent in either of the survey years.

3.2.7 General Observations

Several observations can be made about the TMC surveys in 1995 and 1998:

1. Twenty-eight percent more pieces of debris were collected and analyzed by the TMC study team in 1998 than in 1995. Factors giving rise to this increase were high summer temperatures in the southwest United States and increased interstate speeds (75 mph) in the western United States (Commonwealth of Virginia, 2000).
2. Belt separation as a probable cause of failure accounted for the majority of OE and retread truck tires inspected. The primary reason for belt separation is underinflation of the tire. Thus, many retread tire advocates conclude that underinflation (and not the tire being a retread per se) is the cause that generates the tire debris found on the Nation's interstates. Under/overinflation is a maintenance issue that underscores the necessity for all truck operators and owners to develop, enforce, and maintain a tire maintenance regimen.
3. More than 60 percent of the debris collected and analyzed was derived from commercial (i.e., medium- and wide-base) truck and bus tires. Jason Carey in his summation of the TMC studies asserted that retread truck tires were overrepresented in the sample of medium- and wide-base truck/bus tires (87% and 84% respectively for 1995 and 1998). Carey goes on to state that "the distribution of tire debris suggests that retreads are more susceptible to failure regardless of the cause" (Carey, 1999). However, the extent of overrepresentation or tire failure propensity cannot only be based on the volumes and types of debris found, but it is also directly related to other factors such as the location, ambient temperatures, or vehicle-traffic mix (section 5.6 discusses this issue further).
4. In the samples assessed in 1995 and 1998, five percent and eight percent, respectively, of retread tires were classified as failing due to manufacturer error. This finding can be compared to zero percent (in either year) for the OEs assessed. As stated earlier failure of a retread due to manufacturing process error may be due to the lack of quality controls in the retread manufacture process (i.e., improper tread application, inappropriate repair, etc.) when compared to the OE process and not necessarily because the tire is a retread.
5. In the survey year 1998, there was a marginal percentage point increase (from 1995) in failures due to road hazards and tire maintenance issues for both new tires and retread tires. This development may in part be due to increased traffic volumes (a potential generator of highway debris [e.g., litter, construction items]) and VMT on the Nation's interstates.

3.3 Need for Standards for Recapped Tires

In 1999, the Commonwealth of Virginia tasked the Virginia Department of State Police to study the need for State standards for recapped vehicle tires. The occurrence of tire debris along Virginia's highways gave rise to the perception that retread truck tires were to blame. The study would determine whether there was any substance to the perception.

3.3.1 Study Objectives

The two primary objectives of the Virginia study were to determine whether there were any problems associated with retread tires and whether State standards would correct these problems. Section 2.12 discussed the lack of nationally mandated standards for retread tires, which has led some States to unilaterally promote the introduction of legislation to fill this gap. However, in the majority of cases such legislative initiatives have not been passed.

3.3.2 Composition of Study Team

A number of consultants, State and Federal representatives, and tire industry officials were contacted and their input sought before commencing the Virginia study. Several of these officials also formed part of the recapped study committee tasked to execute the study.

3.3.3 Study Period

The Virginia study was conducted over an eight-week period during the summer of 1999 (May 30 to August 30).

3.3.4 Locations

The interstates to source tire debris were heavily trafficked sections of Interstates 95, 81, 77, and 295, all within Virginia.

3.3.5 Methods

Highway maintenance officials from the Virginia Department of Transportation (VDOT) were tasked with collecting and weighing tire debris found on the designated interstates. Retrieved debris was then placed in secure VDOT highway maintenance facilities for further examination. A sample of the debris was then examined, coded, and photographed by a tire expert in the presence of VDOT officials.

3.3.6 Results

Approximately 42,997 pounds of debris were collected from I-95; 42,475 pounds from I-81, and 42,050 pounds from I-295 and I-77. In total more than 127,000 pounds of tire debris were collected from 658 miles of interstate during the eight-week survey period. The Virginia report gives detailed findings for 27 tires only, which are summarized in Table 3.3.

Overall, the results indicated the dominance of radial tire types over bias-ply tires, which is to be expected (see section 2.18). Retread tires accounted for 67 percent of all tire debris tested and 85 percent of the non-passenger-vehicle/light-truck tires. Taking note of the COV study focus, there was only one case (Table 3.3, item #9) where the cause of the tire failure was directly linked to manufacturer or human error in the retread process. In the nine cases where probable failure could be determined for retread tires, failure due to road hazards accounted for approximately 90 percent of these cases.

Table 3.3 – Commonwealth of Virginia Tire Debris Study Results

Item #	Radial/Bias	Tire Type	Vehicle Type	Probable Cause of Failure
1	Radial	OE	PAX/LTruck	Unknown
2	Radial	OE	PAX/LTruck	Low Pressure
3	Radial	OE	PAX/LTruck	Aged
4	Radial	OE	PAX/LTruck	Low Pressure
5	Radial	OE	PAX/LTruck	Overloaded/heat
6	Radial	OE	PAX/LTruck	Unknown
7	Radial	OE	Trailer	Low Pressure
8	Radial	RT	Trailer	Road Hazard/Puncture
9	Radial	RT	Trailer	Manufacturer/Human Error
10	Radial	RT	Trailer	Road Hazard/Puncture
11	Radial	RT	Trailer	Road Hazard/Puncture
12	Radial	RT	Trailer	Road Hazard/Puncture
13	Radial	RT	Trailer	Unknown
14	Radial	RT	Trailer	Unknown
15	Radial	RT	Trailer	Road Hazard/Puncture
16	Radial	RT	Tractor/Drive Wheel	Road Hazard/Puncture
17	Radial	RT	Tractor/Drive Wheel	Road Hazard/Puncture
18	Radial	RT	Tractor/Drive Wheel	Unknown
19	Radial	RT	Tractor/Drive Wheel	Unknown
20	Radial	RT	Tractor/Drive Wheel	Road Hazard/Puncture
21	Bias/ply	Unknown	Intermodal	Heat
22	Bias/ply	RT	Intermodal	Unknown
23	Bias/ply	RT	Intermodal	Unknown
24	Bias/ply	RT	Intermodal	Unknown
25	Bias/ply	RT	Intermodal	Unknown
26	Bias/ply	RT	Intermodal	Unknown
27	Bias/ply	OE	Intermodal	Unknown

Key:
PAX Passenger Tire
LTruck Light Truck
RT Retread Tire
OE Original Equipment Tire (i.e., new)

3.3.7 General Observations

The primary conclusion from the Virginia study "revealed that the quality of materials and methods of producing retreaded tires are not major factors in the problem of tire debris along the highways" (Commonwealth of Virginia, 2000). The primary study objective was not proved through the evidence collected and analyzed. Of the tire debris items analyzed, only one case was directly linked to manufacturing error in the retread process. Noting the spatial diversity of the hundreds of tire retread manufacturers around the Nation, tire debris appearing in one State may be unrelated to the number and quality of retreaders in that particular State. The Virginia study also concluded that regulating retread tire manufacturers in Virginia would have a limited impact on the volume of tire debris deposited in Virginia. Thus, the consensus on the second study objective (see section 3.4) was that "the establishment of State standards would have little, if any, impact on the [tire debris] problem" resulting in the initiative to create legislation governing retread standards in Virginia to fall away (Commonwealth of Virginia, 2000).

3.4 Survey of Tire Debris on Metropolitan Phoenix Highways

The existence of tire debris on the Nation's highways not only impacts other road users but also has environmental and financial implications. In 1999, the Arizona Department of Transport (AZDOT) tasked a consultant with assessing the direct and indirect effects of tire debris on selected regions of the State. Not only did the study look at the sources of tire debris found on AZDOT interstates (i.e., OE or retread, passenger vehicle or truck), but it also researched highway safety implications (i.e., number of traffic crashes) and the financial cost to the State to dispose of this material. The results of the study (Carey, 1999) form the basis for the study overview presented here.

3.4.1 Study Objectives

The AZDOT study had three principal objectives:

- Investigate the sources and precipitating events of tire debris on metropolitan Phoenix roadways;
- Estimate the impact of tire debris on AZDOT, in terms of the financial costs to collect and dispose of the debris; and
- Estimate the impact of tire debris on highway safety in metropolitan Phoenix and Arizona.

3.4.2 Composition of Study Team

Tire industry professionals from the Phoenix area were responsible for determining the probable cause of failure for the tire debris analysis.

3.4.3 Study Period

The AZDOT study was executed over a one-month period (September 1999).

3.4.4 Locations

Tire debris samples were collected from four AZDOT highway maintenance yards in the Phoenix metropolitan area.

3.4.5 Methods

Tire samples (debris and whole casings) were taken from four AZDOT highway maintenance yards. At some of these sites, it was necessary for the study team to sort the tire debris from other debris collected. Each sample randomly selected was categorized as OE or retread; passenger car, light truck, or medium truck; and by probable cause of failure. The study team also took note of the highway debris collection and disposal regime at each survey site. Depending on the arrival of the study team at each survey site, "aged" debris items available for sampling may have been around for some time when compared to "younger" debris items that may have been recently collected.

However, as pointed out in the report "it is by no means certain that tire fragments collected recently also failed recently" (Carey, 1999).

3.4.6 Results

Tables 3.4 and 3.5 present details of the tire debris items collected and identified according to collection site, OE/retread status, and vehicle type. It is evident that approximately 58 percent (495 of 859) of the samples collected could be identified according to size and other criteria (e.g., vehicle type, OE versus retread, etc.) set by the project team. Of the tire debris items that could be identified, approximately 78 percent were new tires (including light vehicle and light truck tires), and the balance was retreads.

Table 3.4 – Distribution of Tire Debris Collected and Identified by Tire Status

Maintenance Yard	Tires Collected	Tires Identified	Percent	OE	Percent	Retread	Percent
Agua Fria	134	120	89.6%	86	71.7%	34	28.3%
East Metro	267	140	52.4%	100	71.4%	10	7.1%
Mesa	211	125	59.2%	99	79.2%	41	32.8%
Durango	247	110	44.5%	99	90.0%	26	23.6%
Total	859	495	57.6%	384	77.6%	111	22.4%

Source: Carey, 1999

Table 3.5 – Distribution of Tire Debris Collected and Identified by Tire/Vehicle Type

Maintenance Yard	Passenger auto		Light Truck		Medium/Heavy Truck	
	Count	Percent	Count	Percent	Count	Percent
Agua Fria	41	34%	29	24%	50	42%
East Metro	51	46%	37	34%	22	20%
Mesa	49	35%	38	27%	53	38%
Durango	72	58%	23	18%	30	24%
Total	213	43%	127	26%	155	31%

Note: Only the identified debris items (i.e., 495)
Source: Carey, 1999

Approximately 155 tires identified (31%) were medium- or wide-base truck tires; 213 were passenger cars (43%), and 127 were light trucks (26%). It should come as no surprise that the percentages of identified tire debris differ from that found in other studies such as the TMC (see section 3.2). However, the extent and type of tire debris found on the Nation's highways is a function of location, permissible speeds, weather, vehicle mix, etc. Figure 3.5 presents results of the probable causes of failure for the truck tires identified.

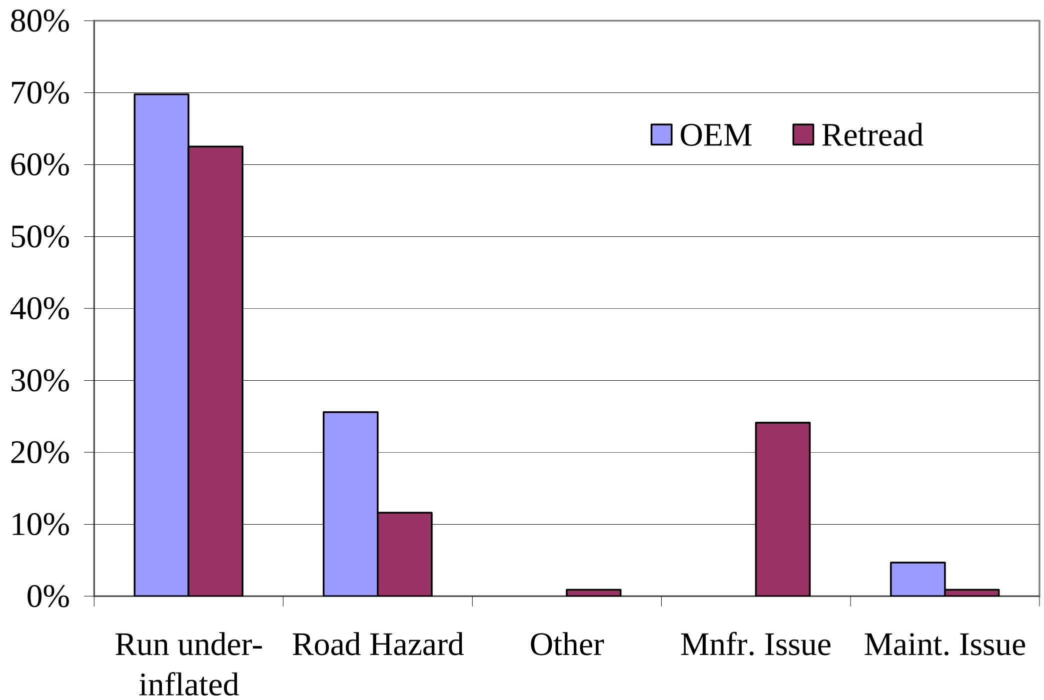


Figure 3.5 - Probable Cause of Failure for Truck Tires in Metropolitan Phoenix, 1999
Source: Carey, 1999

It is evident from Figure 3.5 that truck tire failure resulting from underinflation dominates the five available categories of probable failure cause. Underinflation is a maintenance issue directly related to the extent and regularity of tire inspections of the tractor and trailer by truck operators/drivers or fleet technicians. Failure due to road hazard was the second-most common probable cause in the case of OEs, whereas for retreads, it was manufacturing issues. For those truck tire samples failing due to a manufacturing issue, precipitating factors were deemed to be bond failure, missed nail hole, or repair failure. All of these factors are associated with the retread tire manufacturing process. The lack of manufacturing issues as a probable cause of failure for OEs is a similar result to that found in the TMC studies (see section 3.2).

3.4.7 General Observations

The AZDOT study found that the majority of tire debris assessed originated from passenger cars and light trucks. This finding goes against public perception, which assumes that the tire debris found on the roadsides originates from medium- or wide-base truck tires. For example, in the TMC studies, the largest proportion of debris assessed originated from medium- and wide-base truck tires. Nevertheless, as pointed out earlier, location-specific factors can and do influence the type and extent of tire debris found on a particular stretch of highway. In both the TMC and AZDOT studies, the significant contributing factors to tire failures were belt separation and underinflated tires. These causes are interrelated and were responsible for 50 to 70 percent of truck tire failures in either study.

The AZDOT study was one of four studies presented in this chapter where tire debris sourced in the southwest was subsequently analyzed to determine probable cause of tire failure. The excessively high summer temperatures and long travel distances occurring in the southwest States (e.g., Arizona) has made this region an area of choice in sourcing tire debris for failure analysis. Comparing the results of the AZDOT and TMC studies, there are notable similarities and differences in results. However, some of these differences may be explained by the aggregation of results (i.e., from 12 sites around the Nation) in the TMC studies compared to four sites specific to a particular region/metropolitan area in the AZDOT study.

3.5 How Long Do Commercial Truck Tires Last? Study

In 2000, Bridgestone Firestone initiated a tire longevity study through the collection and analysis of unserviceable truck tires. Of all the tire debris studies described in this literature synthesis, the Bridgestone Firestone study is unique in that its research focus was to understand the tire lifecycle through the study of truck tire casings (and not tire debris). In addition, it was conducted over several years (2000 to 2005). Presentation of the study findings was made at the annual Tire Industry Conference in 2006 (Walenga, 2006). The summary presented here is based on the conference presentation and not on a study report (which was not produced for public consumption).

3.5.1 Study Objectives

This study conducted by Bridgestone/Firestone determined how long a truck tire lasts from the time of its manufacture to its permanent withdrawal from service (leading to its subsequent environmentally managed destruction/disposal). It should be noted that the focus of this particular study was not to determine probable cause of unserviceable tires. However, insight was gained into the extent of OE versus retreaded tires and the number of retreads these casings had in their lifetimes.

3.5.2 Composition of Study Team

The study team was comprised of tire forensic officials from Bridgestone Firestone.

3.5.3 Study Period

Tire casings were collected and assessed between 2000 and 2005. Technically the Bridgestone Firestone project was not a longitudinal study per se as each tire was only assessed once (at the end of its life) rather than multiple times over the six-year study period.

3.5.4 Locations

Unserviceable tires were sourced from all geographic markets in the United States. The conference presentation does not indicate the numbers or proportions of tires sourced from specific geographic regions, nor the casing selection methodology employed.

3.5.5 Methods

Unserviceable truck tires were sourced and collected from tire fleet and dealer enterprises. Information as to the methodology or process followed to determine the lifecycle of each casing inspected is not known. However, from the presentation it can be determined that visual and tactile inspections were undertaken. The recording (and capture in a database) of select casing characteristics (i.e., DOT codes) was performed for subsequent analysis.

3.5.6 Results

Of the approximately 10,300 casings inspected, 7,161 (69%) were retreads and 3,124 (31%) were OEs. The primary applications of these tire casings were line and regional haul (long-distance) services. All of the tire casings inspected were manufactured between 1990 and 2005, with the largest number (1,450 or 14%) manufactured in 1998. Numbers of tires assessed according to year of submission to Bridgestone Firestone for analysis were: 1,816 (18%) in 2000; 2,480 (24%) in 2002; 1,039 (10%) in 2003; 2,452 (24%) in 2004; and 2,504 (24%) in 2005. From the data, it is evident that there were zero tire casings assessed in 2001.

Table 3.6 presents the results of tire status according to its OE or retread status. As indicated in section 2.10, it is possible to determine the number of times a casing has been retread from retread manufacturer identification marks branded on the casing sidewall. In all survey years, the majority of tire casings assessed had undergone at least one retread. The proportions of tire casings that had two or more retreads fell considerably.

Table 3.6 – Tire Status According to Survey Year*

	2000		2002		2003		2004		2005	
	#	%	#	%	#	%	#	%	#	%
Original	708	39	570	23	239	23	834	34	751	30
1st Retread	781	43	1265	51	509	49	1128	46	1227	49
2nd Retread	272	15	496	20	249	24	417	17	476	19
3rd Retread	54	3	149	5	42	4	74	3	50	2
Total	1,816	100	2,480	100	1,039	100	2,452	100	2,504	100

*The numbers of casings with 4 or 5 retreads were very small in each of the survey years and are not shown.
Source: Walenga, 2006

3.5.7 General Observations

Surveyed tires at the end of their useful life ranged in age from 10 to 15 years (Walenga, 2006). Indeed, the majority of tires assessed in this study had at least one retread, while a minimal number had a maximum of five retreads. The consistency in the proportions of casings within each survey year with at least one retread (ranging from 67% [2002 to 2003] to 61% [2000]; see Table 3.5) alludes to the robust construction of OEs and their durability for multiple retreads and repairs. However, the lack of data on factors precipitating the withdrawal of the tires assessed from service does not permit a comparison with other tire debris studies discussed earlier.

3.6 Summary

Four studies involving the analysis of tire debris were presented in this chapter. These studies involved assessors going into the field to collect and inspect tire debris items. The majority of these studies concluded that a tire's retread status is not a primary contributor to its failure potential; instead it is the thoroughness and regularity of tire air pressure maintenance. A summary of tire debris studies conducted since 1990 is presented in Table 3.7.

Table 3.7 - Tire Debris Studies in the United States Since 1990

Study	Year	Season	Location	Performing Organization	Pieces/Weight Collected	Sponsor
Rubber on the Road Study	1995	Summer	National	Technology Maintenance Council (ATA)	1,720 tire items*	American Trucking Associations
Rubber on the Road Study	1998	Summer	National	Technology Maintenance Council (ATA)	2,200 tire items*	American Trucking Associations
Recapped Tire Study	1999	Summer	Virginia	Department of State Police VA/ Department of Transportation VA	127,522 pounds (of tire items*)	Virginia General Assembly
Survey of Tire Debris on Metropolitan Phoenix Highways	1999	Summer	Phoenix	Jason Carey	859 tire items*	Arizona Department of Transportation
Longevity of Commercial Tires	2000 - 2006	All Seasons	National	Bridgestone Firestone	10,291 casings	Bridgestone Firestone
Commercial Medium Truck Tire Debris Study	2007	Summer	National	University of Michigan Transportation Research Institute	1,196 tire fragments & 300 casings	National Highway Traffic Safety Administration

***** Tire items include whole casings and tire fragments.

4 REVIEW OF COMMERCIAL MEDIUM TIRE FAILURES

4.1 Introduction

This chapter presents an overview of commercial medium- or wide-base truck tire failure. There have been relatively few longitudinal studies on this issue due to difficulties in the tracking of a tire from its date of manufacture to its removal from service or at failure. Therefore, this section can only consider tires at the point of failure as we know little of their histories.

4.2 What is Tire Failure?

A tire failure in the context of this study is a sudden and catastrophic failure of the tire resulting in the production of tire debris or impacting vehicle or highway safety.

- **Casing Failure**
  The failure of the casing due to the carcass, belts, or body of the tire failing. This can be manifested through belt-to-belt separation; zipper (sidewalls) lateral rupture; belt edge separation; separation of tread, sidewall, ply cord, inner liner or bead; broken cords; etc.
- **Chunking**
  The breaking away of pieces of the tread or sidewall.
- **Cracking**
  The parting within the tread, sidewall, or inner liner of the tire extending to cord material.
- **Cushion Gum/AZ Strip-Stock Problems**
  The use of cushion gum that has exceeded its sell-by date or gum that is not fully cured or stored at the correct temperature.
- **Driver Assisted**
  Tire failure resulting from driver action (e.g., running over objects, striking curbs, overloading the vehicle, etc).
- **Faulty Tread Rubber**
  Tire failure resulting from porosity in the tread rubber due to lack of cure, lack of pressure, lack of buffing (reducing adhesive potential), contamination of the tread, etc.
- **Incorrect Application**
  The misapplication of tread patterns and size to casings through a disregard of tire and retread processing/application standards.
- **Incorrect or No Fleet Maintenance**
  Tire failure as a result of fleet negligence and the lack of proper tire maintenance.
- **Open Splices**
  Parting at any junction of tread, sidewall, or inner liner that extends to the cord material.
- **Process Failure**
  Tire failure as a result of the retreading process such as bad repairs, contamination of the rubber, curing problems, etc.
- **Repair Material Problems**
  Contamination of repair patches or other components during the tire construction process.

- **Sudden Loss of Inflation Pressure**
  The rapid loss of tire air pressure.

An alternative view defining tire failure is put forward by Rohlwing (2004) where he states that "tires, by themselves, don't fail. Maintenance, road survey conditions, and driving skills determine what happens to tires."

4.3 Study Methods of Tire Failure

Understanding the factors contributing to tire failure is an effort that requires much time, expertise, and diligence. Tire failure analysis can be undertaken by four distinct methods:

- **Forensic Analysis**
  "Tire forensic analysis requires the use of many pieces of information gleaned from a visual and tactile inspection of the tire pieces to determine the most probable cause of a tire's failure" (Daws, 2007).
- **Failure Analysis**
  "Tire failure analysis is often focused on the mechanism of the separation of the tread and outer steel belt from the tire casing and inner steel belt. The analyst must determine the point of origin of the separation from the appearance of the fracture surfaces" (Daws, 2003).
- **Microscopic Analysis**
  This technique has been used in the study of tire failure analysis where a microscope is used to study the topographies (i.e., surfaces) of a failed tire or debris item.
- **Fractography**
  Fractography is the study of the fracture surfaces of materials. The importance of this science is that it tries to determine the cause of failure by studying the characteristics of the fracture surface. Different types of crack growth produce unique characteristic features on the surface, which can be used to help identify the failure mode.

4.4 Cost Impacts of Truck Tire Failures

There are significant financial cost implications resulting from a truck tire failure, to the trucking company, to parties directly impacted by the tire failure, and to the wider society. In interviews with major trucking fleets, Bareket et al. (2000) found that some fleet managers viewed [tire] blowout prevention as more of a cost issue than a safety issue. In another synthesis study of alternative truck and bus inspection strategies (Cambridge Systematics & Maineway Services, 2006) it was stated that "the rising cost of diesel fuel has the potential to be a key factor affecting commercial vehicle safety. Diesel fuel costs are a motor carrier's second largest cost component – behind only labor. As such, when these costs rise dramatically, some motor carriers feel pressure to cut back on other costs – including maintenance and safety programs." Thus, for some trucking fleets/owner operators micromanaging financial costs at the expense of safety may inadvertently result in an oversight of routine tire maintenance.

The above trucking management philosophy does have a tendency to backfire in more ways than one, including premature tire failure. Deierlein (2003) noted that "tire failures of one sort or another are responsible for 50 percent of all emergency road calls resulting in down time (industry average in excess of 2½ hours), freight delays (and perhaps loss of the next load), and the high cost of servicing the breakdown." Indeed, the volume of road callouts vary by month and season with most callouts relating to tire problems occurring in the summer months. Table 4.1 presents aggregated FleetNet road call data for the years 2000 and 2001. FleetNet is one of the largest U.S. roadside service operators assisting the commercial trucking industry.

Table 4.1 – FleetNet Roadside Assistance Statistics 2000 and 2001

Year 2000 Data				
Description of Repairs	**# Occurrences**	**% of Total**	**Downtime Hours**	**Downtime per Occurrence (hrs)**
Tire Failures (Consolidated)	12,369	48.9	31,560	2.55
Jump or Pull Start Unit	2,030	8.0	4,260	2.10
Towing & Other	2,016	8.0	10,837	5.38
R&R or Repair Air Line or Hose (each)	1,471	5.8	3,934	2.67
R&R or Repair Wiring, Plugs, Lights	1,297	5.1	3,146	2.43
Remove & Replace Alternator	1,024	4.1	4,366	4.26
R&R Fuel Filter or Fuel Additive	1,012	4.0	2,754	2.72
R&R Brake Chamber	900	3.6	5,584	6.20
Year 2001 Data				
Description of Repairs	**# Occurrences**	**% of Total**	**Downtime Hours**	**Downtime per Occurrence (hrs)**
Tire Failures (Consolidated)	14,260	55.3	36,321	2.55
Jump or Pull Start Unit	1,798	7.0	3,621	2.01
Towing & Other	1,637	6.4	10,061	6.15
R&R or Repair Air Line or Hose (each)	1,591	6.2	4,240	2.67
Remove & Replace Alternator	1,077	4.2	5,796	5.38
R&R Fuel Filter or Fuel Additive	1,016	3.9	2,803	2.76
R&R Brake Chamber	1,044	4.0	3,258	3.12

Source: Kreeb et al, 2003

4.5 Vehicle Impacts Arising From Tire Failure/Disablement

Fay and Robinette (1999) state that "the effects of tire disablement on vehicle operation depend on the type of disablement." Indeed, "The effects of underinflated or deflated tires are known to increase rolling resistance and to cause a steering effect wherein the vehicle tends to steer to the side of the vehicle with the deflated tire" (Robinette & Fay, 2000). These potential negative impacts from tire failure or disablement can have fatal consequences. However, the extent of these consequences is dependent on how each vehicle driver (i.e., the driver of the ill-fated vehicle(s) and/or drivers of adjacent vehicles) assess their situation and maneuver their vehicles. Table 4.2 and Figure 4.1 summarize potential vehicle impacts from tire failure.

Table 4.2 – Vehicle Impacts Resulting From Tire Failure or Disablement*

Tire Disablement (i.e., Slow Constant Air Loss)	Tire Failure (i.e., Sudden Air Loss)
• Increased drag and flexing of disabled tire(s) • Reduced rolling radius of disabled tire(s) • Reduced lateral stiffness leading to understeer if culprit tire is on a front axle or oversteer if culprit tire is located on a rear axle	• Heavy vibrations affecting the vehicle • Rough riding of the vehicle • Weaving or wiggling of rear tire(s)

Source: Fay & Robinette (1999)
*Impacts may differ (in degree and outcomes) for commercial trucks

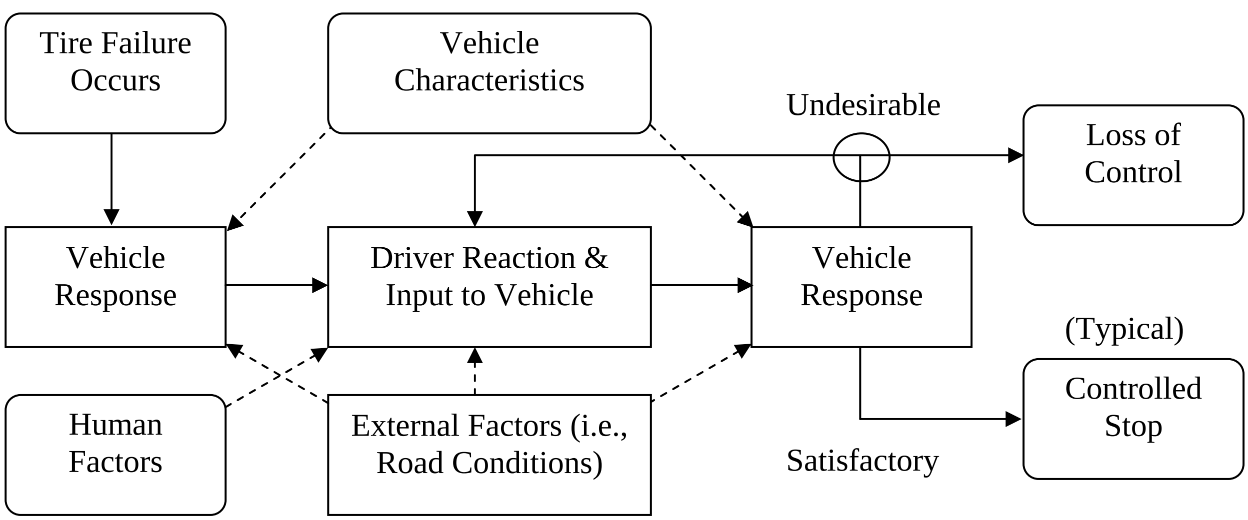


Figure 4.1 – Processes/Influences Following In-Service Tire Failure
Source: Gardner & Queiser, 2005

4.6 Tire Failure as a Possible Contributor to Traffic Crashes

Chapter 7 presents analysis and results from several traffic crash datasets where failure of a truck tire may have contributed to a crash. However, determining whether a failed tire generated debris which directly caused a crash of the same vehicle or following vehicles is more of a challenge to assess. Bareket et al. (2000) noted that "no [traffic crash] file directly codes any information that identifies [roadside] debris from truck tires (which can include retreads), much less tire debris directly associated with truck tire blowout events." A similar finding was arrived at by Forbes (2004) who noted the difficulty to determine precisely the proportion of crashes that are caused by vehicle-related road debris as the source of non-fixed objects on the roadway typically are not recorded on crash report forms. However, a variable in the Fatality Analysis Reporting System (FARS) dataset can be used to infer a fatal crash resulting from debris in the road, although tire debris *per se* is not explicitly defined in this variable. This variable describing driver-related factors depicts a crash where a vehicle was "skidding, swerving, or sliding due to debris or objects in the road" (Transportation Data Center, 2006). Thus, roadside debris in this case must be taken in its widest sense, to include fallen trees, lost cargo, tire debris, etc. Table 4.3 indicates the number of vehicles involved in a fatal crash where a driver swerved to avoid roadway debris. Table 4.4 presents the numbers of deaths arising from crashes where vehicles swerved to avoid roadway debris.

Table 4.3 – Vehicles in Fatal Crashes Where Drivers Swerved to Avoid Debris in the Roadway 1995 – 2005

Year	# Vehicles swerving to avoid debris in roadway in a fatal crash	# Vehicles involved in all fatal crashes	% Vehicles swerving to avoid debris of all vehicles in a fatal crash
1995	47	56,524	0.08%
1996	88	57,347	0.15%
1997	51	57,060	0.09%
1998	71	56,922	0.12%
1999	77	56,820	0.14%
2000	81	57,594	0.14%
2001	64	57,918	0.11%
2002	66	58,426	0.11%
2003	102	58,877	0.17%
2004	104	58,729	0.18%
2005	80	59,495	0.13%
Total	831	635,712	0.13%

Source: author's analysis of FARS dataset

Table 4.4 – Deaths From Fatal Crashes Where Drivers Swerved to Avoid Debris in the Roadway 1995 – 2005

Year	# Deaths arising from vehicles swerving to avoid debris in roadway in a fatal crash	# Deaths from all fatal crashes	% Deaths (of all fatalities) arising from vehicles swerving to avoid roadway debris
1995	50	41,817	0.12%
1996	98	42,065	0.23%
1997	56	42,013	0.13%
1998	75	41,501	0.18%
1999	83	41,717	0.20%
2000	83	41,945	0.20%
2001	69	42,196	0.16%
2002	76	43,005	0.18%
2003	113	42,884	0.26%
2004	120	42,839	0.28%
2005	91	43,510	0.21%

Source: author's analysis of FARS dataset

In Tables 4.3 and 4.4 it is evident that in any year, the respective percentage of vehicles swerving to avoid roadway debris of all vehicles involved in a crash, or deaths resulting from these vehicles swerving to avoid roadways debris of all deaths, have consistently been below half of one percent (summarized in Figure 4.2). Forbes (2004) noted that roadway debris "causes far fewer crashes than many other causative factors, such as speeding and impaired driving, and hence it may not be a significant road safety issue." Additionally, Forbes estimated that between 80 and 90 lives per year are lost through these types of accidents. Indeed, for the majority of the years shown in Table 4.3, the actual numbers of fatalities as a result of swerving to avoid roadway debris are below this range. However, for the years 2003 and 2004, the number of roadway debris fatalities exceeded Forbes's estimates.

4.7 Tire Pressure or Failure Studies

The literature review undertaken revealed a paucity of studies directly related to the causes or factors precipitating commercial medium- or wide-base tire failure. There are several tire failure/forensic studies and reports about the Firestone ATX and AT tires (sold during the 1990s). However, these tires were used predominately by sport utility vehicles (SUVs) and not commercial trucks. Indeed, no OE manufacturer wants its products to be susceptible to failure and all strive to produce products that are at the cutting edge of tire design and safety. However, as stated before, the effectiveness of any tire design and safety enhancements is subject to an effective tire maintenance regime that is followed by the owner or driver of the vehicle.

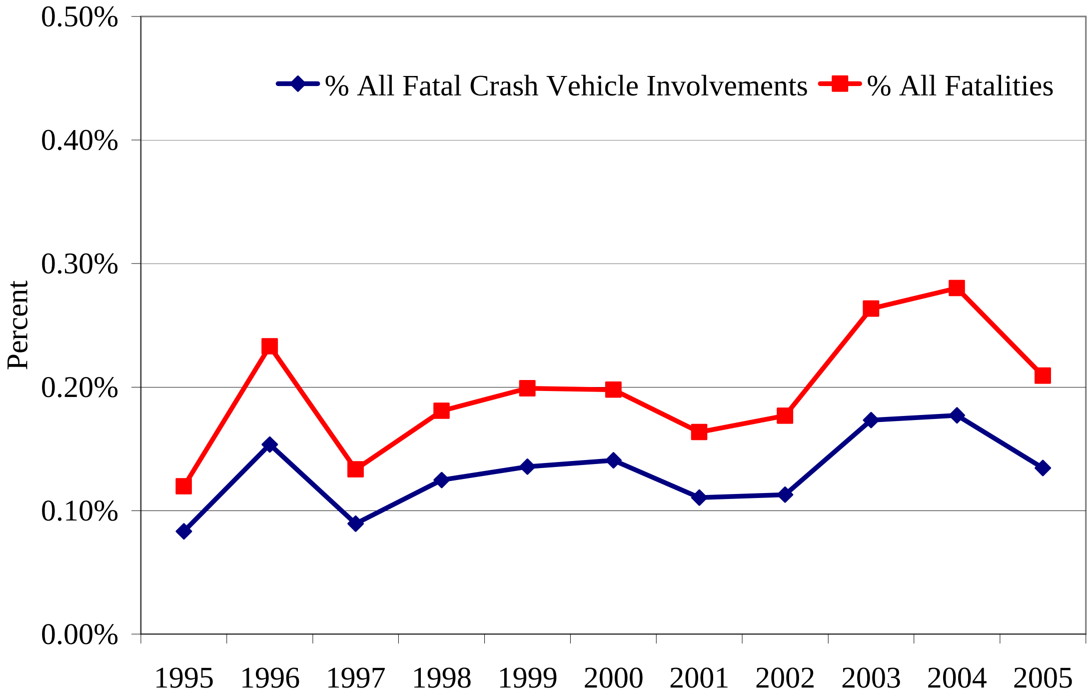


Figure 4.2 – Percentage of Fatalities or Fatal Vehicle Involvements Due to Swerving to Avoid Roadway Debris
Source: author's analysis of FARS Data

Table 4.5 presents several studies relating to tire failure or pressure analysis. The majority of these studies focused on tires used by passenger cars or light trucks or the handling of a vehicle after a tire failure event. The studies presented in Table 4.5 also differ from the tire failure studies discussed in Chapter 3 by way of the latter studies involving the actual collection and/or analysis of tire debris rather than the mathematical modeling or simulation of highway safety or vehicle maneuverability impacts resulting from roadway tire debris.

Table 4.5 – Tire Failure and Pressure Studies 1990 – 2007

Study	**Year**	**Vehicle Type**	**Performing Organization**
Failure Testing Study (30 and 42 Tires)	1990	Light Truck	UMTRI
Tire-Rim Mismatch Explosions	1990	Light Truck	Rice University
Theory and Experiments of Tire Blow-Out Effects	1994	Passenger Vehicle	University of California
Three-Dimensional Simulation of Vehicle Response to Tire Blow-Outs	1998	Passenger Vehicle	William Blythe (Consultant)

Table 4.5 – Tire Failure and Pressure Studies 1990 – 2007 (continued)

Study	Year	Vehicle Type	Performing Organization
Vehicle Stability and Handling Characteristics	1999	Passenger Vehicle	Fay Engineering Corp.
Vehicle Handling with Tire Tread Separation	1999	Passenger Vehicle	Collision Engineering Association and others
Blowout Resistant Tire Study for Commercial Highway Vehicles	2000	Commercial Truck > 10,000 lbs	UMTRI
TMC Tire Air Pressure Study	2002	Commercial Truck > 10,000 lbs	TMC
Investigation of Driver Reaction to Tread Separation Scenarios in the National Advanced Driving Simulator	2003	Passenger Vehicle	NHTSA

- **Failure Testing Study**
  In this study inflated tires incorrectly mounted on wheel rims were inflated until the bursting point. The first experiment mounted 30 tires and the second mounted 42. The objective of this study was to determine the inflation pressure required to fail 16-inch light-truck tires mounted on 16.5-inch wheel rims (note mismatch between tire and rim sizes). As Winkler[a&b] (1990) found "it is possible to improperly install a 16-inch tire on a 16.5 wheel." However, "if inflation pressure is then elevated, the improper seating of the tire can generate excessive stresses in the bead wire, eventually resulting in failure of the wire and explosive deflation of the tire as the integrity of the bead seat is lost."

- **Tire-Rim Mismatch Explosions: Human Factors Analysis of Case Studies Data**
  This study (using secondary data) assessed 13 crashes (i.e., person injuries or deaths) resulting from light-truck tire failure. The tire failure was a direct result of mismatching 16-inch tires and 16.5-inch rims during the tire mounting process. These tire failures did not occur on the road but at the tire mounting location. Laughery et al. (1990) found that tire mounters could not differentiate between 16- and 16.5-inch rims, thereby causing in some cases a mismatch between the tire mounted and actual wheel rim size. This scenario developed into a situation defined as "hazard entrapment" by Laughery et al., where the person selecting the tire or rim was not the same person who mounted it. Thus, the person mounting the tire was placed into a hazardous situation that was partly created by his associates.

- **Theory and Experiments of Tire Blow-Out Effects and Hazard Reduction Control for Automated Vehicle Lateral Control System**
  This study assessed vehicle dynamics after a tire blowout in an intelligent vehicle highway systems (IVHS) environment, where automated vehicle lateral control systems replace the human driver. Mathematical models (i.e., non-linear differential equations) were built to

simulate several aspects of a tire blowout and the resultant impacts on passenger-vehicle dynamics (e.g., steering and the trajectory followed). These models were then validated through on-the-road experiments using a 1982 AMC Concord sedan.

- **Three-Dimensional Simulation of Vehicle Response to Tire Blow-Outs**
  Blythe et al. (1998) engaged a vehicle simulator to model the transient effects in vehicle maneuvering resulting from a tire blowout. The modeling of these transient effects (with respect to passenger cars) were made possible through the three-dimensional and 15-degrees-of-freedom capability of the Engineering Dynamics Vehicle Simulation Model (EDVSM) vehicle simulator. The study team noted that previous tire failure models did not adequately model real-world situations. The 3D capability of the EDVSM enabled a greater flexibility at the required level of detail (i.e., before and after the tire failure event). The experiments conducted showed that overall "a tire blow-out alone does not lead to an inevitable loss of control" (Blythe et al., 1998).

- **Vehicle Stability and Handling Characteristics Resulting From Driver Responses to Tire Disablements**
  Fay and Robinette (1999) reviewed studies of tire disablements and the impact on vehicle maneuverability. It is likely that the majority of these studies focused on tire disablements of passenger vehicles rather than commercial trucks. Fay and Robinette conducted their own tire disablement experiments on a dynamic test track using passenger vehicles. They found that "tire disablements are generally a driver controllable event and that accident following tire disablement must be explained by driver induced and in-use factors." They also noted that tire disablements can but do not necessarily result in the loss of control and vehicular accidents.

- **Vehicle Handling With Tire Tread Separation**
  Tires for passenger vehicles were manually prepared to precipitate a tire failure in controlled experiments. The objective of the study was to understand how a driver controls a passenger vehicle after a sudden tire failure. Dickerson et al. (1999) also noted that at the time of their study that "the literature on tire failure testing is small in comparison to that concerned with the effects of tires on performance and handling of vehicles." The experiments confirmed that tire failure does have an effect on the vehicle's handling characteristics. However, the extent of the effect is dependent on, among other things, the position of the compromised tire on the vehicle.

- **Blowout Resistant Tire Study for Commercial Highway Vehicles**
  Bareket et al. (2000) presented an analysis of secondary data (i.e., crash datasets) relating the extent and impacts on highway safety of commercial-truck tire blow-outs. The status quo in the then current understanding and extent of tire blow-outs was achieved by conducting a literature synthesis as well stakeholder interviews. No actual on-the-road experiments of tire blow-outs were performed. One of the key findings was the strong linkage between front-left tire blow-outs and fatal crashes. A tire failure in this tire position would cause a sudden veer towards the left often into the path of oncoming traffic.

- **TMC Tire Air Pressure Study**
  In 2001, TMC field service engineers went out on the road to sample and record tire pressures of commercial trucks. Two trucking events (Walcott Truckers Jamboree and the Reno Truckerfest) were used as venues to collect truck tire pressures. Over 35,000 commercial medium and wide-base truck tires were tested from 4,700 truck/tractor combinations, 1,300 trailers, and 1,500 motor coaches. Approximately "90 percent of tire failures examined as part of this exercise were caused by underinflation which had either existed for a substantial period of time or had been caused by road hazards" (Tire Repair and Retread Information Bureau, 2008).

- **Investigation of Driver Reaction to Tread Separation Scenarios in the National Advanced Driving Simulator**
  This study investigated drivers' reactions to tread separation scenarios (i.e., tire failure) using the National Advanced Driving Simulator. No actual on-the-road trials were performed during this study and all scenario testing was laboratory-based using an SUV as the experimental vehicle. One hundred and eight human subjects experienced two tire failures (one expected and one unexpected). The experiments showed how driver reaction to the blow-out in terms of vehicle maneuvering and steering is key to maintaining control of the vehicle. In fact "decreasing vehicle understeer was strongly associated with the likelihood of control loss following both the unexpected and expected tire failures" (Ranney et al., 2003).

4.8 Summary

Tire failure is a sudden and catastrophic event that can take many different forms. This chapter presented several assessment methods and studies that have been developed or executed to investigate this type of incident which can adversely impact costs and/or fleet operations. Investigation of traffic crash datasets indicated that less than half of one percent of vehicle involvements or fatalities arises from tire failure. Since 1990 more than eight studies have researched tire failure and its impacts. However, many of these studies have involved passenger vehicles and focused on driver reaction to tire failure rather than the actual blow-out event and/or factors leading up to it. Despite the usefulness of these studies, there is the potentially limited applicability of the results with respect to commercial heavy trucks considering their vehicular characteristics compared to passenger vehicles.

5 REVIEW OF TRUCK ORIGINAL EQUIPMENT AND RETREAD TIRE SAFETY AND DURABILITY ISSUES

5.1 Introduction

This section presents a review of commercial medium- or wide-base tire safety and durability issues with particular reference to retread tires, and also discusses methods to estimate the amount of tire debris on the Nation's highways.

5.2 Highway/Roadside Litter or Debris Volumes

Determining the volume of roadside tire debris is a formidable task as debris can take many forms, appears on all roadway types, and is collected by various agents (e.g., State departments of transportation, lawn contractors, contracted convict labor, etc.). The Disposal of Roadside Litter Mixtures study (Andres, 1993) is one of the few research projects that investigated the problem and extent of roadside debris, finding that 4.4 million tons or 2.7 percent of discarded solid municipal waste in 1990 was rubber and leather. However, the ratio (volume to weight) of these materials approximated 2.2 the highest of the 11 materials categorized. This indicates that while rubber and leather may not be significant debris sources contributing to roadside litter, their volume-to-weight ratio necessitates a considerable amount of cost and effort for removal and disposal. In addition, the environmental implications of rubber tires according to their difficulty of disposal ranked it in first place at 65 percent of the 50 States surveyed by Andres. The collection and disposal of tires necessitated additional sorting of any roadside debris collected (as many landfills did not accept casings or tire debris) the disposal of which negatively impacted municipal finances.

5.3 Highway/Roadside Litter or Debris Environmental Impacts

Rubber tire debris on roadsides can also negatively impact the environment. In a study conducted in 1978 and 1979 by the Environmental Protection Agency (EPA) "debris collected along highways was considered a major contributor to pollution via runoff water" (Andres, 1993). It is now known that rubber tires are potential sources of lead and zinc which when entering into the local ecosystem (through runoff water) can contribute to pollution.

According to the Keep America Beautiful Campaign (KAB, 2008) trucks are listed as one of the seven primary sources of litter. However, this is with respect to their uncovered loads and not to tire debris. A Visible Litter Survey (VLS) performed in Florida in 2002 listed vehicle and tire debris as the top source of litter (14%) by proportion of large litter items collected (R.W. Beck, 2007). Andres also indicates that "rural interstate roads and expressways generally offer less opportunity for litter deposits because of the high speed nature of the roadway and a lack of access to commercial establishments." However, high speeds and the predominance of long distance traffic make rural interstate roads and expressways the prime location for tire debris. Indeed, "as litter items (i.e., vehicle and tire debris) these are the most closely connected to use on the roadway and therefore the most likely items to fail to make it into proper disposal channels" (Center for Solid and Hazardous Waste Management, 2002).

5.4 Actual Volume of Debris Collected From Roadways

It is evident that not all tire debris is collected by highway maintenance crews. Discussions with highway maintenance managers revealed that members of the public may report large pieces of tire debris in the roadway to the local emergency authorities. Members of the emergency services team may remove debris from the roadway without notifying the highway maintenance department. Indeed, the debris collected by the emergency services may not be transferred to the highway maintenance yards. Thus, the volume of tire debris collected by highway maintenance crews may not be 100 percent of the debris deposited on the local roadways and thus may not entirely reflect the extent of tire failure in a particular location.

5.5 Truck Operating Regimen and Tire Debris Generation

Another factor influencing the amount of tire debris on highways is the operating policy of trucking companies. Some "Fleet managers often instruct their drivers to avoid stopping on a highway with problems if they can avoid it. Instead, most fleet managers instruct their drivers to continue driving to the nearest truck stop if they encounter a non-hazardous tire problem" (Galligan, 1999). This policy, aiming to minimize the financial cost of tire repair by reducing the need for a road call, though understandable, may contribute to other negative events.

Debating the extent of roadway tire debris and its generation, Larry Harris of Firestone Mileage Sales (2007) responding to the Ban Retread Tire? Not So Fast article by Phelan (2007) disputed the public perception that tire shreds are the direct result of a tire blowout. He stated evidence from experiments conducted by his company where steel truck tires traveling at 70 mph were deliberately punctured. From these experiments it became evident that the "shredding results from a driver continuing to drive on the tire after its air loss." In other words, shreds aren't caused by the blow-out itself but by continuing to drive unknowingly with the affected tire. Figure 5.1 illustrates a failed tire (inside left rear trailer axle in a dual position). The driver of this vehicle only realized a tire had failed while on a routine break at a truck stop (personal communication by O. Page with the driver of truck on August 15, 2008).

Carey (1999) discussed other trends in the trucking industry that may foster increased levels of tire debris generation. The intense competition evident in the line haul trucking industry has led some operators to consider using smaller wheels on their fleets. Longer trailers with smaller wheels increase the efficiency of the tractor trailer combination, but also come with costs. Smaller wheels enable a lower cargo floor to be permissible enabling a greater cargo volume to be carried while maintaining the same trailer height. However, these smaller wheels "make more rotations to travel at the same speed as larger wheels. The added number of rotations means that the smaller wheel must spin more quickly, increasing the amount of heat and friction to which the tire is exposed" (Lang quoted in Carey, 1999). The generation of additional heat may ultimately lead to premature tire failure. Longer trailers are more difficult to maneuver in congested areas, increasing the potential of tires to be subject to curbside damage.

Figure 5.1 – A Failed Medium-Duty Truck Tire

5.6 Estimates of Roadside Tire Debris and Proportions by Tire and Vehicle Type

Carey (1999) put forward a methodology to estimate the volume of tire debris on the highway by comparing the type of tire debris found on the highway originating from various vehicle types (e.g., passenger car, light truck and medium/heavy truck) to the actual proportions of tire debris assessed in the TMC and Arizona studies. Commercial medium- and wide-base truck tires were overrepresented in the tire debris mix. By comparison, Strawhorn (quoted in Forbes & Robinson, 2004) indicated that in the TMC studies retread tires were not overrepresented. .

Table 5.1 presents Carey's method for estimating the proportion of tire debris by type. The method incorporates the annual vehicle miles traveled (VMT) and the average number of tires per vehicle. Accounting for the differences in the average number of tires per vehicle type allows for an adjustment of VMT shares to be made. This adjusted share reflects the proportions of tires/wheels by type that pass over the Nation's highways. According to Carey's method in both of the national TMC studies (see Chapter 3), the share of debris for medium/heavy trucks collected was significantly higher than their estimated adjusted share (64% in either 1995 or 1998, respectively, to the estimated adjusted share of 18.5%). Carey therefore concludes an overrepresentation of medium/heavy truck tire debris. Though this method produces only an estimate, the extent of overrepresentation of medium- or wide-base truck tire debris may be somewhat high as it is very much dependent on the location and local vehicle mix. Using national values may hide significant local realities.

Table 5.1 – Share of Travel versus Share of Debris on U.S. Highways

Tire Type	Share of Tire Travel on U.S. Highways				Share of Debris[1]	
	VMT Share	Average # Tires[2]	Adjustment[3]	Adjusted Share[4]	TMC 1995	TMC 1998
Passenger Auto	59.80%	4	2.392	48.48%	27.40%	25.00%
Light Truck[5]	32.60%	5	1.630	33.04%	8.50%	11.00%
Medium/Heavy Truck	7.60%	12	0.912	18.48%	64.10%	64.00%
Total	100.00%		4.934	100.00%	100.00%	100.00%

1) Aggregate shares of debris collected in TMC samples. 2) Average number of tires by vehicle configuration. 3) Adjustment made by multiplying share of VMT by number of tires. 4) Adjusted share equals "Adj." by type divided by sum of adjustment values. 5) Includes 2 axle-6 tire SUV/trucks.
Source: Carey, 1999

Table 5.2 revisits Carey's method replacing the average number of tires per vehicle with values based on the particulate emission estimation work of the EPA (1995). According to the EPA particulate emission methodology, the average number of tires according to vehicle type is: passenger auto = 4, light duty gasoline or diesel truck = 4, and medium/heavy truck (i.e., heavy-duty diesel vehicles) = 18. The results indicate that a revision in the average number of tires per vehicle (in particular medium/heavy trucks) reduces the extent of overrepresentation of medium/heavy trucks tires when compared to the TMC studies (27 to 64% [Table 5.2] compared to 18 to 64% [Table 5.1]).

