

Retreaded Tire Use and Safety: Synthesis

Prepared for
Paula J. Hammond
Secretary of Transportation
Washington State Department of Transportation

Prepared by
Kathy Lindquist, WSDOT Research Office
Michel Wendt, WSDOT Library

September 3, 2009

Transportation Synthesis Reports (TSRs) are brief summaries of currently available information on topics of interest to WSDOT staff. Online and print sources may include newspaper and periodical articles, NCHRP and other TRB programs, AASHTO, the research and practices of other state DOTs and related academic and industry research. Internet hyperlinks in the TSRs are active at the time of publication, but host server changes can make them obsolete.

Request for Synthesis:

Paula J. Hammond, Secretary of Transportation, Washington State Department of Transportation, requested information related to road debris and the relationship to retreaded tires, the safety of retreaded tires, safety issues related to road debris, whether the use of retreaded tires is increasing, and state and federal laws regulating their manufacture and use. Information in this synthesis is gained from WSDOT staff and reviewed literature sources

Are retreaded tires safe tires and are they responsible for most of the rubber on the roadway?

According to a spokesperson for TRIB, the Tire Retread Information Bureau. Retreaded tires are as safe as comparable new tires, a fact documented by several studies. Yet, retreads have a bad reputation.

The perception that retreads are the primary cause of rubber on the road is wrong as a National Highway Traffic Safety Administration study confirms. Tire debris on highways (also known as rubber on the road or road alligators), is not caused by retreads, according to the NHTSA findings in the *Commercial Medium Tire Debris Study*. The NHTSA study found in its analysis of tire fragments and casings collected that the proportion of tire debris from retread tires and original equipment (OE) tires is similar to the estimated proportion of retread and OE tires in service.

Examination of tire fragments and tire casings (where the OE or retread status known) found in the NHTSA study:

- 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
- Manufacture defects accounted for 16 percent.
- Analysis of tire fragments found that excessive heat was evident in 30 percent of the samples examined.

The study results suggest that the majority of tire debris found on the Nation's highways is not a result of manufacturing/process deficiencies.

The Arizona DOT study, *Survey of Tire Debris on Metropolitan Phoenix*, found that for all types of tires, under-inflation and damage due to roadway hazards and debris were the most common causes of tire failure. Due to the minimal safety hazard posed by tire debris, the over-representation of different tire types in the Phoenix sample, and the attribution of most tire failures to driver negligence or infrequent maintenance, the study did not recommend that a policy be adopted targeting specific types of tires.

More tire debris along the roadways is evident. Does this pose a safety concern?

The studies do not show that retreads on the highway are a significant safety concern. The University Michigan Transportation Research Institute study, *Roadside Alligators and the UMTRI Tire Debris Survey*, found the data does not specifically identify crashes related to debris from truck tire blowouts in the roadway, but the more general category of object in the roadway shows that, 0.16 percent of fatal crashes, and 0.53 percent of all crashes are related to objects in the roadway. The study noted that these percentages form the upper limit to the proportion of crashes caused by debris from tire blowouts. The likely true percentage from blowouts alone is much lower.

Who is using retread tires and what is the incentive?

Retreads used on all types of vehicles, but mostly trucks, because they are less expensive than new tires. According to the *Tire Retread & Repair Information Bureau*, retreaded truck tires represent a savings of over \$3 billion dollars annually for truckers and trucking companies in North America. For most fleets, tires represent the second largest item in their operating budget, right after labor and fuel costs.

Is there more usage now than there used to be?

More vehicles are on the roadways and retreads are cheaper, so one could assume more are in use. The rubber pieces seen on the road come from both new and retreaded tires. Most of the rubber on the road is from truck tire blowouts and mainly due to under inflation, overloading, and tire abuse.

Who governs tire manufacture - particularly for retreads? What are the laws?

USDOT has a certification required for all retread tires. Few states have laws. CA requires checking tires for proper inflation when serviced.

Is there any documented safety hazard?

Not just from retreads; studies show new tires are just as prone to breaking away.

What are most common causes of tire failure?

Road hazard is the most common cause of tire failure (38%), with debris and operational issues next (32%), then excessive heat (30%), and manufacture defects last (16%).

WSDOT Staff Comments

Do WSDOT incident response forms collect information about tire tread debris?

Rico Baroga, WSDOT Assistant State Maintenance Engineer: *In the normal course of maintenance work, there is no formal tracking/documenting retread tire debris separate from other litter/debris. Road kill carcasses are tracked separately but that is about it for debris-specific data. I seem to recall that Ecology has done some litter characterization studies so there may be some information there that may be helpful.*

Ted Trepanier, WSDOT State Traffic Engineer: *Similar to the maintenance work, the Incident Response tracking forms only capture the fact that a response was due to debris, there is not a record of the specific type of debris unless it happens to be noted in the comments.*

Pasco Bakotich, WSDOT State Design Engineer: *RE: the "apparent more retread tire debris". This may be in part because, during the summer, maintenance has many other activities in addition to picking up litter.*

Has the transportation safety community discussed tire tread debris?

Dave Olson, WSDOT Design Policy, Standards & Research Manager: *We haven't done any work to evaluate safety related to tire debris or loss of control from having a tire separate. I'm not aware of anything underway elsewhere, but I'll ask around. This is more of a hot weather issue. Hotter pavements lead to hotter tires. Excessive heat in the tires leads to delamination of the tires (particularly with retreads). I think the "what's the incentive for retreads" question will lead to a financial answer