Table 5.2 – Share of Travel versus Share of Debris on U.S. Highways Using EPA Estimates

Tire Type	Share of Tire Travel on U.S. Highways				Share of Debris[1]	
	VMT Share	Average # Tires[2]	Adjustment[3]	Adjusted Share[4]	TMC 1995	TMC 1998
Passenger Auto	59.80%	4	2.392	47.24%	27.40%	25.00%
Light Truck[5]	32.60%	4	1.304	25.75%	8.50%	11.00%
Medium/Heavy Truck	7.60%	18	1.368	27.01%	64.10%	64.00%
Total	100.00%		5.064	100.00%	100.00%	100.00%

1) Aggregate shares of debris collected in TMC samples. 2) Average number of tires by vehicle configuration taken from the EPA, Document Reference: EPA-AA-AQAB-94-2 (February 1995). 3) Adjustment made by multiplying share of VMT by number of tires. 4) Adjusted share equals "Adj." by type divided by sum of adjustment values. 5) Includes 2 axle-6 tire SUV/trucks.
Adapted from: Carey, 1999

In the last example, VMT data for a specific tire debris collection location (I-5 in Taft, California) is combined with the EPA average-number-of-tires-per-vehicle estimates. Figure 5.2 indicates the traffic count site and the length of the tire debris collection regime. This length will form the basis for estimating VMT for this particular site. Additional assumptions include:

- VMT is estimated from the length traveled (i.e., 43 miles) multiplied by the number of vehicles traveling;
- State of California (2006) traffic data for this location (milepost #52.145 in Kern County) in 2005 were: 65,500 annual average daily traffic (AADT) consisting of 45,398 cars, 3,666 light trucks (2 axles), and 16,436 medium- or heavy-duty trucks (3+ axles) (see Appendix C); and
- VMT proportions are estimated by multiplying each AADT (by vehicle type) by the distance traveled and then dividing each answer by the sum of VMT for all vehicles.

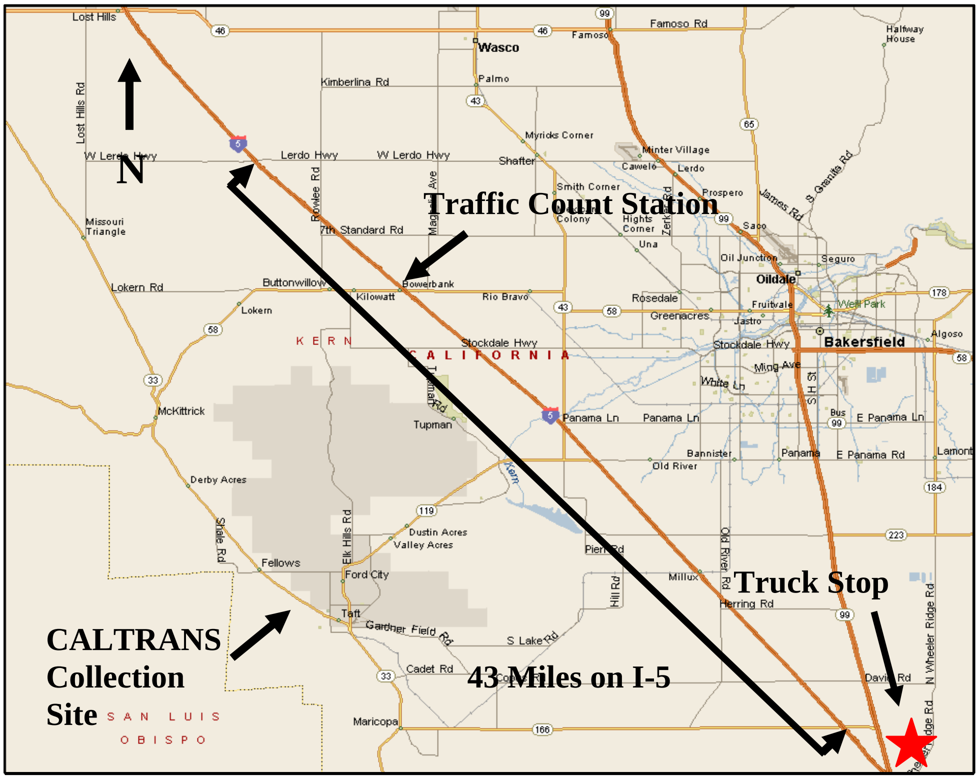


Figure 5.2 – Taft, CA Tire Debris Collection Jurisdiction

The results are presented in Table 5.3. In this example, the use of actual traffic count data coupled with the EPA values (i.e., average number of tires per vehicle) changes significantly the adjusted VMT shares. The resulting high adjusted VMT share for medium/heavy trucks of 60 percent is to be expected and is confirmed by the 2+ truck axle vehicle count proportion for this site which exceeded 75 percent (i.e., 75% of the 2+ axle trucks passing over this site were configured with five or more axles). The change in medium/heavy truck share of travel on I-5 in the Taft study area substantially reduces the overrepresentation of tire debris when compared to the TMC studies. In fact, the estimated share of medium/heavy truck tire debris of 60 percent is in the same ball park as the TMC studies at 64 percent.

Table 5.3 – Share of Travel versus Share of Debris at Taft, CA Tire Debris Collection Site

Tire Type	Share of Tire Travel on I-5 (Taft, CA)				Share of Debris[1]	
	VMT Share	Average # Tires[2]	Adjustment[3]	Adjusted Share[4]	TMC 1995	TMC 1998
Passenger Auto	69.31%	4	2.772	36.90%	27.40%	25.00%
Light Truck[5]	5.60%	4	0.224	2.98%	8.50%	11.00%
Medium/Heavy Truck	25.09%	18	4.517	60.12%	64.10%	64.00%
Total	100.00%		7.513	100.00%	100.00%	100.00%

1) Aggregate shares of debris collected in TMC samples. 2) Average number of tires by vehicle configuration taken from the EPA (1995) Document Reference: EPA-AA-AQAB-94-2. 3) Adjustment made by multiplying share of VMT by number of tires. 4) Adjusted share equals "Adj." by type divided by sum of adjustment values. 5) Includes 2 axle-6 tire SUV/trucks. Adapted from: Carey, 1999

The results of Table 5.3 may be considered by some readers to be an unrepresentative case particularly when comparing shares of tire travel at a specific location with national estimates of tire debris types as found in the TMC studies. However, if medium- and heavy-truck traffic is considered exclusively, another tire debris generation scenario may result. Discussions with industry representatives suggested that approximately 60 to 80 percent of medium- and/or heavy-truck tires running on the Nation's highways are retreads. In the TMC study findings, 87 percent of medium-duty truck tires assessed in 1995 were from retreads and in 1998 this proportion decreased to 84 percent (see Table 3.2). These proportions of debris derived from retreads are slightly above the industry estimates of retread tires on the roads but the discrepancy is small and may not be statistically significant. The TMC studies did not incorporate any information on the prevailing traffic volume and vehicle type composition (to estimate the volumes of axles running) for each collection area. Thus, depending on the metric used or average number of tires per vehicle, the proportions of medium- and wide-base truck tire debris collected may in fact approximate the actual proportion of this tire type traveling over the survey area.

5.7 Tire Safety

In recent decades, substantial advances have been made in the design, performance, and safety of commercial medium- and wide-base tires. OE manufacturers have sought to maximize the performance characteristics of tires without compromising safety, which can also create a competitive edge. However, "because a tire has failed does not necessarily mean that it was unsafe" (Gardner & Queiser, 2005). They define two primary elements to tire safety, 1) tire servicing and maintenance, and 2) on-vehicle, in-service conditions.

5.7.1 Air Pressure Maintenance

Despite many years of experience, the tire maintenance technician may still be challenged to determine correct air pressure in a tire by visual inspection. "It is hard to see much of a difference between a properly inflated radial tire and one that's as much as 50 percent low on air. All radial tires have a certain amount of bulge when properly inflated" (Deierlein, 1996). With so many tires to check and deadlines to meet, drivers or tire maintenance technicians may not give the same attention to all tires during pre- and post-inspections. This scenario is confirmed by Kreeb et al. (2003) who noted "The act of tire pressure maintenance is labor- and time-intensive. An 18-wheeled vehicle can take from 20 to 30 minutes to check all of the tires and inflate perhaps 2 or 3 tires that may be low on air. To complete this task once each week on every tractor and trailer becomes a challenge for many fleet operators. As a result, tires are often improperly inflated." Indeed, some observers perceive that the checking of the air pressure on the inside tires of dual-wheel arrangements is the least likely to be performed as this requires the most effort on the part of the driver or tire technicians. The tire failure depicted in Figure 5.1 alludes to this. However, Kreeb et al. (2003) disputed the belief that inside tires (on dual assembly) were not maintained to the same extent as outside tires, finding instead that there were only slight differences in air pressures between inner and outer tires surveyed.

Ideally, random checking of tire air pressure should be performed when the tire is cool (e.g., the TMC Air Pressure Study team (see section 4.7) waited three hours after each truck was parked before taking the air pressure). Checking air pressure when the tires are still warm gives incorrect readings. Trucks may not spend enough time at truck stops for their tires to cool if deadlines have to be met. On the other hand, if air pressure checking is performed at night there are security and safety concerns to consider. In some cases, a cursory visual tire inspection may also lead a tire technician to assume that the size of the bulge indicates a level of under inflation and that air is required to correct this. However, Deierlein (1996) warns that such an action may lead to overinflating the tire precipitating negative consequences affecting fuel costs, vehicle operations, etc., similar to those summarized in Figure 5.3.

It is a tire industry accepted fact that proper tire air pressure is the key to maintaining the tire in optimal operating condition and thereby increasing its longevity. In addition, there is no one tire pressure that can be used as a benchmark for a particular tire size or type, as the vehicle's "loads determine inflation" (Goodyear, 2003). Indeed, many of the studies discussed in Chapter 3 concluded that under inflation was a contributing factor to tire failure. Thus, there will be a constant focus on air pressure maintenance by any trucking operator concerned about their tire investment. However, "even properly maintained tires are subject to potential air loss through regular use, punctures, road hazards, and changes in the weather" (Birkland[a], 2005). Each of the factors that impact or can be impacted by air loss are depicted in Figure 5.3.

5.7.2 Air Loss or Expansion: the Perennial Enemy of the Truck Operations

Any change in tire air pressure has the potential to impact the entire business of the trucking operator. For example, underinflated tires can lead to increased fuel consumption and in extreme

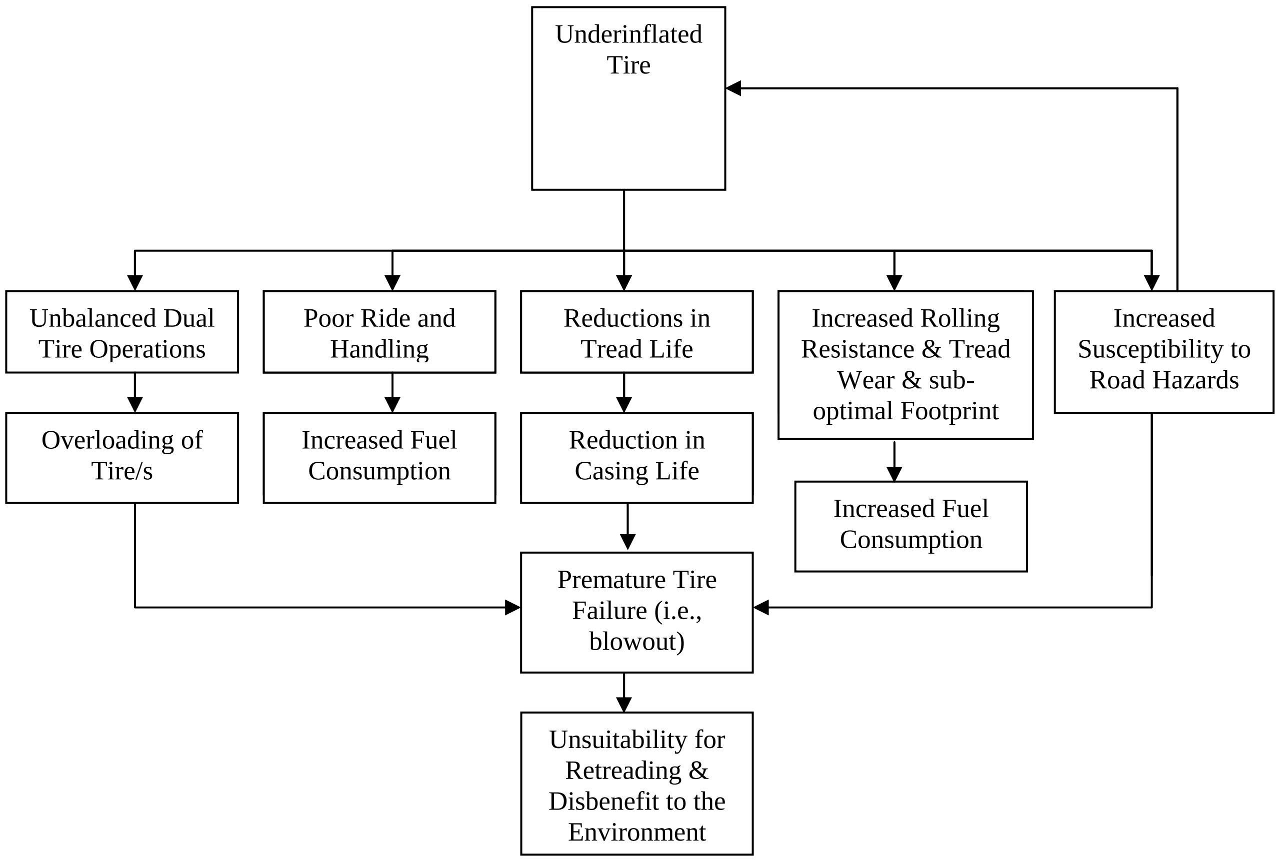


Figure 5.3 – Potential Negative Impacts Resulting From Tire Underinflation

cases may significantly increase the highway safety risk of the vehicle to itself and other road users (see Figure 5.3). Excessive heat is an enemy of optimal tire operation. Indeed, "when the tire is properly inflated, it runs its coolest" (Decker quoted in Birkland[b], 2005). Tire air pressure is dynamic and cannot be taken for granted. Maintaining tires at their optimal performance levels requires the implementation of an aggressive tire maintenance, education, and tire monitoring regime. Empirical results indicating how under inflation can negatively impact tire life and fuel mileage are presented in Table 5.4. These empirical data were produced by the American Society for Testing Materials and the RMA.

Table 5.4 – Negative Impacts of Tire Underinflation

Underinflation Percentage	Impact on Tire Life	Impact on Fuel Mileage
9%	-5%	-1.9%
16%	-22%	-3.1%
22%	-28%	-4.4%
31%	-37%	-6.2%

Source: Deierlein, 1992

5.7.3 Air Pressure and Trucking Fleet Size

Kreeb et al. (2003) found that there was a "strong correlation between fleet size and tire pressure maintenance" in that as fleet size increased, the proportion of underinflated tires decreased. Reasons for this could be due to the fact that larger fleets can engage better tire maintenance programs and may employ staff who are only responsible for tire maintenance/monitoring and nothing else. Smaller fleets, on the other hand, may lack the human resources (or tire specialists) and, coupled with the volume of trucking operation tasks, may inadvertently not give the highest priority to tire air pressure monitoring or maintenance.

5.7.4 Truck Tire Failure and Highway Safety

Typical crash datasets, e.g., FARS and TIFA, do not contain the required detail to differentiate whether a crash was influenced by a primary (i.e., tire blow-out) or secondary (i.e., tire debris) factor. Chapter 7 presents the results of analyses of fatal traffic crash databases where truck tire defects were recorded. Bareket el al. (2000) also noted that between the years 1972 and 2000, only six truck crashes (involving tire blow-outs) were investigated by the National Transportation Safety Board (NTSB). Between 2001 and 2007, inspectors from the NTSB did not investigate any traffic crashes resulting from truck tire blowouts. However, three investigations were undertaken of crashes resulting from tire blowouts of other vehicle types, namely:

- May 2001 – 15-seater passenger van involved in a single-vehicle rollover crash (U.S. Route 82, Henrietta, TX);
- July 2001 – 15-seater passenger van involved in a single-vehicle rollover accident (U.S. Route 220, Randleman, NC); and
- September 2005 – Motorcoach fire on Interstate 45 during Hurricane Rita evacuation.

5.8 Tire Durability

Durability is defined for the purposes of this section as "the structural integrity of the tire in service" (Gardner & Queiser, 2005). As a commercial medium- or wide-base tire is exposed to different surfaces, loads, and operating regimes, how each tire performs and endures these situations relate to its durability. However, a "failed [tire] does not necessarily mean that there was anything deficient in its design or manufacture." (Gardner & Queiser, 2005). One of the keys to sustaining a tire's durability is engaging an effective tire maintenance regime. This section discusses several in-service issues that may directly impact retread tire durability.

5.8.1 Tire Design and Manufacturing Defects

Gardner & Queiser (2005) note the difference between a tire design defect and a tire manufacturing defect:

- **Tire Design Defect**
  A defect that occurs in a tire during the design and development phase (i.e., the tire was manufactured according to the required processes and standards but remains defective).
- **Tire Manufacturing Defect**
  A situation where a tire was designed and developed according to the required processes and standards but during production it deviated from the design specifications.

Either of these two types of defects can affect the performance of a tire and subsequently its safety and the safety of the vehicle to which it is attached.

5.8.2 Retread Splicing

In Chapter 2 the three types of truck tire retread processes were described and illustrated. In the pre-cure process, a splice is used to cut the new tread to the correct size of the casing. A splice correctly incised is unlikely to cause any future problems in the operation of the retread tire (see Figure 2.21). However, a misaligned splice can precipitate other tire problems that will result in premature tire failure, such as:

- Starting point for irregular wear;
- Starting point for ride disturbances; and
- Premature tire/tread failure.

The above problems (though rare) emanating from retread splicing are often used as selling points promoting retread tire processes that do not use splicing (e.g., ring tread or mold cure). Figure 5.4 indicates a misaligned splice on a retread.

Figure 5.4 – Misaligned Splice on a Pre-Cure Retread Casing
Source: O. Page

5.8.3 Higher Operating Speeds

Higher permissible speed limits for trucks (e.g., 75 mph in Arizona) have enabled higher commercial truck operating speeds with the anticipated result of shorter journey times. However, "faster speeds force tires to put a wider footprint on the road, which increases rolling resistance. Rolling resistance influences fuel economy while excessive heat degrades a tire. A typical tire casing contributes 30-

40 percent of the tire's rolling resistance while the tread accounts for 60-70 percent" (Kenworth Truck Company, 2003). Thus, shorter journey times may make a trucking operation more competitive, but they may also have long-term negative impacts increasing tire costs. Figure 5.5 illustrates an underinflated tire operating at high speed. Overdeflection of the underinflated tire is noticeable (when compared to the correctly inflated tire) and the resulting footprint is suboptimal.

Figure 5.5 – Underinflated Tire
Note: Tire Size 295/75R22.5, 5770 lbs, Speed 70 MPH and Load 5,770 pounds
Courtesy Bridgestone/Firestone

Heat produced by higher speeds is the main culprit in driving up tire operating costs (Cullen, 1996). Indeed, "traveling at 75 mph can produce a 25º F temperature difference in the shoulder area, compared to running at 55 mph" (Cohn quoted in Cullen, 1996). Excessive heat is an enemy in the optimal operation of a tire and operating under such conditions for an extended period will erode tire performance and durability, leading to premature failure. Research has shown that "increased heat decreases rubber tear resistance which promotes crack initiation and propagation" (Gardner & Queiser, 2005). As heated rubber becomes more brittle its inherent elastic characteristics required to successfully counter overflexing in the shoulder area or potential damage from the road surface significantly decrease.

5.8.4 Dual Tire Operations

According to Walenga (quoted in Birkland[b], 2005), "80 percent of fleet tires are in dual positions." Tires operating in this position need to be the same size, have the correct air pressure, and have minimal differences in air pressure between the tires. If one of the dual-tires is running underinflated and the other is correctly pressured, the difference in air pressures results in differences in tire sizes (one of the dual-tires is smaller than the other) and rolling resistance. Tires in dual operation must cover the same distance in a single revolution. Thus, a mismatch in air pressure between dual tires results in one tire being dragged along the road surface while the other operates correctly. In this uneven dual-tire operation, the tire that is dragged generates excessive heat and may eventually fail, and the remaining tire is subjected to carrying more weight than it was designed for and can also fail.

5.8.5 Tire Tread Mileage and Useful Tread Mileage

An article by McCormick (2003) estimated that the typical annual mileage covered by a typical regional linehaul operator is 30,000 to 80,000 miles (within a 300-mile or less operating area) and above 80,000 miles signified linehaul operations. However, Deierlein (1992) discussed the results of a Goodyear investigation into useful tread mileage (UTM) (i.e., wear). The term UTM refers to the average miles traveled per $1/32^{nd}$ (i.e., $1/32^{nd}$ of an inch or 0.793 mm) of tread depth. A fleet manager may designate a useable tread threshold and when a tire reaches that threshold (i.e., wear point) the tire is removed from service, and usually sent to be retread. This tread threshold level can change dramatically depending on the percentage of tread wear available when the initial calculation is performed. It is best to have at least 30 to 50 percent of the tire tread worn before you make the calculations in order to have a meaningful resultant miles per 32^{nd} of wear (Walenga, 2008).

Walenga (2008) further states that per Federal regulations (e.g.., FMCSA 49 CFR 393.75 and 49 CFR 571.119 [Office of the Federal Register[C&D], 2007]), a truck tire can operate on the steer axle down to a minimum of $4/32^{nds}$ tread depth at which point it is considered unsuitable for steer axle operation and must be removed. If you have a steer tire that starts with $19/32^{nds}$ of original tread depth (OTD), subtracting the $4/32^{nds}$ (i.e., the mandated minimum) remaining tread depth (RTD) leaves $15/32^{nds}$ of Useful Tread Depth (UTD). The miles accumulated while consuming the $15/32^{nds}$ of tread depth would be the UTM and that total mileage divided by the $15/32^{nds}$ would yield the average miles per 32^{nd} of wear, i.e., the wear rate. For drive, dolly, and/or trailer tires, the Federal minimum RTD is $2/32^{nds}$ (i.e., 1.6 mm). It is generally considered that the tires with the highest wear rate (i.e., the most average miles per 32^{nd} rate of wear) will yield the highest total removal mileage.

In the Goodyear investigation, comparable OE Goodyear tires were mounted on steer-and-drive axles on tandem-axled tractors. However, each tractor was of a different design, e.g., cab over engine (COE) or pick-up and delivery (P&D) had a different operating regime (e.g., line or regional haul) and operated in different geographical areas. Results presented in Table 5.5 indicate service conditions have a major impact on truck tire tread wear evidenced by the linehaul steer tires getting the best mileage when compared to P&D operators. This should come as no surprise as the wear on tire tread is directly proportional to the rate of parking, stopping, and turn maneuvers of the truck. The UTM of the pure linehaul (COE) example in Table 5.5 is 15,174 miles, meaning that for the total mileage seen during the evaluation period divided by the tread depth used in 32^{nds} of an inch increments, the steer tires on these vehicles in this service category averaged 15,174 miles per 32nd of tread wear.

Table 5.5 – Useful Tread Mileage Before Replacement or Retreading According to Operating Regime

Operating Regime	Useful Tread Mileage Attained per 1/32nd Inch
Pure line haul (COE)	15,174
Regional linehaul (COE)	9,868
Combination P&D/linehaul (conventional)	8,233
Combination P&D linehaul (COE)	8,065
Pure P&D (conventional)	6,127

Source: Deierlein, 1992

5.8.6 Timing of Retread

Deierlein (1996) noted that too many truck fleet operators waited until tire tread depth had been worn down past the point of safety before removing the tires for retreading. This practice (possibly engaged as a cost-saving or purchase delay exercise) negatively impacts the casing's suitability for retreading (i.e., durability for multiple retreads). This is because there needs to be a minimum amount of tread on the casing to reduce the potential of steel belt damage. Note that retreaders buy casings from trucking operators or other sellers and resell the new retread tire back to the original seller or another party. Discussions with tire retreaders have revealed that used casing buyers may receive credit for casings purchased which are subsequently deemed unsuitable for retreading. Minimizing the potential of rejected casings being returned for credit is another reason for trucking companies to implement tire maintenance and/or monitoring programs.

5.8.7 Multiple Retreads and Tire Durability

Anecdotal evidence from the retread truck tire industry suggests that a properly maintained medium- or wide-base truck tire casing can be retreaded four or five times. However, retreading more than three or four times is the exception. Each successive retread of a casing necessitates a rebuffing of the casing and the branding of mandated retreader marks (see section 2.10). However, rebuffing can only be done if there is sufficient tread depth to maintain the minimum height required between the bottom of the original tread to the top of the uppermost belt. As to determining the durability of a retreaded casing, if the date (i.e., week and year of manufacture) of the OE is known and all subsequent retread information is evident (i.e., branded), it is possible at the time of ultimate disposal of the tire to estimate the casing's life and intervals between each retread. The tire study by Walenga et al. (discussed in Chapter 3) follows this methodology. Figure 5.6 illustrates a casing that has been retread twice by the same retreader. This may be the usual practice for large truck operators (i.e., to use the same retread plant). Also some of these operators may contract specific retread plants to maintain their tires for the complete life of the casing. In the example shown in Figure 2.5, the tire was retread by K&K Tire Inc. (of Kansas City, Kansas) during the 31st week of 2002 (July 29 to August 3) and again during the 44th week of 2005 (October 31 to November 5) .

5.9 Other Factors Impacting Tire Durability

There are other factors outside the in-service characteristics of a tire operating regime that may negatively impact tire durability. These vary from the quality standards of imported tires to the practice (by some retreaders) of not branding all retreaded casings manufactured with the mandated markings. A discussion of these issues is presented in this section.

Figure 5.6 - Tire Casing With Multiple Retread Codes

5.9.1 Tire or Casing Importation

Section 2.13 presented data on the top 10 countries ranked according to the number of tire manufacturing permits issued by NHTSA enabling these OE manufacturers to supply tires to the U.S. domestic tire market. It was evident from Table 2.3 that the 10 countries listed accounted for nearly 70 percent of all permits issued and China alone accounted for 30 percent. It becomes apparent that a significant percentage of new tires sold in the United States are manufactured abroad.

There has been an ongoing debate about the practice of allowing used tires to be imported into the United States for the purpose of retreading. It is alleged that some of these tires may not have DOT branding (i.e., TIN as described in section 2.10) and by implication may be substandard. Advocates against this practice argue that such tires may not meet current NHTSA standards and therefore are a potential safety hazard. However, in light of these concerns, the following can be stated (Svenson, 2007):

- NHTSA does not have any regulations restricting the importation of used tires for retreading. The only regulations in force apply to new tires and if the tire has the DOT symbol on it, it states that the tire must pass the minimum specifications contained in CFR 571.119 and the DOT symbol represents that the manufacturer self-certified the tires. When a used casing is retreaded, regardless of its origin, it must comply with CFR Part 574.5 for tire identification requirements, which requires a DOT-R be placed in front of the assigned plant code and date code.

- NHTSA places no restriction on which countries can export tires to the United States.
- If the tire to be retreaded is a non-passenger car tire (e.g., for medium or large trucks), it can be retreaded in the United States if it does not have a DOT stamp. However, if it is a passenger car tire, then it must have a DOT marking from its new tire life.
- NHTSA does not have any regulations on retread tires other than for passenger car tires contained in Federal Motor Vehicle Safety Standard (FMVSS 117).
- CFR Part 574.5 requires the DOT-R symbol (see section 2.10) to be marked on all retreaded tires used on motor vehicles as described below. The retread plant must stamp the retreaded tires with their retread plant code (DOT-R).

5.9.2 Self-Imposed Standards of the Trucking Industry

Current U.S. trucking industry practice discourages the use of retreads on steer axles. However, there are exceptions, "Concerning retreads on a front axle, the norm in industry practices is to install the newest tires on the front axle because of the crucial impact of that location in regards to tire failure. As the tire becomes unsuitable for the steer axle location, it is generally moved rearward onto successive axles. There are exceptions to this practice, however, as in the case of trash truck. Because of the abuse that their front axles are subjected to and the multiple retreadings they receive, the "freshest" tire is not always mounted on the front axle" Baraket et al. (2000). Each trucking operator has the option of whether to adopt or reject industry standards. A fatal crash in 1999 bears witness to the fact that industry standards may be flouted, precipitating calls for government intervention. In this case, a retread tire on the front left steer axle of a concrete mixer truck failed. The truck lost control, crossed the center line, and smashed into an oncoming vehicle, killing its two occupants (Mikolajczyk, 1999).

5.9.3 Independent or Franchised Tire Retreader

Section 2.12 noted that there are no nationally mandated performance and quality standards for medium- or heavy-duty retread tires. The major OE manufacturers (as franchisors) have therefore developed their own. It is generally accepted that the retread tire industry has improved it standards evidenced by the quality of retread tires available today. It is clear that as with most industries there is a substantial variation in the quality of retread operations and therefore some retreaders may not adhere to retread industry best practices.

The Commonwealth of Virginia study (2000) noted that the major rubber companies (e.g., Goodyear, Bridgestone Firestone, etc.) have manufacturing quality control over their retread tire franchises. This control extends to franchisees complying with retread standards, training levels, and the retread process used. It was estimated at that time that 70 percent of retreaders were operated under some form of franchise arrangement. However, what of the other 30 percent? What retread manufacturing process and quality regimens do they follow?

5.9.4 Unscrupulous Tire Retreaders

Retreader details branded on the sidewall of the tire casing are required for every casing retreaded for sale to a third party (see Chapter 2). Thus, a tire casing that has been retreaded twice should have two branded retread codes (as shown in Figure 2.5). Industry practice indicates that each successive retread branding is placed in close proximity to previous brandings to permit easy assessment of the tire casing retread history by each subsequent retreader. However, not all retreaders follow this practice. Discussions with staff at several truck stops (visited as part of this study) indicated that during their tire repair and maintenance careers, they had witnessed instances where retreaders had not branded their retread markings on the tire casing as mandated.

5.9.5 Tire Operating Environment

The durability of a tire may also be affected by the anticipated tire operating regime that the tire will be exposed to. To the purchaser of tires, it is imperative that the tire best suited for its probable use is selected, in order to optimize the durability of the new tire. However, everything goes back to the tire maintenance regime once the tire is in use. No matter how durable a tire may be, inconsistent tire maintenance may thwart any potential gains from this investment. A study by Newport Communications (1998) researched OE and retread drive axle tire use by type of business. The respondent results are presented in Figure 5.7.

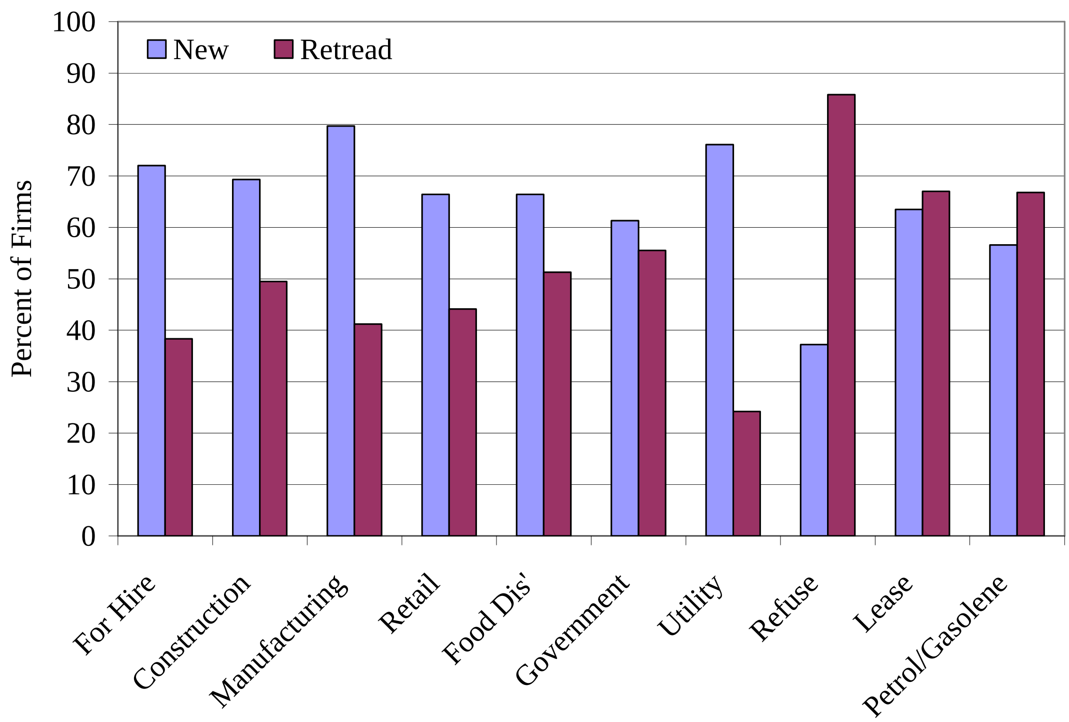


Figure 5.7 – Types of Tires Used on Drive Axles
Source: Newport Communications, 1999

It is evident from Figure 5.7 that respondents from the refuse industry had the highest use of retread tires on drive axles. This is partly due to the operating regime that garbage trucks operate in, which necessitates the use of retread tires. Garbage trucks operate in residential areas with winding and narrow streets, in constant stop-start operation, which increase the potential of curb strike as well as tire scrubbing. The collection of refuse from construction or dump sites, etc., may expose tires to areas strewn with all types of hazardous debris. Indeed, the constant abuse of tires on garbage trucks requires constant tire change to maintain the truck in an optimal operating condition. Retread tires offer considerable cost savings and investment advantages to trucking companies operating in such a business environment.

5.9.6 Tire Maintenance Environment

The tire maintenance environment is another influential factor on tire durability. Anecdotal evidence from the trucking industry indicates that pre- and post-inspection of tire air pressure is conducted for each and every trip. Such inspections may be visual or use simple tools, and may be carried out by dedicated staff (i.e., tire technicians) or the operator of the truck. The Newport Communications Study (1998) asked respondents how frequently tire air pressure was checked with a gauge. The results are presented in Figure 5.8.

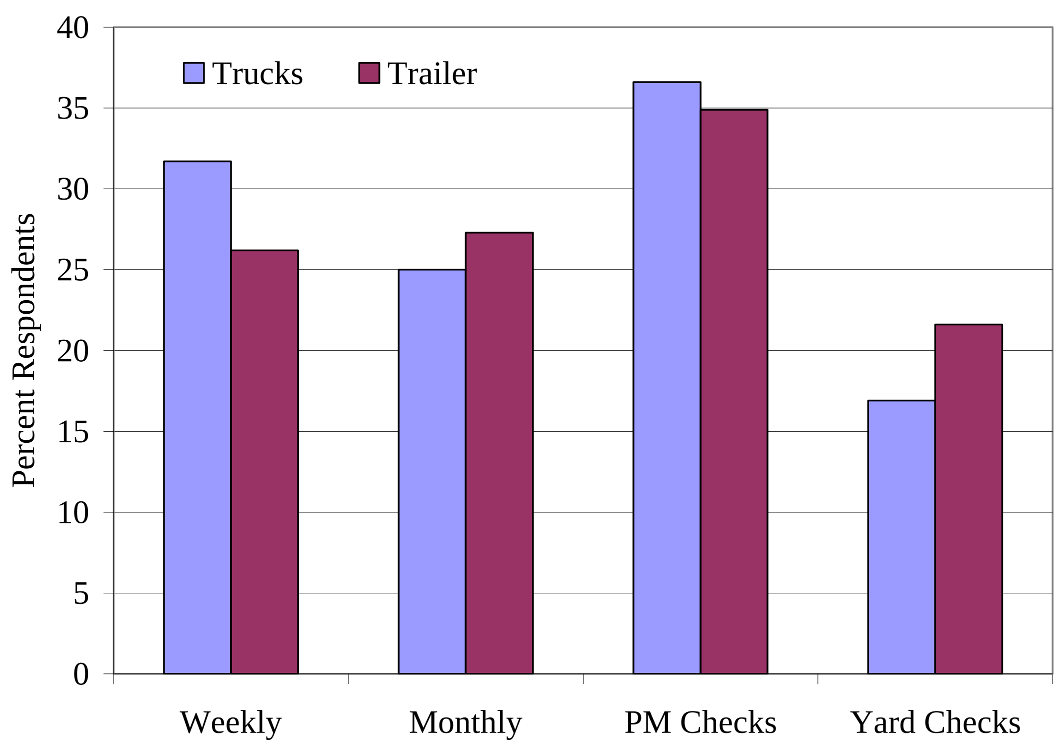


Figure 5.8 – Tire Air Pressure Checking Frequency
Source: Newport Communications 1998

Figure 5.8 indicates a wide fluctuation in the frequency of checks, whether the vehicle is a truck or trailer. For both trucks and trailers, regular preventative maintenance checks afforded the best opportunity for checking air pressures. The higher frequency of weekly checking for trucks when compared to trailers may be due to the fact that in typical trucking operations the truck/tractor covers more miles than a trailer. It is assumed that the higher the mileage to be covered, the greater the necessity for more frequent air pressure checking. The higher frequency of checking for trailers stationed in yards could be due to the fact that these trailers may not have been in service (i.e., still functional but awaiting pickup). The Newport Communications Study also found that the frequency of tire air pressure checking was positively correlated with fleet size (i.e., the larger the fleet size, the more likely they are to check tire pressure).

Discussions with industry representatives also revealed another situation that may affect the regularity of tire air pressure. Pre- and post-checking of tire pressure is an accepted practice in the trucking industry. However, who performs these checks can be a point of contention exacerbated by the number of tires that have to be checked. Noting that the task of tire pressure maintenance is labor- and time-intensive (see section 5.7.1), the person(s) who perform(s) this task may be inside or outside their contractual responsibilities (i.e., job description). Larger fleets may have a dedicated team of tire technicians whose job is to maintain and check tires. A hired-in driver of a truck belonging to such a fleet may choose to focus on the contracted task (driving) and opt to rely on or assume that the tires have been checked by the tire technicians. On the other hand, owner-drivers hauling a trailer for a third party will ensure that air pressure for their truck/tractor is adequate for the task at hand. However, they might assume that the tire air pressures of the trailer to be hauled have been taken care of by a third party. Trucking industry representatives, while accepting that these situations do happen, also stated emphatically that a driver of a truck/tractor is always responsible for the pre- and post-checking of air pressure on the truck/tractor as well as the trailer for each trip.

5.10 Challenges of Legislating Retread Tire Durability Standards

In a 2006 article by Mike Manges, Guy Walenga of Bridgestone Firestone said “They’ve [NHTSA] done high-speed and durability testing on retreads like they have on new tires. They’ve [NHTSA] had more retread failures than new tire failures,” which has led to some concern on their part. However this article also discusses the challenges of legislating enforceable standards for retreads:

- What is evaluated, the retreading process or the retread? Different retread processes may all result in high-quality retread tires, but the same processes may not lead to the same quality retread. Different input variables during the retread process, even among retreaders using similar standard casings, do not necessarily lead to the same result.
- With the number of retreaders varying between 500 and 5,000 (see section 2.9), are samples taken at random and how often? Considering the time and effort that would be needed to conduct such an exercise as well as the correctly calibrated equipment, all the necessary requirements may not fall into place for such an exercise to be efficient.
- A retreader may be franchised to an OE manufacturer and yet retread casings from a competing OE manufacturer. What complicates this process is that during a tire’s life it may undergo several retreadings using different processes, retreaders, and/or treads. The effects of these variations on retread tire performance remain largely unknown.

5.11 Summary

This chapter highlighted several operational aspects impacting commercial truck tire safety and durability. Estimates of the proportion of truck tire debris that may be found on the roadside are not only dependent on the aggregate number of vehicles but also on vehicle mix, location, and average number of axles per vehicle. This chapter also presented other factors outside of the fleet operational environment (e.g., imported versus locally manufactured tires) that may adversely affect tire safety and durability. Challenges in the potential effort required to develop appropriate and effective legislation in the retread industry were also discussed. However, whether a tire is mobile or stationary, maintaining the correct tire air pressure is the key to optimal tire performance, safety, and durability.

6 STAKEHOLDER PERSPECTIVES ON COMMERCIAL/RETREAD MEDIUM AND WIDE BASE TIRES

6.1 Introduction

To complement the findings of the literature review, stakeholder perspectives on the retread issue were sought from several organizations/institutions. Interviews were conducted with representatives from a brand-name truck tire manufacturer, a line haul truck operator, and several members of a tire industry association. Unfortunately, input was not received from any advocacy group or institution championing a prohibition in the retread of medium- and heavy-duty truck tires, despite strenuous efforts by the principal investigator to incorporate the opinions of such groups. To preserve the privacy of the responses presented in this chapter, respondents are not identified by name and in some cases affiliation. Their responses represent their personal opinions and must not be taken to represent the standards or policies of the organizations, industry, or institutions that they represent.

6.2 Discussion Topics and Responses

6.2.1 Heavy-Truck Operations and Tires

- **Importance of Healthy Business Relationships**

Discussions with the respondents noted the importance of tire dealers and their potential contribution to maintaining the quality of retread tires. Business relationships between fleet managers and retread tire dealers, and between retread tire dealers and retreaders, were also seen as being vitally important. Good business relationships will clear up any misunderstandings or misperceptions about retread tires. For example, the retread tire dealer often is the primary source for retread and OE tires for fleets and independent truck operators, and can offer repair workshops and give advice on the proper tire required for an intended application. Guidance may also be given in proper tire maintenance or vehicle alignment techniques that will keep a casing in optimal condition.

If a fleet manager is unhappy about the performance of a retread tire, the tire dealer can get into contact with the OE or retreader (i.e., if it is a third party) if there is an issue that cannot be resolved between the fleet manager and tire dealer. To minimize such a situation, it is important for each tire dealer to know the expectations of their customers with respect to tire performance. For example, some fleet managers do not want retread tires to be prepared from casings that have four or more nail holes or they don't want repairs overlapping or close to each other. In another case, the fleet manager may accept section repairs to their retread casings, but they want these casings identified so they are only used on trailers. Fleet managers are at liberty to determine their own criteria as to how they want their casings dealt with. It works both ways, too. A good tire dealer will be able to visit a customer (e.g., a fleet manager), go out to their yard, and inspect and bring back all the information and inform the fleet manager that they need "X" number of tires, "Y" percent of tires require repairs, and "Z" percent of tires need to be changed out, etc. The realization of high customer expectations will be futile unless they are relayed by the fleet manager to the retread tire dealer.

- **Proportion of Retreads of the U.S. Trucking Fleet**

Respondents were asked to estimate the proportion of retread versus new tires in the U.S. trucking fleet. One respondent indicated that approximately 34 to 36 million medium-duty truck tires are sold in any given year, of which half are new and half are retreads. The retreads tend to go to trailers and have a longer physical life because trailers don't generate as many miles.

Another respondent indicated that in their trucking operations, 50 percent of tires were retreads if averaged over the last three years. In fact, 50 percent of the drive tires in their fleet were retreads and tire sales were about 2 to 1 for retreads versus OE tires. Focusing on the trailer fleet, the proportion of retread tires increased to between 70 and 100 percent of tires according to two respondents. Indeed, one of these respondents indicated that when communicating with other fleet managers, just about every large fleet that they knew of used retreads except for fleets adding new vehicles. One respondent noted that it is policy in some fleets that new trailers come with OE tires that are quickly replaced with retreads. The OE tires from trailers are put into the inventory until needed. If trailers in service have OE tires, this may be due to the non-replacement of the tires at that point in time or a fleet manager purchasing OE tires as a result of over-the-road tire failure. This respondent also approximated that nationally, retreads constituted 66 percent of all tires and OE tires constituted 33 percent.

- **Estimates of Average Number of Wheels per Truck**

Section 5.6 presented a methodology (incorporating the average number of wheels per vehicle) for calculating truck share of VMT. However, respondents felt that obtaining an estimate of the size of the commercial vehicle fleet in order to estimate the number of truck tires on the road was more of a challenge. Respondents suggested 3.8 million commercial vehicles with on average 14 wheels per vehicle are currently running on U.S. highways. However, there are so many different types of truck, tractor, and trailer combinations (with four, six, 10, or 18 wheels) that a better average number of wheels per truck might be eight. This figure is similar to that used by Carey in his VMT analysis (see section 5.6).

- **Tire Application and the Placement of Retread Tires on the Vehicle**

Continued discussion with the respondents explored where a typical retread tire would be placed on a truck in terms of axle location. One respondent indicated that typically most retreads go to trailers. Industry experts say that in general the only time a trailer sees new tires is the day it is delivered. The trailer owners may leave the OE tires on or they may take them off and put them someplace else (i.e., on another axle of another vehicle) and replace them with retreads right away. To take advantage of competitive OE tire pricing, some fleet managers when ordering new trailers will ask for specific OE tires that are not normally used for trailer applications. For example, they will order trailers with drive tires to get a cheaper OE tire price. The new trailers are delivered with drive tires which are then removed and replaced with retreaded tires. The OE drive tires are subsequently put in stock for replacement on tractors.

Noting the importance of where the retread tire is placed on the vehicle, one respondent also indicated the importance in understanding the tire operating environment. Section 5.9.5 discussed the propensity of different industries in their use of retread tires noting the waste industry in particular as an important consumer. The application environment has much to do with what type of tires can be retreaded and how many times. Fleet managers of waste disposal, long haul, pickup, and delivery services all will make different demands on their retread dealers with respect to the acceptable number of retreads, casing age, and number of repairs, etc. of retreaded tires that they use on their vehicles.

Lastly, casings submitted for retreading are inspected and rated each and every time they enter a retread plant. During this phase a decision is taken as to whether the casing is retreadable or not. If the casing has been deemed retreadable by an inspector, what can be done with the casing? Is it retreaded and put back onto a drive axle, or retreaded and put on a trailer axle? Is it retreaded and put into a line haul service type of application or retreaded and put on a pick-up and delivery application? To account for these variations casings submitted for retreading are categorized according to different quality standards such as A, B, and C quality casings. "A" casings after retreading may be put back on tractors if possible while "B" and "C" casings will normally be sent to trailer axles.

- **Tire Inspection Regimen and Tire Durability**

One of the respondents confirmed the widely held belief that tires positioned on trailer axles received the least maintenance. In the ratio of 3 to 1 (i.e., 3 trailers to every 1 tractor) trailers will often sit around until hooked up to a tractor. In many cases the trailer is not owned by the company that owns the tractor so there is little incentive for the driver to monitor the tires on the trailer. In the typical truck environment, the tractor drive tires may get a little less maintenance than steer tires which tend to get more attention than other tires on other vehicle axles. Drive tires outside on the left of the vehicle get looked at because that is where the driver has to pass by to get into the cab, however, visual inspection is no substitute for pressure measurement. Inside tires are less likely to get examined unless a comprehensive tire inspection is conducted. Two respondents indicated that the worse tires with respect to durability (i.e., air pressure maintenance and potential impacts from road hazards) are often found on the right side of the trailer. On the back axle of a trailer, in particular, the wheels on the right side often hit curbs when the truck maneuvers right-hand turns.

- **Cost Performance of Retread Tires**

Typically, when a retread tire is mounted on an axle the date and tractor/trailer mileage should be noted. When the retread tire is used up it is pulled off and the mileage traveled on the specific axle of the tractor/trailer at the time of tire removal noted. This figure represents the total removal miles, (i.e., the miles that the tire yielded). In order to determine a cost per mile, the number of removal miles obtained is divided by the cost of the OE or subsequent retreads. It is very important that the correct measure is used to ascertain performance in terms of tire longevity or durability. Well-maintained casings that are properly retreaded and placed in the correct application will render good "removal" miles and represent good financial value.

A respondent was of the opinion that retread tires, when positioned on the drive axles, have the potential to generate more miles when compared to positioning on a trailer axle (in the same application). However, if retread tires go into high-scrub applications (e.g., waste haulage) they might not generate more miles (when compared to OE tires). Retread tires in high-scrub applications often go through several retread processes. For example, tires used in the waste industry routinely are retreaded three, four, or five times and may only last 90 to 120 days at each retread. In the waste disposal application, retread tires wear out quickly because it is such a high-scrub application, so such a tire has virtually no age but keeps on getting retreaded. Eventually, a road hazard may render the casing non-repairable before it is permanently removed from service.

Tire tags and other technological measuring devices allow fleet managers/owner operators to accurately monitor the mileages that trailer tires are traveling. Currently, many fleet managers speculate when estimating individual tire mileages. However, some fleet managers do a better job than others, and not all fleets managers identify tire cost per mile in the same way. In fact, some fleet managers would state that it is just the cost of the tire and others would state that it is the cost of the tire plus maintenance, mounting, balancing, etc. Each fleet manager may apply a different methodology to identify what the tire cost per mile is. This cost, put simply, is tire cost divided by miles traveled.

- **Number of Retreads per Casing**

The environmental and cost benefits of retreading tires were discussed in section 2.6. The five- to six-year study casing by Walenga (discussed in section 3.6) saw casings that had been retreaded up to five times. The question as to how many times a casing can be retreaded was put to the respondents and their responses are presented here. One respondent indicated that there is no limit on the number of times a casing can be retreaded. If there is a limit it is dependent upon the retread inspector, casing repair personnel, and what type of repairs are required before the casing is sent for retreading. Another respondent stated that in their fleet a casing can be retreaded "up to three times" as long as the casing meets age and repair criteria. However, this respondent went on to state that "among many fleet managers, preference is sometimes given to an OE brand tire."

A respondent knowledgeable of the retread manufacturing process indicated that the casing inspector looks at the appearance of the inside and external rubber on the casing/tire submitted for retreading. Externally, the inspector looks for signs of ozone cracking (i.e., the tire's natural aging process). If ozone cracking gets worse, it is accepted as industry practice that no reputable retreader will retread the tire, and the casing is rejected. OE tire manufacturers formulate compounds that resist ozone cracking and, if properly cared for, tires can remain in excellent condition over several years without ozone cracking.

- **Non-DOT-Compliant Tire Use and U.S. Market Share**

Respondents were asked whether they had any idea as to the market share of non-DOT-compliant tires generally imported into the United States. Concerns have been expressed in the tire industry about the importation of casings lacking DOT certification and the presumption that such casings may be substandard posing a potential safety risk.

One respondent was of the opinion that tires operating in the United States must have DOT approval to be permitted on a U.S. highway. This respondent went on to state that first the OE tire manufacturer must state that their product meets all requirements supported by a proper DOT mark. If the casing does not have a DOT mark and is submitted for retreading, the retreader, by placing their retread DOT marks on the casing, certifies that the casing has met all Federal standards that would apply. Either way, the tire should have a valid DOT mark to run on U.S. highways. If there is no DOT marking on the casing or on the retread it should not be permitted to operate on U.S. highways and should be removed and scrapped.

Another respondent shared his experience with imported casings by stating that in his opinion such casings produced by major manufacturers are as retreadable and as safe as domestically produced tires with DOT markings. Many imported tires with DOT markings are not believed to have the same quality as those produced by major manufacturers without DOT markings. The imported tires produced by non-major manufacturers are utilized as new tires in the United States but have been considered by retreaders to be less retreadable than tires produced by major manufacturers. However, it should be noted that although these tires are perceived to be less retreadable, they are not necessarily less safe due to the inspection procedures practiced by reputable retreaders. Indeed, this is an evolving situation as foreign manufacturers modify and improve their products.

6.2.2 Roadside Debris Generation and Composition

- **Which Vehicle Types Generate the Greatest Share of Roadside Tire Debris**

A question was put to the respondents hypothesizing that the long haul trucking fleet is the main culprit in the generation of tire debris found on the Nation's highways. It was pointed out by one respondent that this supposition is not known with certainty and another respondent replied emphatically that in their opinion it was incorrect to conclude that the majority of rubber found on the Nation's highways originates from trucks running on retreaded tires. Indeed, retread tires are on construction trucks, all kinds of vehicles and even on school buses.

- **Estimated Proportion of Roadside Tire Debris Composition**

Respondents were all aware of the TMC studies in 1995 and 1998 where more than 50 percent of the highway debris assessed came from medium/heavy-duty truck tires. These studies formed the basis for the subsequent discussion. In their opinions the respondents revealed that approximately 70 percent of truck tires would be retreads. If trailers are the focus, this proportion could increase to 80 percent or more. At these percentages the probability of finding retreads tire debris on the highway are higher than finding debris from OE tires. One respondent indicated that in his opinion overall it is somewhere between 50 and 60 percent and that there should be no surprises in these proportions given that whether there are two retreads to every one OE tire sold, the dominance of retread proportions are what we should expect to see on the road. Another respondent expressed that typically some large fleets do not retread their drive tires because of their concerns about the reliability of retread tires. " There are fleet managers who believe that the drive axle is not a good spot to put a retread and they end up putting all retreads on the trailer.

6.2.3 OE and Retread Tire Manufacturing Processes

- **Problems in the Retread Tire Process or Industry**

Respondents were asked to share their views on whether they thought there were or were not any problems in the retread industry. With respect to the product of the retread industry (i.e., the retread tire), one respondent stated, "no." He then went on to say that the product is a very suitable product for its intended use. The process for retreading has been refined, tested, and retested over many years. With the development of new materials and the steady improvement in the processes, the respondent again confirmed his belief that there is not a problem with the retread product. However, the respondent sated that no matter how rigorous the retreading process may be, the person/technician who does the actual work may be a weak link in the manufacturing process chain. People involved in the retread manufacturing process need to know what they are doing.

In days gone by, a casing was put on a buffing machine and a person would buff it by hand. Now this step in the process is computerized. The casing is rolled onto a machine and inflated up to 20 to 25 psi. The tire characteristics are input, the machine automatically adjusts itself to the proper radius, and it performs the buffing. With such standard and automated processes, the risk of human error is reduced.

All of the inspections, tools, and automations in general terms are similar across the industry. Each detailed procedure among retread process may be slightly different from franchisee to franchisee. However, all casings submitted for retreading are inspected, staff at all retread franchisees are trained to perform the specific tasks, all franchisees use shearography, and every retread franchisee plant generally does the same thing. Despite the retread process similarities, there is not one standard universal procedure followed by all retreaders (i.e., manufacturers and franchisees). This situation is not uncommon to most manufacturing sectors.

- **Integrity and Subjectivity of the Retread Manufacturing Process**

The big three U.S. retread manufacturers – Michelin, Goodyear, and Bridgestone (Bandag) – have each developed unique retreading processes. Each of these three OEs market their retread processes through their agents, as franchisees. These franchisees, in turn as tire dealers, may also be involved in selling new tires, executing tire repairs (e.g., section repairs, nail-hole repairs), wheel refurbishing, tire pressure checking and monitoring, as well as retreading, in addition to all sorts of services for contracted fleets. Each franchisee is taught how to use all the retread process equipment and what each process is. They also have to buy certain proprietary equipment and supplies, and they have to follow certain retread procedures.

Ensuring a consistently high standard in the "branded" retread processes the retread manufacturers can and do send officials to franchisee plants to observe retreading practices and advise them on the criteria used to determine which casings submitted for retreading are rejected as not retreadable. These OE manufacturing representatives inspect retread casing production records to see if quality control graphs of non-retreadable casings (i.e., those that have been rejected) are smooth, or whether peaks and valleys are evident in the readings. The OE manufacturing representatives investigate whether franchisee staff know what they are doing (i.e., in executing their required tasks) and what they are looking at (i.e., how they interpret machine images/readings). The OE manufacturing representatives also collect some of the rejected casings and personally investigate them. They try to ascertain what their franchisees (i.e., retread tire manufacturers/dealers) are doing and their thoroughness in task execution. If the OE manufacturing representatives find an issue, they may engage in retraining the franchisee staff. In light of these controls, the retread manufacturing process is ultimately a sound process.

One respondent noted that all retreaders use shearography as an integral part of the retread process. However, this respondent also felt that the OE/retread manufacturers have been unable to prove (i.e., through peer-reviewed publications) that the use of such high-tech equipment has measurably reduced over-the-road costs for premature failures or the amount of tire debris. In other words, what is an acceptable abnormality in a casing and, once retreaded, will it perform in terms of the number of removal miles covered in its new tread when compared to an OE tire? This opinion expressed was based on observations by a respondent of a retread tire manufacturer where a potential abnormality within a casing would be identified and the retread technician would have to make a determination that the casing may or may not prematurely fail before the new tread is worn down.

In order to increase the probability that the casing submitted for retreading would survive the predicted tread life, the retread technician may err on the side of caution (i.e., by engaging their subjective assessment) and reject the casing if they see something that does not look right. This assessment may drive a fleet manager's retread tire costs up by scrapping/rejecting more casings than may be required. The fleet manager would then have to supplement this loss by purchasing OE tires, new retread tires, or new casings. In this situation, the respondent was concerned that no OE/retread manufacturer had been able to prove (i.e., by documented evidence) to them that "X" percent of those rejected casings, if repaired, would ever make it through the predicted life of the new tread. It was also suggested that if such information were made available, it could be used as a selling point to state that when the retread tire is put into service, the retreader can guarantee that so many thousands of removal miles will be performed by this retread.

- **Ownership of Casings During the Retread Process**

Discussions with respondents revealed that a fleet manager ideally should be able to identify their casings that they use in their fleets which they are now submitting for retreading. Retread tire dealers may advise fleet managers who are contemplating retreading that they should purchase a premium tire to increase the probability that they will have a premium casing left for each retreading. Fleet managers may also be advised that when casings are submitted for retreading, they need to ensure that they get their and only their casings back. How can this be achieved? Fleet managers can develop a relationship with retread tire dealers in addition to using unique identifiers (i.e., branding) on their casings. Fleet managers, when communicating with their retread tire dealer, can emphasize that they want their casings back and not those belonging to another fleet/individual.

The retreaders know how to track specific casings through the retread process and make sure that casings submitted by ABC Trucking, and not the casings of some other provider, are returned to ABC Trucking. Retreaders can ensure retread casing differentiation and can control the progress of individual casings going through their plants. If a relationship between a fleet manager and retread tire dealer is not developed, submitting 10 tires for retreading may return 10 retreaded tires from unknown owners with the possibility that these retread casings were not well maintained. A competent fleet manager, aiming to maintain the safety and quality of corporate tire investments, will strive to get his/her submitted casings for retreading back.

- **The Current Retread Tire Quality Control Regimen and Challenges**

OE/retread tire manufacturers routinely have their field engineers go out to visit retread tire plants and dealerships (discussed earlier in this section). On these visits they inspect retread materials and machinery as well as observe retread plant operations. These inspectors will look at the progression of truck tires through the retread process; they will pick up and look at tire/rubber scraps; they'll also look at returned tire reports. On this issue a respondent noted that a critical piece of successful retreading is the inspection process, the repair processes and the criteria around how many injuries are evident in the casing that is about to be retread. This respondent believed that some years ago the larger retreaders (e.g., Bandag, Goodyear, and Michelin) had stringent internal quality control policies over their franchisees. However, at the current time it was perceived that there had been a weakening in the control of what tires would be rejected or retreaded (i.e., the franchisees had more freedom to make this decision within prescribed retread guidelines).

From a different perspective, a respondent was able to present their views with respect to the possibility of subjective interpretation of retread process results. Installation of new equipment to be used in the retread process (e.g., shearography machine is often followed by training sessions of plant personnel who will be using the machine). However, the use of a shearographer is not as clear-cut as it seems. The shearography machine is a tool that can find hidden problems in a casing/tire. Nevertheless, there is some subjectivity in interpreting any casing information presented and determining how best to correct a problem comes from experience and has to be learnt by the operator. Skill is required to correctly interpret a picture that the shearography machine operator is observing.

All retread tire franchisees are required to send listings of tires that are returned as non-retreadable to the supplier of the casings. OE/retread tire manufacturers through these inspections are able to track various aspects of the retread tire manufacturing process to see whether there are any variations in the quality of casings received compared to retreaded casings output and sold by dealers. Observing retread tire quality records (at retread plant or dealer level) inspectors look for unusual trends or patterns. Such patterns may indicate that the retread plant is not performing properly. Inspectors may then go back and retrain the retread plant staff. Graphical outputs which constantly go down may also indicate a problem in that the retread staff may not know what they are doing. Again, inspectors undertake the task of retraining retread plant staff. OE/retread tire manufacturer inspectors use historical records of the retread plant before introducing new technology or inspection techniques to ensure that the dealer’s flow of quality retreads remains constant. Any increase in the numbers of returned retreaded tires (i.e., back to the retread plant or OE) or repeated complaints from customers are tell-tale signs that retread tire quality may have been compromised. Through such quality control efforts the OE/retread tire manufacturers can attempt to police the retread tire process.

Another challenge in developing a uniform retread tire standard is accommodating multiple combinations of brand casings, retread processes, and brand tread designs, each having unique performance standards and ratings. As one respondent indicated, a retreader can retread brand casings from Bridgestone Firestone, Michelin, Goodyear, BFG, Khumo, Yokohama, or from lesser known medium/wide base OE tire manufacturers. In other words a retreader can retread any OE manufacturer’s casing. The only aspect of the retread process that remains the same is the tread. Is the product output from any of these potential combinations lower in retread quality in each case when compared to another? Figure 6.1 illustrates this situation.

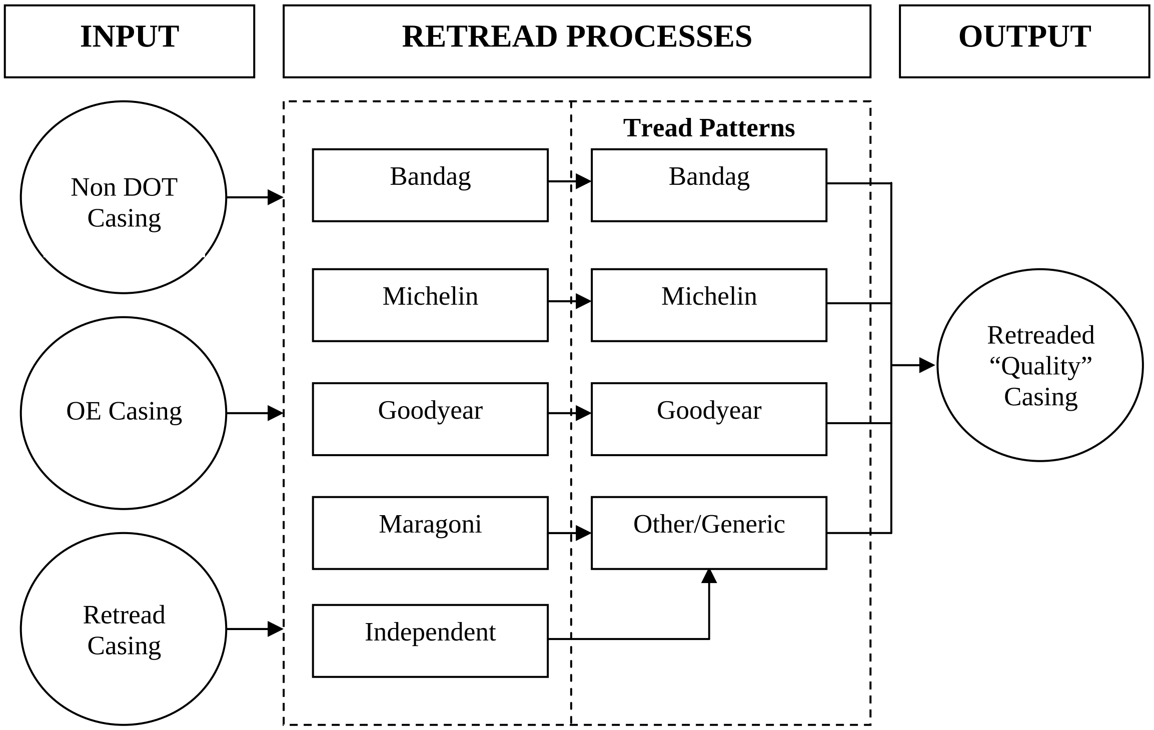


Figure 6.1 – Product Quality Combinations and Retread Processes

6.2.4 Retread Tires Regulations and Standards

- **Nationally Mandated Retread Manufacturing Process Standards**

Section 2.12 indicated the lack of a nationally mandated quality standards for retread truck tires. Some advocates against the retreading of truck tires have voiced their concerns with this legislative shortcoming. However, all respondents accepted that this situation was real and there currently is no nationally mandated retread process standard. Some respondents went further to state that they do not think that at the present time there is a need for such a standard. This opinion was partly because in one respondent's opinion there was concern about whether the government (i.e., NHTSA) totally understood the retread industry. Establishing a standard without the required knowledge of the industry would be self-defeating.

Another challenge in creating a universal retread standard is developing an appropriate test to measure tire durability. A respondent indicated that it is possible for OE tire manufacturers to make the ultimate durable tire. However, in all probability such a tire would not obtain similar removal miles and definitely would not achieve the rolling resistance or retreadability levels that currently are characteristic of the typical commercial medium- or wide-base truck tire. In developing a tire durability test there will also be a need to police tire quality. If the test is such that a tire fails in a manner that it would not normally fail in the real world, then that test could be deemed suspect or non-representative. Test developers may have a preference to develop a test under laboratory conditions, accelerated testing procedures or creating various axle load scenarios. However, testing a 22.5” rim, low-profile tire on a 1.7-meter drum may generate a lot of stress and heat in a tire that may never occur in the real world at any speed or load.

The effects in the calibration of various testing regimes are a potential stumbling block in the development of appropriate tire durability tests. In order to avoid any extreme externality (i.e., effects that can accelerate the degradation of the tire), this may require a lowering of a load or a lowering in the speed in order for the tire to survive long enough to prove its durability. However, if the tire works well in the real world under normal circumstances with at least some maintenance, how can the same tire not work well under test conditions that are identical? This again implies that something may be suspect with the proposed test. Therefore, before any institution or advocacy group can get deep into developing regulations on retreads, there will be a need to develop a testing regimen that can accurately measure tire durability against real-world conditions.

- **Policing Retread Standards Without Government Intervention**

Respondents were then asked how the retread industry can self-enforce retread standards without government intervention (the current status). One respondent indicated (quoted response below) that the retread tire manufacturing industry is already policing retreads using several techniques such as:

- Market acceptance – The retread manufacturer operates in a free market economy. If the product is of poor quality then the customer is free to select another supplier;
- Franchisor controls and inspections – Retread franchisee inspections were discussed in section 6.2.3. However, a respondent indicated that in recent years they had witnessed a continuing trend of consolidation in the industry. Over their career they had seen the retread industry go from a large group of very small independent dealers using a wide variety of processes to the current situation where there is a limited number of processes and the manufacture of retread tires is much more controlled. Indeed, this respondent’s company had very strict controls for the raw materials used in the manufacturing process and these controls were passed down and enforced to franchisees where appropriate. Control of the retread process is essential to the production of a quality product.
- Support of industry associations – Retread industry stakeholders should continue to support organizations like TRIB and the Tire Industry Association (TIA) in their efforts to educate trucking fleet customers about retreading. In particular, TRIB and TIA members should continue to provide assistance to TMC. This is the TMC recommended practice for evaluating retreaders.
- Conduct Routine and Random Retread Plant Inspections – Every retread plant should be subject to independent quality auditing processes/inspections. These tasks may be performed by a retread rubber supplier (e.g., Bandag, Goodyear, etc.) or an industry group (e.g., TIA).

6.2.5 Safety Issues for Retread Tires

- **Retread Tire safety Issues**

According to several respondents, the primary safety issue for retreads – air pressure maintenance -- is the same for all tires regardless of whether they are new or retread. In other words, according to these respondents, there are no distinguishable differences in safety issues based on a tire’s OE or retread status. Engaging retreads in a different tire maintenance regime from new tires does not hide the fact that air pressure maintenance is the key to tire safety, longevity, and durability. Indeed, there are people in the trucking and tire industries that just don’t agree with the above statement.

They treat a retread with little less respect than a new tire. A retread tire is still a major investment and it requires engagement in a maintenance regime just like any other OE tire.

Focusing on the thoroughness of the retread inspection process, another concern raised by one of the respondents was the integrity of inspection processes that are followed by retreaders when they are inspecting and retreading the casing. This concern was from the perspective of a large retread franchise (i.e., of a major OE/retread manufacturer) when compared to a smaller independent dealership. This respondent went on to state that "There is a need for somebody to go around and conduct the necessary checks and inspections." This respondent was aware that the larger OE/retread manufacturers (e.g., Goodyear, Bandag, etc.) do have inspectors who systematically conduct audits at all of their franchise locations to make sure that these plants are following all of the inspection and process criteria that have been put in place.

Despite the above concerns, a respondent that extensively uses retread tires in his trucking fleet was very pleased with the quality levels. Furthermore, in his career he had not seen substantive evidence of manufacturing process problems in the retread tires that he had managed. Indeed, in his opinion retreading technology had made substantial improvements over the last 10 years. This respondent also indicated that throughout 28 truck maintenance sites under his control, prompt action is taken if any lapse in retread tire quality comes up. Inspectors at these truck maintenance sites contact the respondent to report a suspect tire, photographs are taken, and then the suspect tire is forwarded to the respondent. Again, this respondent emphasized that he had seen relatively few cases of retread tires failing because of manufacturing issues.

6.2.6 Durability and Performance Standards of Retread Tires

- **Vehicle Maneuvering and Tire Durability**

Taking into account the preponderance of retreads on trailer axles, one respondent was of the opinion that vehicle maneuvering and road hazard positioning may disproportionately affect such axles and exacerbate the generation of tire debris. The likelihood of this happening increases when tractor/trailers maneuver around corners. This same respondent estimated that a truck tractor making a right turn on a narrow four-lane road hits the curb with the trailer wheels at least 60 percent of the time. This respondent, as a fleet manager, reported that he has witnessed that the outside right tires appear to suffer from more damage (i.e., road hazards) than the other tractor/trailer tires.

In another case when a road obstacle such as a nail is hit with the steer or drive axles, these hazards are somewhat funneled underneath the truck tractor configuration, eventually striking tires on the trailer axles. This is a direct result of "tracking" where, as a result of road hazard funneling, trailer tires are prone to suffer more injury than steer or drive tires. The propensity of tires on trailer axles to suffer more injury is compounded in normal trucking operations in the following scenario. If a driver of a tractor/trailer combination traveling down a highway sees something (e.g., a road hazard) in the highway, he/she will engage a defensive maneuver and veer the vehicle to avoid the road hazard. However, due to the articulated nature of the tractor/trailer combination, the trailer will follow the path of the tractor eventually. Therefore, tires on the trailer axles still have the potential of running over the road hazard that the driver has tried to avoid. Thus, if greater proportions of trailer tires are retreads, in the scenarios presented here, they are going to be subject to more road hazards than steer or drive tires on the same tractor/trailer combinations.

- **Tire Longevity and the Million Mile Tire**

Respondents were asked their views on the typical life of a tire. This concept can be seen as the lifespan of a typical tire (i.e., from the time of OE purchase to the time taken out of service) or how many miles can be attained in the lifetime of a tire. One respondent noted that in their fleet the typical service lifespan of a tire was seven years. However, this only applied to major brand name casings. Respondents continued to share their views on whether OE or retread truck tires had similar durability and longevity characteristics. One respondent resoundingly said "yes" with respect to retread versus OE durability. However, longevity would depend on the retread compound and the tread depth. A second respondent also gave an affirmative response to this question and furthermore indicated that in some cases retread tire durability was even better than non-retread tires. Another respondent indicated that it depends entirely upon the starting axle position of the tire (i.e., the axle position of the OE tire when first used), the maintenance regimen followed, and the load that it is expected to carry. This respondent went on to describe an operating methodology on how a tire can achieve one million removal miles.

First, it is necessary to start with the drive tires (i.e., the deepest drive tire), on a twin-screw tractor in line haul operations such as coast to coast with light loads. It is generally accepted in the trucking industry that tractor wheels get the majority of mileage of any wheels in a tractor-trailer combination. A commercial medium-base truck tire in such an application (all things being equal) will last on average 500,000 to 600,000 miles (assuming multiple retreads). Take these drive tires and put them back on a trailer and you could run them up to two years in this position. However, these tires may only travel up to 30,000 miles in a year. After this time, buff and put another drive tread on them (i.e., retread) at a tread depth of 24 or 26, 32^{nds} of an inch. In order to achieve one million travel miles of a tire, it will be necessary to put the casings after their first retread back on to the drive axles. These tires would have achieved 660,000 miles (600,000 miles as OE drive axle tires and another 60,000 miles as OE trailer axle tires). At this point in time these tires could be at least four or five years into their lives. Once these tires (now retread) are back on the tractor they should achieve another 300,000 miles (total 960,000 miles). After these drive axle retreads are down to a tread depth of 8 or 10, 32^{nds} of an inch they are then sent again to the trailer axles. In this position they only have to run up to 40,000 miles before the one-million-mile threshold is reached. At this stage the casing may be "finished" and ready for disposal. The time for the million miles to be achieved may be eight years or more, but according to the respondent putting forward this methodology it is possible to get a million miles out of a casing. Typical trucking industry operations see a backward repositioning of tires after each retread (i.e., from steer or drive to drive or trailer and ultimately to trailer axles). However, there may be a minority of cases where worn or retreaded tires from a non-drive wheel position are repositioned to the drive axles.

Discussions with retread industry stakeholders revealed that if a retreaded tire is well maintained it can have the same (or exceed) durability, performance, and longevity characteristics of an OE tire. As discussed above, longevity of a tire can be measured in time units or miles traveled until removal. One respondent noted that with increased technological applications going into tire construction and the retreading process, in some ways this development was having a positive impact on tire longevity (i.e., tires are currently constructed to last for multiple retreads). However, if you measure longevity by the number of removal miles (the miles traveled on a casing before it is removed either for retreading or complete destruction) traveled, a retread generally will not achieve the same number of removable miles as an OE. In most cases this is because the new tread material (i.e., the retread) is shallower and there is less useable tread depth compared to the casing in its OE state. This situation was confirmed by another respondent who in his professional experience noted that there will be a small reduction in removal miles, as retreads (in particular the drive axle) typically have fewer 32^{nds} (i.e., tread depth).

- **OE versus Retread Tire Fuel Efficiency**

One respondent in his career had evidence of differences in the fuel efficiencies between OE and retread truck tires. This respondent had observed small gaps between certain brands of OE tires (in particular the more efficient ones) and retreads with respect to their individual fuel efficiency. This was something that this respondent felt warranted more research or interest by NHTSA. From this respondent's perspective, there are pretty substantial cost savings between different tire types, and there is a need to design retreads to achieve better fuel economy. For this respondent, reducing the observed fuel efficiency differentials involved working with fuel suppliers and OE tire manufacturers. Additionally, as retreads cost roughly 30 percent of the price of an OE tire and with the costs of raw materials, crude oil, and everything else continuing to increase, it becomes more important to close this fuel efficiency differential according to OE/retread tire type.

- **Cradle to Grave Concept**

The discussion on tire longevity continued and respondents were asked their opinions about this issue taking into account the cradle-to-grave concept. Defining this concept, one respondent indicated that he would look at only the financial cost of a new tire, its total use in mileage terms, and the final costs of subsequent retreads until it could not be retreaded anymore, after which the casing goes into the waste stream (Formula #1 below). However, there is also a cost to the tire owner for tire disposal and this has to be added into the equation. Disposal of tires into the waste stream may generate certain benefits to society. Discarded casings may be used as tire-derived fuel, turned into rubberized asphalt, developed as fuel for electricity or cement kilns, or made into car mats. These economic benefits (i.e., savings accruing to society through the correct disposal or recycling of tires) can also be accommodated in the cost-per-mile estimate (Formula #2). The two types of cost-per-mile estimates as follows:

$$\frac{OE + Rt^1 + Rt^2 + Rt^n}{MilesTraveled} \qquad (1)$$

$$\frac{OE + Rt^1 + Rt^2 + Rt^n + D - Rc}{MilesTraveled} \qquad (2)$$

where:

OE — \$ cost of OE tire

Rt^1, Rt^n — \$ cost of retread #1, #2….*n*

D	$ cost of casing disposal to tire owner
Rc	$ benefit of casing recycling to society

6.2.7 Other Issues

- **Centralized Tire Pressure Monitoring Systems**

All respondents were aware of tire pressure monitoring systems and that it is currently possible to purchase such a system specifically designed for trailers. Equipping the worst maintained tires with the lowest mileages on trailers with these central tire monitoring systems may be somewhat effective in reducing tire debris generation. Such systems may be plumbed through the axles and not only monitor tire pressure, but also maintain tire pressure, commonly referred to as central inflation systems. Respondents felt that applying such a system is a good way to go for all tires. One respondent indicated that, despite this advance in tire technology, there is a downside as some drivers/fleet managers could become overconfident and assume that the pressure is being taken care of by the automated system and that they don't have to inspect the tires as frequently. A central inflation system can give truck operators an opportunity to limp home if necessary before doing irreparable damage to a tire with a slow air leak.

6.3 Summary

This chapter presented three stakeholder perspectives discussing several issues across the spectrum of tire debris: its generation, impacts, and minimization. Discussions revealed that effective tire management by fleet managers is dependent on implementing and enforcing a strict maintenance regime, while OE or retread tires in service migrate from drive or steer to trailer axles. Nevertheless, the self-policing of tire quality standards by commercial tire stakeholders does not completely resolve the challenge (or mute the call) to develop and legislate a uniform retread tire standard that accommodates multiple combinations of brand casings, retread processes, and brand tread designs. Stakeholders concluded that the quality, durability, and performance characteristics between OE and retread tires are generally marginal and the current status quo in the tire industry is robust. However, it is the operating and maintenance regime that a commercial tire is subjected to that is the key to its optimal performance and longevity.

7 TRUCK HIGHWAY SAFETY AND CRASH INVOLVEMENTS

7.1 Introduction to Truck Highway Safety

Safe trucking operations have the potential to positively impact highway safety levels for all road users. However, in recent years there have been several calls for greater oversight of the trucking industry in order to enhance the highway safety environment. A 1998 article in *The Detroit News* discussed that traffic safety advocates reasoned that if limits have been placed on the use of retread tires for passenger vehicles (by government mandate), similar restrictions should also apply to truck tires. In addition, these advocates stated that the presence of tire shreds on the Nation's highways posed a safety hazard to road users, despite the lack of empirical data to validate their claim (Cole, 1998). This chapter presents the effect of trucks (with emphasis on tire debris) on the highway safety environment through the analysis of traffic crash injury and fatality data.

7.2 Truck Tire Debris Traffic Crash Scenarios

Figure 7.1 depicts potential scenarios that may result from truck tire failure. The highway safety implications of truck tire debris are wide ranging, as not only the vehicle from which the debris originated (i.e., primary incident) may immediately be involved in a crash, but vehicles traveling alongside, traveling immediately behind, or otherwise engaged in a maneuver to avoid the offending debris may also be endangered (i.e., secondary effects). Research has shown that downstream disruptions in the normal flow of traffic due to a traffic crash have a tendency to increase the risk of crashes upstream (Forbes, 2004).

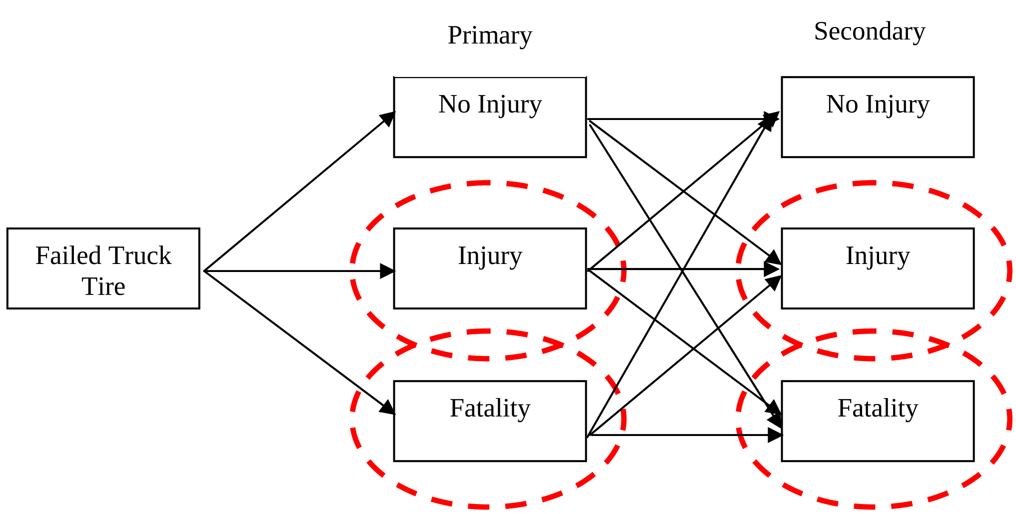


Figure 7.1 – Truck Tire Failure Injury/Crash Scenarios

Figure 7.1 schematically represents potential injury/crash scenarios resulting from a truck tire failure. The failure of a truck tire may result in a one-vehicle crash with minimal injury or multiple fatalities to the occupants of the primary, immediately following, or adjacent vehicles. Other vehicles in the roadway, pedestrians, or cyclists may also be at risk as they try to avoid the tire debris or are struck by it. An example of such a crash occurred in Raleigh, North Carolina, where a driver was killed after hitting a concrete median as she swerved to avoid a three-foot piece of tire tread in the roadway (Lim & Locke, 2007). As this example shows, the extent of injury to people in the secondary incident is not dependent on whether any injury has occurred to the occupants of the primary vehicle. The truck safety overview presented in this chapter focuses on injury and fatalities, whether they are the direct result of the primary vehicle or the resulting secondary effects (i.e., the circled boxes in Figure 7.1).

7.3 Time and Space Separation Between Primary Incident and Secondary Effects

Identification through dataset analysis of whether a crash is the primary incident or the result of a subsequent effect is a challenge as "no available crash files identify events at the required level of detail" (Bareket et al., 2000). However, accident datasets do provide information on crashes as the result of vehicles avoiding highway debris (see section 4.6) and "counts of such crashes provide an upper limit to the proportion of crashes related to truck tire and other types of roadway debris" (Bareket et al., 2000).

Observation of the damaged tire after the effects of the failure result in a disconnect between the primary incident (i.e., tire blow-out) and the secondary effect (i.e., resulting crash of a vehicle while trying to avoid the tire debris) in both time and space. An example illustrating this scenario occurred in Nashville, Tennessee, in October 2004, where one woman was killed and another was critically injured. A car traveling westbound on I-440 was struck by a piece of truck tire. Witnesses said "the driver accelerated to more than 70 mph on the left-hand shoulder," apparently trying to catch up with the truck. The driver lost control and the car struck a light pole, flipped several times, and came to rest upside down in the eastbound lanes (Demsky, 2004).

7.4 Secondary Effects in Traffic Crashes Resulting From Tire Debris

Section 6.3 described the potential spatial and temporal differences between the primary incident and secondary effects resulting from tire debris strewn on a highway. Kahl et al. (1995) investigated object-related traffic crashes and how objects on the roadway may affect stopping-sight distances. The study found that:

- The more common objects on all types of roads included tires, hay bales, car parts, poles, trees or branches, construction barrels, rail road ties, and metal debris.
- "Other-object crashes" occur when the driver strikes something that would not normally be encountered in the roadway environment and this encounter results in a crash.
- "Evasive-action crashes" occur when a driver attempts to avoid a hazard on the roadway. The driver is usually successful in his/her attempt to avoid the hazard but may subsequently strike another roadway element or user. Two examples of this type of crash occurred in 2007. In one case, New Haven, Connecticut, police investigated a fatal car crash that shut down a part of Route 91. The crash occurred when a driver changed lanes to avoid tire debris. His car struck another and that second car hit the metal guardrail and then rolled over, killing the driver (sole occupant) (nbc30.com, 2007). In another case, a driver swerving to avoid tire debris crashed into a concrete median on the Raleigh Beltline (Lim & Locke, 2007).

- The prevailing light condition is often an important contributor for the type of crash involvement. However, the prevailing light condition is a more critical feature for crashes involving objects in the road. In fact, the study by Kahl et al. showed that many of the object-related crashes occurred at night where adequate light conditions (in addition to the headlights) could have helped improve the chances of the motorist avoiding the debris and subsequent crash.

7.5 Truck Registrations and Vehicle Miles Traveled

An important aspect of highway safety is the level of exposure to roadway traffic through travel. Vehicle miles traveled (VMT) is a measure of the distance traveled by a vehicle during a specified time period. The typical truck/tractor travels significantly more miles per year than the family sedan and therefore has higher levels of traffic exposure with the potential to become involved in more traffic crashes. In 2006, the average VMT for passenger cars was about 12,500 miles, compared to 66,000 miles for a combination truck (Office of Highway Policy Information, 2007).

Table 7.1 presents annual estimates of the U.S. truck population and respective VMT. During the 12-year period, 1995 to 2006, the absolute numbers of registered trucks in the United States had grown from approximately 5 million to 9 million. The proportion of trucks registered, compared to the entire motor vehicle fleet, fluctuated between 3.3 and 3.6 percent. VMT for trucks increased from 178 to 223 billion miles during the same period. This change represented an overall 25-percent increase between 1995 and 2006 or a 2.2-percent year-on-year increase. The 1.9-percent year-on-year increase of truck VMT was marginally lower than the corresponding year-on-year increase in truck registrations (2.3%), and the U.S. population (1%) for the same period. Nevertheless, truck VMT as a proportion of total VMT for all motor vehicles (column #7 in Table 7.1) has remained relatively unchanged at approximately 7 percent each year.

7.6 Trucks and Fatal Crashes

The characteristics of large trucks and their potential secondary effects (e.g., the generation of tire debris) could in some cases be contributing factors in primary crashes and associated secondary effects. According to the Insurance Institute of Highway Safety (IIHS), “Large trucks (tractor-trailers, single-unit trucks, and some cargo vans weighing more than 10,000 pounds) account for more than their share of highway deaths. Large trucks have higher fatal crash rates per mile traveled than passenger vehicles” (IIHS, 2007). To better understand the highway safety environment with specific reference to large trucks, an overview is presented using statistics derived from several publicly available traffic crash datasets.

Table 7.1 - Registered Trucks[a] and Vehicle Miles Traveled in the United States (1995 to 2006)

Year (1)	Truck Registrations (Millions)[b] (2)	Motor Vehicle Total (Millions)[b] (3)	Truck % of Total Motor Vehicles[c] (4)	Truck VMT (Billions)[b] (5)	Motor Vehicle VMT (Billions)[b] (6)	Truck % of Motor Vehicle VMT[d] (7)
1995	6.7	205.4	3.3%	178.2	2,422.7	7.4%
1996	7.0	210.4	3.3%	183.0	2,485.8	7.4%
1997	7.1	211.6	3.3%	191.5	2,561.7	7.5%
1998	7.7	215.5	3.6%	196.4	2,631.5	7.5%
1999	7.8	220.5	3.5%	202.7	2,691.1	7.5%
2000	8.0	225.8	3.6%	205.5	2,746.9	7.5%
2001	7.9	235.3	3.3%	209.0	2,797.3	7.5%
2002	7.9	234.6	3.4%	214.6	2,855.5	7.5%
2003	7.8	236.8	3.3%	217.9	2,890.5	7.5%
2004	8.2	243.0	3.4%	220.8	2,964.8	7.4%
2005	8.5	247.4	3.4%	222.5	2,989.4	7.4%
2006	8.8	250.9	3.5%	223.0	3,014.1	7.4%
Average	7.8	228.1	3.4%	205.4	2,754.3	7.5%

Sources and Notes:

a. Single-unit 2-axle 6-or-more-tire vehicles and combination trucks

b. Office of Highway Policy Information. Highway Statistics Series. Table VM-1

c. Column 2 as a proportion of column 3

d. Column 5 as a proportion of column 6

7.7 Fatality Analysis Reporting Dataset

FARS is a dataset that contains data on all fatal traffic crashes within the 50 States, the District of Columbia, and Puerto Rico. The dataset became operational in 1975 and contains data only on fatal crashes (those resulting in death within 30 days of the crash).

7.7.1 Truck Involvement in Fatal Crashes by Body Type

Table 7.2 tabulates the numbers and proportions of large trucks that were involved in fatal accidents for the period of 1995 to 2006. Annually, trucks are involved in approximately 8 percent of all fatal crashes. These statistics can be compared with the truck proportions of the motor vehicle fleet or VMT (as shown in Table 7.1). During the 12-year period (1995 to 2006), approximately 3 percent of the total U.S. motor vehicle fleet and 7 percent of VMT were attributed to trucks. The proportions of truck involvements in fatal crashes (column 4 shown in Table 7.2) indicate an over-involvement when compared to their respective proportions of the motor vehicle fleet and VMT shown in columns 4 and 7 of Table 7.1 (supporting the IIHS conclusion made in section 7.6). Figure 7.2 shows annual truck crash proportions as well as the proportion of trucks in the total motor vehicle fleet and their corresponding share of VMT.

Table 7.2 – Truck Involvement in Fatal Crashes 1995 – 2005

Year	# Trucks in Fatal Crashes[1 2]	# All Vehicles in Fatal Crashes[1]	% Trucks in Fatal Crashes
1995	4,526	56,524	8.0%
1996	4,822	57,347	8.4%
1997	4,983	57,060	8.7%
1998	5,000	56,922	8.8%
1999	4,977	56,820	8.8%
2000	5,044	57,594	8.8%
2001	4,892	57,918	8.4%
2002	4,665	58,426	8.0%
2003	4,791	58,877	8.1%
2004	4,963	58,729	8.5%
2005	5,012	59,495	8.4%
2006	4,778	57,943	8.2%

1 FARS data downloaded and analyzed April 14, 2008

2 Heavy/Medium Truck (weighing 10,000 pounds or more)

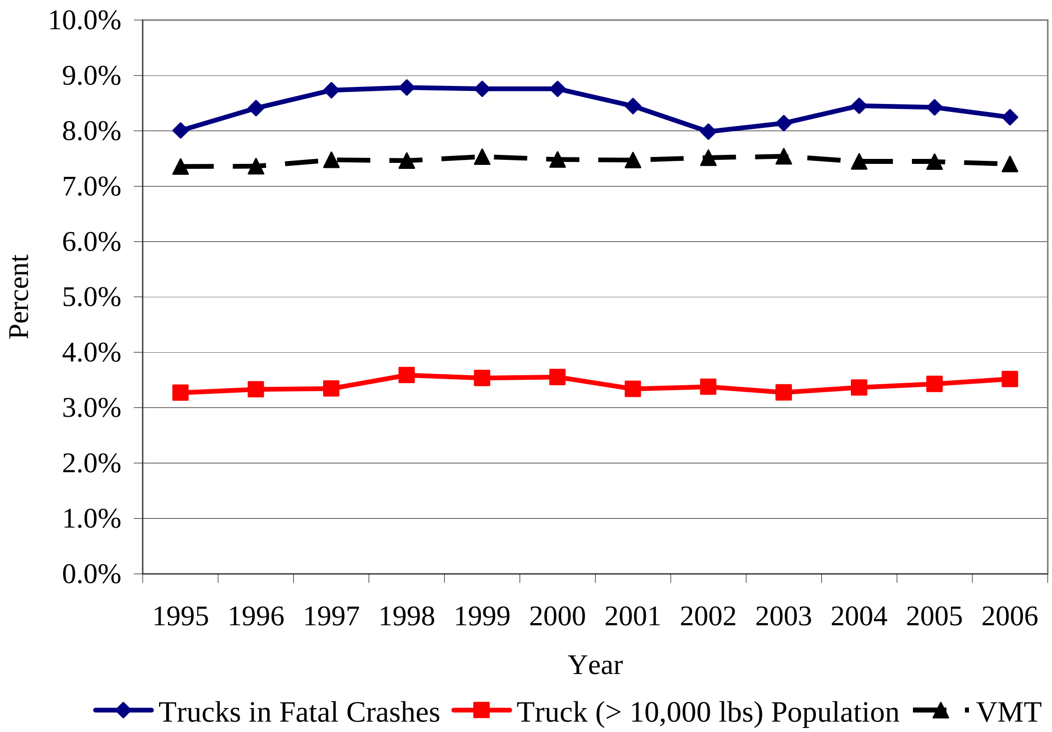


Figure 7.2 – Truck Proportions of Fatal Crashes, Motor Vehicle Fleet, and VMT

7.7.2 Truck Involvement in Fatal Crashes – Vehicle Miles Traveled

As discussed, VMT can also be used to gauge the level of driving exposure. Comparing the number of fatal crashes to VMT produces a rate of fatal crash involvement per mile traveled. Differences between each vehicle type and associated fatal crash rates per mile traveled may indicate the propensity of that particular vehicle type to be involved in a fatal crash. Table 7.3 presents fatal crash rates by VMT for trucks and automobiles, whereas Figure 7.3 presents the same information graphically. It is evident from Figure 7.3 that trucks had a higher rate of fatal crash involvement per million VMT for all years shown (i.e., the truck line is always above the passenger car line). Over the 10-year period depicted in Figure 7.3, the crash involvement rate for passenger cars consistently declined. However, for trucks, the downward trend is less consistent than for passenger cars. The 1995 fatal crash involvement rate per 100 million VMT by vehicle type was approximately 1.5 and 2.5 for passenger cars and trucks, respectively. In 2006, these rates were 1.2 versus 2.1, respectively, with passenger cars showing the largest improvement.

Table 7.3 – Fatal Crash Involvement Rate by Vehicle Type 1995 – 2006

Year	Truck VMT (millions)[1]	Passenger Cars & 2-Axle 4-Tire VMT (millions)[1]	# Trucks in Fatal Crashes[2]	Passenger Cars & 2-Axle 4-Tire Fatal Crashes[3]	Trucks Fatal Crash Involvement Rate[4]	Passenger Cars & 2-Axle 4-Tire Fatal Crash Involvement Rate[4]
1995	178,156	2,228,323	4,526	34,279	2.54	1.54
1996	182,971	2,286,394	4,822	34,502	2.64	1.51
1997	191,477	2,353,295	4,983	34,206	2.60	1.45
1998	196,380	2,417,852	5,000	33,606	2.55	1.39
1999	202,688	2,470,122	4,977	33,009	2.46	1.34
2000	205,520	2,523,346	5,044	33,377	2.45	1.32
2001	209,032	2,571,539	4,892	33,547	2.34	1.30
2002	214,603	2,624,508	4,665	34,159	2.17	1.30
2003	217,917	2,656,174	4,791	33,861	2.20	1.27
2004	220,811	2,727,054	4,963	33,521	2.25	1.23
2005	222,523	2,749,472	5,012	33,349	2.25	1.21
2006	223,037	2,771,684	4,778	32,351	2.14	1.17

Sources and Notes:
1. Office of Highway Policy Information. Highway Statistics Series. Table MV-1
2. FARS data downloaded and analyzed 04/14/2008 FARS Body Type Variable Codes: 60 to 79
3. FARS data downloaded and analyzed 04/14/2008 FARS Body Type Variable Codes: 1 to 19
4. Per 100 million Vehicle Miles

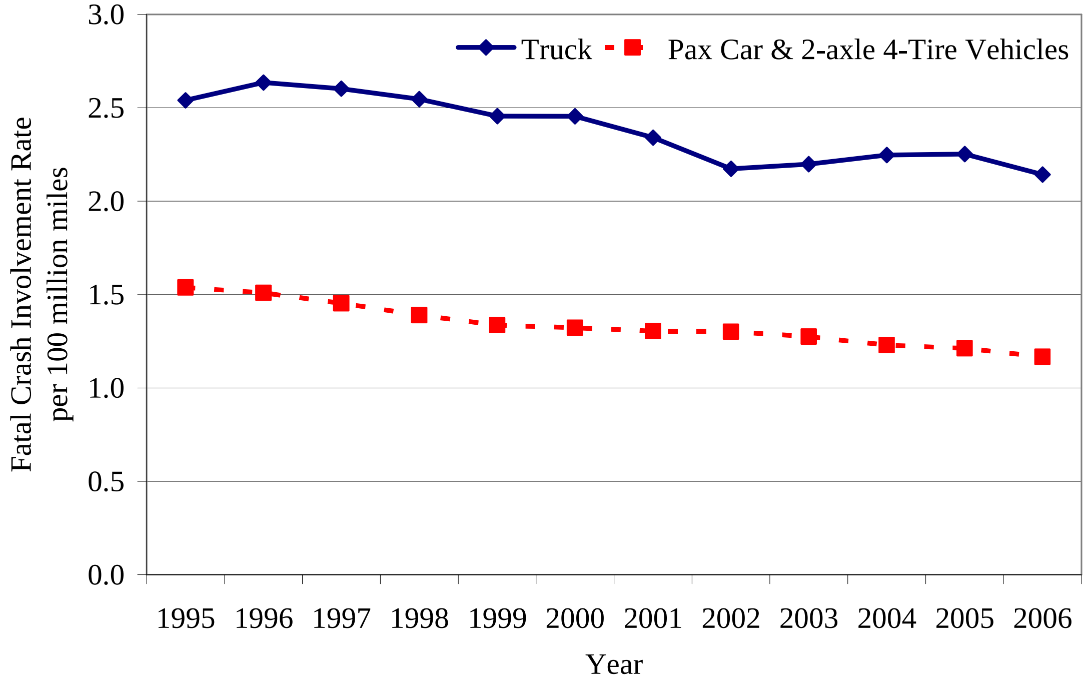


Figure 7.3 – Fatal Crash Involvement Rate by Vehicle Type (1995 to 2006)
Source: FARS & Office of Highway Policy Information

7.8 Trucks Involved in Fatal Accidents

The Trucks Involved in Fatal Accidents (TIFA) crash data file is produced by the Center for National Truck and Bus Statistics at UMTRI. The TIFA file is a survey of all medium and heavy trucks (gross vehicle weight rating [GVWR] greater than 10,000 pounds) involved in fatal crashes in the United States. Candidate truck cases are extracted from NHTSA's FARS file, which is a census of all traffic crashes involving fatalities in the United States. To collect data for the TIFA survey, police reports are acquired for each crash, and UMTRI researchers contact drivers, owners, operators, and other knowledgeable parties about each truck. The TIFA survey collects a detailed description of each truck involved, as well as data on the truck operator and the truck's role in the crash. Survey data includes the physical configuration of the truck, such as the GVWR, weights and lengths of each unit, cargo body style, type of cargo (including hazardous materials), and cargo spillage. Motor carrier data includes carrier type (private/for-hire) and area of operation (interstate/intrastate). The crash file constructed from this data includes all variables from the FARS file, which captures the crash environment and all other vehicles and people involved in the crash.

The TIFA file includes the vehicle-related factors from the original FARS file. FARS analysts coded up to two vehicle-related factors, which consist of vehicle defects or other conditions that are identified in the police accident report or other investigation. Coded factors only indicate the presence of the factor, not necessarily the judgment of the reporting officer that the factor contributed to the crash. Most of the code levels available identify defects in vehicle components. (There is also a set of codes which identify special circumstances, but none are germane to the current analysis.) Up to two vehicle defects may be recorded. These codes are the only FARS or TIFA data that can be used to identify tire defects. However, in combination with the other descriptive data available in the TIFA file, they can be used to identify crash, vehicle, and company factors that may be associated with tire defects. Note that “tire defects” includes all types of tire problems, including blowouts, tread separation, sidewall failure, and worn or bald tires. It is not possible to determine the nature of the tire defect recorded.

7.9 General Estimates System

The General Estimates System (GES) file is compiled by the National Center for Statistics and Analysis (NCSA) of the NHTSA.[1] It is a nationally representative sample of police-reported traffic crashes. The GES file covers crashes of all severities and all vehicle types. GES data include a description of the crash environment, each vehicle and driver involved in a crash, and each person involved in a crash. GES data are coded entirely from police reports. GES cases are the product of a complex stratified sampling procedure, and sampling errors for subpopulations are relatively large. Each record includes a case weight variable, which may be used to determine national population estimates.

Medium and heavy trucks (GVWR greater than 10,000 pounds) can be identified in the GES data. In addition, the GES data include two variables that can be used to identify crash involvements related to truck tire defects. The first is P_CRASH2 and captures the vehicle’s critical event (the event that precipitated the vehicle’s involvement in the crash). One of the code levels is for tire failure leading to loss of control. Neither TIFA nor the FARS file that TIFA supplements includes this information. GES data also include a variable that captures “vehicle factors,” including tire defects. This variable is similar to the “vehicle-related factors” variable in the TIFA data. As in TIFA, the tire defect’s vehicle factor includes all problems relating to tires, such as blowouts, tread separation, and worn or bald tires. An analytical file containing four years of data was built for the current analysis.

7.10 Crashworthiness Data System

The NASS Crashworthiness Data System (CDS) crash data file is also compiled by NCSA. While GES provides a comprehensive overview of traffic crashes with great breadth, the CDS file provides a more in-depth examination of a smaller sample of crashes. The CDS file is based on a sample of police-reported crashes involving passenger cars, light trucks, and vans that were towed due to damage. The CDS file includes many of the same data elements in GES that are used to capture the events of the crash (that is, pre-crash movement and critical event), but also a researcher’s summary of crash events, diagrams, and photos of the scene and vehicles.

The CDS file is used to estimate the size of the crash problem related to truck tire debris left on the road. The CDS file is based on a sample of light vehicles, and includes trucks only if involved in a crash of a sampled vehicle, so it is not possible to use the CDS file to address truck problems directly. However, to estimate the size of the crash problem related to light vehicles striking truck tire debris on the road, a method was developed to search the researcher’s narrative for any mention

1 *National Automotive Sampling System (NASS) General Estimates System (GES) Analytical User’s Manual, 1988-2002.* U.S. Department of Transportation, National Highway Traffic Safety Administration. Washington, DC.

of tire debris (not necessarily identified as coming from trucks) in the crash. The full narrative was then read to determine whether the debris was causally related to the crash and whether the debris was from a truck tire. Five years of NASS CDS data, from 2001 through 2005, were searched for this purpose.

7.11 Large Truck Crash Causation Study

The Large Truck Crash Causation Study (LTCCS) was a three-year project conducted by the Federal Motor Carrier Safety Administration (FMCSA) in cooperation with NHTSA, from 2001 through 2003.[2] Crashes involving large trucks (GVWR greater than 10,000 pounds) with a serious (fatal, incapacitating, or non-incapacitating but evident) injury were sampled from 24 data collection sites. Researchers from NHTSA's NASS system and State truck inspectors investigated each sampled crash. The data collected incorporated many of the same data elements as the NASS GES and CDS, as well as many other data elements, to form the richest truck crash data file available. Each case includes an extensive researcher's narrative, scene diagram, photos of the scene and involved vehicles, as well as nearly 1,000 data elements on all aspects of the crash and the vehicles involved. Part of this data is a post-crash truck inspection to determine, among other things, the mechanical condition of the truck prior to the crash.

LTCCS data were used to identify the proportion of crashes related to tire failure. Each case was reviewed, including the researcher's narrative, in order to determine the nature of the failure, and how the failure contributed to the events of the crash. In addition, the truck inspection data were used to characterize the condition of the tires on all trucks in the crashes. Since these data are based on actual inspections conducted by a trained truck inspector, they provide more reliable estimates of truck tire defects in the crash population.

7.12 Results From the TIFA File

7.12.1 Construction of Multiyear File

For the purpose of this analysis, a multiyear file was constructed. Seven years of TIFA data were combined into a single analytical file. Tire defects are rarely recorded, so combining many years of data provides more robust and stable relationships to the crash and other factors examined. Seven years of TIFA data were combined into a single analytical file. The TIFA files for 1999 through 2005 were used for this purpose. Those files are the most recent TIFA data available. Results are presented in Table 7.4.

---

2 *Large Truck Crash Causation Study Analytical User's Manual.* (2006). Federal Motor Carrier Safety Administration. Washington, DC: National Highway Traffic Safety Administration.

Table 7.4 - Average Annual Vehicle Defects Coded TIFA 1999-2005

Vehicle Defect	N	%
None	4,842	93.2
Tires	45	0.9
Brake System	97	1.9
Steering	7	0.1
Suspension	6	0.1
Power Train/Engine	5	0.1
Exhaust System	1	0.0
Headlights	3	0.0
Signals	3	0.1
Other Lights	7	0.1
Horn	1	0.0
Wipers	0	0.0
Driver Seating	0	0.0
Body, Doors, Other	1	0.0
Trailer Hitch	7	0.1
Wheels	2	0.0
Air Bags	0	0.0
Other	15	0.3
Unknown	89	1.7
Total trucks	5,194	100.0

7.12.2 Vehicle Defects

Vehicle defects recorded are originally identified by the original reporting police officer or other crash investigator. Generally, police officers are not trained to identify vehicle defects so it is highly likely that only the most obvious vehicle mechanical problems are noted and recorded. Thus, it is very likely that the incidence of vehicle defects, including tire problems, in fatal truck involvements is underreported. Table 7.4 shows that no vehicle defect was noted for 93.2 percent of trucks involved in a fatal crash in the TIFA data. Problems that are readily observable, such as blowouts or tread separation, are more likely to be recorded than more subtle problems, such as marginal tread depth. On the other hand, it could be noted that the events of greatest interest here (i.e., tread separation and tire failure) are also the most likely to be observable by a crash investigator.

The most common vehicle defect noted in fatal truck crashes occur in the brake system, but tire defects are the second most common. On average, 97 trucks in fatal crashes are recorded with brake system problems, and 45 trucks with tire defects. Over the period from 1999-2005, the years of the TIFA data set used for this analysis, almost 5,200 trucks were involved in fatal crashes annually, so the incidence rates of tire and other defects are very low. Only 0.9 percent of the trucks were recorded with tire defects; and brake defects were identified for only 1.9 percent. All the other defect types were recorded at much lower rates. Given how few vehicle problems are identified every year, it is appropriate to combine many years of data. Over the seven years of fatal crash data used here, there were 318 cases where tire defects were recorded.

In the analysis that follows, we will compare the characteristics of those 318 cases with the crashes where no tire defects were identified. The results suggest some factors that are associated with tire defects in fatal crashes.

7.12.3 Injuries and Fatalities

Table 7.5 shows the distribution of injuries in fatal crashes by whether the truck was coded with tire defects. Not surprisingly, truck crashes in which trucks were coded with tire defects account for a small fraction of the total fatalities and other injuries. Over the seven years of the TIFA crash data, an average of 55 people were killed in crashes involving truck tire defects, compared with an annual average of 5,528 overall. Over 9,900 people sustained injuries in fatal truck crashes, 100 of whom were injured in crashes where trucks were coded with tire defects. The percentage of trucks with tire defects in the TIFA data is small (only 0.9 percent) and the number of people with injuries in the crashes is proportionate. Overall, tire defects crashes do not appear to vary significantly from other fatal crashes in terms of the number of injured persons.

Table 7.5 - Annual Fatalities and Injuries in Fatal Truck Crashes, by Coded Tire Defects, TIFA 1999-2005

Injury Severity	Tire Defects	No Tire Defects	Total
Fatal	55	5,474	5,528
A-injury	19	1,508	1,527
B-injury	16	1,561	1,577
C-injury	10	1,257	1,268
Unknown severity	0	17	17
Total	100	9,816	9,916

7.12.4 Month and Roadway Factors

A variety of factors were examined for association with tire defects. This includes the month of the crash, to test if tire defects are more common in the summer months when temperatures are high, or lower in months when temperatures are on average lower. Figure 7.4 shows the distribution of tire defects and other fatal crash involvements by month. The curves are consistent with the higher temperatures of summer months associated with more identified tire defects. The mechanism may be that tires are more likely to fail when operated in hotter temperatures. The ambient temperature is not available directly in the crash data. Month is used as a surrogate. Note that unlike passenger vehicles, commercial trucks are not driven more during the summer months than during the winter months as their patterns of use are roughly the same throughout the year.

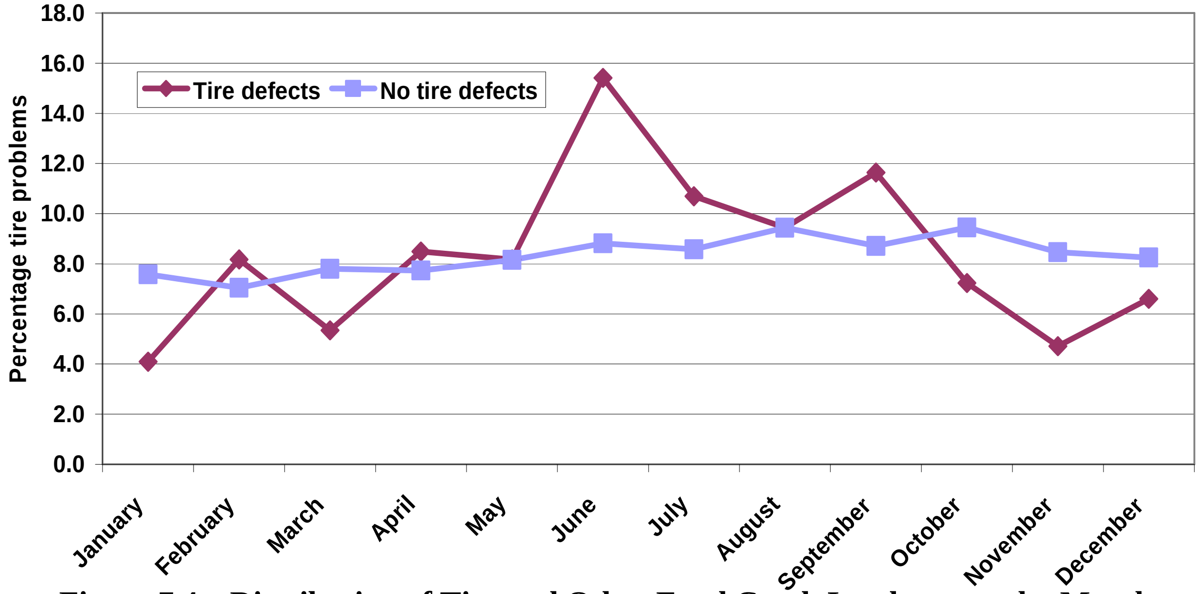


Figure 7.4 – Distribution of Tire and Other Fatal Crash Involvements by Month, TIFA 1999-2005

Tire defects are more likely to occur on relatively high-speed roads. Figure 7.5 shows the distribution of cases coded with tire defects by route signing. The distribution of cases with no tire defects is shown for comparison. About 42 percent of tire-defect involvements occurred on interstate-quality highways, compared with only about 26 percent of the involvements that did not have an identified defect.

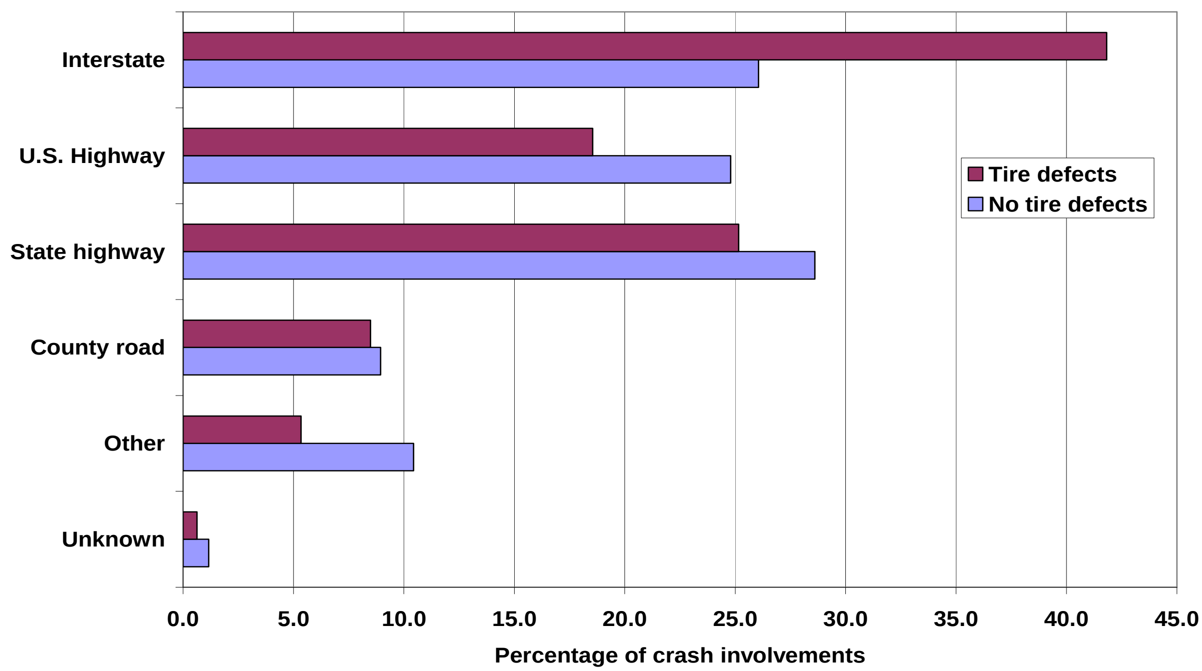


Figure 7.5 – Distribution of Tire and Other Fatal Crash Involvements by Route Signing, TIFA 1999-2005

The effect of road speed is more directly shown in Figure 7.6, which shows the percentage of tire defects identified in crashes by the posted speed limit on the road. The incidence of tire defects stays low at around 0.6 percent on roads with posted speed limits up to 55 mph. On roads with speed limits from 60 mph to 70 mph, the percentage essentially doubles to about 1.2 percent, and then doubles again to 2.3 percent on roads with posted speed limits of 75 mph. In combination with the distribution of tire-defect-related fatal truck crashes by route signing, this suggests that high speeds and the related heat generated are associated with the incidence of tire defects.

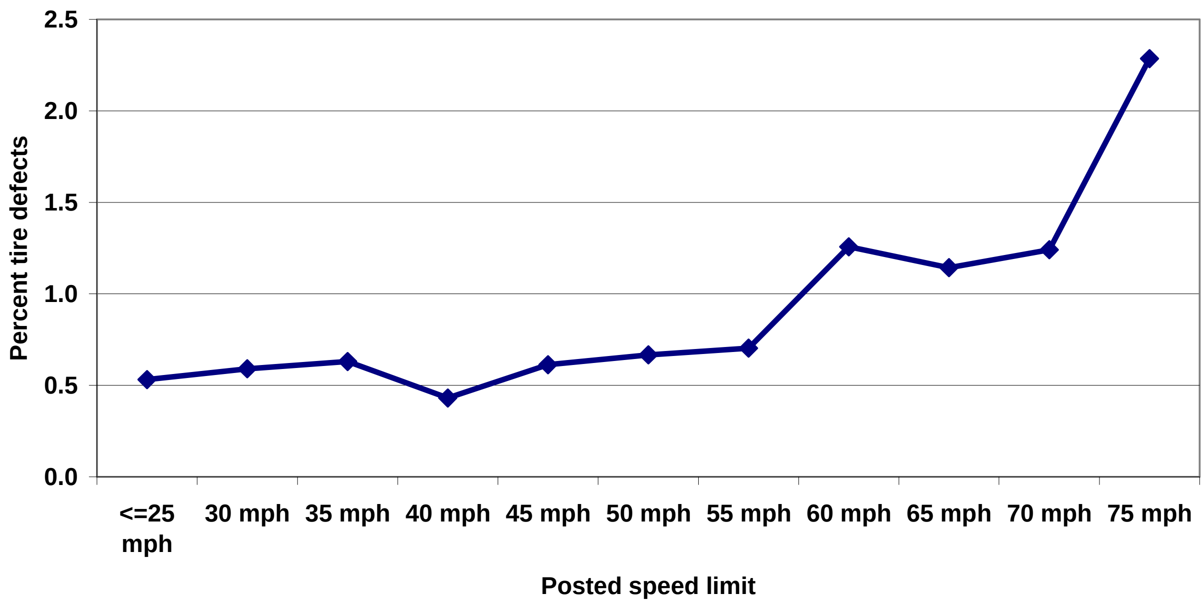


Figure 7.6 – Incidence of Tire Defects in Fatal Crash Involvements by Posted Speed Limit, TIFA 1999-2005

7.12.5 Crash Characteristics

The next several figures show the association between tire-defects in fatal truck crashes and the events or characteristics of the crashes. The coded tire-defects include only tire problems that exist prior to the crash. Thus, they are in a sense literally preconditions for the crash, since they are conditions that exist prior to the crash. The coded tire defects can encompass a range of conditions that would affect the nature of the crash in different ways. Worn or bald tires would affect the handling and control of the vehicle, reducing the friction available in stopping or maneuvering on slippery surfaces. Trucks with worn tires would have longer stopping distances and less ability to maneuver to avoid crashes. So a truck with worn tires might be at greater risk of a crash in which braking is the primary crash-avoidance mechanism, such as rear-end crashes. At the same time, a truck with worn tires, because of the reduced friction available, might also be less able to maintain control on high-speed curves and lose control.

The coded tire defects also include various forms of catastrophic tire failure, including blowouts, tread separation, and sidewall failure. Unlike collision-avoidance maneuvers that involve braking, catastrophic tire failures do not occur in direct relation to other vehicles on the road, but somewhat randomly with respect to other road users. In other words, while the risk associated with worn tires often is expressed in relation to other vehicles, as when the truck has to brake in response to stopped or slowing vehicles, the risk of a blowout generally occurs randomly with respect to other vehicles. Thus, if a steering axle fails and the truck loses control, whether the resulting crash includes another vehicle depends on whether another vehicle happens to be in the path of the truck when it loses control. Accordingly, it is expected that tire defects-related crash involvements would be likely to have a higher proportion of single-vehicle crashes than other fatal truck crash involvements. One would also expect higher rates of crash types involving loss-of-control, such as rollovers and jackknifes, as well as more crashes that involve running off the road and colliding with fixed objects. The following set of figures compare the fatal crashes along these dimensions of trucks coded with tire defects and other trucks in fatal crashes.

Trucks with tire defects in fatal crashes are much more likely to be involved in single-vehicle crashes than other trucks. Figure 7.7 shows that about 38 percent of fatal crashes involving trucks with tire defects are single-vehicle crashes, compared with only about 17 percent for other trucks. Accordingly, the percentage of two-vehicle crashes is much lower (42.5% compared to 62.3%) for trucks not coded with tire defects, though the percentage of involvements with three or more vehicles is about the same.

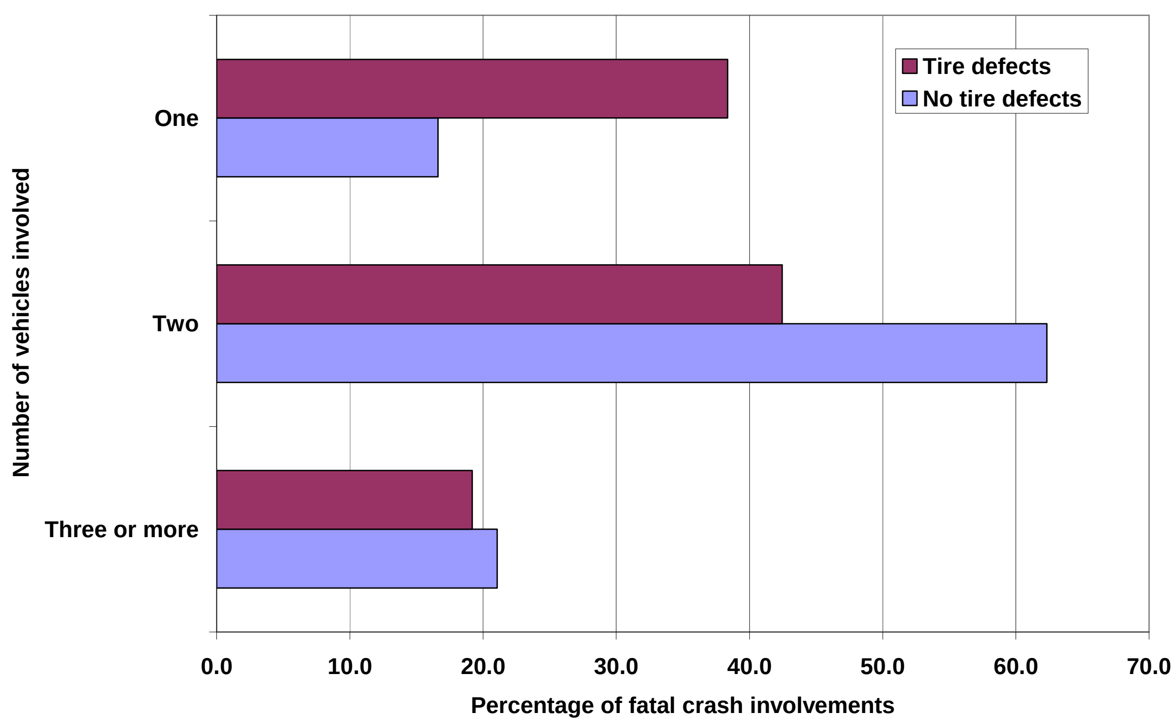


Figure 7.7 – Distribution of Tire-Related and Other Fatal Crash Involvements by Number of Vehicles Involved, TIFA 1999-2005

The distribution of first harmful event (Figure 7.8) in the crash is also quite different for trucks coded with tire defects. As expected, the first harmful event in fatal crashes of trucks with tire defects is much more likely to be a collision with a fixed object than other fatal truck crash involvements. In over 25 percent of tire-defect-related crash involvements, the first harmful event was a collision with a fixed object, which implies (generally) that the truck departed the road and collided with a tree, sign, bridge abutment, or some other permanent roadside object. Other loss-of-control type first events are much higher for tire-defect involvements. Over 12 percent of tire-defect involvements include a first-event rollover, compared to about four percent for trucks without tire defects. The "other non-collision" category is not further specified unfortunately, but may include road departures not involving an overturn or collision with an object. Note that collisions with other motor vehicles are proportionately reduced.

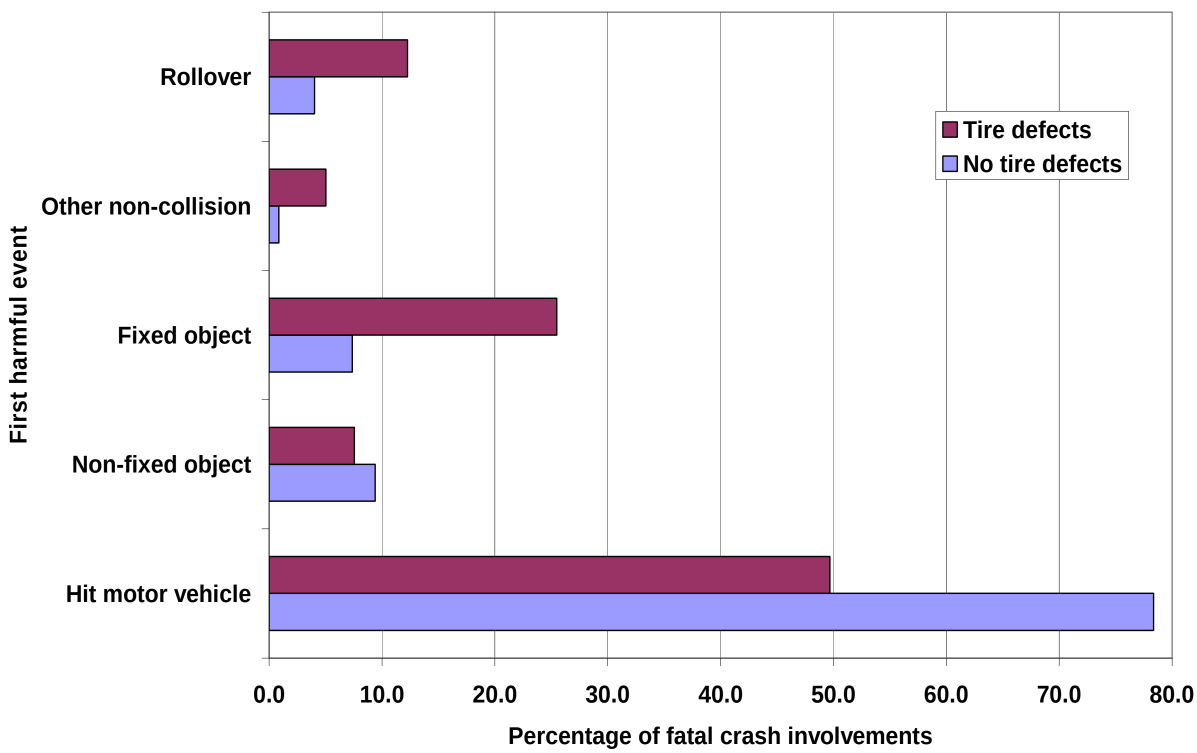


Figure 7.8 – Distribution of First Harmful Event for Tire-Related and Other Fatal Crash Involvements, TIFA 1999-2005

Rollovers and jackknifes are both more likely in tire-defect-related fatal involvements than where no tire defect is identified (see Figures 7.9 and 7.10). The proportions of both first and subsequent rollovers are much greater for tire-defect fatal involvements; combined, one-third of tire-defect involvements include a rollover, compared with about 13 percent of other involvements. Rates of jackknife, specifically first event jackknife, are higher in tire-defect involvements.

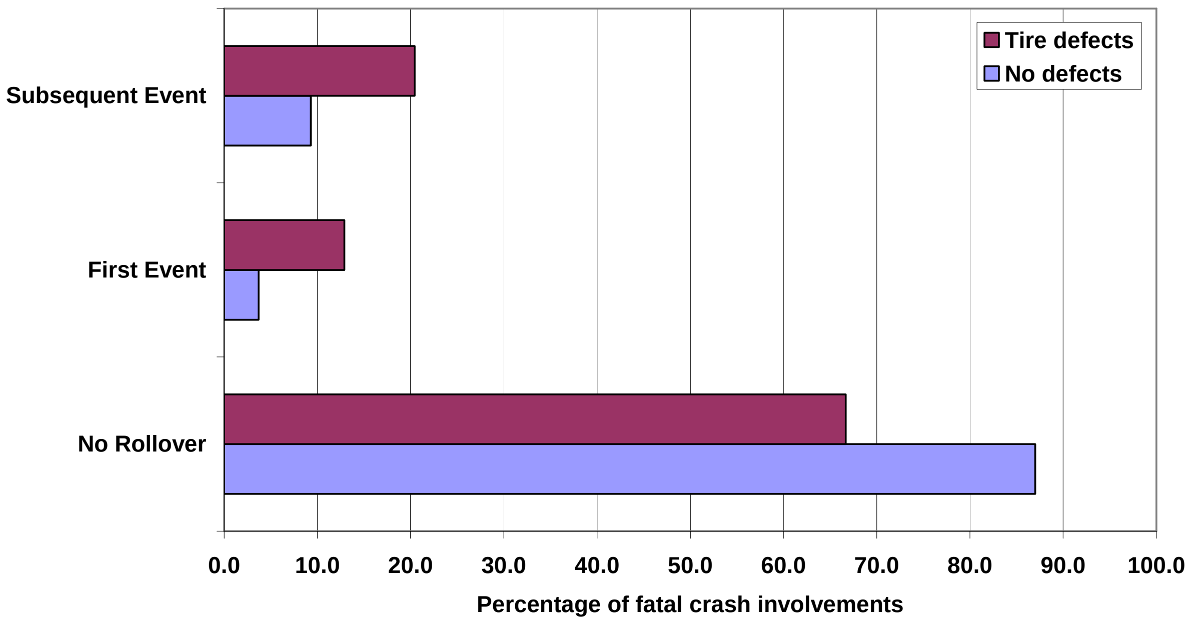


Figure 7.9 – Rollover and Tire-Related and Other Fatal Crash Involvements TIFA 1999-2005

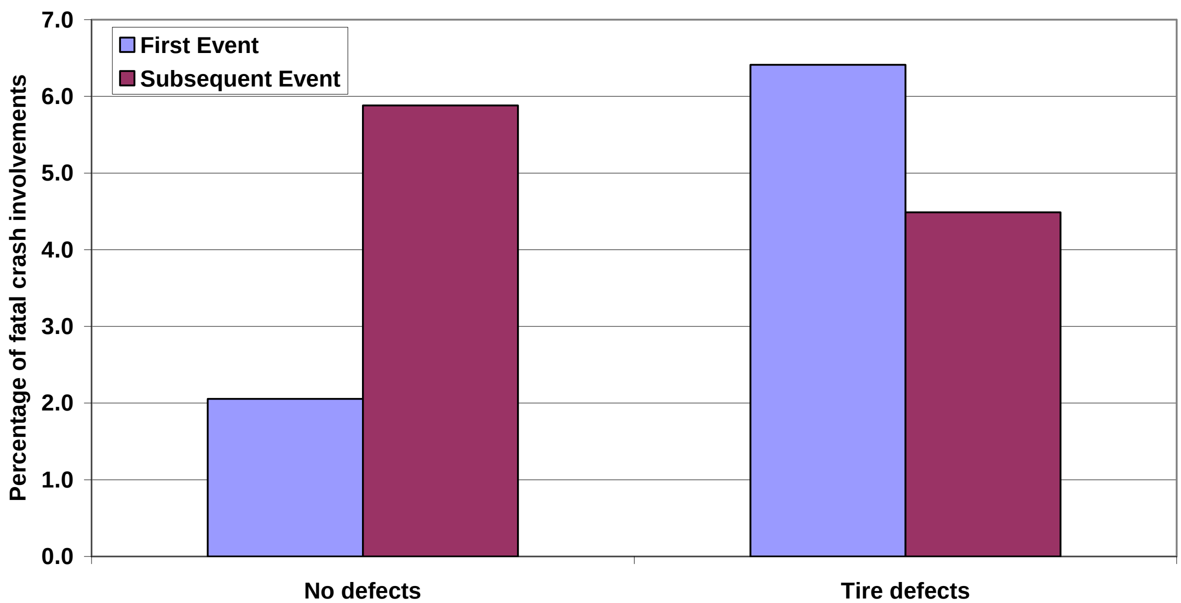


Figure 7.10 – Jackknife and Tire-Related and Other Fatal Crash Involvements TIFA 1999-2005

Vehicle and Carrier Type

Tire defects are also associated with different characteristics of the vehicle and of the carrier operating the vehicle. The next figures illustrate some of the differences. While the question of maintenance cannot be specifically addressed here, because there is no information about the practices of the carriers, the results are consistent with an association with smaller, more local firms having higher rates of tire defects.

Interestingly, rates of tire defects in fatal crash involvements are highest for straight trucks and straight trucks pulling a trailer. Figure 7.11 shows that over 1.4 percent of straight trucks involved in fatal crashes were coded with tire defects, compared with 0.9 percent overall and about 0.6 percent for tractor semi-trailers, the most common truck configuration in fatal crashes. Straight trucks pulling a trailer also had an elevated rate compared to any of the tractor combinations. The rate of incidence was lowest for bobtails, possibly because that combination typically only has two or three axles and so less exposure, in terms of number of tires, to a tire failure. Also, bobtails by definition operate without a trailer and so the tires may experience less stress. The rates of identified tire-defects are about the same for tractor semi-trailers and tractor-doubles combinations. Typically, about 90 percent of tractor semi-trailers have five axles (three-axle tractor and two-axle trailer) and about 70 percent of doubles have five (50%) or six (20%) axles on the combination, so the exposure in terms of tires is about the same.

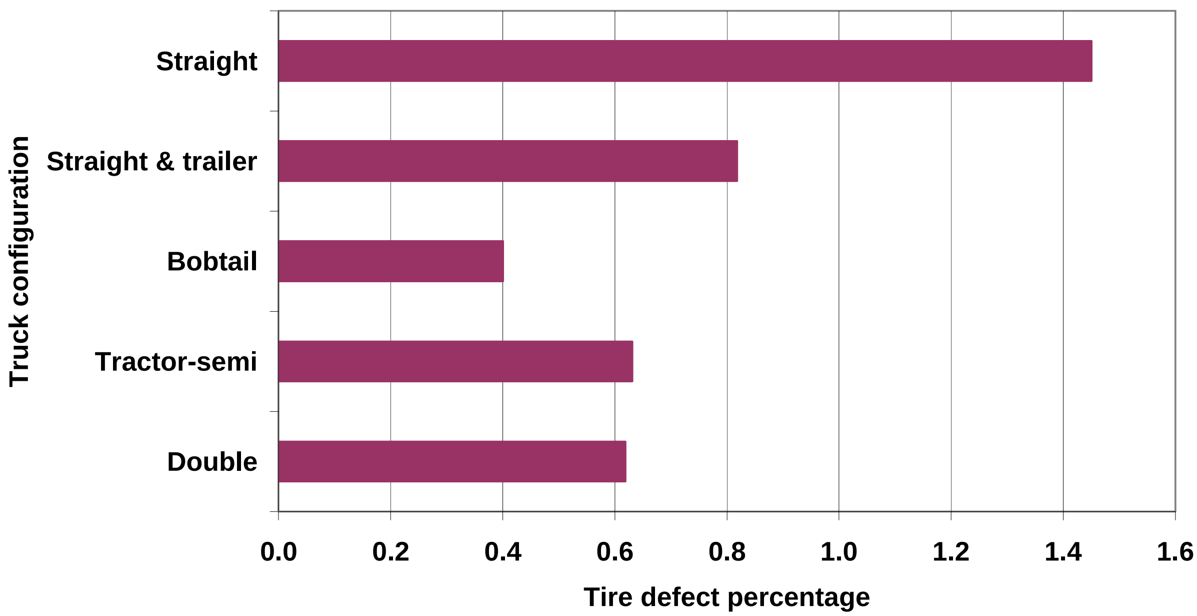


Figure 7.11 – Incidence of Coded Tire Defects by Truck Configuration, TIFA 1999-2005

The age of the power unit has a substantial and significant association with the incidence of tire defects. Figure 7.12 shows that the incidence of tire defects increases by the age of the power unit at the time of the crash. It shows a fairly consistent trend that older power units tend to have higher rates of tire defects identified in fatal truck crashes. For power units up to 11 years old, rates vary from 0.5 percent to about one percent. These trucks account for about 80 percent of all trucks involved in fatal crashes. Older trucks have much higher rates. About 2 percent of 20-year-old trucks were coded with tire defects, while about 4 percent of trucks in fatal crashes that were 24 to 29 years old had tire defects. While big effects are observed in very old vehicles, one also notes that the incidence of tire defects doubles from the newest models to those just six to eight years old. The overall pattern is likely related both to wear associated with use, changes in use patterns as vehicles age, and possibly less maintenance on older vehicles. It is emphasized, however, that the crash data cannot address these hypotheses directly.

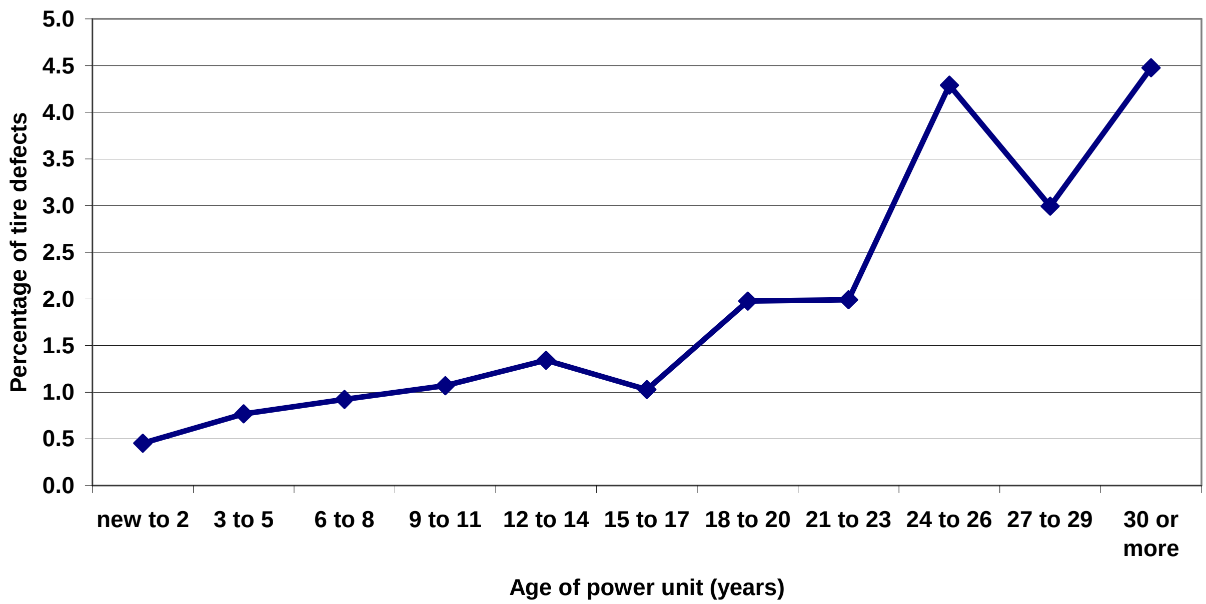


Figure 7.12 – Incidence of Coded Tire Defects by Power Unit Age, TIFA 1999-2005

Tire defects also seem to be associated with differences in the type of carrier operating the vehicle. Figure 7.13 shows the incidence of tire defects by carrier type for trucks in fatal crashes. Carrier type is classified by whether it operates in interstate commerce or exclusively intrastate, and by whether it is private (transports its own goods) or for-hire (i.e., freight-haulers). Both intrastate/for-hire and intrastate/private carriers have about the same rate: 1.2 percent of trucks operated by those carrier types are coded with tire defects. Both of the interstate carrier types have lower rates, and interstate/for-hire (which accounts for about half of all trucks in fatal crashes) have the lowest incidence of tire defects. Though all trucks are subject to an inspection regime, intrastate-only vehicles are not subject to FMCSA's regulation. It is also possible, however, that this finding reflects the fact that large interstate/for-hire trucking companies are more likely to operate new equipment, while intrastate firms, particularly private companies, are more likely to operate straight trucks and older vehicles.

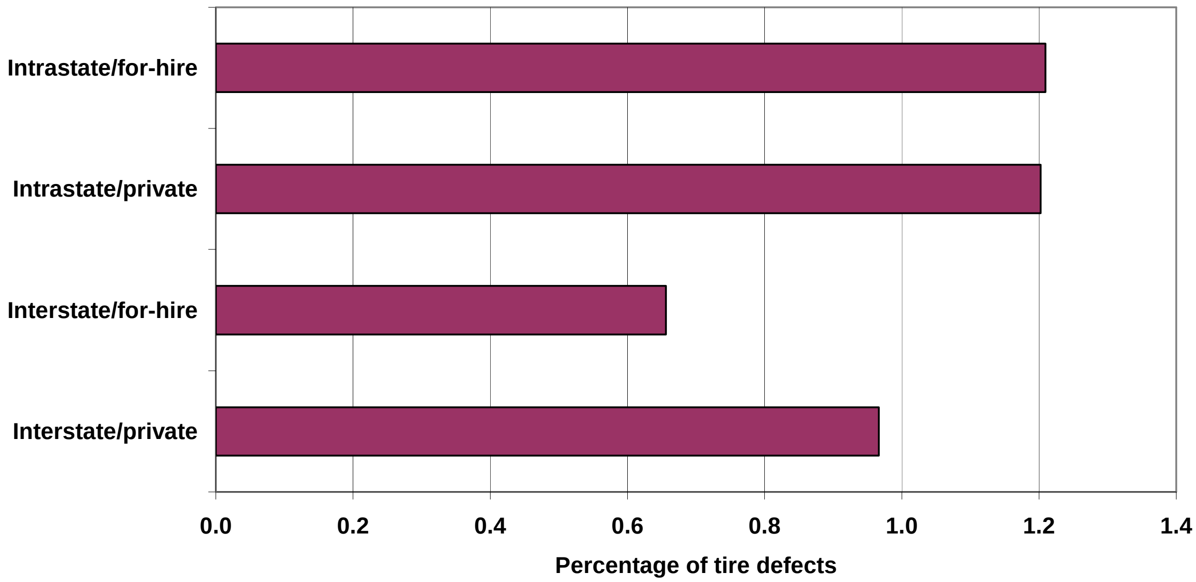


Figure 7.13 – Distribution of Carrier Type for Tire-Related and Other Fatal Crash Involvements, TIFA 1999-2005

Finally, the TIFA data include a classification of the trip type the truck was on at the time of the crash. This variable records the intended one-way distance of the trip, not the distance the truck had actually gone. As such, the variable reflects the type of operations of the carrier. Trucks operated on local trips tend to have higher rates of coded tire defects than those on any length of an over-the-road trip (Figure 7.14). The incidence of tire defects was a bit over 1 percent on local trips, but fell to around 0.8 percent for trucks on trips between 50 and 100 miles, and to around 0.7 percent for trucks on longer trips. Again, this finding is consistent with the finding on truck configuration, power unit age, and carrier type. Intrastate carriers, straight trucks, and older trucks all tend to be operated closer to home base, while newer trucks are more often tractors used in interstate commerce for long-haul operations.

7.13 Results From GES Data

Four years of data were combined because the structure of the data stays relatively stable over that period, facilitating the process of combining the data sets. Tire defects are captured in a different way from TIFA. There are two variables that identify tire-related factors in the data. The first is part of a vehicle-related factors variable. The other place in the GES data where tire defects may be captured is in the critical event variable, a variable that is used to identify the event that precipitated the crash. One of the code levels available is loss of control due to blowout or tire failure.

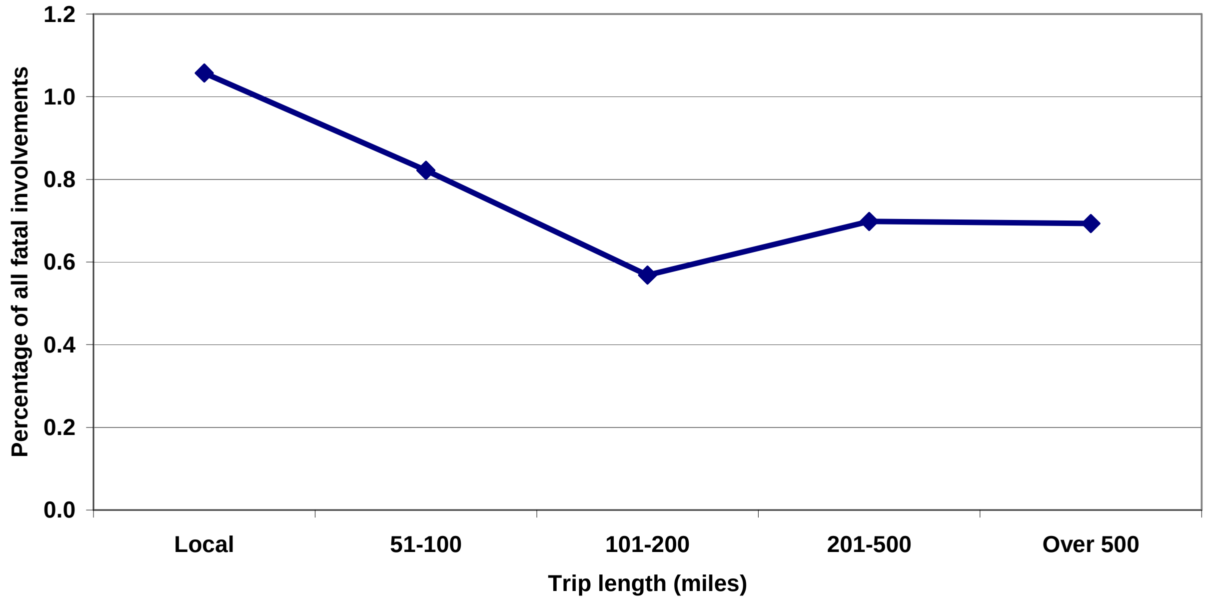


Figure 7.14 – Incidence of Tire Defects by Type of Trip in Fatal Crash Involvements, TIFA 1999-2005

Unlike the coding instructions for FARS, in GES the instructions are to code vehicle factors that contribute to the crash. In FARS the instruction is to capture the presence of the factor. However, one may note that GES coders are restricted to the police report, and FARS analysts have access to other investigative resources, in practice FARS analysts probably have access to the same type of information. The fact is that the condition of the vehicle is not generally reviewed unless there is a reason to suspect a problem. Some fatal truck crashes may include an inspection as a matter of routine, which should record the presence of a tire defect. But practically speaking, it is likely that when a police officer mentions a tire problem, it is because he believes that it contributed to the crash. Since FARS analysts also work from police reports primarily, they would code the same information. There will be cases where FARS analysts have access to other information, such as post-crash truck inspections, which should pick up vehicle defects that are present, regardless of whether they contributed to the crash, but in practice it is likely that the differences between GES and FARS on this score are not great.

In the analysis of GES data, cases identified as loss-of-control due to tire failure and tire-related defects were combined to identify all cases in which tire defects were identified. The number of tire failure and tire defect cases is so small that it is not worthwhile to analyze them separately. As Table 7.6 shows, only 0.3 percent of truck crash involvements were precipitated by tire failure, and tire defects were identified in an additional 0.6 percent. Moreover, there is no such distinction in TIFA data.

Table 7.6 - Annual Incidence of Coded Tire Defects in TIFA and GES Crash Files
TIFA 1999-2005; GES 2002-2005

	TIFA (Fatal)		GES	
	N	**%**	**N**	**%**
Tire defect	45	0.9	4,140	0.9
Flat or other failure	n/a	n/a	1,347	0.3
Other tire defect	n/a	n/a	2,794	0.6
All other involvements	5,103	99.1	431,943	99.1
Total	5,149	100.0	436,083	100.0

Table 7.6 shows the average annual number and proportion of truck crash involvements related to tire defects in fatal (TIFA) and all police-reported (GES) crashes. Tire defects are detected in a relatively small number of cases each year. It is interesting and even somewhat surprising to note that the proportion is the same in fatal and all police-reported crashes at 0.9 percent. That the proportions are the same is surprising because there are so many differences between the sources, beyond the fact that TIFA is restricted to fatal crashes and GES includes crashes of all severities. TIFA is a census file compiled by State-based analysts with access to a variety of source materials, while GES is based on a hierarchical stratified sample of police reports, and the information is coded entirely from the police reports. Standard errors of estimates in GES are relatively large, so estimates will vary simply from sampling error. Four years of data were combined to produce more stable estimates, and from the results that strategy was apparently useful. Detected tire defects in truck crashes are relatively rare.

7.13.1 Month and Roadway Factors

As in fatal crash involvements, it appears that the incidence of detected tire problems is higher in summer months than at other times of the year. Figure 7.15 shows the lowest rates of tire defects in truck crash involvements typically from November through February and the highest rates in June through October. This pattern is similar to that shown in fatal truck crash involvements and may be an indication that the rate of tire defects is related to ambient temperatures. Though the crash data do not include current temperatures, this finding is consistent with the fact that excessive heat is a known failure mode for truck tires, so, all other things being equal, a higher rate of tire failures would be expected in the summer months. However, it is emphasized that both the precise nature of the defect and the mechanism of the failure cannot be established in the crash data. The finding here is suggestive only.

7.13.2 Posted Speed Limits

Coded tire defects are also related to posted speed limit, which may also indicate a relationship with temperature. Figure 7.16 shows the incidence of tire defects by posted speed limit. The shape of the curve here is very similar to the finding in TIFA data (see Figure 7.6), though incidence rates here are much higher on high-speed roads. But note that rates are relatively low through the 55 mph speed limit, and then trend higher as the speed limit increases. The incidence of tire defects increases dramatically on roads with a 75 mph speed limit. This finding is also consistent with a failure mechanism related to operating temperatures, since higher speeds result in higher tire temperatures.

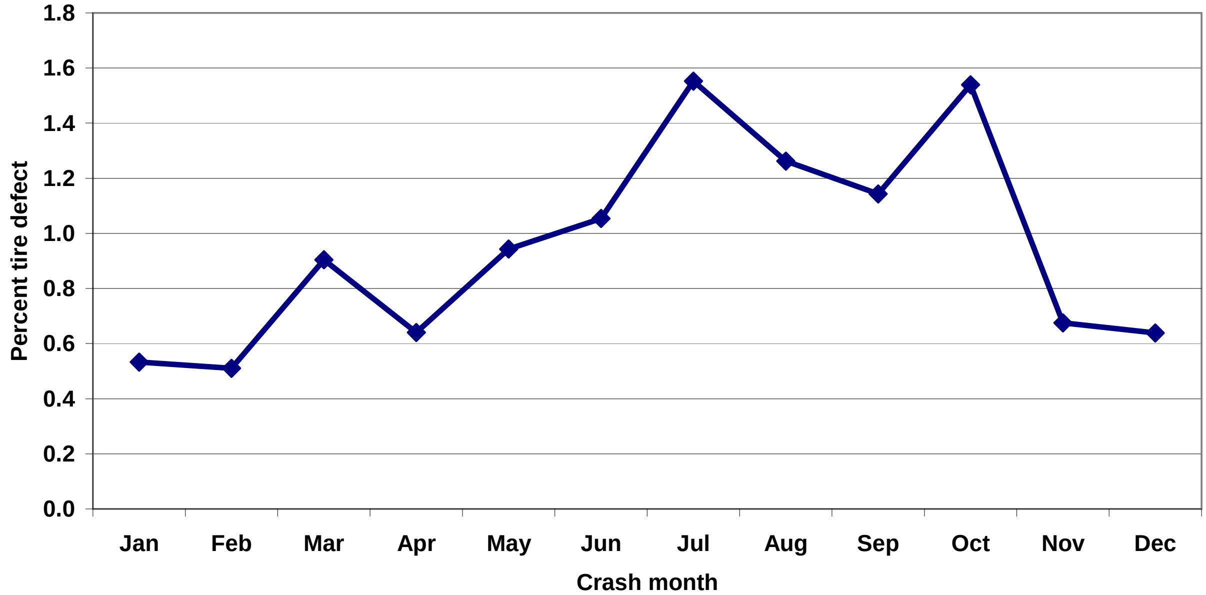


Figure 7.15 – Incidence of Tire Defects by Month of Crash, TIFA 1999-2005

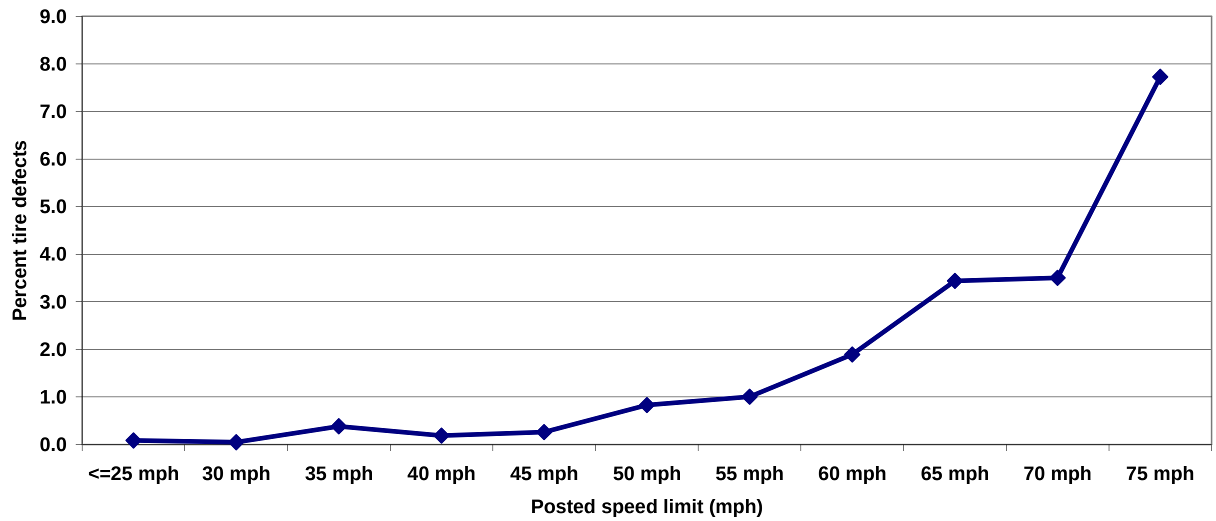


Figure 7.16 – Incidence of Tire Defects by Posted Speed Limit, GES 2002-2005

7.13.3 Crash Characteristics and Power Unit Age

Crashes related to truck tire defects are much more likely to result in single-vehicle involvements than other truck crashes. Figure 7.17 shows that almost 50 percent of truck involvements related to tire defects resulted in single-vehicle crashes, compared with about 25 percent of involvements in which no tire problems were detected. The percentage of two-vehicle crashes related to tire defects is reduced accordingly, while involvement in crashes with three or more other vehicles is not significantly affected. This pattern is very similar to that observed in fatal truck crashes (see Figure 7.7).

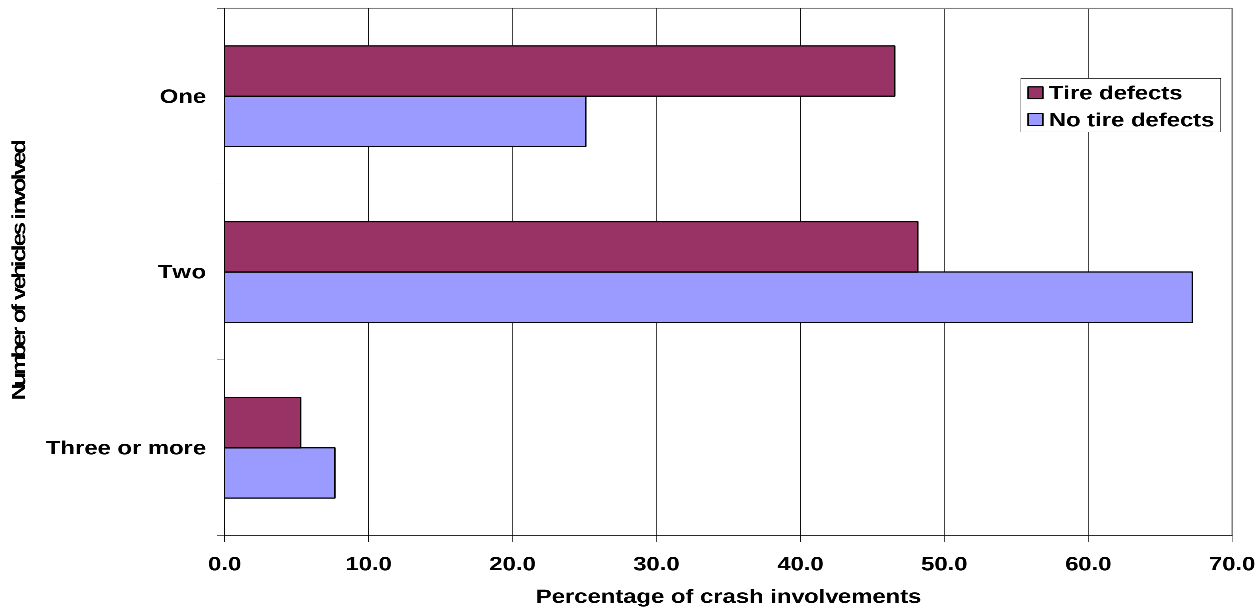


Figure 7.17 – Distribution of Tire Defects by Number of Vehicles in Crash GES 2002-2005

Comparison of results in GES with regard to first harmful event also was attempted, since the results in the fatal crash data from TIFA were useful. However, it appears that GES codes the variable differently from the way it is coded in FARS. Almost 60 percent of the cases with tire defects are coded "other non-collision event" on first harmful event, suggesting flat tires are considered harmful events of the crash. As a result, it could not be determined whether the vehicle ran off the road or crashed in some other way. It is likely, though, particularly since the proportion of single vehicle crashes is so similar to the fatal data, that the distribution of crash types is also similar.

Rollover is also captured in a different format in GES. While rollover in TIFA distinguishes first-event rollovers from other rollovers (e.g., related to a collision), in GES rollover is captured in terms of the roll mechanism. However, the proportion of rollovers can be determined, and it appears that rollover is much more common among trucks with tire defects. Almost 12 percent of trucks coded with tire defects rolled over as part of the crash, compared with only 3.4 percent of trucks that were not identified as having tire defects. In the TIFA data, the comparable percentages were 33 percent and 13 percent, respectively, so while rollover overall is more common in fatal crashes, the relative proportion of rollover between trucks with defects and those without is very similar. Trucks with tire defects in crashes are about three times more likely to roll as those without detected tire defects.

The age of power unit also has a fairly consistent effect on the incidence of tire defects. Figure 7.18 shows that the incidence of coded tire defects increases with the age of the power unit. This is the same pattern observed in TIFA fatal crash data (see Figure 7.12). The incidence for power units up to two years old is less than 0.8 percent. The oldest power units, those over 18 years old, have an incidence of tire defects over twice as high. It is likely this pattern is related to the different uses of older vehicles and less frequent maintenance.

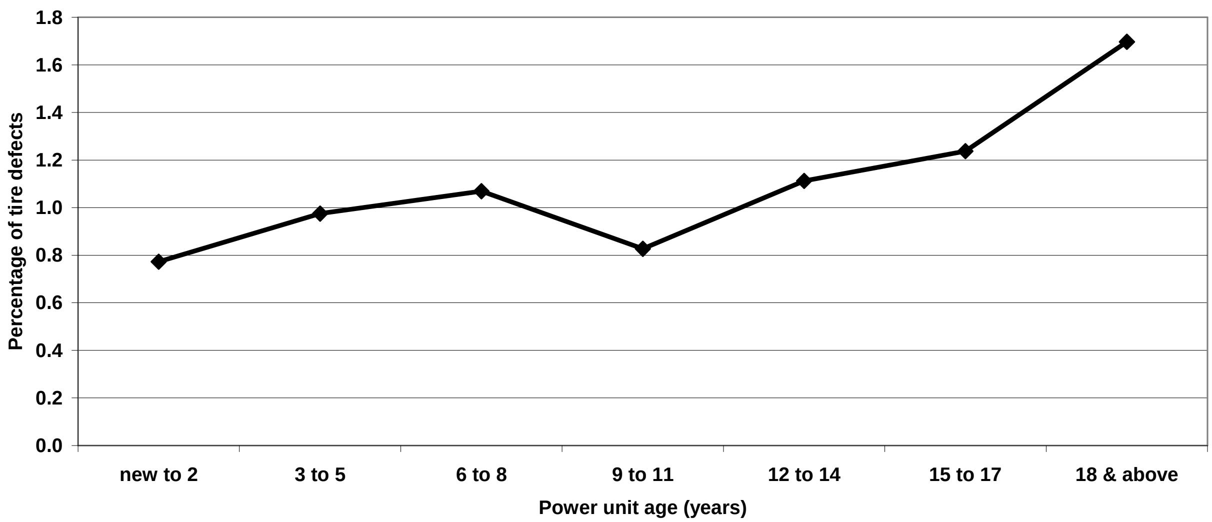


Figure 7.18 – Incidence of Tire Defects by Power Unit Age
GES 2002-2005

7.14 Results from the LTCCS

The LTCCS provides much more detailed and richer crash data than either TIFA or GES data, but for a more limited number of cases. Just as in GES, the LTCCS data includes a variable that identifies crashes that were precipitated by tire failure. The primary additional level of detail offered by the LTCCS is the information from post-crash vehicle inspections and the researcher's narrative and description of the crash events. In this section, we describe the results of analyzing LTCCS for the effect of tire defects and failures on truck crashes.

The LTCCS crash data include a Level 1 inspection on all the trucks involved in the crashes. In fact, not all trucks were inspected, for various reasons, but in practice about 90 percent of the involved trucks did receive an inspection. The inspection is conducted under a method developed by the Commercial Vehicle Safety Alliance and is the standard and most thorough truck inspection protocol.[3] Table 7.7 lists the tire-related violations recorded in the inspections, with the specific Federal Motor Carrier Safety Regulation (FMCSR) section violated, a short description of the

3 North American Uniform Out-of-Service Criteria, Commercial Vehicle Safety Alliance, 2000.

violation, and the percentage of all tire violations identified. Generally, the violations fall into three categories: damage to the tire, tread depth, and inflation. About half of all the violations discovered have to do with tread depth (44.9%). About 41.4 percent were for some sort of damage to the tire, either flat, tread separation, or fabric exposed, or air leaks; and about 10 percent were related to inflation or exceeding the load limit.

Table 7.7 - Tire-Related Violations in LTCCS Truck Inspections

FMCSR* Section	Violation Description	Percent of Tire Violations
393.75A	Flat tire or fabric exposed	20.2
393.75A1	Tire-ply or belt material exposed	6.9
393.75A2	Tire-tread and/or sidewall separation	3.8
393.75A3	Tire-flat and/or audible air leak	3.0
393.75A4	Tire-cut exposing ply and/or belt material	7.5
393.75B	Tire-front tread depth less than 4/32 of inch	4.9
393.75C	Tire-other tread depth less than 2/32 of inch	40.0
393.75F	Tire-load weight rating/under inflated	1.3
393.75F1	Weight carried exceeds tire load limit	0.2
393.75F2	Tire under-inflated	7.9
396.3A1T	Tires (general)	4.2
Total tire violations		100.0

* Federal Motor Carrier Safety Regulations

Overall, 14.3 percent of the trucks inspected in the LTCCS crash data had at least one tire violation. About 3.3 percent of the trucks had tire violations serious enough to qualify as out-of-service. In all these cases, the tire defect existed prior to the crash, so about 3.3 percent of the trucks involved in the crashes would have been put out of service if they had been inspected prior to the crash. Tires were not the most frequent violations. Brakes (35.8%), log books (23.0%), lights (22.4%), traffic violations (15.6%), and inspection/maintenance records (15.5%), all accounted for a higher proportion of trucks with violations than did tire defects.

However, note that the proportion of tire defects in the LTCCS crash data is much greater than that noted in the TIFA and GES data. In the TIFA and GES data discussed above, tire defects were coded in only 0.9 percent of all truck crash involvements. The percentage was the same for fatal truck involvements (TIFA) and truck involvements of all crash severities (GES). But the determination of tire defects in TIFA and GES was made, primarily, from police crash reports, so it is expected that the incidence of tire defects would be underreported. In the LTCCS data, the most thorough truck inspection is made, resulting, not surprisingly, in a higher tire defect rate, with 14.3 percent.

The LTCCS identifies crash involvements in which tire problems played a role in two ways. The "critical event" variable captures crashes in which the precipitating event in the crash was a tire failure. The specific code level is for crashes in which a tire blowout or other failure caused the truck to lose control and crash. The second source is the "critical reason" variable, which records the researcher's judgment as to the proximate reason for the critical event. "Tires/wheels failed" is the code level used to identify crash involvements to which tire defects may have contributed. All available materials, including the researcher's narrative, were reviewed for each case.

Obviously, critical event and critical reason are related, so there is a large overlap in cases coded as relating to tire defects by the two variables. A total of seven cases were identified as precipitated by tire failure (critical event is blowout followed by loss of control). Each case was reviewed. Tire/wheels failed was cited as the critical reason for 11 cases, and all 7 blowouts were included in the list. Three of the other four were cases where the truck experienced axle separation. The fourth case involved a blowout followed by loss of control, so it probably should have been included with the other seven blowouts.

Each case of a tire blowout leading to a crash was reviewed. All of the tire blowouts involved a steering axle tire failing. There were no cases precipitated by tire failure on any other axle. In each case, the tire failure was followed by a loss of control toward the side where the tire failed. In two cases, the right side steering axle tire failed and the truck swerved to the right, going off the road. In the other six cases, the left steering axle tire failed and the truck swerved left, either into oncoming traffic, overturning on the road, or going off the road to the left. In sum, then, eight crashes in the LTCCS were precipitated by a blowout. These eight cases account for 0.5 percent of all cases in the LTCCS (using the case weights) which is quite comparable to the estimates of 0.9 percent from TIFA and GES crash data.

7.15 Crashes Related to Tire Debris on the Road

Identifying traffic crashes related to truck tire debris left in the road after a blowout or tread separation is a challenge. To our knowledge, no State or national crash data set that is publicly available includes information to directly identify such crashes. So directly estimating the size of the crash problem related to truck tire debris on the road is not possible. However, to address the problem, two alternative methods were developed, using the NASS Crashworthiness Data System (CDS) and GES data. CDS data were used to estimate a lower bound to the size of the crash population related to truck tire debris, and the GES data were used to estimate an upper bound. It is acknowledged, though, that both estimates are highly speculative and included here primarily as the only feasible means to address the problem.

The CDS crash data file is primarily directed, as its name implies, at crashworthiness issues; that is, understanding the source of injuries in crashes in order to reduce them in number and severity. However, the CDS system includes a detailed on-site crash investigation, along with a researcher's narrative of the crash sequence and circumstances. To identify crashes related to truck tire debris on the road, this narrative was searched for certain key words and phrases that might be used to describe crashes related to tire debris. All cases where a search string was found were reviewed to determine if the crash was related to tire debris on the road and, optionally, whether the debris was identified as coming from a truck. All CDS cases from 2001 through 2005 were searched.

Table 7.8 shows the list of search strings that were used, along with the number of “hits” or cases where the string was found in the researcher’s narrative. Over the 5 years of CDS cases searched, 81 cases were identified for further review. The narrative from each of the 81 cases was reviewed to determine if tire debris was involved, if the tire debris came from a truck, and if the debris apparently contributed to the crash.

Table 7.8 - Text Strings to Search CDS Narratives

String	Hits
Tire piece	0
Tire debris	2
Tire fragment	0
Object in road	1
Tire tread	17
Tire carcass	0
Tire chunk	0
Tire shred	0
Truck tire	2
Rubber	56
Alligator	0
Retread	0
Piece of tire	3
Total	81

Review of the full narratives showed that only a few of the cases were related to tire debris or debris of any sort in the road. In only 10 of the cases was tire debris in the road a factor in the crash. In many of the cases in which tire tread was mentioned, the event was tread separation on a light vehicle followed by loss of control. All of the cases in which the string “rubber” was found referred to “shrubbery,” an illustration of one of the pitfalls of text searching. In most of the cases related to tire debris, a vehicle maneuvered to avoid a piece of tire debris, lost control, and crashed, either off the road or with another motor vehicle. The tread was identified as coming from a truck in 4 of the 10 cases. The origin of the tire debris was unknown in the other six.

The result of the search of CDS cases to identify crashes related to truck tire debris was to identify very few such crashes. As stated above, only 10 cases were found in 5 years of CDS records. Using the case weights to estimate a national proportion, these 10 cases would indicate that only 0.01 percent of traffic crashes are related to tire debris in the roadway. That is one one-hundredth of a percent, or one out of 10,000 crashes. The CDS samples crashes that result in a vehicle towed from the scene, so it covers a subset of crashes that qualify for GES, which are all police-reported crashes. Nevertheless, it is very doubtful that if all crash severities were included, that it would result in significantly more crashes. The search of CDS cases found very few crashes related to tire debris in the road. The estimate of 0.01 percent of crashes should be regarded as the lower boundary of any estimate of crash incidence related to truck tire debris.

GES data include a variable that captures events in which the driver maneuvered to avoid an object on the road. The nature of the object is not further identified, and there is no narrative to search to further identify the object, so it may include any number of other objects on the road in addition to truck tire debris. Note that other vehicles, pedestrians, other nonmotorists, and animals are all excluded from this code. The objects avoided are all inanimate and not motor vehicles. As such, it may be used to provide an upper boundary to the size of the crash population related to truck tire debris on the road.

To estimate the upper boundary, four years of GES data were combined and searched for all crashes in which a driver maneuvered to avoid an object on the road. Over the four years of GES, 0.2 percent of the crashes included a driver maneuvering to avoid an object in the road. Since the object may be anything, the proportion of traffic crashes related to truck tire debris in the road likely will be lower that 0.2 percent, but by an unknown amount.

7.16 Discussion of Crash Data Analysis

Crash data from all available sources were reviewed, including UMTRI's TIFA file, GES and CDS data from NHTSA, and LTCCS data from FMCSA. Crashes related to truck tire defects and debris are a small part of the crash problem, so extracting meaningful statistics is challenging. Where possible, multiple years of the data were examined, in order to produce more robust and stable results.

TIFA and GES data were used to estimate the scope of the truck crash problem related to tire defects and to identify factors that may be related to the incidence of tire defects in the crashes. It is likely that tire defects in crashes are underreported in these files because the identification of tire defects in the crashes is based primarily on police reports. The reporting officers typically do not have the training or responsibility to determine the role of mechanical condition in crashes, beyond obvious failures. LTCCS data provide a more detailed look at tire failures in truck crashes, as well as a much better estimate of the overall incidence of tire defects than TIFA or GES. CDS data were used to address another aspect of the crash problem related to truck tires – crashes caused by truck tire debris on the road.

TIFA and GES data provide the opportunity to identify factors associated with tire defects. While it is true that LTCCS data identify tire defects much more accurately, since the identification comes from qualified truck inspectors, the number of cases is too few to do aggregate analysis. Combining multiple years of data in TIFA and GES collects sufficient data to produce intriguing results.

Truck crash involvements with coded tire defects seem to be associated with warmer weather and high-speed roads. In both TIFA and GES data, coded tire defects were more common in the summer months than at other times of year. In GES, the incidence of tire defects was about twice as great from July through October as in the rest of the year. TIFA data also showed a higher percentage of crash involvements related to tire defects from June through September. In addition, both files showed much higher incidence of tire defects in truck crashes on roads with posted speed limits at 60 mph and above. The incidence of tire defects was particularly high on roads posted at 75 mph. Both of these findings may be an indication of the role of heat in tire failure.

Tire-defect-related crashes are about twice as likely to be single-vehicle crashes and to involve loss of control as other truck crash involvements. This was true in both GES and TIFA files. Many of the crashes involved running off the road and rolling over. Rollover itself was much more likely in crashes in which trucks had tire defects, than other crashes. The analysis of tire blowout cases in LTCCS shows how this may usually occur. In the LTCCS, all of the cases in which the precipitating event was a tire failure occurred as a blowout on a steering axle tire. When the tire failed, the truck driver lost directional control. In every case, when the tire failed, the truck swerved toward the side where the failure occurred, so if the left front tire failed, the truck lost control to the left, and if the failure was to the right front tire, the truck went to the right. Whether another vehicle was involved was primarily a matter of chance. Rollover was also often a consequence, either on the road or after going off the road.

TIFA data allow an examination of factors related to truck type and the type of operator. Coded tire defects are associated with straight trucks, older vehicles, private carriers, and intrastate carriers. The incidence of tire defects in straight trucks involved in fatal crashes is about twice as great as any other common truck configuration. Trucks operated by intrastate, private carriers are also more likely to have coded tire defects, and trucks from older model years have higher rates of tire defects than more recent models.

These factors—truck type, carrier type, and vehicle age—may all be related. Straight trucks tend to have a longer "life expectancy" than tractors, and in fact many older tractors are converted to straight trucks as their usefulness in long-haul operations declines. Intrastate private carriers also tend to operate straight trucks more often in their business than tractors. It may also be noted that intrastate carriers fall under a different regulatory regime than interstate carriers. In addition, it is possible that small carriers perform less maintenance on older vehicles. Finally, straight trucks may see more severe service than tractors.

Overall, it seems clear that the incidence of tire failures contributing to truck crashes is relatively rare. Both TIFA and GES coded the presence of tire defects in the crash. As has been argued here, it is likely that subtle problems like underinflation, overinflation, and tread wear are typically not identified unless they lead directly to a crash either through a blowout or excessive skidding on a slippery surface. So it is arguably reasonable to regard tire defects identified in TIFA and GES as approximating tire failures. Less than one percent of the crash involvements in TIFA and GES included an identified tire defect. Annually, that translates to about 55 fatalities and 45 other injuries in fatal truck crashes in which tire defects are noted, out of about 5,500 fatalities and 4,400 other injuries. In the LTCCS data, only 0.5 percent of crash involvements are coded as precipitated by tire failures.

We also attempted to determine the incidence of light vehicle crashes related to truck tire debris left on the road from blowouts, tread separation, and other tire failures. This information is not captured directly in any crash data files, but two methods were developed to attempt to address the question. In the first, the researcher's narrative in NASS CDS cases was searched for any mention of tire debris in the roadway. Candidate narratives (i.e., narratives that contained one of the search strings) were reviewed to determine if tire debris was involved in precipitating the crash and if the debris was identified as coming from a truck tire. NASS CDS cases from four years were searched, but only 10 cases were confirmed as involving tire debris, and in only four was the debris identified as coming from trucks. This method resulted in an estimate that truck tire debris is involved in 0.01 percent of all traffic crashes.

In the second methodology developed to estimate the possible effect of truck tire debris, the NASS GES file was used to determine the proportion of traffic crashes in which a driver swerved to avoid an object in the road. GES data do not include the original police reports, nor is a "researcher's narrative" part of the data file, as it is in the NASS CDS. So it is not possible to know anything further about the object in the road, beyond the fact that the object was not a motor vehicle, person, or animal. Thus, the object could be any number of things other than truck tire debris. Accordingly, the number of traffic crashes in which a driver swerved to avoid an object on the road would be the upper bound of the range of crashes related to on-road truck tire debris. This method produced an estimate of 0.2 percent of crash involvements related to an object in the road.

While the two methods developed clearly are not optimal, they do represent an effort to use existing data, with all its limitations, to at least put plausible bounds around the possible scope of traffic crashes related to on-road truck tire debris. The range implied is from 0.01 percent to 0.2 percent of all traffic crash involvements.

7.17 Summary

Chapter 7 presented an analysis of large truck and commercial medium- or wide-base truck tire debris contribution to highway safety with respect to traffic crashes. Overall, noting the numbers of large trucks as a percentage of the total U.S. motor vehicle fleet, large trucks are overrepresented in their involvement in fatal traffic crashes. No available crash data allows an estimate to be made of the direct contribution of truck tire debris (as opposed to all types of roadside debris) on the road to traffic crashes. Two alternative methods were used to develop estimates from available data. In the first, crash narratives were searched to identify crashes in which the researcher indicated that tire debris contributed to the crash. This resulted in an estimate of 0.01 percent of all traffic crashes. The upper bound was estimated from the GES file, which includes a variable that identifies crashes in which the driver maneuvered to avoid a non-traffic object in the road. This analysis produced an upper bound of 0.20 percent of traffic crashes related to objects in the road. The two methods thus produce a range of 0.01 to 0.20 percent of traffic crashes related to truck tire debris in the road. A more comprehensive estimate is not currently feasible in any known data set.

8 COMMERCIAL MEDIUM TIRE DEBRIS SURVEY SUMMER 2007

8.1 Introduction

A tire debris and casings collection exercise was conducted by UMTRI during summer 2007. The objective of this exercise was to collect a representative sample of tire fragments and casings for subsequent analysis (by a tire forensic consultant) in order to determine their OE or retread status and their probable cause of failure. In this chapter a highway maintenance agency and/or a truck stop in the same area comprise a collection site. This chapter describes the survey methodology followed in this collection exercise.

8.2 Selection of Collection Sites

In order for a representative sample of tire debris and casings to be collected the study would have to be national in scope, rather than focused on a particular region or State. Of the six previous tire debris studies conducted (see Table 3.6), only three of them, namely, the TMC (1995 and 1998) and Bridgestone Firestone studies engaged a national sampling approach. To achieve this, the Nation was divided into five regions as depicted in Table 8.1. Average Annual Daily Truck Traffic (AADTT) volumes and routes were superimposed over these regions to identify locations of high truck flows as shown in Figure 8.1. Appendix D presents State-by-State estimated AADTT flow maps for the year 1998. (Note: Analysis of truck traffic volumes along major routes in the United States is one of several freight analysis tasks of the Freight Management and Operations Department of the FHWA).

Table 8.1 – U.S. Regions and Proposed Tire Debris Collection Sites

Region	Southeast	Southwest	Midwest	Mid-Atlantic	West
States	North Carolina South Carolina Georgia Florida Tennessee Florida Alabama	Arizona New Mexico Texas	Nebraska Iowa Kansas Illinois Omaha Michigan Ohio	Maryland Virginia West Virginia Pennsylvania New Jersey Delaware District of Columbia	California Nevada Colorado Utah Idaho Oregon Washington
Original Proposed Site	I-75 Gainesville, FL	I-40 Chambers AZ	I-80 Ohio Turnpike Sandusky, OH	I-81 Wytheville, VA	I-5 Taft, CA
Confirmed Site	I-75 Gainesville, FL	I-10 Tucson	I-65, I-94 & I-80 Gary, IN	I-81 Wytheville, VA	I-5 Taft, CA

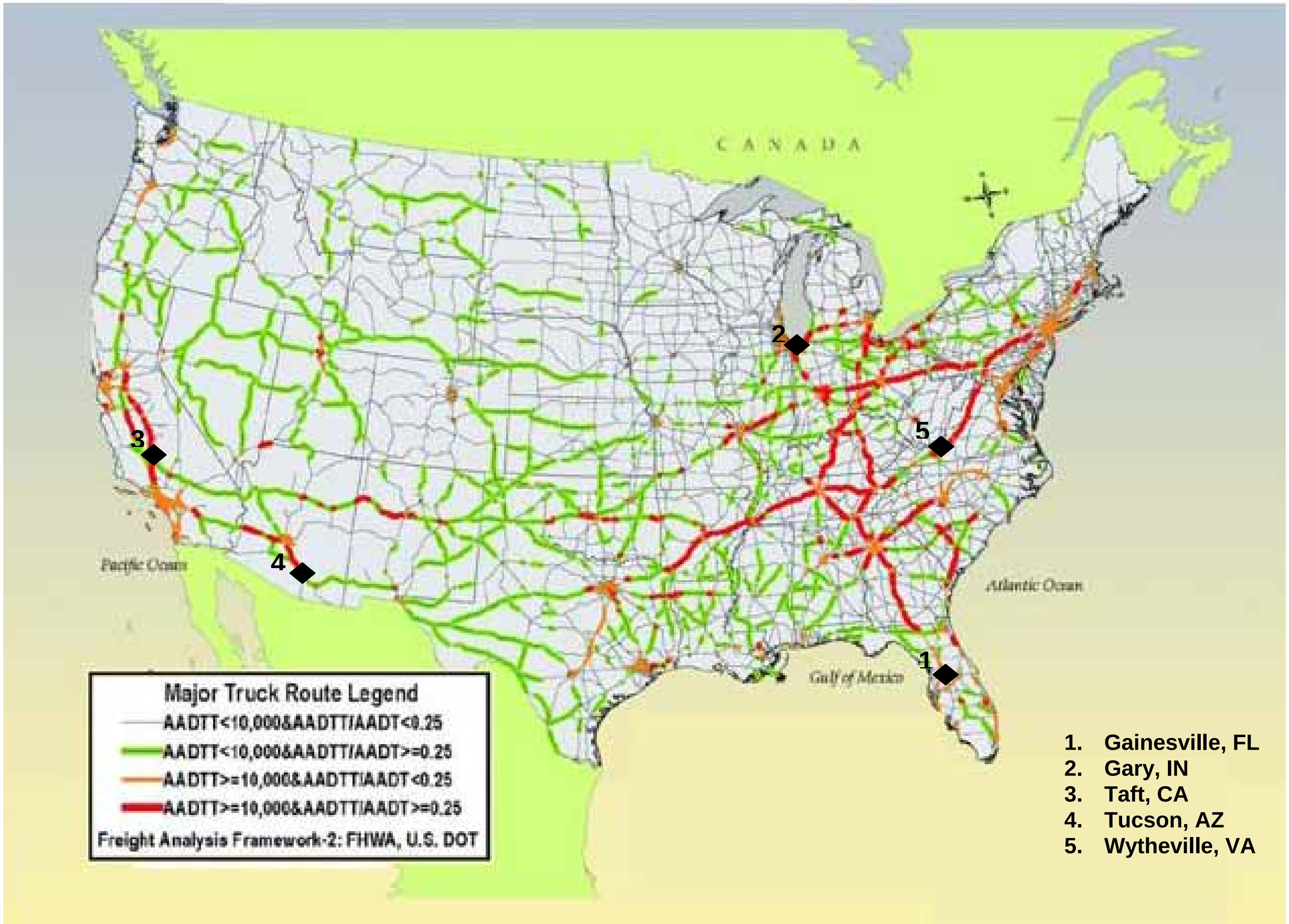


Figure 8.1 - Major Truck Routes on the National Highway System: 2002
Source: FAF

8.3 Collection Site Confirmation

For each of the proposed collection sites contact was established with the State highway office or Toll Road Authority responsible for the highway maintenance at each site. This initial contact was followed by a visit by a representative of the project team. The objective of this meeting was to explain the project, its objectives and requirements; respond to any concerns raised by State officials and ultimately to obtain agreement from the State representatives of their intention to participate in the study. Two meetings did not go ahead at the original sites proposed, namely the Arizona Department of Transport (AZDOT) Chambers Office and the Ohio Toll Road Authority in Sandusky. In one case, another suitable collection location was found within the same State, and in the other, the potential highway maintenance partner declined to participate in the study. In these two cases, the collection sites were subsequently changed to Tucson, Arizona, and Gary, Indiana. Overall, four of the five highway maintenance agencies were State-owned and operated with the exception of Virginia which was outsourced to a private contractor.

8.4 Truck Stop Site Confirmation

During the visits to each of the highway maintenance agencies at the collection sites, truck stops in the same area were identified. One truck stop at each collection site was selected and a meeting was held with a truck stop official (usually the truck maintenance/workshop manager) to explain the project, its objectives and requirements; respond to any concerns raised; and ultimately to obtain agreement of their intention to participate in the study. All five truck stops were for-profit business entities and when approached were keen to participate in the study. This was partly due to the intended benefit that would be received through the proposed collection and disposal of casings at no financial cost to themselves. Table 8.1 presents the State agencies or truck stops that agreed to participate in the collection exercise.

Table 8.2 – Collection Site Participants and Their Collection Tasks

Collection Site	Highway Maintenance Agency	Truck Stop
Gainesville FL	Florida Department of Transportation (FDOT)	Petro Shopping Center - Riddick, FL
Gary IN	Indiana Department of Transportation (INDOT)	TravelCenters of America - Lake Station, IN
Taft CA	California Department of Transportation (CALTRANS)	TravelCenters of America - Wheeler Ridge, CA
Tucson AZ	Arizona Department of Transportation (AZDOT)	Triple ‘T’ Truck Stop - Benson Highway, AZ
Wytheville VA	VMS Inc.	TravelCenters of America - Peppers Ferry, VA

8.5 Collection Site Dynamics and Schedule

Each collection site differed from another in several ways. Table 8.3 summarizes the collection site dynamics of the State/contracted highway maintenance agencies responsible for the tire debris collection within a specified jurisdiction of the national interstate network. Differences were seen in the frequency of collection, roadside debris collection personnel engaged, and interstate length of maintenance jurisdiction. Maps representing the collection sites are shown in Figures 8.2 to 8.6. An explanation of the collection site characteristics is given as follows:

- Terrain – The type of traveling terrain influences how the truck will be driven. In flat terrain higher speeds may be attained. Rolling terrain may necessitate more control over speed using brakes or power resulting in additional tractive forces on the tires. These additional forces have some impact on tire performance.
- Average Daily Max Temp Summer (July - September, 2007) – As stated in previous sections "excessive heat is an enemy of optimal tire operation" and "excessive heat degrades a tire." Tires are affected by heat generated from within the tire and ambient heat levels outside. Temperatures for the 2007 summer season ranged from 75° F in Gary, Indiana, to 97° F in Tucson, Arizona. Arizona has been a popular State for tire failure analysis evidenced by five of the six studies (Table 3.6) having sourced debris from this State. The high summer temperatures and long travel distances occurring in the southwest States have made this region an area of choice for sourcing tire debris for failure analysis.
- Interstate Surface Type Asphalt or Concrete – Highway surface type can influence the levels of rolling resistance experienced by a tire. Different surfaces also have different heat retention and release capabilities, which in turn can influence heat levels to which tires are exposed.
- Maximum Posted Speed Cars or Trucks – Vehicle speed has a strong correlation with heat generated in the tire. Posted speed limits for passenger cars ranged from 65 mph in Wytheville, Virginia, to 75 mph in Tucson, Arizona. Posted truck speeds ranged from 55 mph in Taft, California, and Gary, Indiana, to 75 mph in Tucson, Arizona. In section 5.8.3 it was discussed how high truck speeds can have negative effects on tire durability.
- Highway Maintenance Frequency – The frequency of cleanup programs for interstates in the collection areas varied from daily (i.e., Monday to Friday) to bi-monthly. However, this was dependent on the season.
- Highway Maintenance Crews – Discussions with highway maintenance managers responsible for each collection site indicated that cleanup crews were normally State employees or contracted workers. These agencies varied from landscape management companies (Gainesville, FL) to convict labor (Gainesville, FL) and outsourced highway maintenance enterprises (Wytheville, VA).
- Debris Sorted Onsite – In all but one case, roadside debris was sorted at the highway maintenance yard. The onsite sorting tasks took into account the different methods of debris disposal and suitability of debris for recycling, as well as attempted to minimize cross-contamination between different debris types. Sort categories included construction materials, rubber/tires, and regular trash.

Table 8.3. – Collection Site Physical and Interstate Characteristics

Collection Site	Terrain	Average Daily Max Temp Summer (July – Sept., 2007)*	Interstate Surface Type Asphalt	Interstate Surface Type Concrete	Maximum Posted Speed Cars (mph)	Maximum Posted Speed Trucks (mph)
Gainesville, FL	Flat	90.4	Yes	No	70	70
Gary, IN	Flat	75.4	Yes	Yes	70	55 (urban)
Taft, CA	Flat	95.1	Yes	Yes	70	55
Tucson, AZ	Generally flat (Rolling in East)	97.7	Yes	Yes	75	75
Wytheville, VA	Rolling	82.8	Yes	No	65	65

Sources: Discussions with Highway Maintenance Agency Officers & personal observation by UMTRI Team
* National Climatic Data Center of the U.S. Department of Commerce

Table 8.4 – Collection Site Operational Characteristics

Collection Site	Approx. Miles of Highway (Debris Collection)	Highway Maintenance Frequency	State Highway Maintenance Crews	Private/Contract Highway Maintenance Crews	Highway Debris Sorted onsite	Highway Debris Disposal Authority
Gainesville, FL	35	Bi-Monthly On Call 24/7	Yes	Yes	Yes	Private Contractor
Gary, IN	40	Daily (Monday to Friday) On Call on W/ends	Yes	No	Yes	Private Contractor
Taft, CA	43	Weekly	Yes	No	Yes	Private Contractor
Tucson, AZ	63	Daily (Monday to Friday) On Call on W/ends	Yes	No	Yes	Private Contractor
Wytheville, VA	15	Daily (Monday to Friday) On Call on W/ends	No	Yes	No	Private Contractor

Sources: Discussions with Highway Maintenance Agency officers

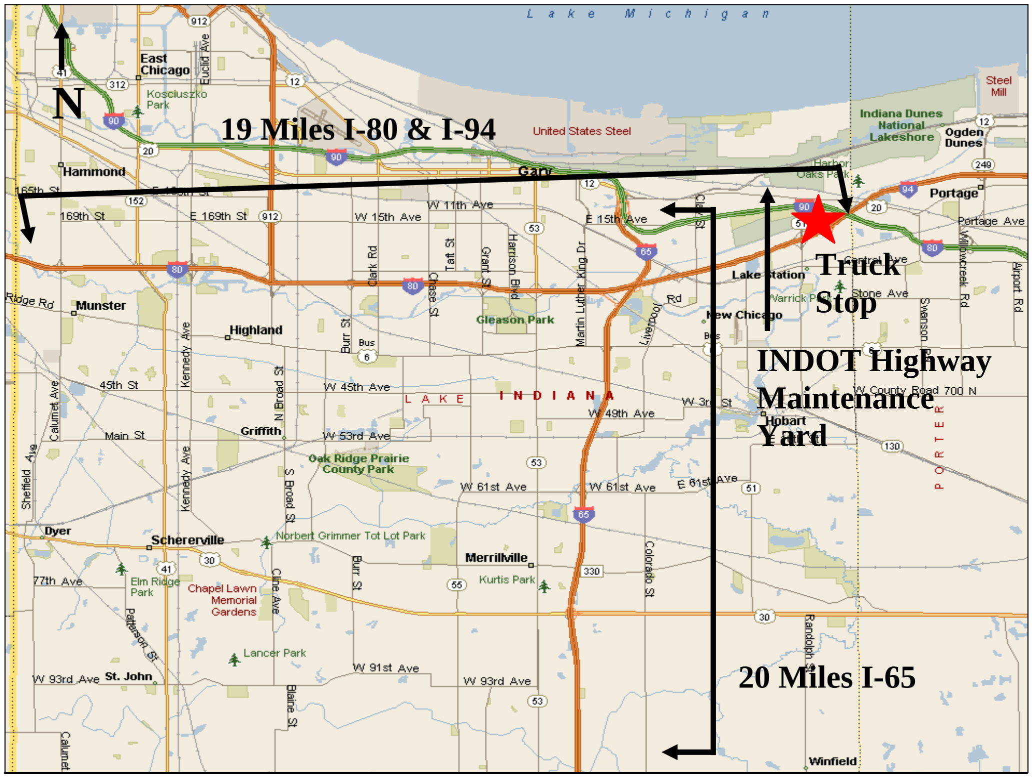


Figure 8.2 – Gary IN Tire Debris Collection Area

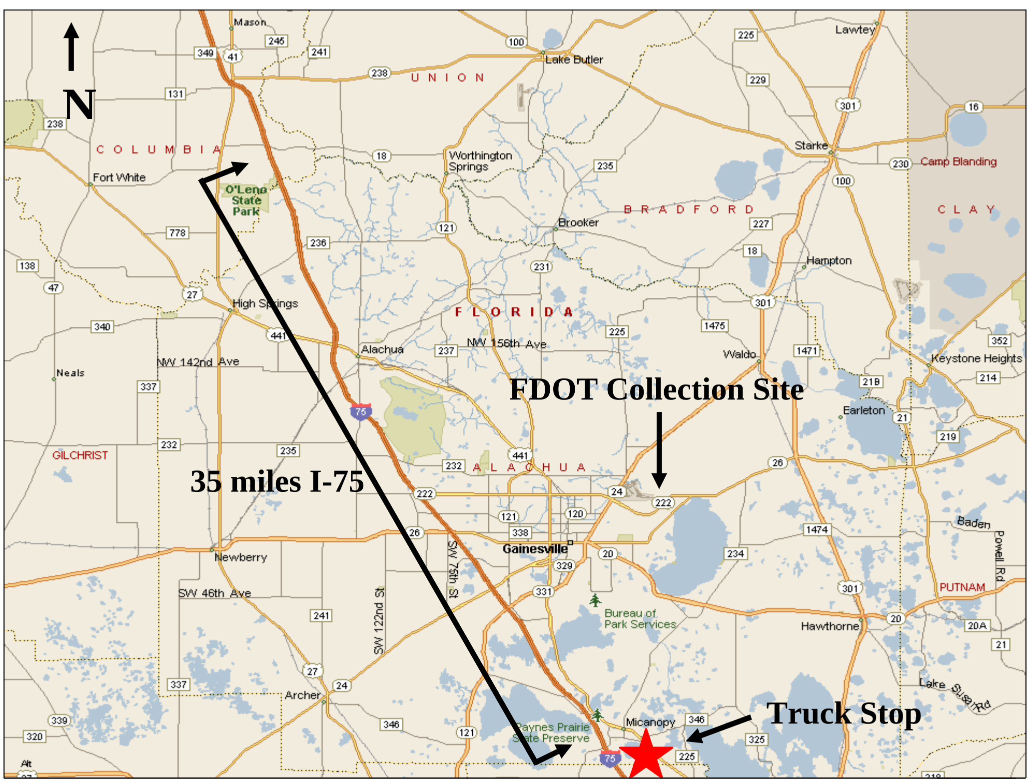


Figure 8.3 – Gainesville FL Tire Debris Collection Area

Figure 8.4 – Taft CA Tire Debris Collection Area

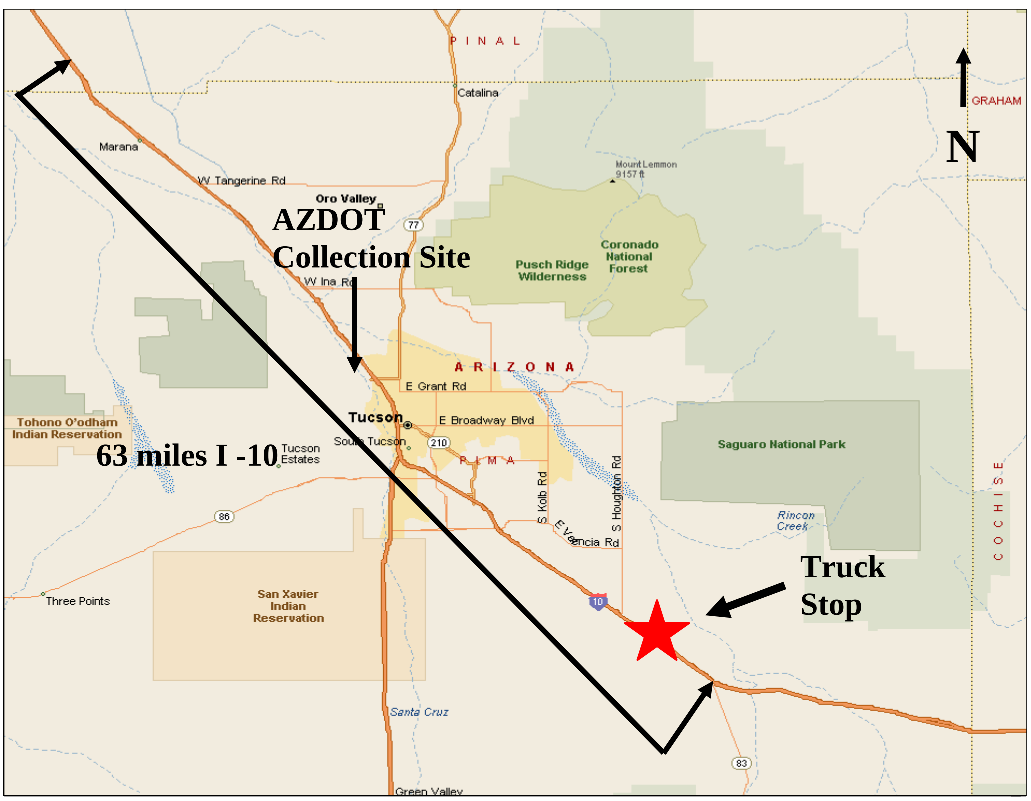


Figure 8.5 – Tucson AZ Tire Debris Collection Area

Figure 8.6 – Wytheville VA Tire Debris Collection Area

- Disposal Authority
  At all collection sites, collected roadside debris items are transferred by private contractors for disposal or recycling. The five highway maintenance agencies are not intimately involved in the disposal of the highway debris collected. Private contractors receive the debris and dispose of it according to local/State environmental regulations. The cost to highway maintenance agencies of disposal would vary according to the weight, sorting required by contractor or type of debris collected.

8.6 Tire Debris Collection Program/Schedule

In order to maximize the collection of tire debris, the summer season was selected as the time to conduct the collection exercise. Logistical constraints (i.e., trailer positioning) and the summer season window resulted in a two-week collection period at each site. At each site both the highway maintenance agency and the associated truck stop collected debris and casings simultaneously for the same collection schedule. However, in some cases collection site schedules overlapped (i.e., more than one collection site operated at the same time). Figure 8.7 presents the collection schedule followed at each of the collection sites.

AUG 07	Day	GARY	WYTHEVILLE	GAINESVILLE	SEPT 07	Day	TAFT	TUCSON
1	W				1	S		
2	T				2	S		
3	F				3	M	LABORDAY	
4	S				4	T		
5	S				5	W		
6	M				6	T		
7	T				7	F		
8	W				8	S		
9	T				9	S		
10	F				10	M		
11	S				11	T		
12	S				12	W		
13	M				13	T		
14	T				14	F		
15	W				15	S		
16	T				16	S		
17	F				17	M		
18	S				18	T		
19	S				19	W		
20	M				20	T		
21	T				21	F		
22	W				22	S		
23	T				23	S		
24	F				24	M		
25	S				25	T		
26	S				26	W		
27	M				27	T		
28	T				28	F		
29	W				29	S		
30	T				30	S		
31	F							
Start		8/6/2008	8/8/2008	8/14/2008			9/6/2008	9/10/2008
End		8/20/2008	8/23/2008	8/28/2008			9/20/2008	9/24/2008
# Collection Days		15	15	15			15	15

Figure 8.7 – Commercial Medium Tire Casing and Debris Collection Schedule

8.7 Tire Debris and Casing Collection Phases

Each collection site followed a pre-determined collection program. There was very little difference between programs followed at each site. Any changes that were made were due to accommodating the local highway maintenance/collection regime. The primary tasks executed during the collection exercise were: positioning the collection receptacles (i.e., trailer or dumpster), collecting and depositing the debris and finally transporting the debris from the collection site to the tire failure consultant. A summary of the collection phases is presented.

8.7.1 Survey Phase 1

Phase 1 of the collection survey involved (see also Figures 8.8 to 8.13):

- Positioning a 53-foot drop-frame (or regular) trailer at each of five truck stops for loading with tire casings;
- Ensuring that there was a dedicated receptacle or area at each highway maintenance agency yard for the storing of collected tire debris and casings;
- The collection of tire shreds and casings for a specified period by the highway maintenance agency and truck stop. The two locations at each collection site were engaged in collecting tire casings/debris simultaneously; and
- At the end of the collection period, the repositioning of the 53-foot drop-frame (or regular) trailer from each truck stop to the highway maintenance agency yard for loading (using laborers) with tire shreds/casings.

Figure 8.8 - A 53-foot drop-frame trailer positioned at TravelCenters of America Truck Stop Lake Station, IN

Figure 8.9 – A dedicated pile of tire debris collected by the INDOT Highway Maintenance Crew at Gary, IN

Figure 8.10 - AZDOT officer getting ready to dash across the I-10 with a tire "alligator"

Figure 8.11 - Casings collected at the TravelCenters of America (Lake Station, IN) truck stop awaiting loading into drop-frame trailer

Figure 8.12 - Loading up of trailer with debris collected at Tucson AZDOT collection site

Figure 8.13 - M&R Service Tractor and Trailer ready to leave collection site with cargo of tire debris and casings

8.7.2 Tire Debris and Casings Collection Guidelines

UMTRI-defined guidelines were given to managers at highway maintenance yards and truck stops at each collection site. The guidelines were to ensure uniformity in the type of debris collected (i.e., only debris or casings from trucks were required), enhance environmental safety and minimize any unforeseen logistical challenges.

Truck Stop Guidelines

- Only casings/shreds from large trucks are required.
- Tire casings are to be stacked one on top of the other starting from the front of the trailer.
- Any casings collected must be rimless.
- If casings have been sitting in the open air and collected any water (or other debris), remove water/debris before placing in the trailer.

- **Highway Maintenance Guidelines**
- Tire debris of a minimum 2 feet (0.61m) long and 4 inches (102mm) wide are to be collected.
- Any casings collected must be rimless.
- Deliberately dumped casings found on the interstates are not required.
- If casings have been sitting in the open air and collected any water (or other debris), remove water/debris before placing in the trailer.

8.7.3 Volumes of Tire Debris and Casings Collected

Table 8.5 presents details of the tire debris and casings collected from each site. Overall, more than 85,000 pounds of rubber was collected from the five collection sites over the survey period.

Table 8.5 – Weights of Collected Tire Debris and Casings

Collection Site	Truck Stop	Highway Maintenance Yard
Gary, IN	25,780 lbs	4,280 lbs
Wytheville, VA	7,400 lbs	1,680 lbs
Gainesville, FL	15,040 lbs	3,380 lbs
Taft, CA	8,140 lbs	6,700 lbs
Tucson, AZ	8,300 lbs	5,328 lbs
Total	64,660 lbs	21,368 lbs
Grand Total	86,028 lbs	

8.7.4 Survey Phase 2

In Phase 2 of the debris and casing collection exercise, one 53-foot trailer (drop-frame or regular) from each site was taken to the contracted tire failure analysis consultant (Smithers Scientific Services Inc.) in Akron, Ohio. The day after the end of the survey period, each trailer which had been at the truck stop for approximately 15 days would be taken to the associated highway maintenance yard to collect tire debris and casings. Therefore, each trailer would contain a mixture of casings (primarily from truck stops) and debris (primarily from highway maintenance yards). Depending on the location of the collection site, transportation of the trailer from the collection site to Akron, Ohio, took between five days (Taft, CA) and one day (Gary, IN).

8.7.5 Survey Phase 3

Phase 3 of the collection exercise involved the visual testing and physical assessment of a representative sample of the tire casings and debris collected from each of the five collection sites. This task was undertaken by contracted consultants. However, members of the UMTRI study team were present on several occasions to observe the procedures of tire failure analysis testing. Details of the failure analysis processes followed and results are presented in Chapter 9.

8.7.6 Survey Phase 4

An important part of the whole survey exercise was the ultimate disposal of the tire casings and debris collected. This task had to be undertaken according to State and University of Michigan standards. In addition, some States (e.g., Florida) required permitting for the transport of waste rubber within and out of their State. UMTRI as the principal investigator and all contractors involved in the collection and transport of the tire casings and debris had to comply with Occupational Safety and Environmental Health (OSEH) regulations of the University of Michigan. Due diligence was performed by OSEH on all potential contractors before the signing of any contract to ensure compliance with OSEH's standards. Ultimately, the casings and debris collected were to be disposed of in Ohio (after the tire failure analysis) and this task was governed according to Ohio Environmental Protection Agency guidelines. After failure analysis testing, the tire casings and debris were taken to Liberty Tire Inc. in Minerva, Ohio, for shredding, and the trailers were returned to a regional depot in Brimfield, Ohio. Figures 8.14 and 8.15 present the tire shredding process.

Figure 8.14 - Rimless casings in the process of shredding

Figure 8.15 - Shredded casings/debris are grouped according to size and subsequently sold

8.8 Comparisons of Tire Debris Survey Methodologies

The primary objective of this and other similar tire debris studies (i.e., indicated in Table 3.6) was tire failure determination. This was achieved through the analysis of collected tire casings and/or debris. However, there are a few notable differences between this current study and those of previous years. These differences are as follows:

- Funding Agency – The current study funded by NHTSA is one of several tire failure studies that has been funded by a national governmental agency since 1990. However, other tire debris studies have been funded by State or regional agencies or a collaborative effort between the public and private sectors.
- Tire Failure Analysis Location – Collected tire casings and debris were transported to the venue of the tire failure consultant. In several studies (e.g., TMC in 1995 and 1998) the debris were analyzed at each collection site by a team of tire failure analysts. This latter strategy necessitated extensive travel, time, and effort by the tire failure analysis teams. By transporting tire debris to the consultant, a unified cost-effective analysis could be conducted.
- Independence of Failure Analysis Consultant – Tire failure analysis was conducted by an independent and nationally recognized tire forensic enterprise. Again, in several previous tire debris studies (e.g., TMC in 1995 and 1998) failure analysis teams were made of representatives from OE manufacturers. This fact may be of little significance, however, some readers may perceive the involvement of these personnel as lacking independence and objectivity.

8.9 Survey Limitations

Overall, the tire casings and debris collection, testing, and disposal went smoothly, although there were several challenges faced which limited the number of tire casings and amount of debris that could be collected.

- Trailer Logistics and Contracting – Certain contractual formalities had to be completed before trailers were available for positioning at each collection site. Drop-frame trailers (see Figure 8.8) were the preferred type of trailer requested for the study. This type of trailer enabled easier access of personnel tasked with loading the trailer with casings or debris. However, the availability of this trailer type around the Nation was limited, and to avoid positioning fees (which were based on mileage), locally available regular trailers were used instead.
- Collection Schedule – Initially the survey was to commence in June and end in September,2007 with one month (i.e., staggered) being made available for tire debris collection at each site. However, the collection survey commenced in July. This late start combined with the need to collect in the summer months and avoid holiday periods (e.g., Independence Day and Labor Day) resulted in an enforced two-week collection period at each site in order to complete the tire debris collection exercise by the end of September. This change in scheduling impacted the coordination between the roadside debris collection schedules of highway maintenance teams and the collection of this debris for testing by the study team, in particular those sites that

collected bi-monthly (see Table 8.4). Thus, the volume of roadside tire debris made available to the study team was not typical for the collection period at some collection locations.

8.10 Summary

Chapter 8 described the UMTRI tire debris collection survey conducted in summer 2007, the fourth tire debris collection survey (conducted on a national scale) in the United States since 1990. Unique operational and physical characteristics were evident at each of the five collection sites selected for the survey. All sites were located adjacent to major interstate routes with high commercial trucking flows. The step-by-step approach (i.e., phases) adopted in executing the tire debris collection exercise minimized the potential of insurmountable logistical challenges. At the end of the collection exercise, more than 85,000 pounds of tire items (casings and fragments) were collected and subsequently transported for tire failure analysis.

9 TIRE FAILURE ANALYSIS METHODOLOGY, RESULTS AND ANALYSIS OF RESULTS[4]

9.1 Introduction

This chapter presents the failure analysis methodology employed in the testing of collected tire casings and fragments by an independent group of tire forensic scientists. Overall, more than 86,000 pounds of tire/rubber casings and debris were collected for this study (see Table 8.5), of which 1,496 items were assessed in terms of determining their probable cause of failure. Results from these tests are presented, as well as an analysis and comparison of these results with previous tire debris surveys.

It was intended that the tire forensic consultant analyze 300 casings and 1,700 tire fragments. In the aggregate, UMTRI provided more than the required numbers of tire fragments to complete this project. However, when sorted to the standard of the project (medium truck tire casings and fragments only) there were a number of fragment samples that could not be included, as they were determined by the consultant to originate from either passenger or light truck tires. Therefore, 300 casings and 1,196 tire fragments (1,496 grand total) were examined in this study.

9.2 Failure Analysis Determination Methodology

Tire failure analysts employed the industry-accepted and validated, scientific "observations to conclusions" methodology for the analyses of the tires, tire casings, and tire fragments. Tire forensic specialists have recognized this method for large sample size evaluation, which involves visual and tactile means, as a practical method for determining the cause, or causes, of tire failure. The methodology applies equally to whole tires, tire casings, or fragments of tires. Ordinarily, the more of the tire that is available for examination, the better, in terms of reaching the most complete conclusion. Simple tools were also used in the tire failure analysis exercise, as depicted in Figure 9.1.

Because of complex nature of tire failure, randomly selected tire casings and tire fragments may not, in all instances, provide enough observable information to reliably make a determination as to the cause of the damage or failure. If the observable facts or information in a given examination are insufficient for the analyst to reach a conclusion as to the most likely reason the tire became unserviceable, that was clearly stated. On the other hand, if it appeared to the examiner that the cause of the disablement was either clearly evident or likely, the sample was assigned to one of the six predetermined descriptive categories of disablement. If the sample did not provide sufficient information to be assigned to one of the six other descriptive categories, it was placed in the "Indeterminate" category.

4 This chapter is coauthored with Mike Bair of Smithers Scientific Services Inc.

Figure 9.1 – Tools Used in Tire Failure Analysis

9.3 Tire Casings and Debris Receiving

The casings and tire fragments arrived from five distinct geographic areas of the United States (see Figure 8.1). The following is a description of the source regions and the number of samples analyzed, as well as the order in which the shipments were received:

- Gainesville, FL – 60 casings and 198 fragments
- Gary, IN – 60 casings and 259 fragments
- Taft, CA – 60 casings and 328 fragments
- Tucson, AZ – 60 casings and 161 fragments
- Wytheville, VA – 60 casings and 250 fragments

A separate trailer was received for each of the five shipments. Upon arrival at the consultant's testing facility, each trailer was backed into the examination facility loading dock, opened, and unloaded. The tire fragments required expert sorting, to eliminate the passenger and light truck samples that did not qualify for analysis in the project. At the completion of the sorting process, the non-qualified fragments were isolated by placing them back into the trailer in which the particular shipment arrived. All of the qualifying contents of each trailer were then analyzed prior to the arrival of the subsequent trailer, eliminating the potential for samples from one geographic region to be intermingled with those from elsewhere. Despite the casing and debris size guidelines given to the highway maintenance teams and truck stops when collecting items for this study (see section 8.7.2), debris and casing items from light trucks and passenger cars were inadvertently collected. It was estimated that 60 percent of the tire items collected (i.e., casings and debris) were from medium/heavy trucks and 40 percent were from passenger cars and light trucks.

9.4 Tire Casings and Debris Inventory and Tracking System

A purpose-specific inventory system was created, in order to ensure complete tracking of each specimen and its accompanying data. Prior to its actual examination, each tire casing or tire fragment was assigned a sequential number (#1-300 for the casings and #1-1,196 for the fragments). The sequential number was physically attached to each sample and the examination was carried out. Based upon the completeness and condition of the articles, certain descriptive information was recorded and retained in a Microsoft Access database as shown in Table 9.1.

Table 9.1 – Tire Casing and Fragment Descriptive Information Variables

Casing Information	Tire Fragment Information

• Item Number
• Tire size
• Tire Manufacturer
• Original Tread
• Retread
• Manufacturer of retread
• Type of retread (mold cure or pre-cure)
• Casing DOT (Tire Identification Number)
• Retread DOT (Tire Identification Number - most recent)
• Number Times Casing Retreaded
• Intact (yes/no)
• Detachment (complete or partial)
• Tread Design Description
  o Straight Rib
  o Straight Rib w/ Sipes
  o Rib with Tied-Together Block Elements
  o Lug
• Likely Wheel Position
  o Steer
  o Drive
  o Trailer
• Tread Depth
• Comments
• Photo description (if photo was taken)
	• Item Number
	• Original Tread
	• Retread
	• Type of retread (mold cure or precure)
	• Tread Design Description
	  o Straight Rib
	  o Straight Rib w/ Sipes
	  o Rib with Tied-Together Block Elements
	  o Lug
	• Likely Wheel Position
	  o Steer
	  o Drive
	  o Trailer
	• Length and Width in mm
	• Content (rubber, steel or both)
	• Manufacturer
	• Tread Depth
	• Comments
	• Photo description (if photo was taken)

9.5 Tire Casings and Debris Damage/Failure Categorization

Immediately following the recording of the descriptive information from each casing or tire fragment, the item was examined in order to determine the most likely category in which to place the sample. Seven general damage categories were utilized, five of which contained further sub-categories. The damage category descriptions utilized are presented in Table 9.2.

Table 9.2 – Tire Casings and Debris Damage/Failure Categories

Damage/Failure Category	Damage/Failure Sub-Category

Overdeflected Operation	• Run Flat
	• Sidewall Flex Fatigue Rupture
	• Detachment
	  o Tread only
	  o Tread and outer belt(s)
	  o Tread & belts from casing
	• Other
	• Three-Piece Flex Break

Excessive Heat	• Excessive Heat Damage
Road Hazard	• Cut/Snag • Impact Break/Rupture • Radial Split • Pinch Shock • Crown penetration • Sidewall Penetration • Other
Maintenance/Operational	• Excessive Wear • Skid-Through • Petroleum Damage • Improper/Failed Repair • Mounting Damage • Vehicle Damage • Unrepaired Puncture • Incorrect Application • Other
Manufacturing/Process Issues	• Bond Failure/Separation (retread) • Improper Repair • Missed Repair • Questionable Remaining Casing Life • Tire manufacturer issue • Other

Table 9.2 – Tire Casings and Debris Damage/Failure Categories (continued)

Damage/Failure Category	Damage/Failure Sub-Category
Indeterminate Cause	• Detachment o Tread Rubber Only o Tread & Outer Belt(s) o Tread and all belts from casing • Runflat • Other
Excessive Intra-carcass Pressurization	• Compromise of Inner Liner • Bead Damage • Other

With respect to tire casings, the majority of these were collected at truck stops. For tires removed from service at truck stops, it would be anticipated that the primary reasons for their removal would be road hazards or maintenance/operations issues, rather than routine, planned removals for replacement.

9.6 Illustrative Overview and General Description of Damage/Failure Categories

For the understanding of the reader, a general definition of each of the damage categories (as shown in Table 9.2) is provided in this section. Photographic examples for each of these categories (with the exception of category 6 – "Indeterminate") are also presented.

9.6.1 Failure Category 1 - Overdeflected Operation

By definition, for purpose of this study, evidence of overdeflected operation was identified when either the internal steel reinforcement material (steel radial sidewall ply) had sustained sufficient cyclic flex fatigue as to allow the material to fracture, or belt/belt package detachment had occurred. Structural damages such as flex fatigue rupture, two- or three-piece flex break or complete belt package detachment were all captured in this category. Overdeflected operation is primarily caused by underinflation, overloading, or some combination of the two factors. Figures 9.2 and 9.3 are illustrative of the failure category overdeflected operation.

9.6.2 Failure Category 2 – Excessive Heat

If a tire is operated while underinflated, overloaded, or at excessive speeds, it can become overheated. Vehicle/mechanical conditions such as a dragging brake or insufficient airflow around the tire can also result in tire damage from excessive heat. Excessive heat can reduce the tear strength of the rubber, thereby potentially allowing bonded components to separate, and perhaps detach, resulting in the tire becoming unserviceable. One classic indication of operating at excessive temperatures is a bluish discoloration of the rubber. Further potential indicators are changes in the appearance/feel of the rubber such as brittleness, or sponginess, or the taking on of a shiny aspect. Figures 9.4, 9.5, 9.6, and 9.7 are illustrative of the failure category "Excessive Heat."

Figure 9.2 - Overdeflected Operation #1 - Apparent nail in outer rib, resulting in slow air loss and flex fatigue damage

Figure 9.3 - Overdeflected Operation #2

Figure 9.4 - Excessive Heat #1 (This overdeflected tire showed vibrant bluish discoloration, characteristic of operating at excessive temperatures)

Figure 9.5 - Excessive Heat #2 (Original tread with very significant heat damage (bright bluish discoloration), including localized reversion of rubber)

Figure 9.6: Excessive Heat #3

Figure 9.7: Excessive Heat #4

Failure Category 3 – Road Hazard

Readers may be generally familiar with this category from their own experience. Road hazard damage can occur from punctures, cuts, and the striking of objects such as curbs, potholes, etc. Road hazard damage may result in a tire immediately becoming unserviceable, as well as potentially becoming unserviceable at some point in the future. Figures 9.8, 9.9, 9.10, and 9.11 are illustrative of the failure category road hazard.

9.6.3 Failure Category 4 - Maintenance/Operational

Typical of this category are damages such as improper repairs, excessive wear, damage from tire or wheel mounting or dismounting, locked brake skid damage, and damage by contact with some part of the vehicle upon which the tire is operating. Figures 9.12, 9.13, and 9.14 are illustrative of the failure category maintenance/operational.

9.6.4 Failure Category 5 – Manufacturing/Process Issues

It is possible that either an original tread tire or a retreaded tire may manifest some manufacturing or process irregularity that can contribute to its becoming unserviceable during operation. For example, during the retreading process a necessary repair can either be missed or potentially made improperly, or a tire with questionable remaining casing life may be mistakenly approved for retreading. This category was intended to capture any original tread or retreading process manufacturing issues that could be expected to contribute to the tire's disablement. Figures 9.15, 9.16, 9.17, 9.18, and 9.19 are illustrative of the failure category manufacturing/process issues.

9.6.5 Failure Category 6 – Indeterminable

Sufficient pieces of the casing/fragment or other information were not available and the analyst could therefore not reach a conclusion as to a damage category assignment, for a particular sample.

9.6.6 Failure Category 7 – Excessive Intracarcass Pressurization

A tire relies upon inflation air pressure to pretension the tire casing, allowing it to carry the load and otherwise function. The inner liner in tubeless medium truck tires is not impermeable, and this is a primary reason that it is necessary to regularly check tire inflation pressure. The inflation air is continually (very slowly) in the process of migrating through the tire's structure, seeking to reach the outside atmospheric pressure level, resulting in the existence of a pressure gradient within the tire's structure. This, again, is normal and accounted for in the design and manufacture of the tire.

If the inner liner is somehow compromised as the result of a road hazard, mounting damage, or by some other means, pressure can enter the tire's structure at excessively high levels. This excessive intracarcass pressure can separate the tire's individual manufactured components and/or separate rubber from the reinforcement material (steel or fabric), resulting in the tire becoming unserviceable. Figures 9.20 and 9.21 are illustrative of the failure category excessive intracarcass pressurization.

Figure 9.8 - Road Hazard #1 - Pinch shock damage. Sidewall separation resulting from excessive intracarcass pressurization, allowed by the pinch shock injury

Figure 9.9 - Road Hazard #2 - Pinch shock damage. Sidewall separation resulting from excessive intracarcass pressurization, allowed by the pinch shock injury

Figure 9.10 - Road Hazard #3 - Unrepaired crown puncture in original tread

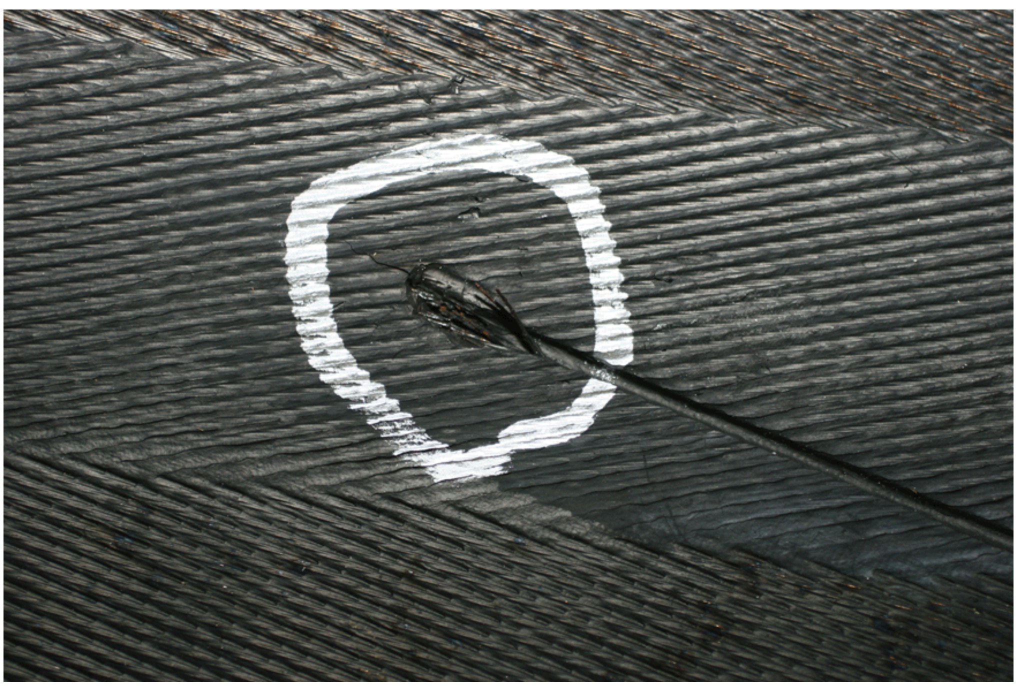


Figure 9.11 - Road Hazard #4 - Unrepaired crown puncture in original tread

Figure 9.12 – Maintenance/Operational #1 - Use of improper (outside-in string plug) repair. Resulted in excessive intracarcass pressurization, sidewall separation, and tire failure

Figure 9.13 – Maintenance/Operational #2 - Use of improper (outside-in string plug) repair. Resulted in excessive intracarcass pressurization, sidewall separation, and tire failure

Figure 9.14 – Maintenance/Operational #3 - Example of drive axle tire with localized accelerated wear

Figure 9.15 - Manufacturing/Process Issues #1 - Retread rubber separated at buff line. This resulted in a "raised" section of the tire's circumference. Localized, accelerated wear (9" in the center of the tread) resulted, extending to the buff line.

Figure 9.16 - Manufacturing/Process Issues #2 - Retread rubber separated at buff line. This resulted in a "raised" section of the tire's circumference. Localized, accelerated wear (9” in the center of the tread) resulted, extending to the buff line.

Figure 9.17 - Manufacturing/Process Issues #3 - Bond failure at buff line

Figure 9.18 - Manufacturing/Process Issues #4 - Bond failure at buff line

Figure 9.19 - Manufacturing/Process Issues #5 - Tire may have been unsuitable for retreading (severe weather cracking)

Figure 9.20- Excessive Intra-carcass Pressurization #1 - Separation as a result of excessive intracarcass pressurization

Figure 9.21 - Excessive Intra-carcass Pressurization #2 - Separation as a result of excessive intra carcass pressurization

9.7 Casing/Tire and Fragment Status

Approximately 127 (42%) of the 300 casings analyzed were retreads and 169 (56%) were original tread casings (the balance being unknown). The roughly 40- to 60-percent split in this analysis is not surprising, based on the experience of tire failure analysts. The percentage of OEs in classes 6, 7, and 8 vehicle service categories can vary from year to year and be significantly influenced not only by general economic conditions and the ebbing and flowing of new truck, tractor, and trailer sales but also by fleet vocation. The percentage of retreaded tires in service in the waste hauling industry, for example, may well be higher than in the general population of vehicles involved in long-haul trucking (discussed in section 5.9.5).

Of the 1,196 tire fragments that were analyzed, approximately 214 (18%) were from original tread tires, approximately 812 (68%) were from retreaded tires, and in approximately 170 (14%) of the examinations no determination as to original tread or retread could be made. Looking at the totals of original tread and retread fragments from each of the five geographical regions, there was no dramatic variance. The original tread fragment percentages ranged from a low of 13 percent in Wytheville, Virginia, to a high of 24 percent Gary, Indiana. The retread fragment percentages were more closely aligned, ranging from 63 percent in Gainesville, Florida, to 73 percent in Wytheville, Virginia, as shown in Table 9.3.

Table 9.3 – Tire Fragment Original Tread/Retread Status

Collection Site	Original Tread		Retread		Unknown		Total
Gainesville, FL	40	20.2%	125	63.1%	33	16.7%	198
Gary, IN	38	23.6%	114	70.8%	9	5.6%	161
Taft, CA	41	16.4%	164	65.6%	45	18.0%	250
Tucson, AZ	61	18.6%	219	66.8%	48	14.6%	328
Wytheville, VA	34	13.1%	190	73.4%	35	13.5%	259
Total	214	17.9%	812	67.9%	170	14.2%	1,196

9.8 Failure/Damage Condition

Of the 300 tire casings that were examined, 275 (approximately 91.7%) provided sufficient information for the tire failure analysts to categorize the most likely reason the particular casing had come out of service. The remaining 25 (approximately 8.3%) were categorized as indeterminable (Category 6). Figure 9.22 illustrates the failure categorization assessed tire casings. Figure 9.23 presents the same findings without the indeterminate category.

The 300 casings were analyzed and assigned to the various categories as follows:
Category 1 – Overdeflected Operation – 43 items
Category 2 – Excessive Heat – 11 items
Category 3 – Road Hazard – 97 items
Category 4 – Maintenance/Operational – 90 items
Category 5 – Manufacturing/Process – 23 items
Category 6 – Indeterminable – 25 items
Category 7 – Excessive Intracarcass Pressurization – 11 items

Of the 1,196 tire fragments examined, 728 provided sufficient information for the tire failure analysts to categorize the most likely reason that the tire containing the fragment had become unserviceable.

The analyses of these remaining 728 tire fragments were assigned to the various categories as follows:

Category 1 – Overdeflected Operation – 19 items
Category 2 – Excessive Heat – 220 items
Category 3 – Road Hazard – 281 items
Category 4 – Maintenance/Operational – 106 items
Category 5 – Manufacturing/Process – 98 items
Category 6 – Indeterminable – 468 items
Category 7 – Excessive Intracarcass Pressurization – 4 items

The remaining 468 (approximately 39%) of the tire fragments examined were categorized as indeterminable (Category 6). Figures 9.22 and 9.23 also illustrate the failure categorization assessed tire fragments/debris.

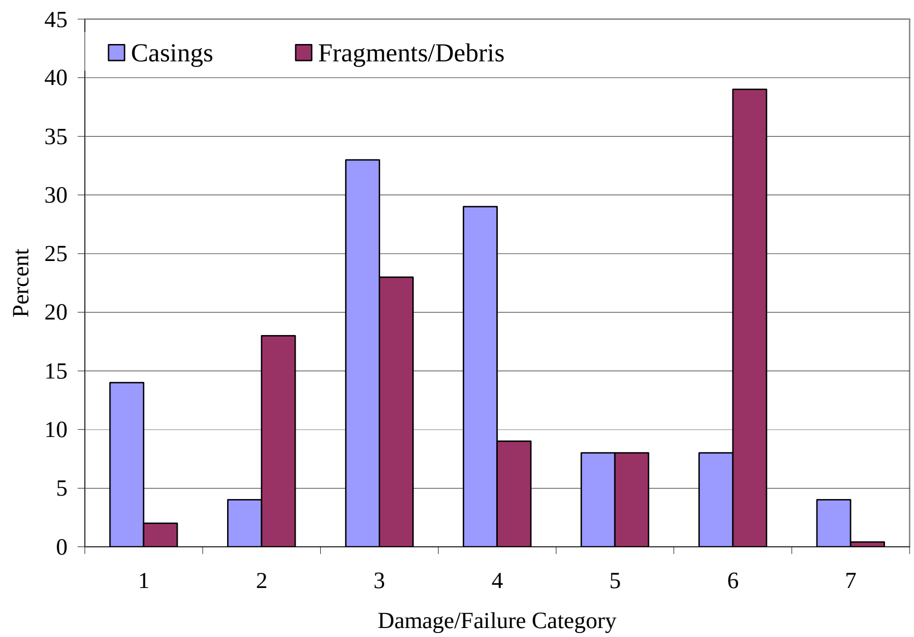


Figure 9.22 - Tire Casings & Fragments Damage/Failure Category Determination

Failure Categories:

Category 1 – Overdeflected Operation
Category 2 – Excessive Heat
Category 3 – Road Hazard
Category 4 – Maintenance/Operational
Category 5 – Manufacturing/Process
Category 6 – Indeterminable
Category 7 – Excessive Intracarcass Pressurization

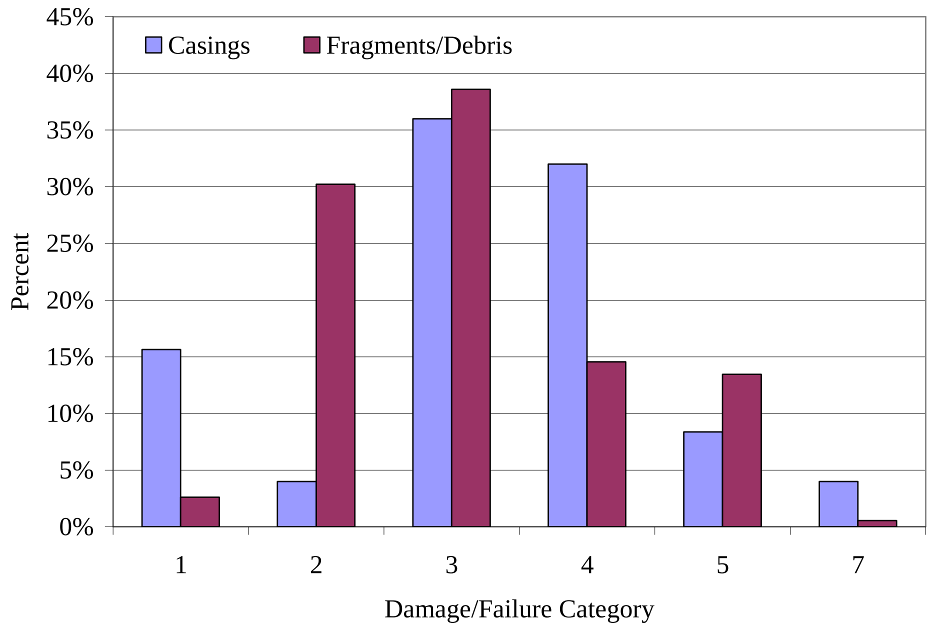


Figure 9.23 - Tire Casings & Fragments Damage/Failure Category Determination (Excluding Indeterminate Category)

Failure Categories:

Category 1 – Overdeflected Operation	Category 4 – Maintenance/Operational
Category 2 – Excessive Heat	Category 5 – Manufacturing/Process
Category 3 – Road Hazard	Category 7 – Excessive Intracarcass Pressurization

Key findings (from Figures 9.22 and 9.23):

- The top three reasons that the casings were removed from service were: road hazards – 97 casings (32%); maintenance/operational factors – 90 casings (30%); and overdeflected operation – 43 casings (14%). If we remove the indeterminate category (25 casings), the ranking is as follows (Figure 9.23): road hazard – 97 casings (35%); maintenance/operational factors – 90 casings (33%); and overdeflected operation – 43 casings (16%). (Note: Tires collected from truck stops may be expected to have a slightly higher percentage of causes for removal relating to road hazard, maintenance, and underinflation, as these removals are generally unplanned.)

- The top three probable causes of failure for fragments examined were: indeterminable category – 468 fragments (39%); road hazard – 281 fragments (23%); and excessive heat – 220 fragments (18%). If we remove the indeterminate category (468 fragments), the ranking is as follows (Figure 9.23): road hazard – 281 fragments (39%); excessive heat – 220 fragments (30%); and maintenance/operational – 105 fragments (14%).

- It should be noted that less than 10 percent of the casings categorized were in the “Indeterminable” category (Figure 9.22). By comparison, approximately 39 percent of the number of tire fragments were categorized as “Indeterminable. This can be readily understood when one considers the amount of the tire that is available for analysis and categorization with a tire fragment, compared to a tire casing.
- The reader will note that in Figure 9.23 the percentage of fragments in the Overdeflected Operation category is substantially less than the percentage for this category among the casings

examined – 3 percent compared to 15 percent, respectively. The fragments typically demonstrate the physical manifestation of the overdefelected operation in the form of excessive heat damage/evidence. While the casings, by comparison, demonstrate the evidence of overdeflected operation ordinarily without the direct evidence of excessive heat.

- The percentage of fragments demonstrating road hazard damage in Figure 9.23 was approximately the same as the percentage of road hazard damage among the casing population examined (approximately 38% and 36%, respectively).

- Approximately 13 percent of the fragments were placed into the Manufacturing/Process category, compared to approximately 8 percent for the casings in the same category (Figure 9.23). The significance of this difference could not be determined in this study. The relative ratios of original tread versus retreaded tires in the casing portion of this study was significantly different than the ratio of original tread to retread in the fragment portion of the study. The impact of those differences on the likelihood of manufacturing process conditions would require additional investigation outside the scope of this study.

- Slightly less than 10 percent of all casings identified in Figure 9.23 showed any manufacturing or process-related conditions that could be expected to contribute to the tire being removed from service. Of this proportion, the vast majority appeared to be retreading process issues, such as casing selection and repair, or tread rubber application issues. The vast majority of casings were removed from service for road hazard, maintenance/operational issues, and overdeflected operation, as would be expected for both original tread casings and retreads.

- For the Maintenance/Operational and Manufacturing/Process categories (Figure 9.23) the percentages, with respect to tire fragments, were approximately 14 percent in each category.

9.9 Damage Condition Categorization According to Tire/Fragment Status

Damage conditions (see the previous section for definitions) according to OE, Retread, or Unknown status of the casings and fragments assessed are presented in Tables 9.4 and 9.5 and graphically in Figures 9.24 and 9.25.

Table 9.4: Tire Casings Damage/Failure Category Determination

Tire Status	Damage/Failure Category (see section 9.8)							
	1	2	3	4	5	6	7	Total
OE	20	4	51	70	8	11	5	169
Retread	21	7	45	20	15	13	6	127
Unknown	2	0	1	0	0	1	0	4
Total	43	11	97	90	23	25	11	300

Table 9.5: Tire Fragments Damage/Failure Category Determination

Tire Status	Damage/Failure Category (see section 9.8)							
	1	2	3	4	5	6	7	Total
OE	6	43	46	42	9	66	2	214
Retread	7	150	206	36	82	329	2	812
Unknown	6	27	29	28	7	73	0	170
Total	20	222	284	110	103	474	11	1,196

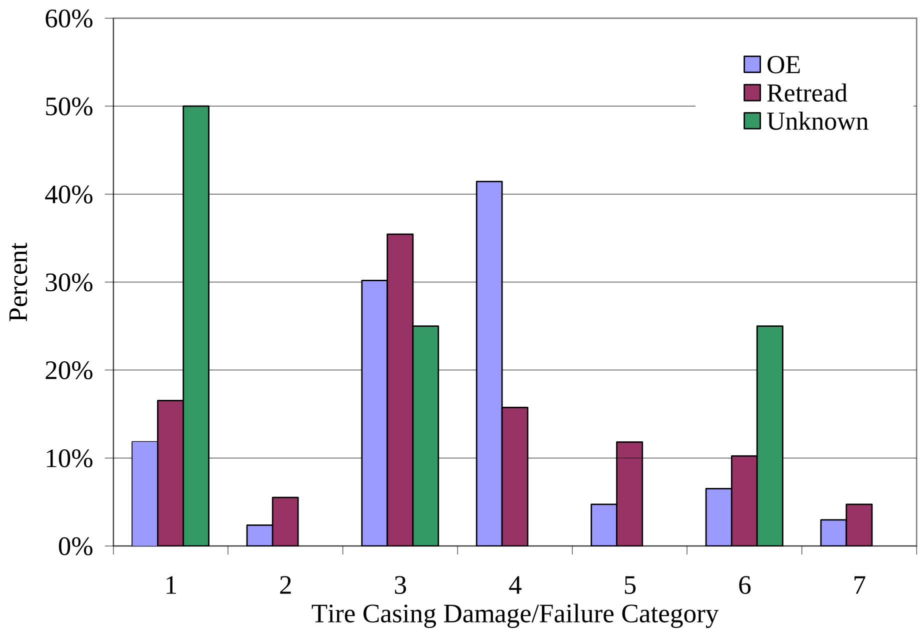


Figure 9.24 - Tire Casings Damage/Failure Category Determination

Failure Categories:

Category 1 – Overdeflected Operation
Category 2 – Excessive Heat
Category 3 – Road Hazard
Category 4 – Maintenance/Operational
Category 5 – Manufacturing/Process
Category 6 – Indeterminable
Category 7 – Excessive Intracarcass Pressurization

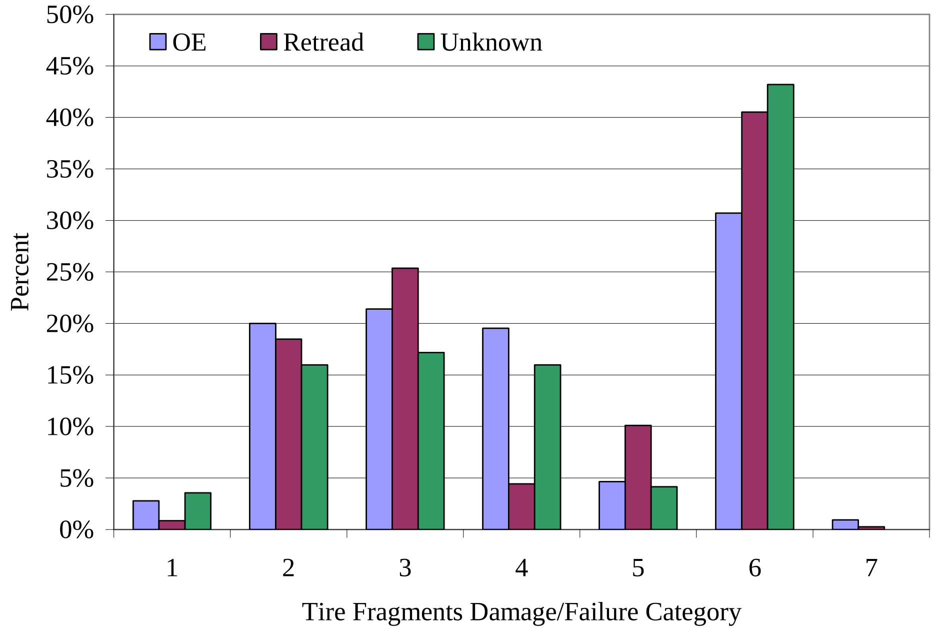


Figure 9.25 - Tire Fragments/Debris Damage/Failure Category Determination

Failure Categories:
Category 1 – Overdeflected Operation
Category 2 – Excessive Heat
Category 3 – Road Hazard
Category 4 – Maintenance/Operational
Category 5 – Manufacturing/Process
Category 6 – Indeterminable
Category 7 – Excessive Intracarcass Pressurization

9.9.1 Casing Manufacturer

All the major OE tire manufacturers were represented in the casings and tire fragments collected for this study. The proportions of casings/fragments collected in Table 9.6 indicate that Bridgestone Firestone as OE manufacturer had the highest percentage at 30 percent. However, it was not possible as part of this study to determine whether this proportion reflected the Bridgestone Firestone market share of medium/heavy duty truck tires or new tread (i.e., for retread). OE tire sales sold in a particular year (see Table 2.4) may yield inconclusive results in predicting market shares for the collected casings and tire fragments manufactured over several years. In other words, does the 30 perent Bridgestone casings/fragments collected suggest that 30 percent of medium/heavy truck tires running on U.S. highways are manufactured by the same OE?

Table 9.6: Casing and Fragment OE Manufacturer

OE Manufacturer	OE	Retread	Unknown	Total	Percent	Rank
Bridgestone	47	42	1	90	30.0%	1
Goodyear	16	28		44	14.7%	2
Michelin	22	22		44	14.7%	3
Yokohama	9	6	1	16	5.3%	4
General	10	5		15	5.0%	5

Table 9.6: Casing and Fragment OE Manufacturer (continued)

OE Manufacturer	OE	Retread	Unknown	Total	Percent	Rank
Firestone	7	5		12	4.0%	6
Dunlop	6	2		8	2.7%	7
Toyo	4	3		7	2.3%	8
BFGoodrich	4	2		6	2.0%	9
Steelmark	4	1		5	1.7%	10
Other	40	11	2	53	17.7%	
Total	169	127	4	300		

9.9.2 Casing Estimated Age by DOT Year of Manufacture

The tire identification number (TIN) as described in Section 2.10 provides information as to the casing week and year of manufacture. Using the last two digits of the TIN it is possible to determine the age of the casing. It should be noted that prior to 1999 the week and year of manufacture consisted of three digits, but in 1999 it was changed to four. This was done partly to overcome any possible confusion that could arise to determine the correct year of manufacture with the onset of the millennium. Table 9.7 presents year of manufacture for the tire casings collected. Figure 9.26 presents the same information graphically by proportions of casings manufactured by year and Figure 9.27 presents a box-plot approach.

Table 9.7: Tire Casing Year of Manufacture

DOT Year	OE	Retread	Unknown	Total	Estimated Age	%
1990	0	2	0	2	17	0.67%
1991	3	0	0	3	16	1.00%
1992	1	0	0	1	15	0.33%
1993	0	1	0	1	14	0.33%
1994	3	0	0	3	13	1.00%
1995	1	4	0	5	12	1.67%
1996	3	3	0	6	11	2.00%
1997	0	3	0	3	10	1.00%
1998	2	5	1	8	9	2.67%
1999	4	10	0	14	8	4.67%
2000	3	17	0	20	7	6.67%
2001	2	15	0	17	6	5.67%
2002	9	21	0	30	5	10.00%
2003	10	13	0	23	4	7.67%
2004	24	13	0	37	3	12.33%
2005	48	8	0	56	2	18.67%
2006	45	0	1	46	1	15.33%
2007	8	0	0	8	< 12 months	2.67%
Missing	3	12	2	17		
Total	169	127	4	300		

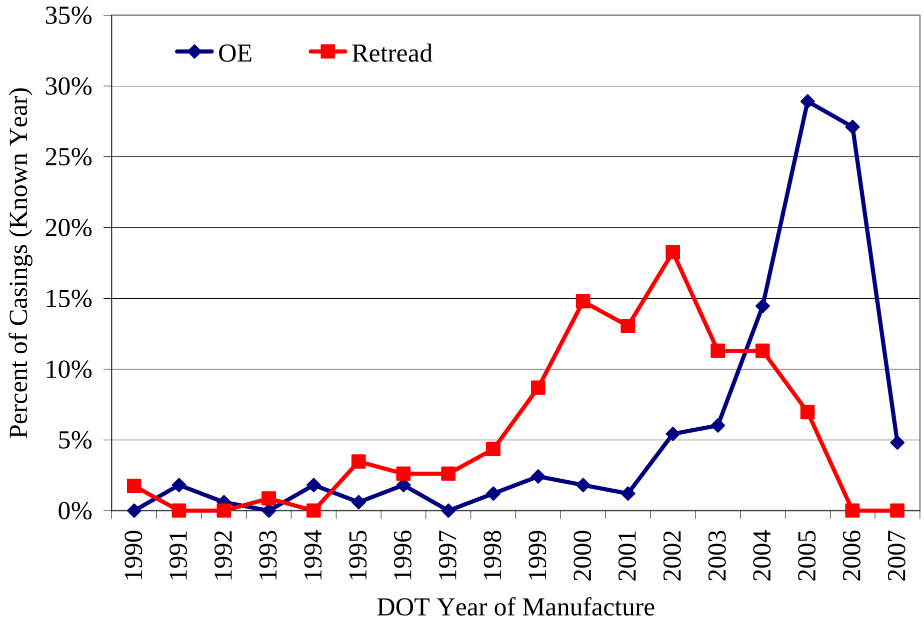


Figure 9.26 – Tire Year of Manufacture (OE or Retread Casings)

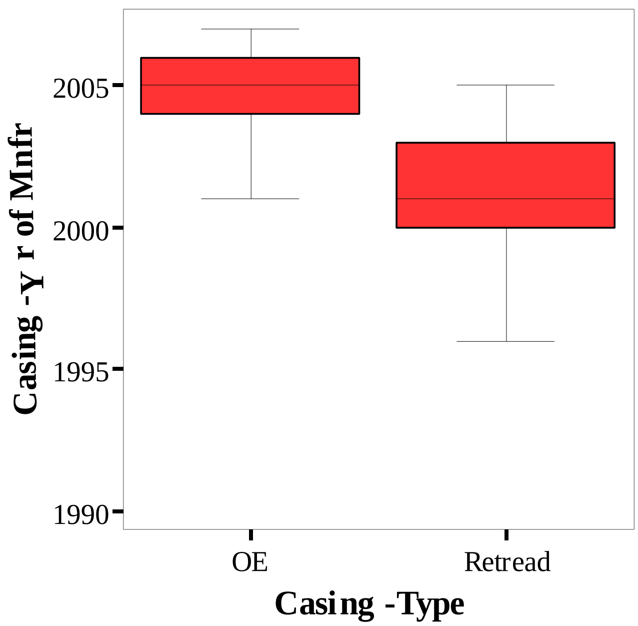


Figure 9.27 – Tire Year of Manufacture (OE or Retread Casings)

Key findings with respect to the age of the collected casings are:

- The casings themselves ranged in age from approximately 1 to 17 years since the week and year of manufacture. The vast majority of the casings were manufactured since the year 2000, which would be consistent with our experience.

- The most-recently retreaded dates ranged from approximately a few months to 13 years. (In cases where the casing had been retreaded more than once, tire failure analysts recorded only the most recent retreader's TIN information.) This range of retread manufacturing dates is consistent with what would be expected.

- The average (i.e., mean) year of manufacture of the 166 OE casings (with valid TIN) approximated 2003 compared to 2000 for the 115 retread casings. The largest proportion of OE casings collected (29%) were manufactured in 2005 when compared to retreads (18%) in 2002. The median year of manufacture (as shown in Figure 9.27) for OE was 2005 and retread casings 2001. The median age of retread casings at four years older than OEs comes as no surprise as it is expected that for a casing to be retread it must have completed several months or years of service.

9.9.3 Number of Casing Retreads

A significant majority (90) of the 127 retread casings (70%) were in the first retread stage with 27 (21 %) in the second retread stage, and 5 (4%) in the third retread stage. In the case of five retread casings, the number of retreads could not be determined. For medium truck retreads in highway service, one would anticipate that the majority of retreaded tires operating would be in the first retread stage, with progressively fewer in the second stage or greater.

9.9.4 Retread Casing Manufacturing Process

The vast majority of the 127 casings that could be identified as retreads were manufactured using the pre-cure process (see section 2.5.1 for a description of retread manufacturing processes). The tire failure analysts anticipated this as, particularly in the U.S. market, pre-cure process retreading has become more the norm. A similar conclusion was seen for fragments where the vast majority of the retreaded fragments had been retreaded with various pre-cure processes, which is consistent with the tire failure analysts' understanding of the pre-cure marketplace presence in the United States. Table 9.8 presents these results.

Table 9.8: Retread Manufacturing Process

Retread Process	Casings		Fragments	
	#	%	#	%
Moldcure	7	5.5%	27	3.3%
Pre-cure	96	75.6%	740	91.1%
Unknown	24	18.9%	45	5.5%
Total	127	100.0%	812	100.0%

9.9.5 Probable Wheel/Axle Position

Discussions with retread tire stakeholders (chapter 6) confirmed the industry practice of OE tires with each successive retread migrating in service toward the trailer axles. The tire failure analysts were asked to determine which axle (i.e., steer, drive, or trailer) the casing or fragment being examined may have been positioned on before it was removed from service or failed. The results are presented in Table 9.9 and Figure 9.28.

Table 9.9 – Probable Wheel Positioning of Casings and Tire Fragments Assessed

Axle Position	Casings		Tire Fragments	
	#	Percent	#	Percent
Steer	31	10.3%	43	3.6%
Drive	65	21.7%	327	27.3%
Trailer	108	36.0%	628	52.5%
Steer/Trailer	17	5.7%	12	1.0%
Drive/Trailer	14	4.7%	101	8.4%
Steer/Drive	3	1.0%	0	0.0%
Steer/Drive/Trailer	1	0.3%	1	0.1%
None	61	20.3%	84	7.0%
Total	300	100.0%	1,196	100.0%

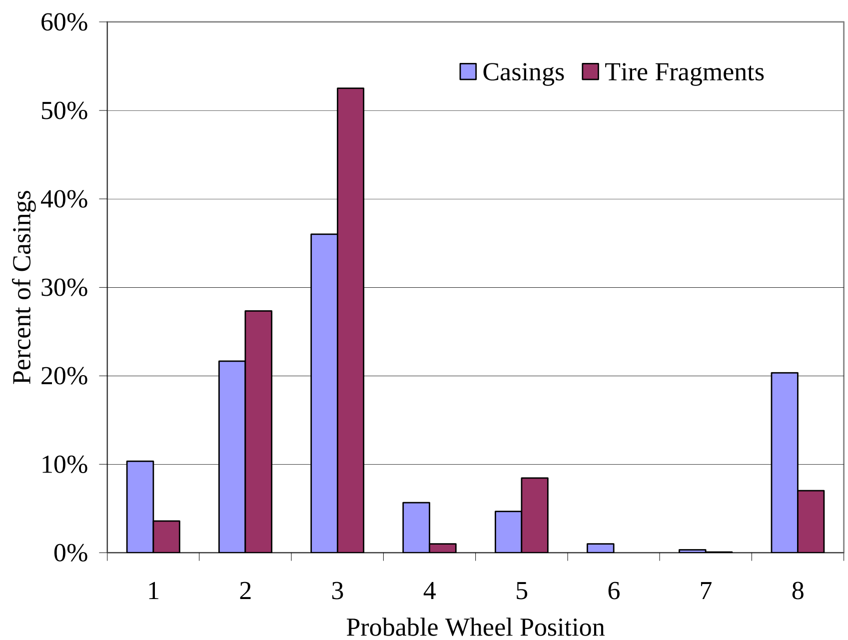


Figure 9.28: Casings and Tire Fragments Probable Wheel Position

Wheel Position Categories:

1 = Steer
2 = Drive
3 = Trailer
4 = Steer or Trailer
5 = Drive or Trailer
6 = Steer or Drive
7 = Steer or Drive or Trailer
8 = Indeterminate

Key findings with respect to axle positioning of the casing/fragments assessed can be listed as:

- With regard to likely axle service, of the majority of the casings examined: 108 (36%) were likely to be exclusively from trailers; 65 (22%) were likely to be exclusively from the drive axle; and 61 (20%) could not be identified as to axle service. This general result was anticipated. In practice, many fleets tend to run first-retread casings on the drive axle and then concentrate retread usage on their trailers. Also, there are many more trailers than tractors in the U.S. commercial vehicle fleet and, as mentioned earlier in section 9.7, the relative percentage of original tread to retread tires in service will vary over time. The wheel positioning for 61 casings (20%) assessed could not be determined.

- With regard to the likely axle service from which the fragments emanated, approximately 628 (53%) were exclusively from the trailer axle; 327 (27%) were exclusively from the drive axle; and 43 (4%) were from the steer axle. The wheel positioning for 84 fragments (7%) could not be determined.

The reader will observe that in some cases, more than one selection as to probable wheel position is indicated. This was due to the fact that the particular tread design could potentially have been used on more than one position (e.g. steer and trailer, etc.). In some instances, the reader will observe that the likely wheel position was not determined (e.g., category 8). This was due to the fact that the sample was not sufficiently complete or intact to allow such a determination to be made.

Disaggregating the casings/fragments status (i.e., OE versus retread) by probable wheel position provides additional information which also confirms industry tire operating practices. Tables 9.10 and 9.11 and Figures 9.29 and 9.30 present this information.

Table 9.10 – Probable Wheel Position and Retread Status (Tire Casings)

Wheel Position	Retread Status				Percent		
	OE	Retread	Unknown	Total	OE	Retread	Unknown
Steer	30	0	1	31	96.77%	0.00%	3.23%
Drive	41	24	0	65	63.08%	36.92%	0.00%
Trailer	57	51	0	108	52.78%	47.22%	0.00%
Steer/Trailer	16	1	0	17	94.12%	5.88%	0.00%
Drive/Trailer	6	8	0	14	42.86%	57.14%	0.00%
Steer/Drive	3	0	0	3	100.00%	0.00%	0.00%
Steer/Drive/Trailer	1	0	0	1	100.00%	0.00%	0.00%
None	15	43	3	61	24.59%	70.49%	4.92%
Total	169	127	4	300	56.33%	42.33%	1.33%

Table 9.11 – Probable Wheel Position and Retread Status (Tire Fragments)

Wheel Position	Retread Status				Percent		
	OE	Retread	Unknown	Total	OE	Retread	Unknown
Steer	38	4	1	43	88.37%	9.30%	2.33%
Drive	45	243	39	327	13.76%	74.31%	11.93%
Trailer	92	468	68	628	14.65%	74.52%	10.83%
Steer/Trailer	9	1	2	12	75.00%	8.33%	16.67%
Drive/Trailer	22	67	12	101	21.78%	66.34%	11.88%
Steer/Drive	0	0	0	0	0.00%	0.00%	0.00%
Steer/Drive/Trailer	1	29	0	30	3.33%	96.67%	0.00%
None	7	0	48	55	12.73%	0.00%	87.27%
Total	214	812	170	1,196	17.89%	67.89%	14.21%

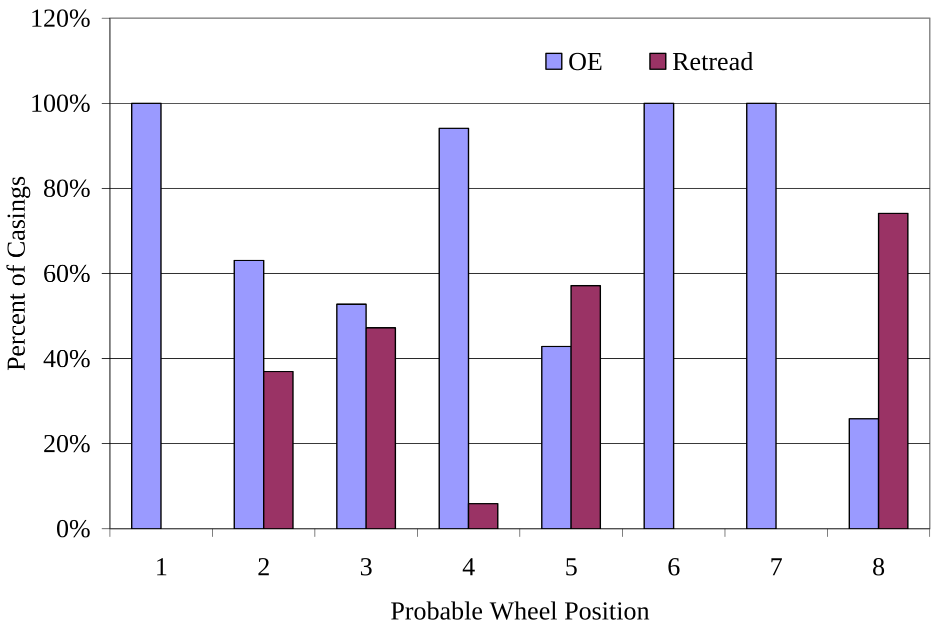


Figure 9.29: Probable Wheel Position and Tire Status (Tire Casings)

Wheel Position Categories:

1 = Steer
2 = Drive
3 = Trailer
4 = Steer or Trailer
5 = Drive or Trailer
6 = Steer or Drive
7 = Steer or Drive or Trailer
8 = Indeterminate

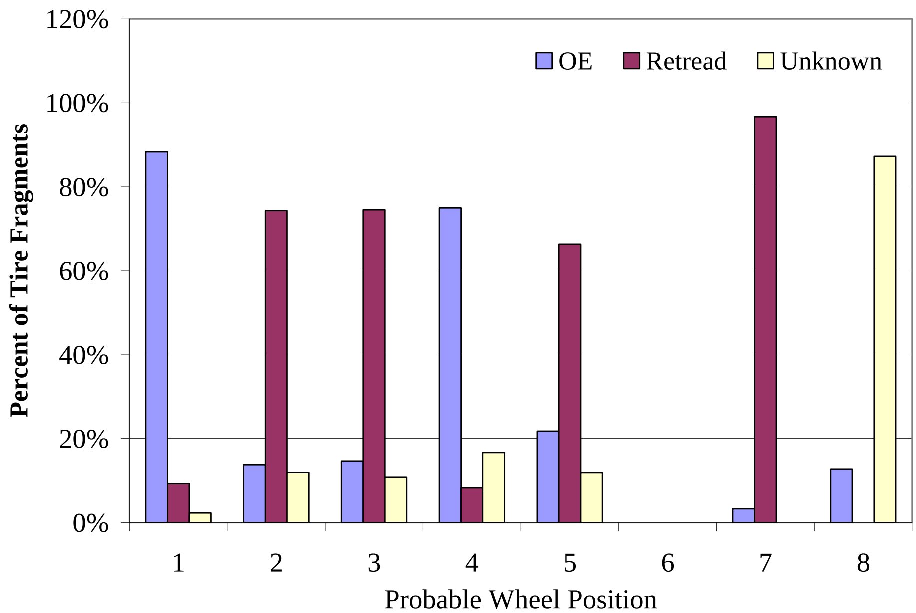


Figure 9.30: Probable Wheel Position and Tire Status (Tire Fragments)

Wheel Position Categories:

1 = Steer	5 = Drive or Trailer
2 = Drive	6 = Steer or Drive
3 = Trailer	7 = Steer or Drive or Trailer
4 = Steer or Trailer	8 = Indeterminate

Key findings from Table 9.10 and Figures 9.29 and 9.30 are:

- Of OE casings where a probable wheel position could be determined (i.e., 154 of the 169), 30 (19%) were placed exclusively on the steer axle. Of these 30 steer axle casings all (i.e., 100%) were OE. This finding favorably compares to an overwhelming majority (88%) of steer axle tire fragments that had a similar OE origin. These results confirm the trucking industry practice and preference for mounting only OE casings on steer axles.

- The majority (61%) of retreaded casings where a probable wheel position could be determined (i.e., 84 of the 127) were likely mounted on trailer axles. A similar result was evident in the case of tire fragments (Table 9.11). In this case at least 60 percent of the tire fragments where a wheel position could be determined (i.e., 468 of 783) were mounted exclusively on trailer axles.

- For OE or retread casings and fragments where a probable wheel position could be determined, the trailer wheel position represented the most probable position from which these failed casings or fragments originated. This finding is not surprising when it is considered that trailer axles may be subject to a weaker maintenance regime than wheels mounted on other axles, road hazard tracking and trailer wheels often operate under dual tire assembly (see sections 6.2.1 and 6.2.6.).

- Any large-scale analysis of medium-truck tire disablements should take into consideration the fact that these tires operate primarily as dual assemblies, either in drive or trailer axle positions. In practice, one of the tires in a dual assembly may (due to damage or lack of maintenance) be operating while underinflated. In such cases, its correctly inflated mate will have to operate in an overloaded condition, carrying some portion of the underinflated tire's load in addition to its own. Subsequently, the properly inflated mate may become the tire that is actually disabled, with no puncture, or other cause, apparent to the tire failure examiner. This is particularly significant because, knowingly or unknowingly, a driver may continue to operate the vehicle after one tire in a dual assembly has failed.

9.9.6 Tread Patterns

The distribution of tread patterns according to tire or tire fragment status is presented in Figures 9.31 and 9.32.

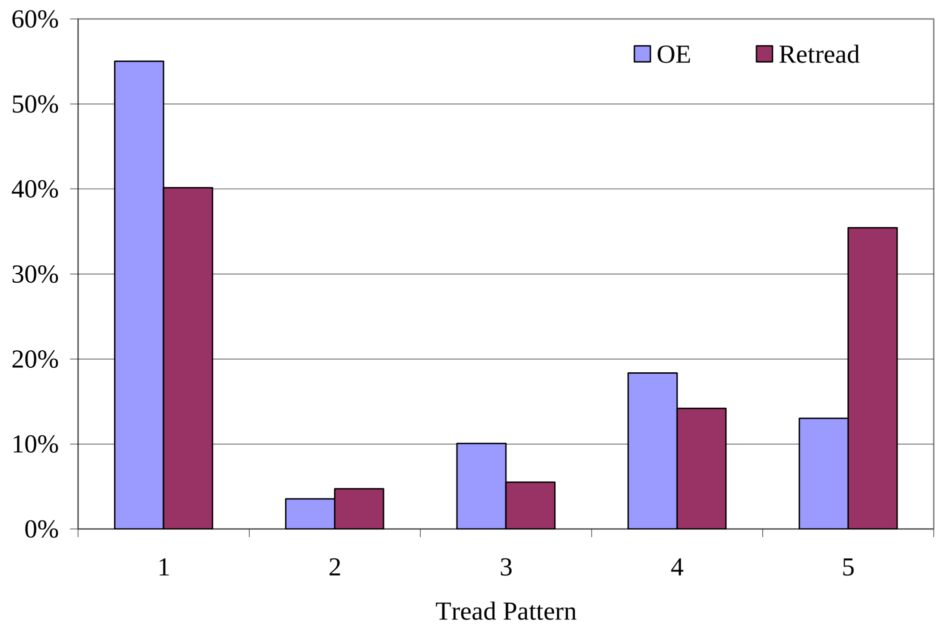


Figure 9.31 – Casings Status by Tread Pattern

Tread Pattern Categories:
1 = Straight Rib
2 = Straight Rib w/Sipes
3 = Rib w/Tied-Together Block Elements
4 = Lug
5 = Other/indeterminate

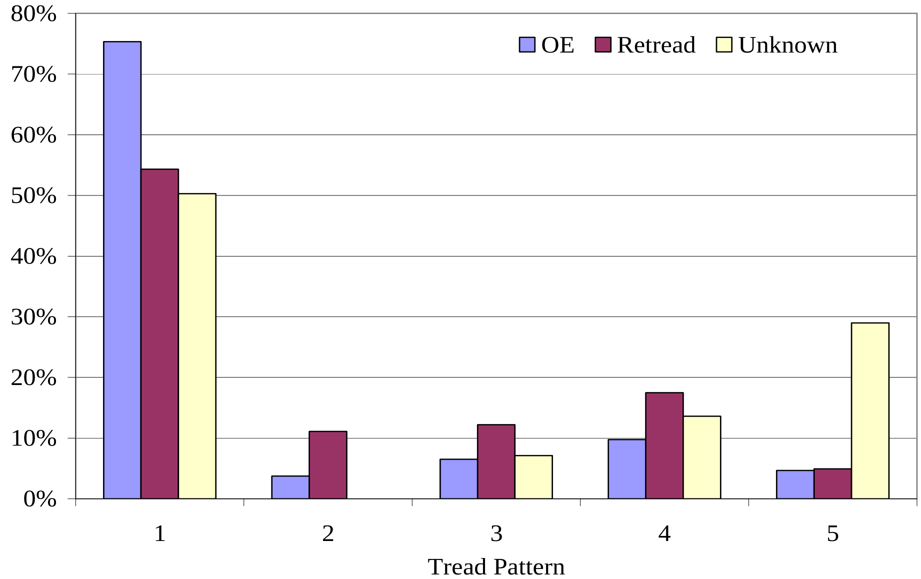


Figure 9.32 – Tire Fragment Status by Tread Pattern

Tread Pattern Categories:
1 = Straight Rib
2 = Straight Rib w/Sipes
3 = Rib w/Tied-Together Block Elements
4 = Lug
5 = Other/indeterminate

Key findings are listed as:

- The straight rib tread pattern is the dominant tread pattern irrespective of tire or fragment status. This tread pattern is predominately used in tires destined for trailer wheel configurations.

- For OE casings where a tread pattern could be determined (i.e., 147 of the 169), 93 casings (63%) were of the straight rib tread pattern. With respect to OE tire fragments, the straight rib proportion increased to 79 percent (162 of the 205 identifiable casings).

- In the case of retread casings with identifiable tread design a similar percentage (63%) when compared to OE casings was evident where 51 of the 82 retread casings were of the straight rib design. However, for retread tire fragments the corresponding proportion fell to 57 percent (i.e., 441 of the 772 fragments with identifiable tread designs).

- Also in some instances, the reader will observe that the tread design description data was not recorded or determined (category #5 Figures 9.31 and 9.32). This was due to the fact that the sample was not sufficiently complete or intact to allow such a determination to be made.

9.9.7 Casing Size

According to RMA statistics, the most popular size sold of OE commercial tire in 2005 was the 295/75R22.5. Tire size data was also collected from the 300 casings assessed and the top 5 sizes are presented in Table 9.12.

Table 9.12 – Tire Sizes of Collected Casings

Tire Size	Number	Percent
295/75R22.5	131	43.7%
11R22.5	46	15.3%
285/75R24.5	31	10.3%
275/80R22.5	28	9.3%
255/70R22.5	23	7.7%
Other	41	13.7%
Total	300	100.0%

Key findings can be listed as:

- The top two tire sizes, namely 295/75R22.5 and 11R22.5, correspond to the top two tire medium and wide base truck tire sizes demanded in 2005 (see Figure 2.29).

- The top five tire sizes accounted for more than 80 percent of the sizes of casings collected.

9.9.8 Intact and Detached Casings

The 300 casings collected came in various states of completeness with respect to the tire structure. Casings described as 'intact' were those that had come out of service for some reason (e.g., road hazard, etc.), but had not sustained a detachment of any of the tire's laminar components. Whereas for casings described as "detached" in these cases, it was evident that one or more of the tire's laminar components had become physically detached from adjacent components (e.g., the tread) or the tread and one or more steel belts had completely detached from the casing. The casing detached status can be further broken down into partial or complete detachment. Tread or belt materials that are missing from only a portion of the casing circumference is described as a partial detachment. On the other hand, tread or belt materials that are completely missing from the casing circumference is described as a complete detachment. Tables 9.13 and 9.14 present casing structural condition according to tire status and Figure 9.33 presents the same information by probable wheel position.

Table 9.13 – Casing Structural Integrity and Failed Condition

Casing	OE		Retread		Other		Total
	#	%	#	%	#	%	
Intact	143	84.6%	68	53.5%	1	25.0%	212
Detached	26	15.4%	59	46.5%	3	75.0%	88
Total	169	100.0%	127	100.0%	4	100.0%	300

Table 9.14 – Detached Casing Structural Integrity and Failed Condition

Detached Casing	OE		Retread		Other		Total
	#	%	#	%	#	%	
Partial	13	50.0%	16	27.1%	0	0.0%	29
Complete	13	50.0%	43	72.9%	3	100.0%	59
Total	26	100.0%	59	100.0%	3	100.0%	88

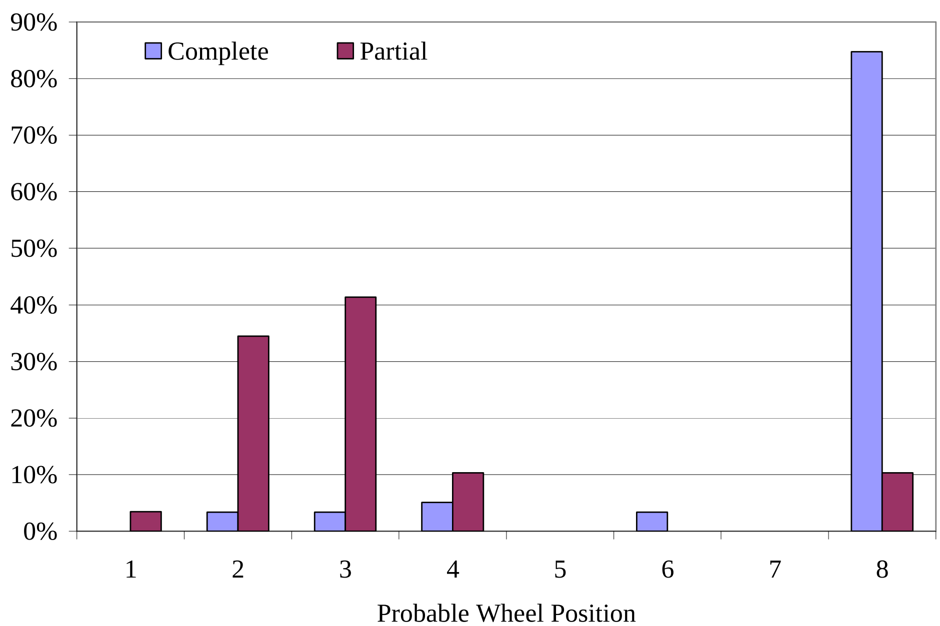


Figure 9.33 – Detachment Status and Probable Wheel Position

Wheel Position Categories:

1 = Steer
2 = Drive
3 = Trailer
4 = Steer or Trailer
5 = Driver or Trailer
6 = Steer or Drive
7 = Steer or Driver or Trailer
8 = Indeterminate

Key findings from Tables 9.13 and 9.14 and Figure 9.33 are:

- More than two thirds (71%) of the 300 casings examined were intact. However, of the 169 OE casings examined, 85 percent were intact compared to 54 percent of the retread casings.

- Of the 88 casings that had suffered some sort of detachment, 59 of these (67%) were retreads. Again, 59 of these 88 casings suffered from complete detachment and the balance partial. A major factor determining whether a detachment is partial or complete would be the point in time and distance traveled by the disabled tire. For example, a puncture through the crown by a large nail may result in some air loss. However, if the driver notices this incident in time and engages in remedial measures (e.g., stopping) it is possible that the injured tire may still be intact or suffer from partial detachment. The low percentage (3%) of steer tire partial detachments may be indicative of this. It would be hard for a driver not to notice injury to the steer axle wheel configuration without taking immediate action.

- The longer a disabled tire is in operation the greater potential for heat generation and severe structural deflection increasing the likelihood that the tire will disintegrate (i.e., complete detachment of the belt and tread materials). Note, too, that 73 percent of casings experiencing complete detachment were retreads.

- It is understandable that without the belt and tread materials available to determine probable wheel positioning this task becomes increasingly difficult. This is borne out in Figure 9.32 where a high proportion (85%) of casings completely detached fall into the indeterminate wheel position category.

9.9.9 Tread Depth Analysis

Continued analysis of the collected casings and tire fragments sought to analyze tread depth data. Table 9.15 present this data for the collected casings.

Table 9.15 – Casing Status by Tread Depth (mm)

Tire Status		N	Min	P25	Median	P75	Max
Casings	OE	169	0.00	0.00	4.76	7.94	21.43
	Retread	127	0.00	0.00	4.76	7.94	20.24
	Unknown	4	0.00	0.00	0.00	5.95	7.94
Tire Fragments	OE	214	0.00	2.38	6.35	8.73	18.26
	Retread	812	0.00	4.76	7.14	9.52	20.64
	Unknown	170	0.00	0.00	3.57	6.75	16.67
Intact Casings	OE	143	0.00	0.00	4.76	7.94	21.43
	Retread	68	0.00	3.97	6.35	8.53	13.49
	Unknown	1	7.94	7.94	7.94	7.94	7.94

Key points from Table 9.15 are:

- The minimum tread depth of OE or retread casings or tire fragments approximated 0 mm (0 32^{nds}) (excluding unknown types). This indicates that in these cases the tire tread had been worn down completely to a “bald’ state.

- The median tread depth values of OE or retread casings sampled (excluding unknown types) exceeded the mandated minimum tire tread depth of $2/32^{nds}$ (1.5875mm) for regular service.

- Looking at casings only, the maximum tread depth for retread tires approximated 20.24 mm (all casings) and 13.49 mm (intact retread casings). These values are less than the corresponding tread depth for OE casings (21.43mm) respectively. This result is not surprising as tread depths for retread tires are generally less than the corresponding tread depths for similar OE tires.

- Further analysis of the 300 casing tread depth results indicate that 70 (i.e., 41 percent) of the casings sampled did not meet mandated minimum tire tread depth of 2/32nds (1.5875mm) for regular service.

9.9.10 Tread Depth by Wheel Position and Tire/Fragment Retread Status

Assessing the tread depth of casings and tire fragments by type (i.e., OE or retread) and probable wheel position may give some indication as to the type of tire operating or service regime followed. Tables 9.16 and 9.17 present this data for the collected casings or tire fragments (Figures 9.34 and 9.35 present the same data graphically in the form of Box Plots). The Box Plot is a simple way of plotting a set of observations. The Box Plot indicates the highest and lowest observations (the top and bottom whiskers) as well as the inter-quartile range (i.e., the difference between the bottom of the box below which 25% of the observations lie and the top of the box above which 25% of the observations lie). The line in the middle of the box plot represents the median above and below which 50 percent of the observations lie. If the median line is not in the middle of the box plot the distribution is skewed. The further away the median line is from the middle of the box plot the more skewed the distribution.

Table 9.16 – Tread Depth (mm) by Wheel Position and Intact Casing Status

Wheel Position & Tire Status		N	Min	P25	Median	P75	Max
Steer	OE	29	0.00	0.79	6.35	9.53	14.29
	Retread	na	na	na	na	na	na
Drive	OE	36	0.00	4.17	7.14	10.91	21.43
	Retread	17	0.00	2.78	6.35	10.32	13.49
Trailer	OE	54	0.00	0.00	0.00	5.95	11.11
	Retread	40	0.00	4.76	6.35	7.94	9.52

Table 9.17 – Tread Depth (mm) by Wheel Position and Tire Fragment Status

Wheel Position & Tire Status		N	Min	P25	Median	P75	Max
Steer	OE	38	0.00	6.15	7.93	10.31	12.7
	Retread	4	4.76	4.86	5.35	5.55	5.55
Drive	OE	45	0.00	4.72	7.93	15.08	17.46
	Retread	243	0.00	6.35	8.73	12.70	20.63
Trailer	OE	92	0.00	0.00	4.72	7.14	14.28
	Retread	468	0.00	4.76	6.35	7.93	19.05

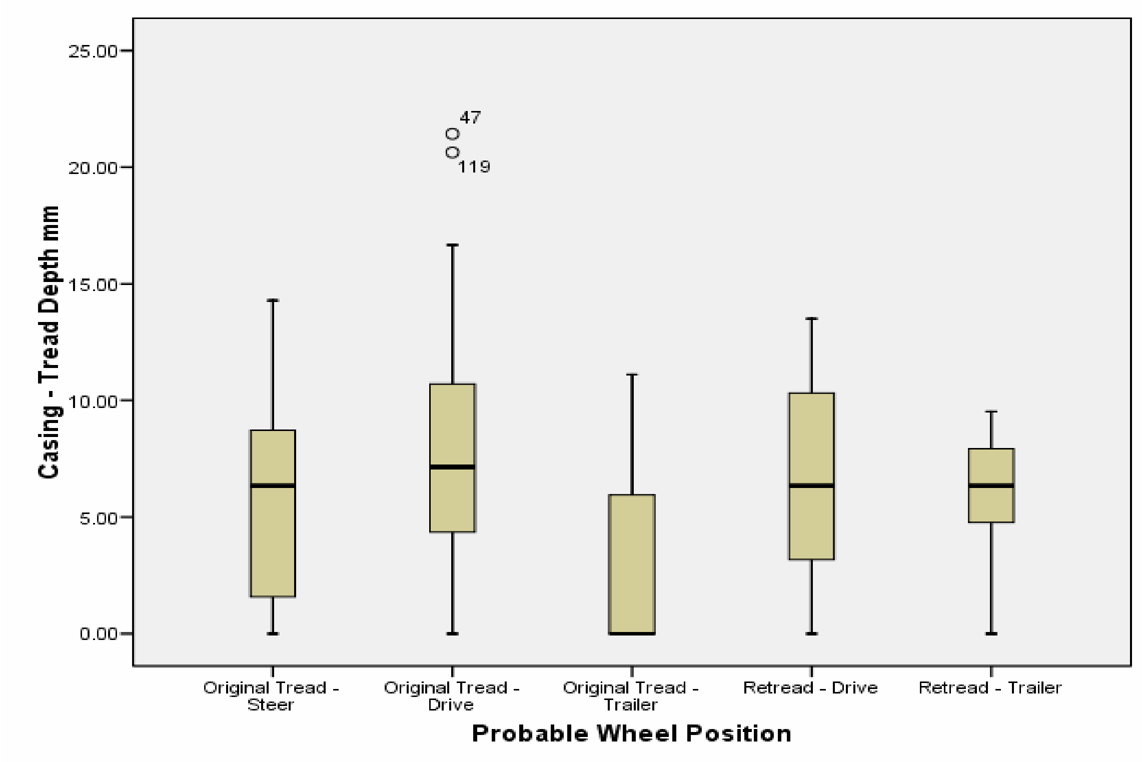


Figure 9.34 – Tread Depth by Wheel Position and Casing Status (n=176)

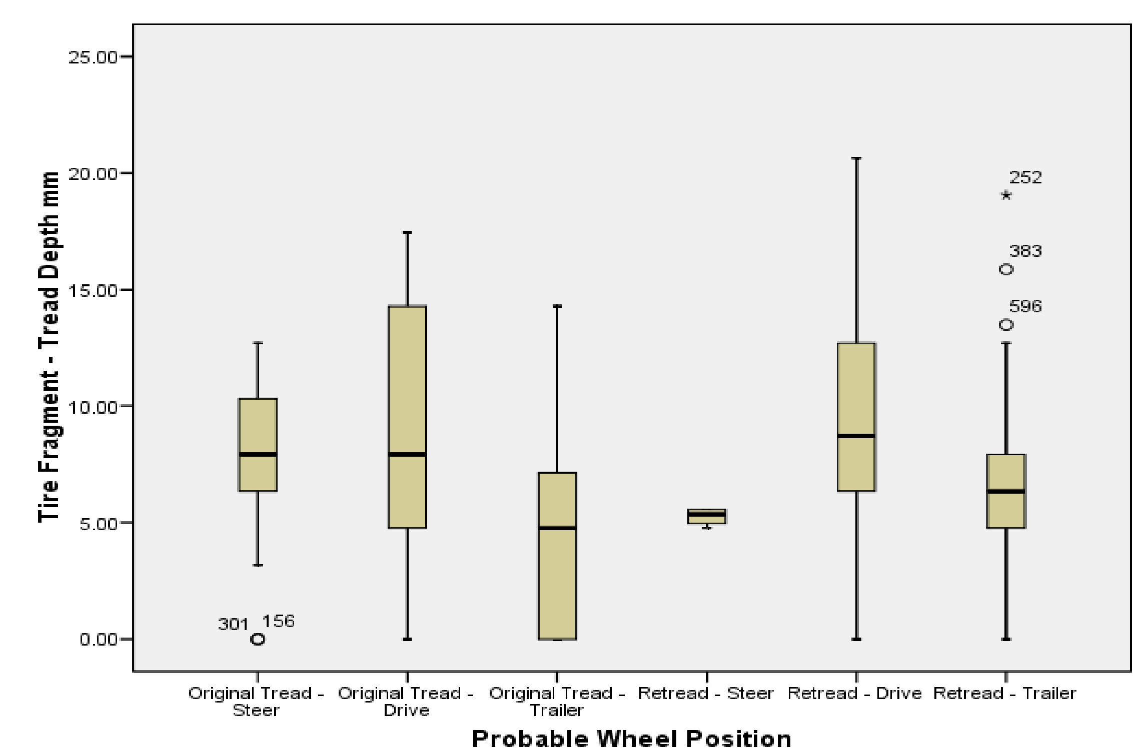


Figure 9.35 – Tread Depth by Wheel Position and Tire Fragment Status (n=890)

Note: Tables 9.16 and 9.17 present tread depth results for the intact casings or tire fragments where tire status was determined (i.e., OE or retread) and positioned exclusively in one probable wheel position (e.g., steer, drive, or trailer). Thus, cases where the tire's retread status was unknown, or a probable wheel position may have been steer and/or drive and/or trailer or any combination of these positions (see Table 9.10) have been excluded. The number of intact casings meeting this criteria equaled 176 (i.e., 59% of original total) and 890 (i.e., 74% of original total in Table 9.11) tire fragments. Key findings from Tables 9.16 and 9.17 and Figures 9.34 and 9.35 can be listed as:

- The median OE casing tread depth for trailers approximating 0.0 mm was lower than any of the lowest OE tire tread depth of tires in other wheel positions (Figure 9.34). Indeed, tread depths for OE tires in the trailer position were skewed towards 0.00 mm. This situation may imply that OE tires progressing from steer or drive to trailer axles (see section 6.2.1) were not being replaced or retreaded before the mandated minimum tire tread (1.5875 mm or 2/32 nds) was exceeded. Compounding this situation is the possibility that a trailer may be operating for extended periods of time away from an owner (or a third party agency) responsible for periodic maintenance.

- In the case of OE tire fragments in the trailer position the 25th percentile approximated 0.00 mm. This was lower than any of the lowest 25th percentiles of tire fragments in other wheel positions (Figure 9.35). It is possible that reasons similar to those in the previous bullet may have given rise to this observed situation.

- The median tread depth for OE casings in a drive axle position approximated 7.14 mm, the highest of any median tread depth of tire casings in any other wheel position. This result does support the industry practice of deeper tread depths for drive axle tires.

- The highest median tread depths for OE casings were evident on casings positioned in drive followed by steer axles. A similar result was seen for OE tire fragments where the highest median tread depths were evident on fragments from casings positioned in drive or steer axles.

- Median tread depths for retread tire casings were the same for casings positioned in drive or trailer axles. However, for retread tire fragments, the highest median tread depths were evident on fragments originating from casings positioned in drive followed by trailer axles.

Appendix E contains Box Plots of data illustrating tread depth by collection location (1 Box Plot), collection location by axle position (5 Box Plots) and axle position by collection location (5 Box Plots) for the 176 intact casings only.

9.9.11 Tire Fragment Length by Wheel Position

Figure 9.36 presents Box Plots on Tire Fragment length (mm) and probable wheel position for 890 (see section 9.9.10 for fragment selection criteria). Key findings from Figure 9.36 are:

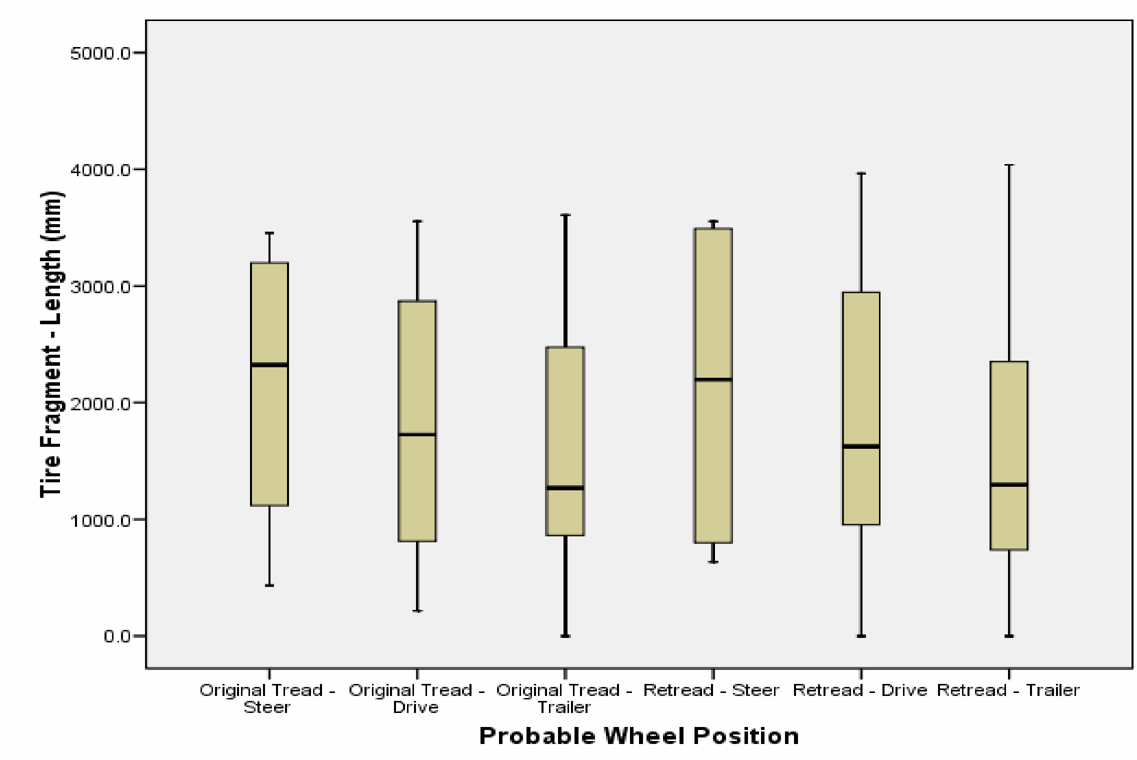


Figure 9.36 – Tire Fragment Length by Probable Wheel Position (n=890)

- Median tire fragment lengths (1,270 mm OE and 1,295 mm retread) for trailers were the lowest of any median fragment lengths in other wheel positions.

- The longest tire fragments (judged by the position of the top whisker) were seen in fragments that originated from casings positioned on trailer axles. The maximum lengths of fragments in this position where 3,606 mm (OE) and 4,038 mm (retread).

9.10 Tire Debris Studies Comparison

The tire debris studies conducted by TMC in 1995 and 1998 (see Chapter 3) have been accepted by many tire industry stakeholders as benchmarking studies that have provided a platform in assessing the durability and/or failure potential of OE versus retread tires. Studies subsequent to the TMC studies have often been compared to confirm or disprove the TMC results and conclusions. Continuing this practice of study comparison, the findings from the UMTRI study will be compared with the TMC studies (1995 and 1998) and the Longevity of Commercial Truck Tire Study (conducted by Bridgestone Firestone from 2000 to 2005).

9.10.1 Study Areas and Seasons

The 48 contiguous States formed the study areas for all three studies (i.e., UMTRI, TMC, and Bridgestone Firestone). Tire debris for the UMTRI study was collected in five States, namely Arizona, California, Florida, Indiana, and Virginia. This compares to the TMC studies that were conducted in 9 States (see Figure 3.1), namely Alabama, Arizona, Nevada, New Jersey, North Carolina, Ohio, Oregon, South Carolina, and Texas. A State-by-State breakdown of the sources of the tires inspected as part of the Bridgestone Firestone study was not available in the study results. Both the UMTRI and TMC studies were conducted in the summer months (i.e., May to September). The Bridgestone Firestone study was conducted over several years and it is likely that the casings assessed were collected during all seasons.

9.10.2 Tire Casings and Debris Items Collected or Assessed

The TMC study of 1995 assessed 1,720 tire items and in 1998 this figure increased by 28 percent to 2,200. The Bridgestone Firestone study assessed 10,291 casings over several years. Comparing the items assessed, the UMTRI study is placed fourth with 1,496 tire items. However, the figure of 1,496 represents commercial medium tires from large trucks that met the study criteria (see section 8.7.2). Many more tire items that met the tire debris size criteria were found in the 86,000 pounds of debris collected. However, these items originated from passenger vehicles or light trucks, tire categories that were excluded in the UMTRI study. If passenger vehicle or light truck tire items from the TMC studies are excluded the number of heavy truck tire items collected in the UMTRI study exceeds the tire items in the same category in both TMC studies (1,102 and 1,407, respectively).

9.10.3 Tire Items Inspected

Table 9.18 presents data for tire items inspected in the Bridgestone Firestone, TMC, and UMTRI studies. Figure 9.37 displays the proportions of the collected items in the three studies according to tire status (i.e., OE, retread, or unknown). Key findings can be listed as:

- The 10,291 tire items inspected in the Bridgestone Firestone Study exceeded by a large degree the numbers of tire items collected in both the TMC and UMTRI studies. However, the Bridgestone Firestone study was conducted over several years compared to several months in both the TMC and UMTRI studies.

- In excess of 80 percent of the tire items inspected in the TMC studies were retread tires. This compares to 70 and 63 percent in the Bridgestone Firestone and UMTRI studies respectively. As discussed in section 3.2.6 the tire item selection process for the TMC studies was not included in the documentation made available for this study.

- The OE and retread proportions in the Bridgestone Firestone and UMTRI studies are in the same range as the estimated proportions stated in the stakeholder interviews (see section 6.2.1).

Table 9.18 – Tire Debris Studies Inspected Medium/Wide Base Tire Items

Tire Item Status	TMC (1995)	TMC (1998)	Bridgestone Firestone (2000 to 2006)	UMTRI (2007)
Original Equipment	139	221	3,124	383
Retread	963	1,186	7,167	939
Unknown	na	na	na	174
Total	1,102	1,407	10,291	1,496

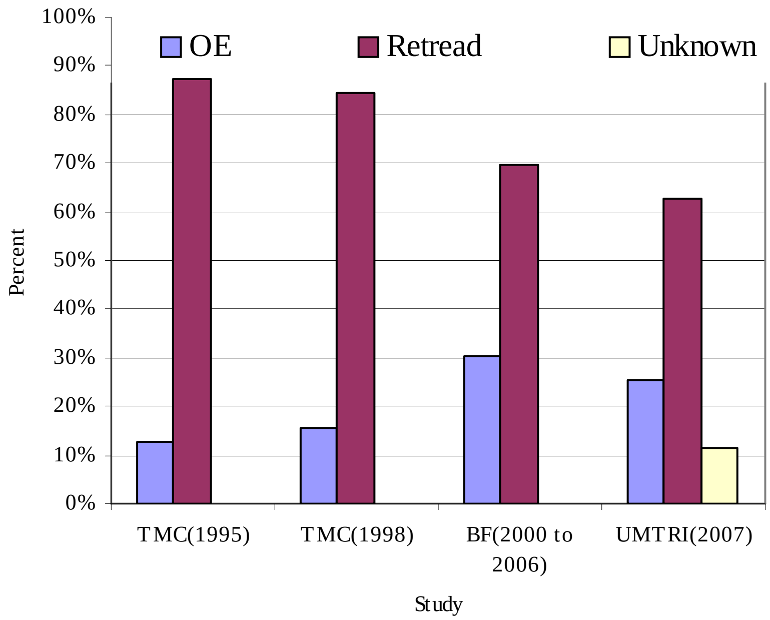


Figure 9.37 – Tire Debris Studies - Inspected Medium Wide-Base Tire Items by Tire Status

9.10.4 Tire Items by Size of Tire

The TMC studies did not report tires assessed by tire size. However, such information was provided as part of the Bridgestone Firestone study. A comparison between the Bridgestone Firestone and UMTRI studies of casings collected by tire size is presented in Table 9.19. Key findings can be listed as:

- Tire size 295/75R22.5 formed the majority of casings collected in both studies (76 and 44%, respectively).

- The proportions of tires collected in each study do differ (some significantly) for most tire size categories. However, this may be due to differences in the lengths of the collection periods.

Table 9.19 – Tire Debris Studies - Tire Sizes of Collected Casings

Tire Size	Bridgestone Firestone (2000-2006)		UMTRI (2007)	
	Number	Percent	Number	Percent
295/75R22.5	7,810	76%	131	44%
11R22.5	860	8%	46	15%
285/75R24.5	373	4%	31	10%
275/80R22.5	na	na	28	9%
255/70R22.5	494	5%	23	8%
Other	754	7%	41	14%
Total	10,291	100%	300	100%

9.10.5 Tire Debris Studies Failure Category

Figures 9.38 and 9.39 summarize failure results for the TMC and UMTRI studies. The Bridgestone Firestone study did not assess failure reasons for the casings collected and is therefore excluded in the comparative analysis here. The TMC failure categories did not match exactly the categories defined by UMTRI. TMC tire items for which a probable failure reason could not be determined (i.e., undecided category) were grouped together with belt separations. Belt separation was not a failure category in the UMTRI study. However, the UMTRI failure categories overdeflected operations and indeterminate cause have been merged in order to be comparable with the Belt Separation/Undecided category in TMC studies. The resulting tire failure data are presented in Table 9.20.

Table 9.20 – Failure Category Comparisons by Tire Item Status

Tire Status	**Failure Category**	**TMC (1995)**	**TMC (1998)**	**UMTRI Casings (2007)**	**UMTRI Fragments (2007)**
OE/New	Belt Sep/Indeterminate	80	105	40	117
	Road Hazard	50	80	51	46
	Mnfr Issues	0	0	8	9
	Repair Failure	15	15	0	0
	Tire Maintenance	0	15	70	42
	OE/Retread Indeterminate	0	0	4	170
	Total1 (Excl. Indeterminate)	145	215	169	214
	Total2 (All)	145	215	173	384
Retread	Belt Sep'/Indeterminate	596	733	47	488
	Road Hazard	217	297	45	206
	Mnfr Issues	51	101	15	82
	Repair Failure	84	38	0	0
	Tire Maintenance	9	22	20	36
	Total	957	1,191	127	812
Grand Total		1,102	1,406	300	1,196

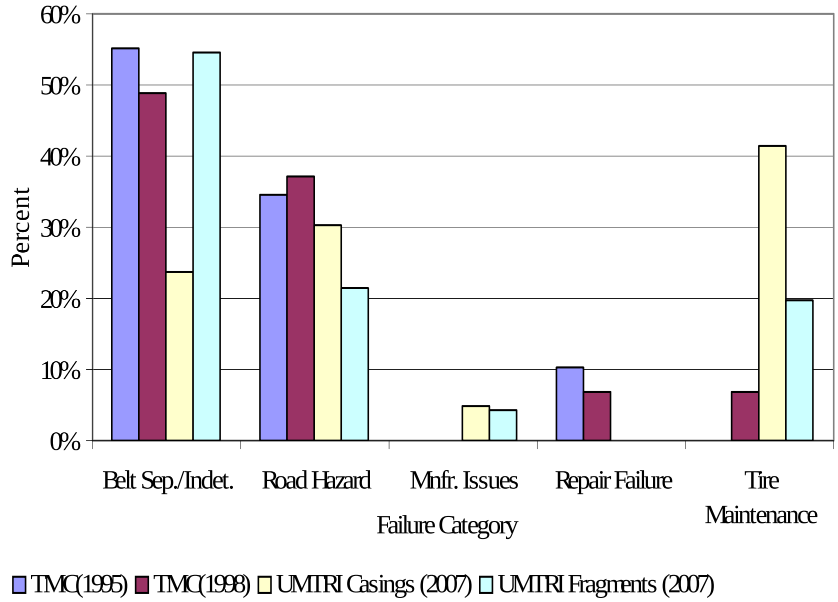


Figure 9.38 - Failure Category Study Comparison OE/New Tires

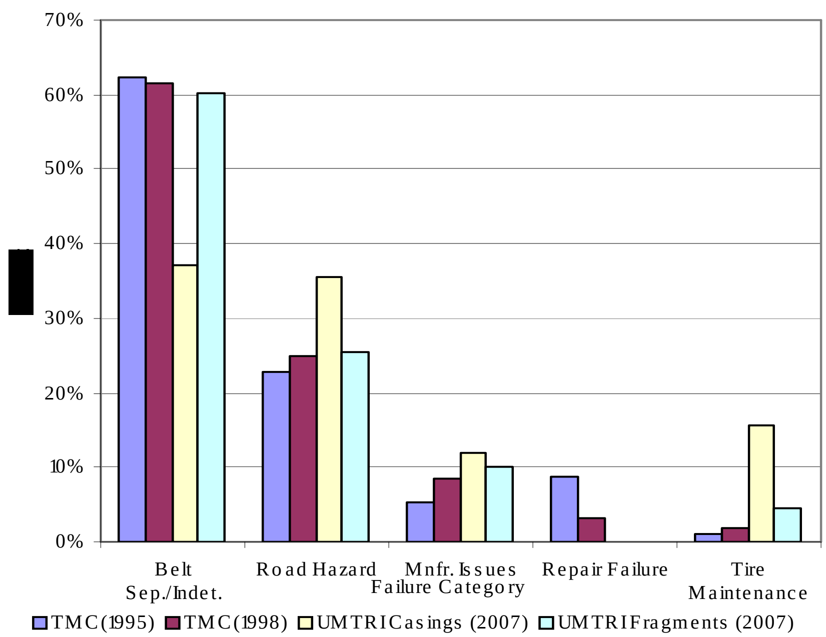


Figure 9.39 - Failure Category Study Comparison Retread Tires

Note: The failure proportions for OE/new tires (shown in Figure 9.38) are based on the Total values in Table 9.20 (i.e., excluding the 170 casing items whose OE/retread status could not be determined).

Key findings in the comparison of failure reasons can be listed as:

- The 117 OE/new tire fragments failing due to belt separations or otherwise indeterminate approximated 55 percent as a proportion of OE/new tires (i.e., 117 of 214). This proportion was in the same range as tire items failing for similar reasons in the TMC studies of 1995 and 1998 which were 55 and 49 percent, respectively.

- Zero percent of new/OE tires assessed in the TMC studies failed due to manufacturing reasons. This compares to between 4 and 5 percent of new/OE casings or fragments assessed in the UMTRI studies categorized by this type of failure.

- The zero percent of casings/fragments failing due to repair failure in the UMTRI study was due to the nonexistence of this category as a failure option. The UMTRI failure categories were determined as the last event before the tire failure (see section 9.6). A deficient repair at some time in a casing's life may have contributed to excessive heat generation or belt separation. Such events that may have occurred just before the tire failed would have been recorded as the failure reason in the UMTRI study.

- There was a strong similarity in results for retread tire fragments assessed in the UMTRI study and the overall results of the TMC studies. For example, failure due to road hazard approximated 23 percent (TMC 1995), 25 percent (TMC 1998), and 25 percent (UMTRI retread fragments 2007). This type of similarity was not seen for retread casings in the UMTRI study when compared to the TMC study results.

9.11 Additional Comments Regarding Tire Failure Analysis Results

9.11.1 Tires in Dual Assembly

Any large-scale analysis of medium truck tire disablements should take into consideration the fact that these tires operate primarily as dual assemblies, either in drive or trailer axle positions. In practice, one of the tires in a dual assembly may (due to damage or lack of maintenance) be operating while underinflated. In such cases, its correctly inflated mate will have to operate in an overloaded condition, carrying some portion of the underinflated tire's load, in addition to its own. The significance of this is that the properly inflated mate may become the tire that is actually disabled, with no puncture, or other cause, apparent to the examiner. This is particularly significant, because we are aware that, knowingly or unknowingly, a driver may continue to operate his vehicle after one tire in a dual assembly has disabled.

The above points, in the context of this study, help explain the number of instances where heat damage and damage from overdeflection (underinflation) were observed by the examiners. This phenomenon would be applicable to either original tread or retreaded tires that are operating in dual assemblies.

Trailer tire maintenance may differ, for example, because the trailer may not, in many instances, be owned by the company pulling it, and also as related to the fact that trailers, in some cases, may remain parked for weeks or even months between usages.

9.12 Summary

The probable causes of tire failure of the 1,496 tire debris items (i.e., casings and fragments) were presented in this chapter. Extensive information variables enabled probable cause of failure to be determined for the majority of casings (99%) and tire fragments (86%). Road hazards (35%) and maintenance/operational factors (33%) were the top two reasons for casing failure or removal from service. This can be compared to the top two reasons for tire failure (i.e., resulting in roadside debris), road hazards (39%) and excessive heat (30%). Continued analysis of the data indicated the preponderance of casings or fragments originating from the trailer axle and this same axle also saw the lowest median intact casing tread depth (0.00 mm [of any axle]) and the lowest median tire fragment length (1270 mm [of any axle]). Comparison of the UMTRI Tire Debris Study with the TMC Debris Studies (i.e., 1995 and 1998) saw a strong similarity in results for retread tire fragments and the overall results of the TMC studies. Overall, during the course of the failure analysis it was observed that there was a lack of any observations that would indicate the existence of any systemic manufacturing or process issues with either OE or retreaded medium-truck tires.

10 CONCLUSIONS AND RECOMMENDATIONS

This study examined 300 discarded tire casings from truck stops and 1,196 tire fragments that were collected along the interstate highway system at five representative locations throughout the country. The casings and tire fragments were examined by tire forensic experts at Smithers Scientific Services (i.e., the consultant) to determine the probable failure type, probable axle location of the failed tire, and the likely reason for the tire failure. The consultant's final report contained the following conclusions.

10.1 Casings

- The tire casings were collected at truck stops. For tires removed from service at truck stops, it would be anticipated that the primary reasons for their removal would be road hazards or maintenance/operations issues, rather than routine, planned removals for replacement based on number of times retreaded or casing age.

- The casings themselves ranged in age from approximately 1 to 17 years since the week and year of manufacture. The vast majority of the casings were manufactured since the year 2000, which is consistent with our experience.

- The most recently retreaded dates ranged from approximately a few months to 13 years. (In cases where the casing had been retreaded more than once, Smithers analysts recorded only the most recent retreader's tire identification number information). This range of retread manufacturing dates is consistent with what would be expected.

- Approximately 127 (43%) of the 300 casings analyzed were retreads and 169 (57%) were original tread casings. The roughly 40 percent - 60 percent split in this analysis is not surprising, based on the experience of consultant's analysts. The percentage of original tread to retread tires in class 6, 7, and 8 vehicle service can vary from year to year and be significantly influenced not only by general economic conditions and the ebbing and flowing of new truck, tractor, and trailer sales, but also by fleet vocation. The percentage of retreaded tires in service in the waste hauling industry, for example, may well be higher than in the general population of vehicles involved in long-haul trucking.

- A significant majority of the retreaded casings (91) were in the first retread stage, with 27 in the second retread stage and five in the third retread stage. For medium-truck retreads in highway service, one would anticipate that the majority of retreaded tires operating would be in the first retread stage, with progressively fewer in the second and later stages.

- The vast majority of the casings that could be identified as retreads were manufactured using the pre-cure process. The Consultant's analysts anticipated this, as, particularly in the U.S. market, pre-cure process retreading has become more the norm.

- The top three reasons that the casings were removed from service were road hazards – 97 (32 %); maintenance/operational factors – 90 (30%); and overdeflected operation – 43 (14%). (Tires collected from truck stops may be expected to have a slightly higher percentage of causes for removal relating to road hazards, maintenance, and underinflation, as these removals are generally unplanned.)

- With regard to likely exclusive axle service, a significant proportion of the casings examined (108) were likely from trailers, 65 were likely from the drive axle, and 61 could not be identified as to axle service. This general result was anticipated. In practice, many fleets tend to run first-retread casings on the drive axle and then concentrate retread usage on the trailers. Also, there are many more trailers than tractors in the U.S. commercial vehicle fleet. However, as mentioned earlier in this section, the relative percentage of original tread to retread tires in service varies over time.

- Slightly less than 10 percent of all casings identified showed any manufacturing or process-related conditions that could be expected to contribute to the tire being removed from service. Of this slightly less than 10 percent, the vast majority appeared to be retreading process issues, such as casing selection and repair, or tread rubber application issues. The vast majority of casings were removed from service for road hazard, maintenance/operational issues, and overdeflected operation, as would be expected for both original tread casings and retreads.

- It should be noted that less than 10 percent of the casings categorized were in the indeterminable category. By comparison, approximately 39 percent of the number of tire fragments were categorized as indeterminable. This can be readily understood when one considers the amount of the tire that is available for analysis and categorization with a tire fragment, compared to a tire casing.

- In the course of examining casings for this tire debris analysis, we did not observe any instance in which a complete retreader's TIN, as defined by Part 574.5 *tire identification* regulation, was utilized. Also, the retreaders' TIN markings, which were hot-branded onto the tires, were frequently less than legible. Legibility issues included light branding and a second light branding with a following attempt to return the iron to the same spot (to brand deeper).

10.2 Tire Fragments

In consideration of tire fragments generally, and particularly of their appearance on the roadside, the reader should be generally aware that tires consist of a number of components. These components, such as the tread and the steel belts (in the case of radial tires), are assembled and cured together to form the complete tire. So when tire damage or operating conditions such as overdeflected operation occur, the various component parts can separate and detach from the casing. Therefore, it is not unanticipated that fragments of tires (from both original tread and retreaded tires) will be seen on the roadway from time to time.

- The size of the fragments examined varied from relatively small sections of tread or tread and belt material, to virtually complete, detached tread and belt packages that, if repositioned on their casings, would reach entirely around the casing circumference. Although a significant portion of the fragments examined did not contain enough information for the Smithers analysts to be able to categorize them, a categorization was made in the majority of instances.

- Of the 1,196 tire fragments that were analyzed, approximately 18 percent were from original tread tires, approximately 68 percent were from retreaded tires, and in approximately 14 percent of the examinations no determination as to original tread or retread could be made.

- Looking at the totals of original tread and retread fragments from each of the five geographical regions, we found no dramatic variance. The original tread fragment percentages ranged from a low of 13 percent in Wytheville, Virginia, to a high of 24 percent in Gary, Indiana. The retread fragment percentages were more closely aligned, ranging from 63 percent in Gainesville, Florida, to 73 percent in Wytheville, Virginia.

- The vast majority of the retreaded fragments had been retreaded with various pre-cure processes, which is consistent with our understanding of U.S. marketplace presence.

- For those fragments examined that could be assigned to a damage category (728 of the 1,196 total), the two top categories for removal from service were road hazard (39%) and excessive heat (30%).

- For the maintenance/operational and manufacturing/process categories, the percentages were approximately 14 percent each.

- The reader will note that the percentage of fragments in the overdeflected operation category is substantially less than the percentage for this category among the casings examined – 3.0 percent compared to 15.1 percent, respectively. The fragments typically demonstrate the physical manifestation of the overdefelected operation in the form of excessive heat damage/evidence. While the casings, by comparison, demonstrate the evidence of overdeflected operation ordinarily without the direct evidence of excessive heat.

- The percentage of fragments demonstrating road hazard damage was approximately the same as the percentage of road hazard damage among the casing population examined (approximately 38.5% and 36%, respectively).

- Approximately 13.7 percent of the fragments were placed into the manufacturing/process category, compared to approximately 8 percent for the casings in the same category. The significance of this difference could not be determined in this study. The relative ratios of original tread versus retreaded tires in the casing portion of this study were significantly different from the ratio of original tread to retread in the fragment portion of the study. The impact of those differences on the likelihood of manufacturing process conditions would require additional investigation outside the scope of this study.

- With regard to the likely exclusive axle service from which the fragments emanated, approximately 628 were from the trailer axle, 327 from the drive axle, 43 from the steer axle, 114 two or more axles, and 84 not determined. It must be recognized that the total 1,196 also includes fragments that were characterized as potentially being from more than one axle type (a given tire could have been in service on either the drive or trailer axle, for example).

- With regard to the population of tire fragments in this study, consideration must be given to the plausibility, or even the likelihood, that one or more fragments could well have come from the same disabled tire. This possibility is inherent, due to the way in which tire debris from a single disabled tire is typically concentrated on a section of highway, and subsequently picked up by State DOT personnel.

10.3 Safety Analysis Conclusions

Crash data from all available sources were reviewed, including UMTRI's TIFA file, the GES and CDS data from NHTSA, and the LTCCS data from FMCSA. The analysis of the available data found that crashes related to truck tire defects and debris are a small part of the crash problem. The conclusions of the safety analysis are as follows:

- Truck crash involvements with coded tire defects were associated with warmer weather and high-speed roads. In both the TIFA and GES data, coded tire defects were more common in the summer months than at other times of year. In GES, the incidence of tire defects was about twice as great from July through October as in the rest of the year. TIFA data also showed a higher percentage of crash involvements related to tire defects from June through September.

- The data show much higher incidence of tire defects in truck crashes on roads with posted speed limits of 60 mph and above. The incidence of tire defects was particularly high on roads posted at 75 mph.

- Tire-defect-related crashes are about twice as likely to be single-vehicle crashes and to involve loss of control than other truck crash involvements.

- Rollover itself was much more likely in crashes in which the truck had tire defects than in other crashes.

- Tire failure on tractor steer axles is associated with vehicle loss of control. In every case examined in detail, when the tire failed, the truck swerved toward the side where the failure occurred.

- Coded tire defects in the TIFA database are associated with straight trucks, older vehicles, private carriers, and intrastate carriers. The incidence of tire defects in straight trucks involved in fatal crashes is about twice as great as any other common truck configuration. Trucks operated by intrastate, private carriers are also more likely to have coded tire defects, and trucks from older model years have higher rates of tire defects than more recent models.

- Less than one percent of the crash involvements in TIFA and GES included an identified tire defect. Annually, that translates to about 55 fatalities and 45 other injuries in fatal truck crashes in which tire defects are noted, out of about 5,500 fatalities and 4,400 other injuries. In the LTCCS data, only 0.5 percent of crash involvements are coded as precipitated by tire failures.

- The number of traffic crashes in which a driver swerved to avoid an object on the road was found to be in the range of 0.01 percent to 0.2 percent of all traffic crash involvements.

10.4 Overall Study Conclusions

The analysis of tire fragments and casings collected in this study has found that the proportion of tire debris from retread tires and OE tires is similar to the estimated proportion of retread and OE tires in service. Indeed, the OE versus retread proportions of the collected tire debris broadly correlated with accepted industry expectations. Additionally, there was no evidence to suggest that the proportion of tire fragments/shreds from retread tires was overrepresented in the debris items collected.

Examination of tire fragments and tire casings (where the OE or retread status was known) found that road hazard was the most common cause of tire failure, at 38 percent and 36 percent respectively. The analysis of tire casings found maintenance and operational issues accounted for 32 percent of the failures while over-defection accounted for 16 percent. Analysis of tire fragments found that excessive heat was evident in 30 percent of the samples examined. These results suggest that the majority of tire debris found on the Nation's highways is not a result of manufacturing/process deficiencies. Similar findings are corroborated in earlier studies of tire debris.

The evaluation of available crash data shows that vehicle crashes related to truck tire failure and truck tire debris are very rare events that account for less than 1 percent of traffic crash involvements.

10.5 Topics for Further Research

10.5.1 Longitudinal Study of the Tire Life Cycle

With the advent of tire monitoring systems it is now possible to follow the service life of a tire from the time of its first mounting to its final dismounting and ultimate destruction. Tire monitoring systems cannot only track the service/operating life of a tire, but can also provide information on the internal tire pressure and temperature of individual tires. Advanced systems not only provide the driver with relevant tire information but the same information can be transmitted to fleet managers located hundreds of miles away.

A longitudinal study of the tire life cycle will yield important information on which factors directly influence tire durability and safety at specific points in the tire's life under different operating conditions. Other research issues that may be answered as part of a tire life cycle research effort would be (Kreeb et al., 2003):

- Understanding the impacts of varying tire pressures, vehicle speeds, and vehicle loads on tread wear, tire life, and fuel economy;
- Understanding the complex relationships involving how the number and location of improperly inflated tires on a particular vehicle affect operating costs and handling;
- Developing datasets related to the effectiveness of automatic tire inflation and pressure monitoring systems for commercial vehicles;
- Determining any actual resulting savings derived from improved tire performance and/or maintenance (e.g., fuel economy and/or reduced road calls); and
- Determining the overall performance, reliability, and accuracy of various types of commercial vehicle tire pressure monitoring and automatic inflation systems. This will also involve the testing of such technologies in detecting small changes in pressure at individual wheels, and under varying speeds, loads, temperatures, and other operating conditions.

Currently, empirical information for several of the above research issues is not available in the public domain. This situation has increased the importance of and need for such research to be undertaken. Nevertheless, the remaining challenge in determining the effectiveness and durability of tire monitoring systems is their continued operability when a tire is put through multiple retreads.

10.5.2 Commercial Medium Wide-Base Tire Failure Study

Chapter 4 noted that the majority of tire failure studies have focused on passenger vehicles and the operability of such a vehicle after a tire has failed. Further research (which is subsequently put into the public domain) is needed on the failure propensity of commercial medium- or wide-base tires.

10.5.3 Longitudinal Tire Debris Study

All tire debris studies presented in this report have involved the collection of debris from several sites around the Nation. However, there is still a need to comprehensively understand the generation of tire debris and subsequent impacts on highway safety over a specified collection site and timeframe. Such a site may be the roadside debris collection area (or segment of an interstate) of a State highway maintenance crew. All roadside tire debris collected over a 12-month period by highway maintenance crews, emergency services, or other agencies would be assessed in terms of its vehicle type, exact pick-up location, and OE/retread status. Additionally, traffic flow volumes and crash data for the collection site would be analyzed. This proposed study would be different from previous studies of tire debris in that accurate volumes of generated tire debris would be determined, along with the associated impacts on highway safety all within the context of highway traffic mix and volumes.

11 REFERENCES

Advocates for Highway and Auto Safety. (1998). *Advocates for Highway and Auto Safety Supports a Federal Standard on Retread Truck Tires and Not a Ban on their Use*. October 1, 1998. Press release. Washington, DC: AAHS.

Andres, D.L. (1993). Disposal of Roadside Litter Mixtures. *NCHRP Synthesis of Highway Practice 184.* Washington, DC: National Academy Press.

Bandag. (2007). *Efficiencies - Retread Facts*. Retrieved April 13, 2007, from www.bandag.com/TireProducts/ RetreadFacts.aspx.

Bareket, Z., Blower, D.F., & MacAdam, C. (2000). *Blowout Resistant Tire Study for Commercial Highway Vehicles*. Final Technical Report (Report No. UMTRI-2000-8). Ann Arbor, MI: University of Michigan Transportation Research Institute.

Bearth, D.P. (2007). Testing Improves Quality of Retread Tires. *Transport Topics*, January 29, 2007, 7-8.

Birkland, C.[a] (2005). Keep the Pressure Up. *Fleet Equipment*, *31*(6), 44-46.

Birkland, C.[b] (2005). It’s in the Air. *Fleet Equipment, 31*(11), 16-20.

Blythe, W., Day, T.D., & Grimes, W.D. (1998). 3-Dimensional Simulation of Vehicle Response to Tire Blow-Outs. In *Accident Reconstruction Technology and Animation VIII* (pp.163-179). SAE SP-1319. Warrendale, PA: Society of Automotive Engineers.

Cambridge Systematics & MaineWay Services. (2006). Alternative Truck and Bus Inspection Strategies. *Commercial Truck and Bus Safety Synthesis 10*. Washington, DC: Transportation Research Board.

Carey, J. (1999). *Survey of Tire Debris on Metropolitan Phoenix Highways* (Report No. ATRC-99-11). Phoenix, AZ: Arizona Department of Transportation.

Center for Solid and Hazardous Waste Management. (2002). *Roadside Litter in Florida* (Report S02-02). Gainesville, FL: Center for Solid and Hazardous Waste Management of the University of Florida.

Cole, K. (1998, September 30). Retread Truck Tires Called Unsafe. *Detroit News*, pp. 1F, 8A.

Commercial Tire Systems. (2001). Every Retread is Custom-Made. *Commercial Tire Systems*, *1*(1), 12-13.

Commonwealth of Virginia. (2000). *Need for Standards for Recapped Tires*. House Document 24. Richmond, VA: Commonwealth of Virginia.

Condra, D. (2007). Gator-Hater Legislator Just Wanted a Dialogue. *Heavy Duty Trucking, 86*(3), 8.

Cullen, D. (1996). Speed Kills Tires, Too. *Fleet Owner, 91*(9), 46-52.

Daws, J. (2003). Failure Analysis of Tire Tread Separations. *Practical Failure Analysis, 3*(5), 73-80.

Daws, J. (2007). Forensic Analysis in Tire Tread Separations. *Rubber and Plastics News,* March 5, 2007, 18-22.

Day, S. (2007). New Life for Used Tires – Stories that Tire Retreads Cause “Road Alligators” Are Myths. *Farm Industry News*, *4*(4), 36-38.

Deierlein, B. (1992). Tires: Those Expensive Round Black Things. *Beverage World,* November, 1992, 72.

Deierlein, B. (1996). One More Time Around! Managing for Retreadability. *Fleet Equipment, 22*(10), 59-63.

Deierlein, B. (2003). Tire Management: An Update. *Fleet Equipment*, *29*(6), 34-38.

Demsky, I. (2004, October 26). I-440 Accident Kills Woman, Seriously Injures Her Aunt. *The Tennessean*, p. 6.

Dickerson, C.P., Arndt, M.W., & Arndt, S.M. (1999). Vehicle Handling with Tire Tread Separation. *Proceedings of the 1999 Society of Automotive Engineers International Congress and Exposition*, Vehicle Dynamics and Simulation Session (SP-1445). Detroit, MI: 25-46.

Environmental Protection Agency. (1995). Appendix: Particulate Emission Factors for Mobile Sources as Calculated in the Model Part 5. In *Draft User's Guide to Part5: A Program for Calculating Particle Emissions from Motor Vehicles*. Report No. EPA-AA-AQAB-94-2. Ann Arbor, MI: National Motor Vehicle and Fuels Emission Laboratory, Office of Mobile Sources.

Environmental Protection Office. (2005). *Profile of the Rubber and Plastics Industry, 2nd Edition*. EPA Office of Compliance Sector Notebook Project. Washington, DC: Office of Enforcement and Compliance Assurance.

Fay, R. J., & Robinette, R.D. (1999). Vehicle Stability and Handling Characteristics Resulting from Driver Responses to Tire Disablements. *Proceedings of the 32nd International Symposium on Automotive Technology & Automation*. Vienna: 165-170.

Forbes, G., & Robinson, J. (2004). *The Safety Impact of Vehicle-Related Road Debris*. Washington, DC: AAA Foundation for Traffic Safety.

Galligan, J. (1999). Unraveling on the Road: Tire Debris Won't Go Away. *Transport Topics*, April 5, 1999, 18-22.

Gardner, J.D., & Queiser, B.J. (2005). Chapter 15 – Introduction to Tire Safety, Durability and Failure Analysis. In A.N. Gent & J.D. Walter (Eds.), *The Pneumatic Tire*. Washington, D.C.: National Highway Traffic Safety Administration.

Goodyear Tire & Rubber Company. (2003). *Radial Truck Tire and Retread Service Manual*. Akron, OH: The Goodyear Tire & Rubber Company.

Harris, L. (2007). *Response to the Phelan article "Ban Retread Tires? Not So Fast."* Retrieved May 31, 2008, from http://suburbanjournals.stltoday.com/articles/2007/10/14/news/sj2tn20071013-1014ndj_retred.ii1.txt.

Insurance Institute for Highway Safety. (2007). *Fatality Facts 2006 - Large Trucks*. Retrieved May 31, 2008, from www.iihs.org/research/fatality_facts_2006/largetrucks.html.

Kahl, K.B., & Fambro, D.B. (1995). Investigation of Object-Related Accidents Affecting Stopping Sight Distances. *Transportation Research Record*, 1500, 25-30.

Keep America Beautiful. (2008). *KAB's Seven Primary Sources of Litter*. Retrieved May 31, 2008, from www.kab.org/site/PageServer?pagename=litter_sevensources.

Kenworth Truck Company. (2003). *White Paper on Life Cycle Cost*. Kirkland, WA: Kenworth Trucking Company.

Kreeb, R.M., Nicosia, B.T., & Fisher, P.J. (2003). *Commercial Vehicle Tire Condition Sensors*. Report No. FMCSA-PSV-04-002. Washington, DC: Federal Motor Carrier Association.

Laubie, D. (1999). *Tire Debris Prevention Efforts: An Industry Update*. Presentation given at the Technical Maintenance Council (of the American Trucking Association) Annual Meeting, March 1999, Nashville, TN.

Laughery, K.R., Mayer, D. L., & Vaubel, K. P. (1990). Tie-Rim Mismatch Explosions: Human Factors Analyses of Case Studies Data. *Proceedings of the Human Factors Society 34th Annual Meeting 1990*. Santa Monica, CA: 584-588.

Lim, P., & Locke, M. (2007, September 26). On Beltline, Tire Debris Turns Deadly: A Swerve to Avoid Tread Causes Crash. *The Raleigh News & Observer*.

Manges, M. (2006). Pandora's Box? Possible Retread Standards Raise Practical Questions. *Modern Tire Dealer, (87)*10, 6.

McCormick, C. (2003). Get on the Right Track. *MotorTruck, (72)*1, 25-28.

Mikolajczyk, S.J. (1999). Steer-Axle Retread Ban Sought: Montana Accident Renews Call for Touch Tire Legislation. *Rubber & Plastics News*, October 25, 1999, 6.

Modern Tire Dealer. (2006). The Top 100 Retreaders in the U.S. *Modern Tire* Dealer, (87), 38-42.

National Safety Council. (1996). *American National Standard Manual on Classification of Motor Vehicle Traffic Accidents*. ANSI D16.1-1996. Itasca, IL: National Safety Council.

nbc30.com. (2007). *Tire Debris Sparks Fatal Crash in North Haven*. Retrieved August 12, 2007, from www.nbc30.com/news/13875433/detail.html?rss=har&psp=news.

Newport Communications. (1998). *Tires and Retreads in the Commercial Truck Market*. Irvine, CA: Newport Communications.

Office of the Federal Register.[a] (2007). *Title 49 Code of Federal Regulations. Volume V*. Part 574, pp. 1108-1119. Washington, DC: Office of the Federal Register.

Office of the Federal Register.[b] (2007). *Title 49 Code of Federal Regulations. Volume V*. Part 571.117, pp. 359-364. Washington, DC: Office of the Federal Register.

Office of the Federal Register.[c] (2007). *Title 49 Code of Federal Regulations. Volume V*. Part 393.75, pp. 425-426. Washington, DC: Office of the Federal Register.

Office of the Federal Register.[d] (2007). *Title 49 Code of Federal Regulations. Volume V*. Part 571.119, pp. 410-415. Washington, DC: Office of the Federal Register.

Office of Highway Policy Information. (2007). Table VM-1, Annual Vehicle Distance Traveled in Miles. In *Highway Statistics, 2006*. Washington, DC: Office of Highway Policy Information - Federal Highway Administration.

Phelan, B. (2007, October 14). Ban Retread Tires? Not So Fast. *Suburban Journals*.

R.W. Beck, Inc. (2007). *Literature Review – Litter. A Review of Litter Studies, Attitude Surveys and Other Litter-Related Literature*. Stamford, CT: Keep America Beautiful, Inc.

Ranney, T.A., Heydinger, G., Watson, G., Salaani, K., Mazzae, E.N., & Grygier, P. (2003). *Investigation of Driver Reactions to Tread Separation Scenarios in the National Advanced Driving Simulator (NADS)* (Report: DOT HS 809 523). Washington, DC: National Highway Traffic Safety Administration.

Robinette, R.C., & Fay, R.J. (2000). *Drag and Steering Effects from Disablements of Run Flat Tires* (Report No. 2000-01-1316). Detroit, MI: Society of Automotive Engineers.

Rohlwing, K. (2004). Tire Debris Investigation Secrets. *Modern Tire Dealer, (85)*8.

Rubber Manufacturers Association. (2006). *Factbook 2006: US Tire Shipment Activity Report for Statistical Year 2005*. Washington, DC: Rubber Manufacturers Association.

Smithers Scientific Services Inc. (2008). *Consultant's Report for Medium Truck Tire Debris Analysis*. Akron, OH: Smithers Scientific Services Inc. (Unpublished).
State of California. (2006). *2005 Annual Average Daily Truck Traffic on the California State Highway System.* State of California Business, Transportation & Housing Agency. Sacramento, CA: California Department of Transportation.
Svenson, A. (2007). *Imported Used Tires*. Email communication to John Woodrooffe, November 26, 2007.
Tire Business. (2006). North American Tire Production Facilities. *Tire Business*, August 28, 2006, 15.
Tire Retread and Repair Information Bureau. (2007). *State by State Vendor Statistics*. Retrieved August 10, 2007, from www.retread.org (members-only area).
Transportation Data Center. (2006). *Data Set Codebook FARS 2005, Version 13-Jun-06*. Report No. UMTRI-2006-23. Ann Arbor, MI: University of Michigan Transportation Research Institute.
Transportation Research Board. (2006). *Tires and Passenger Vehicle Fuel Economy*. Special Report 286. Washington, DC: National Research Council.
U.S. Department of Commerce/U.S. Census Bureau.[a] (2004). *Tire Retreading: 2002*. Economic Census Manufacturing Industry Series. Washington, DC: U.S. Department of Commerce.
U.S. Department of Commerce/U.S. Census Bureau.[b] (2004). *Tire Manufacturing (Except Retreading): 2002.* Economic Census Manufacturing Industry Series. Washington, DC: U.S. Department of Commerce.
Walenga, G. (2006). *How Long Do Commercial Truck Tires Last*? Presentation made at the 22nd Annual Tire Industry Conference, Hilton Head, SC.
Walenga, G. (2008). Personal communication, May 6, 2008.
Waytiuk, J. (2008.) *Denray Tire - The Bandag Process*. Retrieved April 13, 2007 from www.denraytire.com/bandagprocess.html.
Winkler, C.[a] (1990). *Report on Failure Testing of Thirty Tires*. Ann Arbor, MI: University of Michigan Transportation Research Institute.
Winkler, C.[b] (1990). *Report on Failure Testing of Forty-Two Tires*. Ann Arbor, MI: University of Michigan Transportation Research Institute.

APPENDIX A

U.S. COMMERCIAL TIRE MANUFACTURERS

U.S. Commercial Tire Manufacturers (i.e., Original Equipment) as of 2005

Name	Truck/Bus Tire Manufacture[1]	Estimated Daily Tire Production Capacity[2] (# units)
Bridgestone Firestone	Yes	147,600
Carlisle Tire & Wheel	No	33,000
Continental Tire North America	Yes	28,053
Cooper Tire & Rubber	No	119,800
Denman Tire Corp	No	2,600
Goodyear-Dunlop Tire	Yes	16,000
Goodyear Tire & Rubber	Yes	256,000
GPX International Tire Corp	na	822*
GTY Tire Co.	na	2,740*
Hoosier Racing Tire Corp.	No	na
Michelin Aircraft Tire Corp	No	634*
Michelin North America Inc.	Yes	164,197*
Pirelli Tire in North America	No	630*
Specialty Tires	No	4,395*
Titan Tire Corp.	No	23,450
Toyo Tire North America Inc.	Yes	5,479*
Trelleborg Wheel Systems America Inc.	No	2,054*
Yokohama Tire Corp.	Yes	15,068*

Sources: [1]RMA Factbook, 2006 & [2]Tire Business, 2006

*Estimated based on yearly production figures divided by 365 days per year

APPENDIX B

TIRE PLANT MANUFACTURING PERMITS ISSUED

Tire Plant Manufacturing Permits Issued (by Country) as of November 2007

Algeria	2	Hungary	4	Serbia	2
Argentina	4	India	38	Singapore	1
Armenia	1	Indonesia	14	Slovak Republic	2
Australia	9	Iran	1	Slovenia	1
Belarus	2	Ireland	2	South Africa	7
Belgium	3	Israel	2	South Korea	2
Brazil	18	Italy	16	South Vietnam	1
Canada	22	Japan	29	Spain	14
Chile	2	Kenya	1	Sri Lanka	2
China	247	Korea	11	Sweden	8
Colombia	5	Malaysia	8	Switzerland	2
Costa Rica	1	Mexico	18	Taiwan	17
Czech Republic	5	Morocco	2	Tanzania	1
Ecuador	1	Mozambique	1	Thailand	26
Egypt	2	Netherlands	4	Trinidad	1
Ethiopia	1	New Zealand	4	Tunisia	2
Finland	1	Nigeria	1	Turkey	9
France	25	Norway	1	Ukraine	1
Germany	28	Pakistan	1	Uruguay	1
Ghana	1	Peru	2	USA	129
Luxembourg	1	Philippines	5	Venezuela	4
Great Britain	15	Poland	8	Vietnam	6
Greece	1	Portugal	3	Yugoslavia	3
Guatemala	1	Romania	6	Zimbabwe	1
Holland	1	Russia	17	TOTAL	841

APPENDIX C

ANNUAL AVERAGE DAILY TRUCK TRAFFIC

ON THE CALIFORNIA STATE HIGHWAY SYSTEM (2005)

AND VMT CALCULATIONS

2005

Annual Average Daily Truck Traffic
on the
California State Highway System

Compiled by
Traffic and Vehicle Data Systems

State of California
Business, Transportation and Housing Agency
Department of Transportation

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

NOVEMBER 2006

RTE	DIST	CNTY	POST MILE	LEG	DESCRIPTION	VEHICLE AADT TOTAL	TRUCK AADT TOTAL	TRUCK % TOT VEH	TRUCK AADT TOTAL By Axle 2	3	4	5+	% TRUCK AADT By Axle 2	3	4	5+	EAL 1-WAY (1000)	YEAR VER/ EST
005	07	LA	R45.584	A	TUNNEL STATION, JCT. RTE. 14, ANTELOPE VALLEY FREEWAY	197000	19306	9.8	3205	1014	286	14804	16.6	5.25	1.48	76.68	5355	05E
005	07	LA	R53.565	B	SANTA CLARITA, SOUTH JCT. RTE. 126	152000	18939	12.46	3144	994	280	14522	16.6	5.25	1.48	76.68	5253	05E
005	07	LA	R55.48	B	NORTH JCT. RTE. 126	119000	18564	15.6	3082	975	275	14235	16.6	5.25	1.48	76.68	5149	05E
005	07	LA	R55.48	A	NORTH JCT. RTE. 126	103000	17675	17.16	2934	928	262	13553	16.6	5.25	1.48	76.68	4902	05V
005	07	LA	R81.487	B	SOUTH JCT. RTE. 138, ROUTE 138 FREEWAY	71000	17857	25.15	2964	937	264	13693	16.6	5.25	1.48	76.68	4953	05E
005	07	LA	R82.103	A	NORTH JCT. RTE. 138 EAST	73000	18746	25.68	3063	980	345	14358	16.34	5.23	1.84	76.59	5202	05E
005	07	LA	R88.605	O	LOS ANGELES/KERN COUNTY LINE	73000	18936	25.94	3094	990	348	14503	16.34	5.23	1.84	76.59	5254	05E
005	06	KER	R0	O	LOS ANGELES/KERN COUNTY LINE	73000	18936	25.94	3094	990	348	14503	16.34	5.23	1.84	76.59	5254	05E
005	06	KER	R15.858	B	JCT. RTE. 99 NORTH	71000	19951	28.1	3260	1043	367	15280	16.34	5.23	1.84	76.59	5536	05V
005	06	KER	R15.858	A	JCT. RTE. 99 NORTH	32000	8989	28.09	1438	270	180	7101	16	3	2	79	2551	05E
005	06	KER	19.612	A	JCT. RTE. 166	32000	8989	28.09	1438	270	180	7101	16	3	2	79	2551	05E
005	06	KER	38.793	B	JCT. RTE. 119	31000	9136	29.47	1462	274	183	7217	16	3	2	79	2593	05E
005	06	KER	38.793	A	JCT. RTE. 119	32000	9149	28.59	1464	274	91	7319	16	3	1	80	2615	05E
005	06	KER	41.193	B	JCT. RTE. 43	32000	9136	28.55	1462	274	183	7217	16	3	2	79	2593	05E
005	06	KER	41.193	A	JCT. RTE. 43	32500	9279	28.55	1485	278	186	7330	16	3	2	79	2634	05E
005	06	KER	52.145	B	JCT. RTE. 58	32000	9901	30.94	1881	297	198	7525	19	3	2	76	2718	05E
005	06	KER	52.145	A	JCT. RTE. 58	33500	10201	30.45	1785	306	204	7906	17.5	3	2	77.5	2848	05E
005	06	KER	73.017	B	JCT. RTE. 46	33000	10385	31.47	1454	623	312	7996	14	6	3	77	2913	05E
005	06	KER	73.017	A	JCT. RTE. 46	32000	10202	31.88	1428	612	306	7856	14	6	3	77	2862	05E
005	06	KIN	16.595	B	JCT. RTE. 41	31000	9455	30.5	1418	567	284	7186	15	6	3	76	2623	04E
005	06	KIN	16.595	A	JCT. RTE. 41	31000	9300	30	1395	558	279	7068	15	6	3	76	2580	04E
005	06	FRE	14.873	B	JCT. RTE. 198	32000	9901	30.94	1683	347	248	7624	17	3.5	2.5	77	2758	05E

Calculations

AADT	Cars	2 Axle	3 Axle	4 Axle	5+ Axles		Trucks 2+
32,000	22,099	1,881	297	198	7,525	32,000	9,901
33,500	23,299	1,785	306	204	7,906	33,500	10,201
65,500	45,398	3,666			16,436		20,102

Distance (miles)	43.00	VMT Est	VMT Share
Passenger Auto	45,398	1,952,114	69.31%
Light Truck	3,666	157,638	5.60%
Medium/Heavy Truck	16,436	706,748	25.09%
Total	65,500	2,816,500	

Tire Type	VMT Share	Avg # Tires	Adj.	Adj. Share	TMC1995	TMC1998
Passenger Auto	0.69	4	0.028	36.90%	27.40%	25.00%
Light Truck	0.06	4	0.002	2.98%	8.50%	11.00%
Medium/Heavy Truck	0.25	18	0.045	60.12%	64.10%	64.00%
Total	1.00		0.075	1.00	1.00	1.00

APPENDIX D

ESTIMATED AVERAGE ANNUAL DAILY TRUCK TRAFFIC 1998

(SURVEY SITE STATE MAPS)

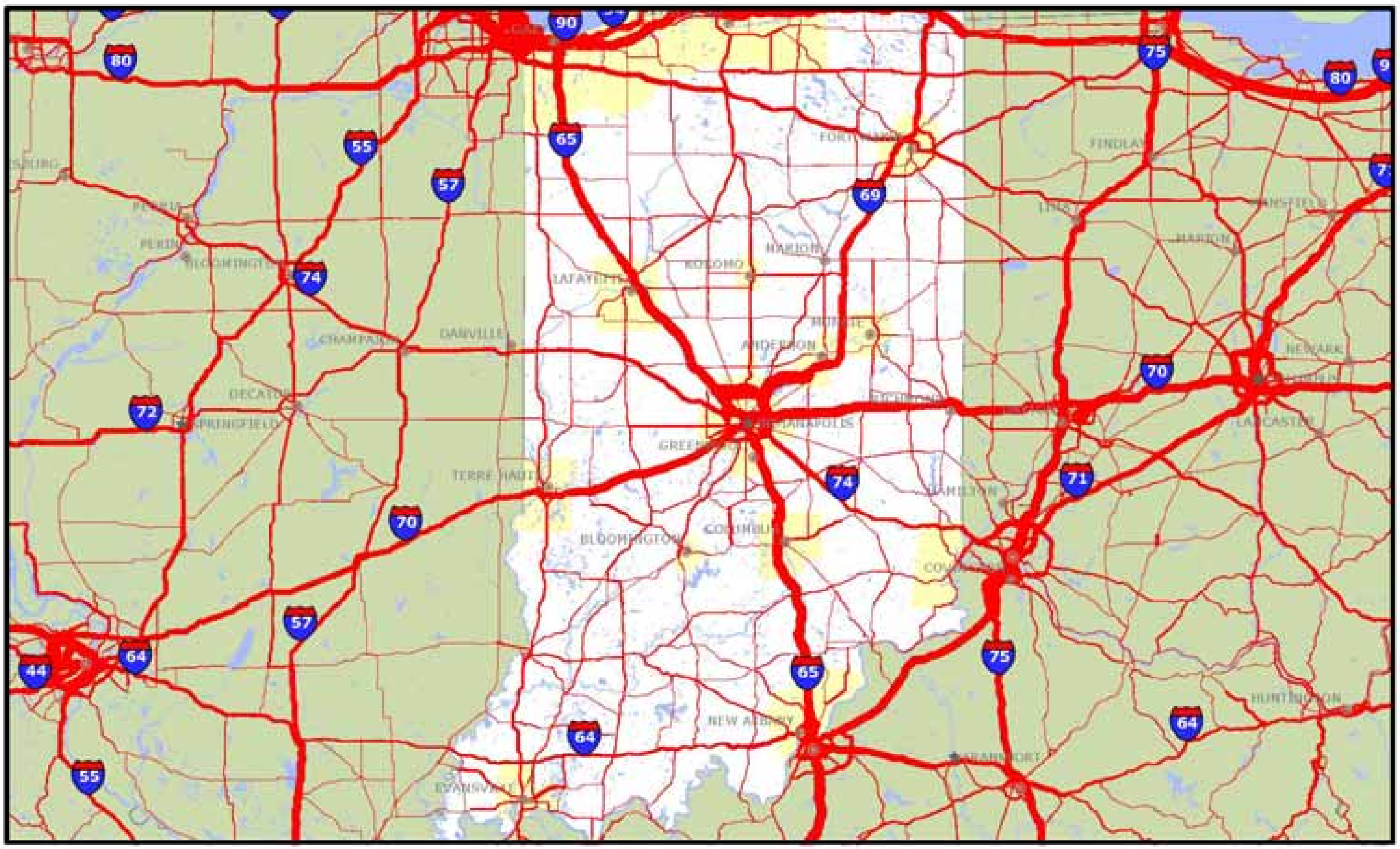
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

Estimated Average Annual Daily Truck Traffic: 1998

FLORIDA

Truck Volume Scale

50,000 25,000 12,500



US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

Estimated Average Annual Daily Truck Traffic: 1998

INDIANA

Truck Volume Scale

50,000 25,000 12,500

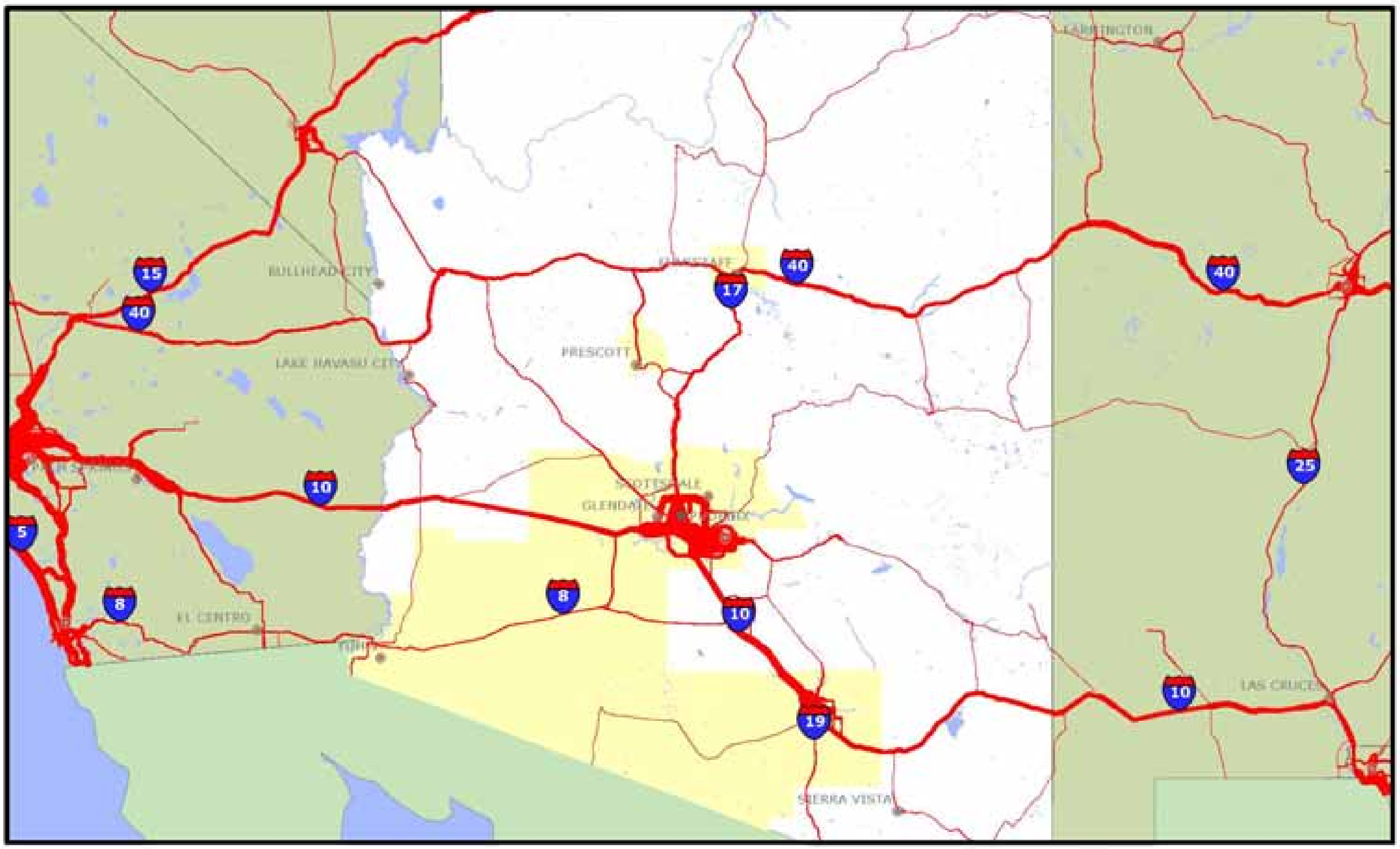
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

Estimated Average Annual Daily Truck Traffic: 1998

CALIFORNIA

Truck Volume Scale

50,000 25,000 12,500



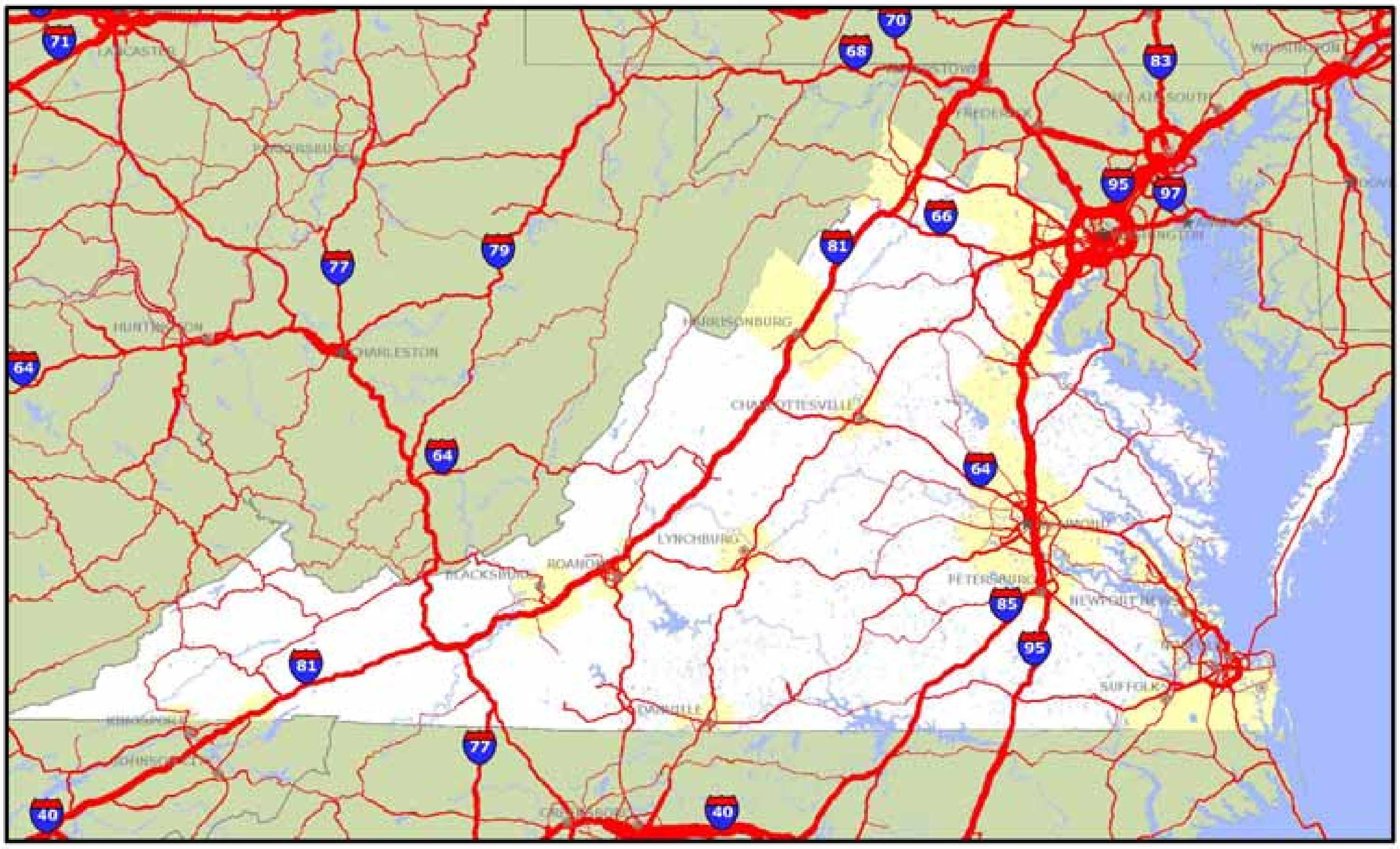
US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

Estimated Average Annual Daily Truck Traffic: 1998

ARIZONA

Truck Volume Scale

50,000 25,000 12,500



US Department of Transportation
Federal Highway Administration
Office of Freight Management and Operations
Freight Analysis Framework

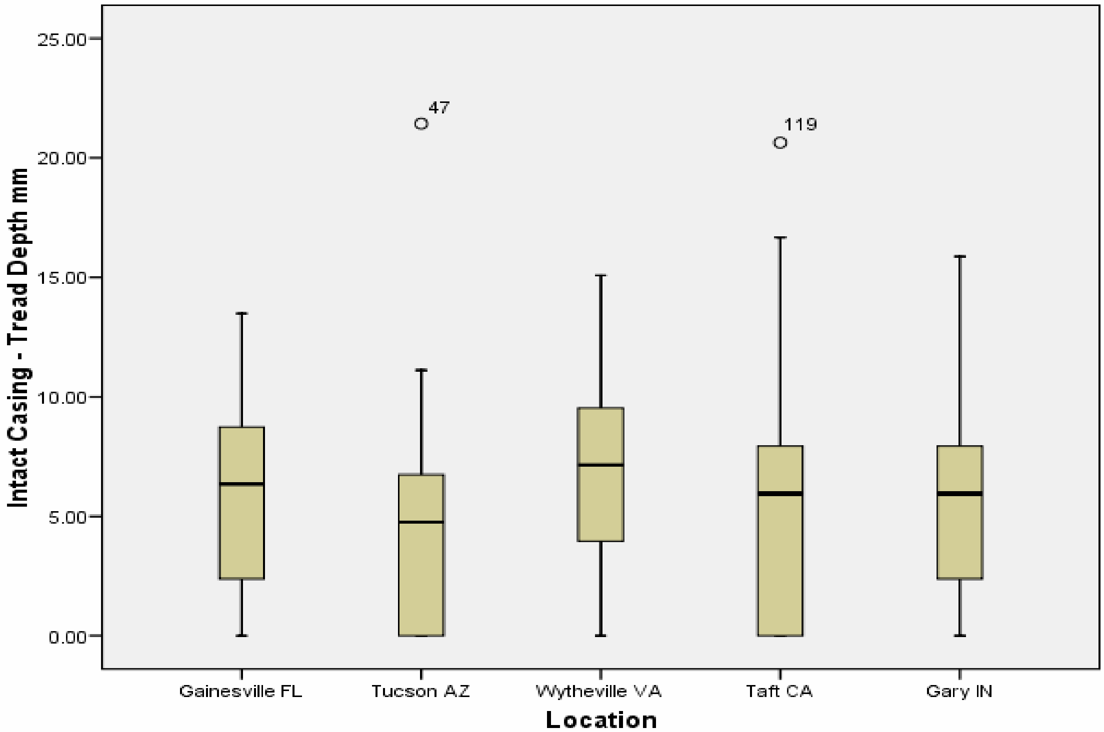
Estimated Average Annual Daily Truck Traffic: 1998

VIRGINIA

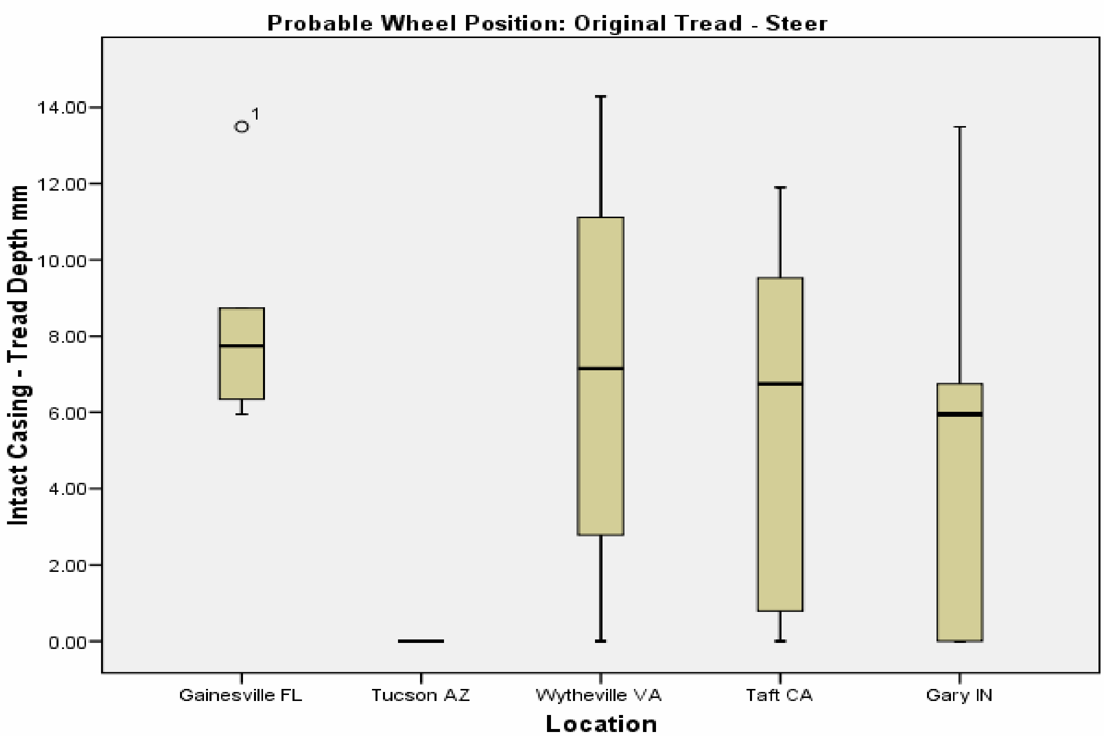
Truck Volume Scale
50,000 25,000 12,500

APPENDIX E

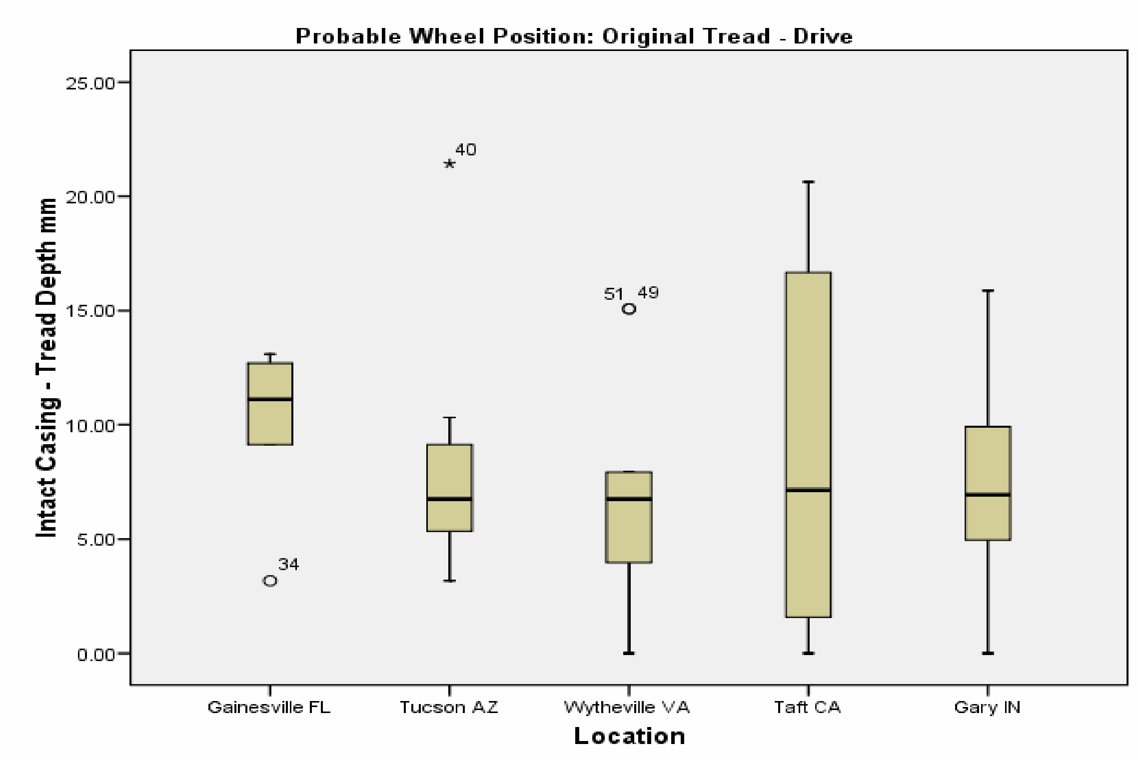
UMTRI 2007 TIRE DEBRIS SURVEY BOX PLOTS

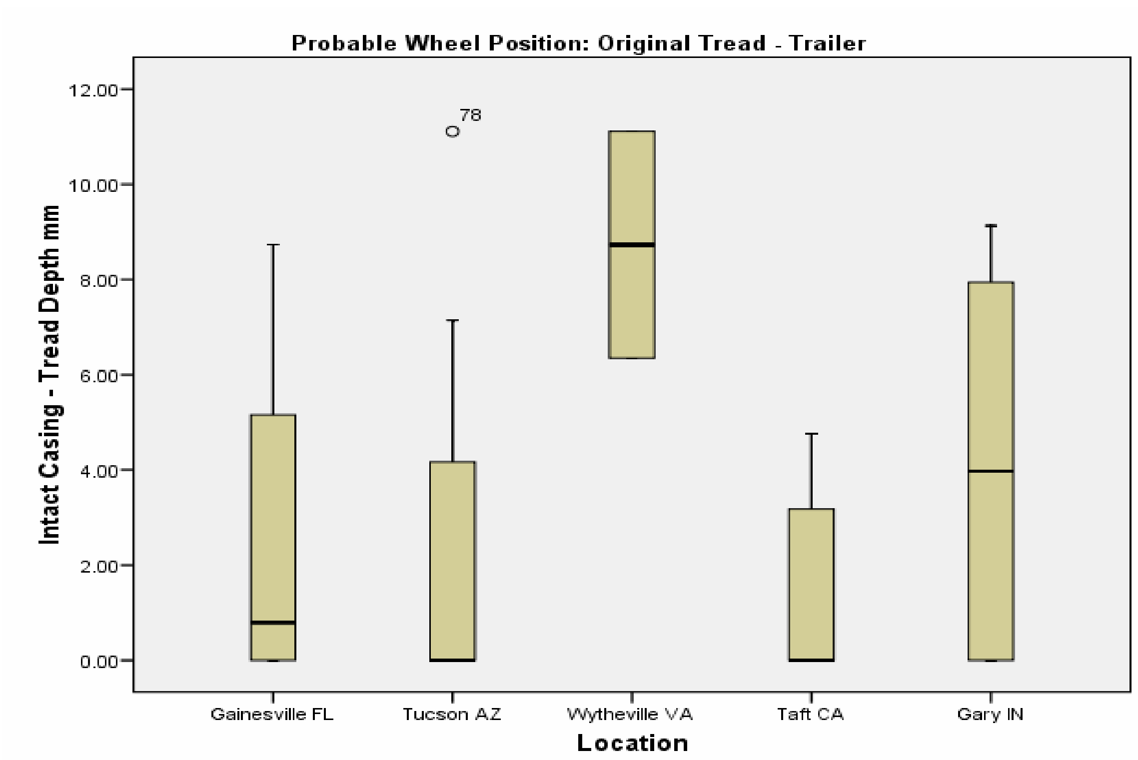


Intact Casing Tread Depth and Collection Location (n=176)

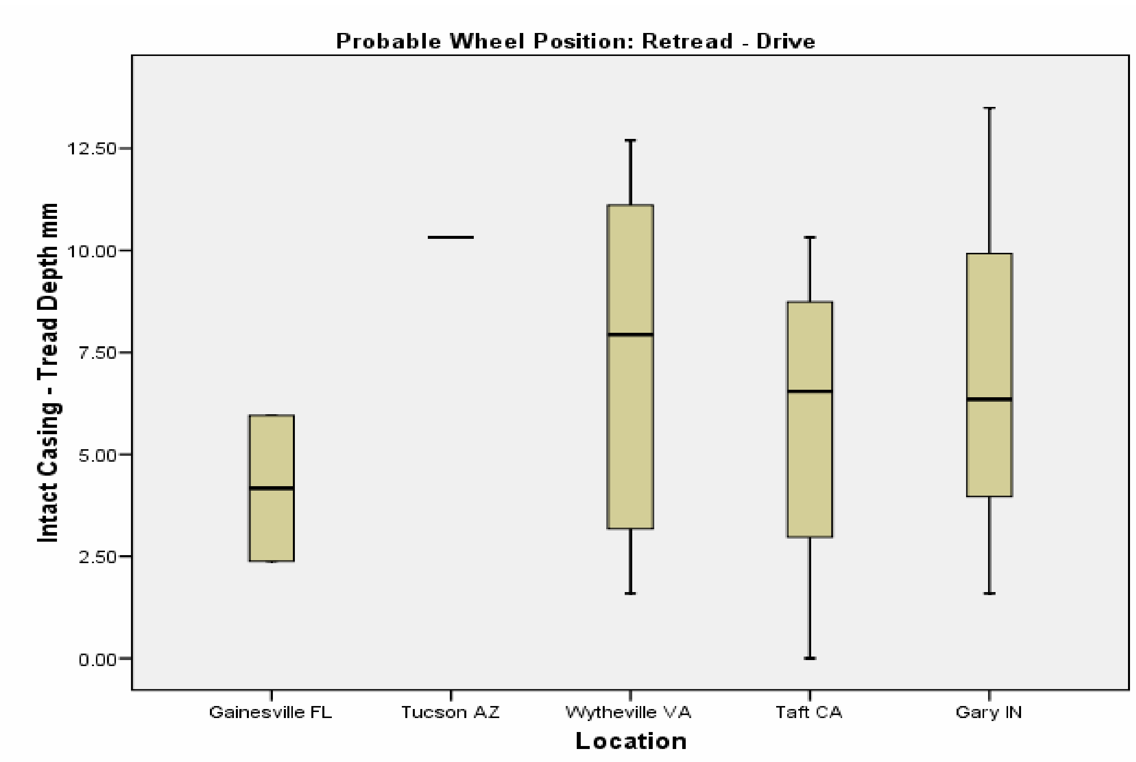


OE Steer Wheel Position by Tread Depth and Collection Location (n=29)

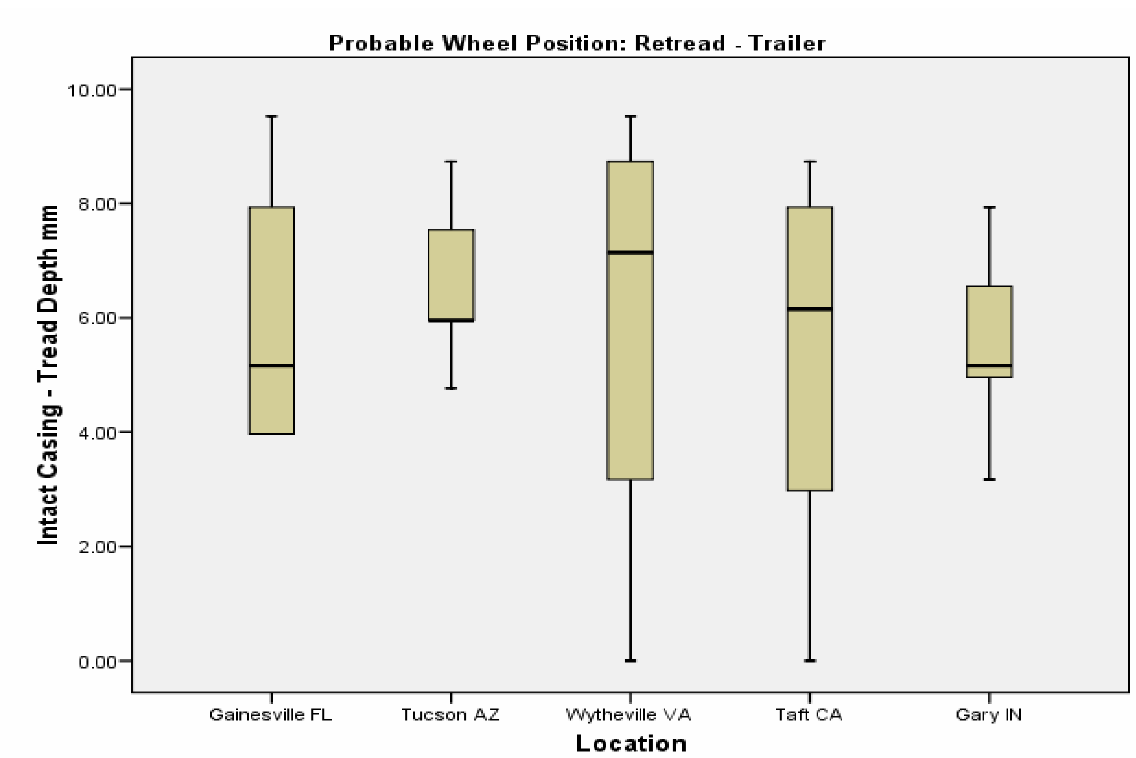




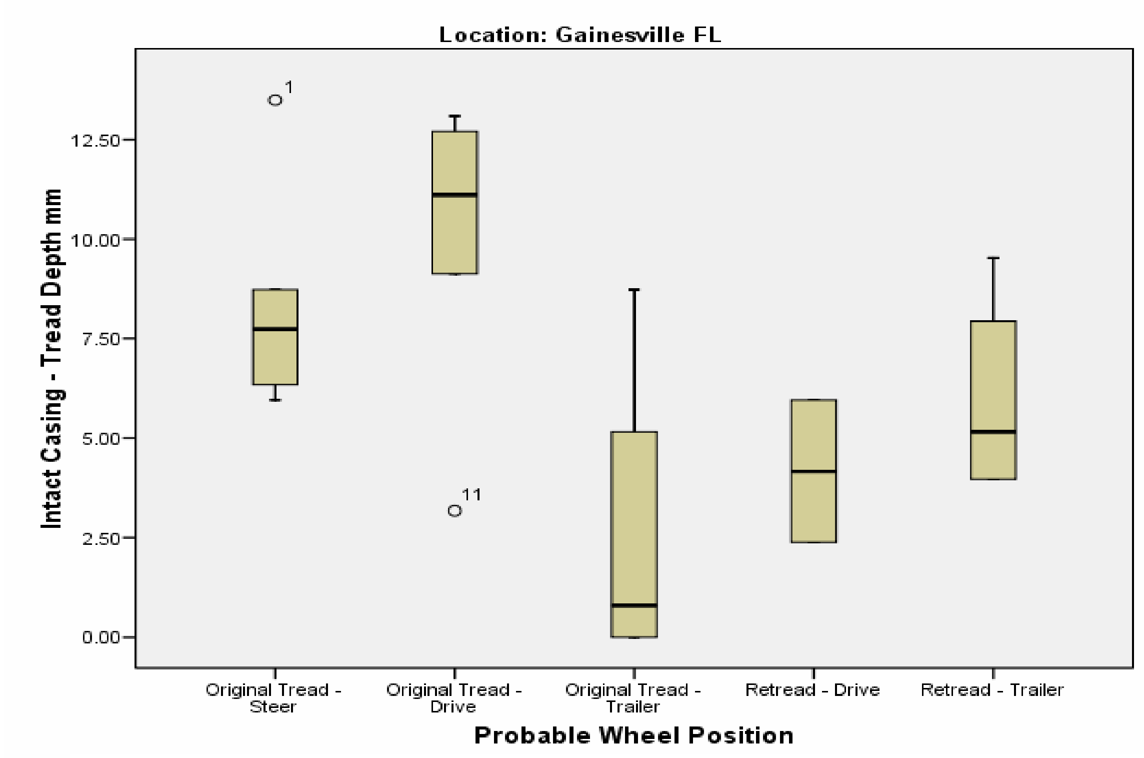
OE Trailer Wheel Position by Tread Depth and Collection Location (n=54)

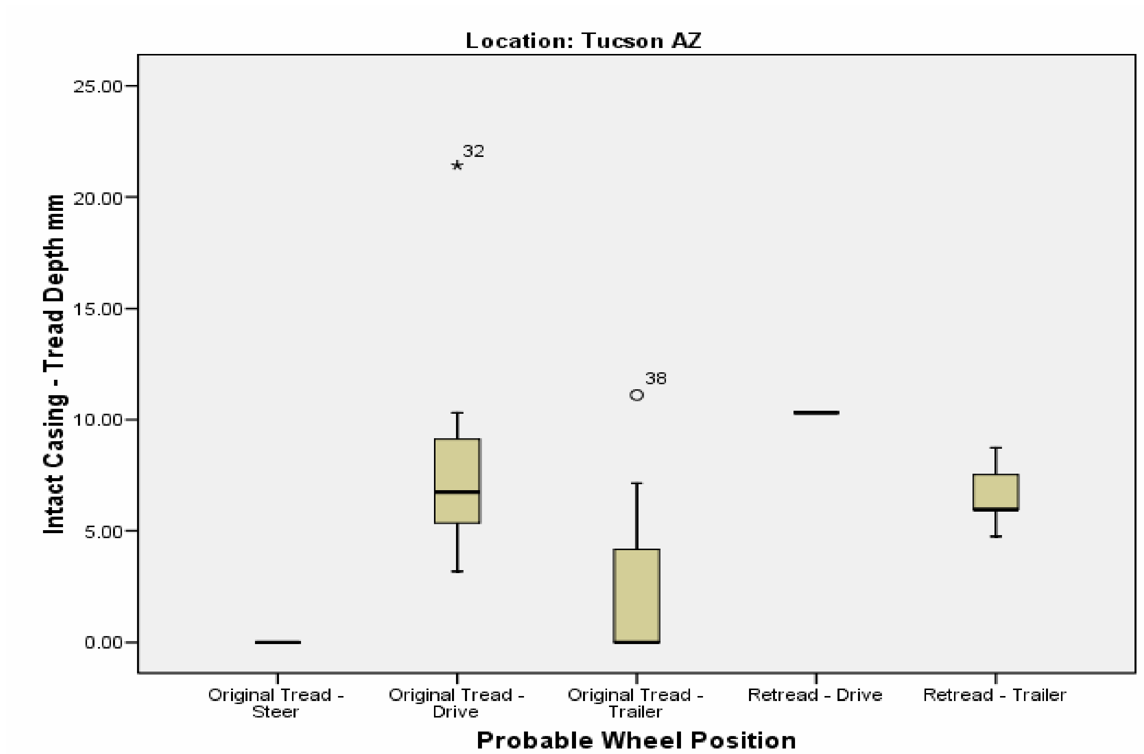


Retread Drive Wheel Position by Tread Depth and Collection Location (n=17)

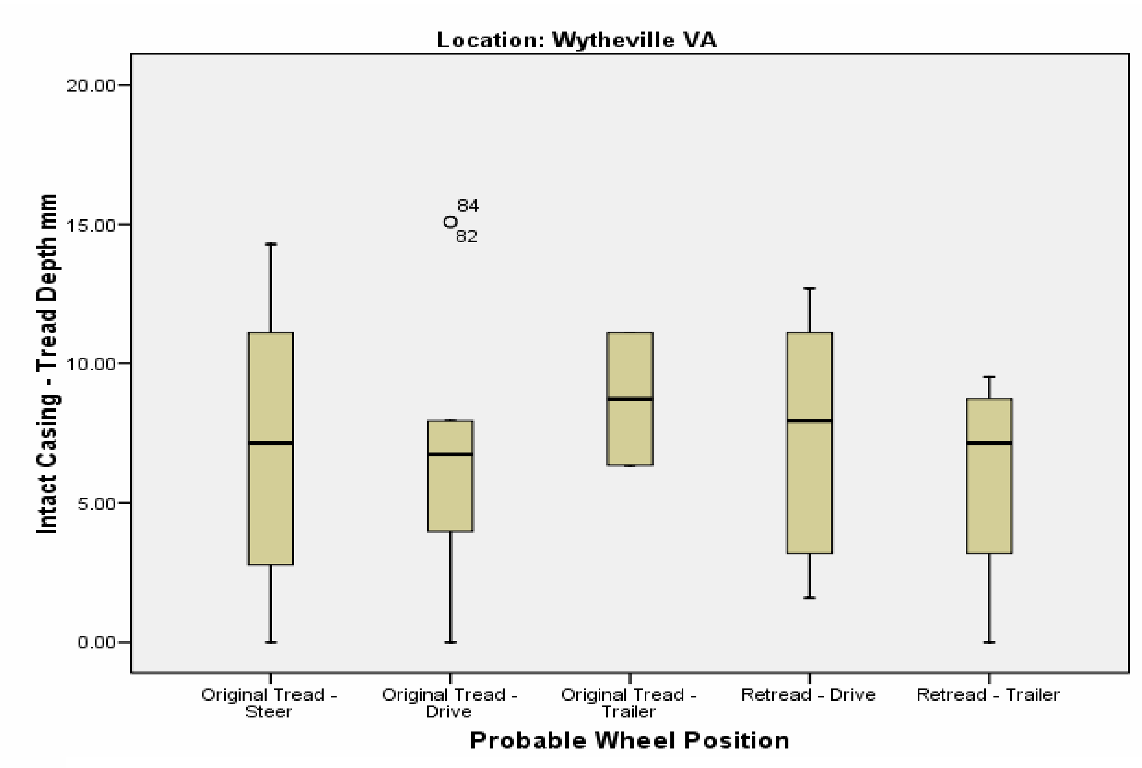


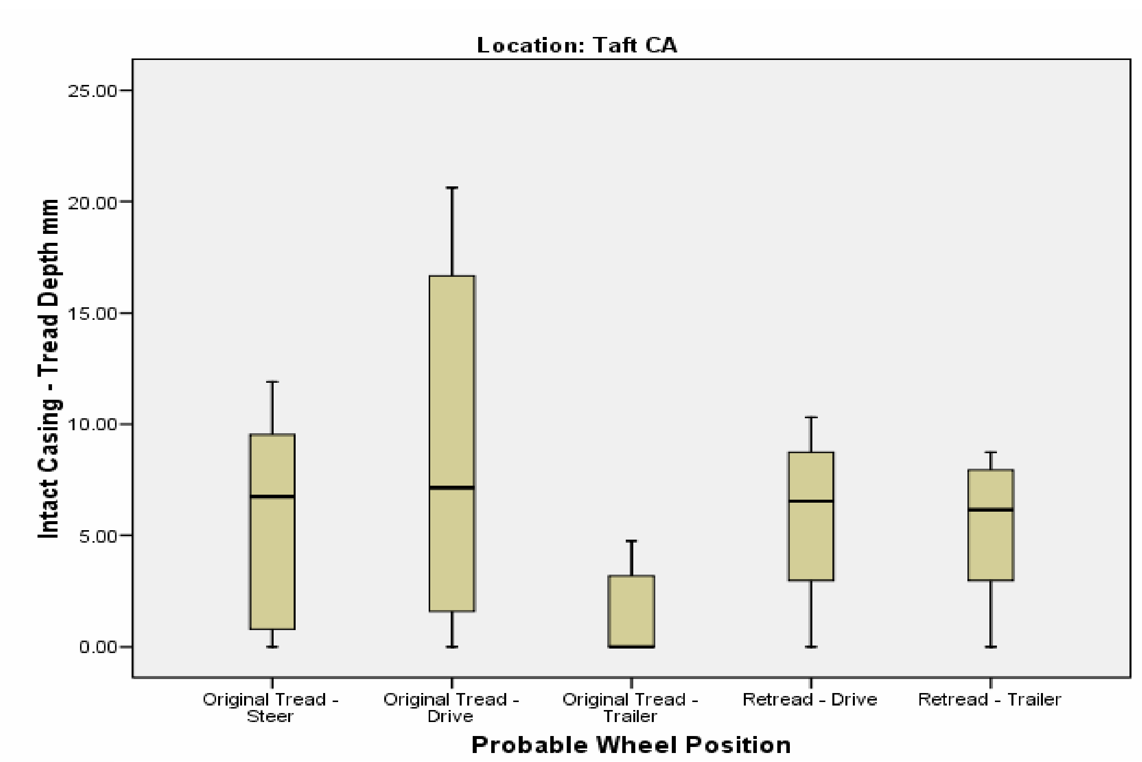
Retread Trailer Wheel Position by Tread Depth and Collection Location (n=40)



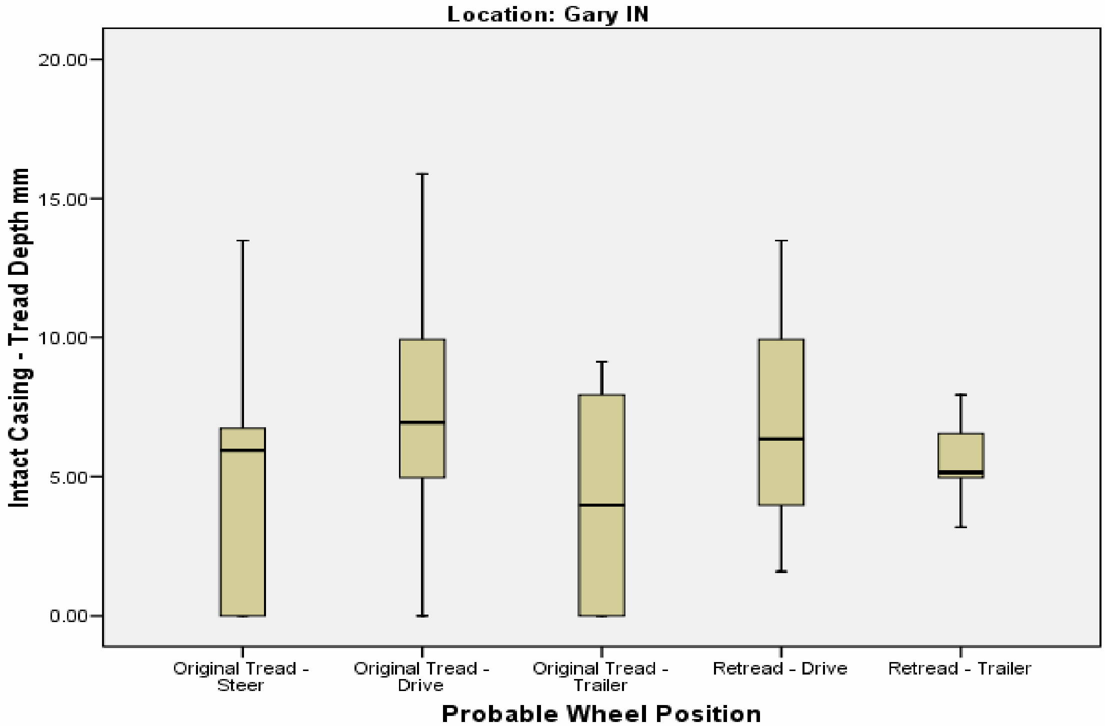


Tucson AZ Probable Wheel Position and Intact Casing Tread Depth (n=42)





Taft CA Probable Wheel Position and Intact Casing Tread Depth (n=31)



Gary IN Probable Wheel Position and Intact Casing Tread Depth (n=39)

DOT HS 811 060
December 2008

U.S. Department
of Transportation
**National Highway
Traffic Safety
Administration**

www.nhtsa.gov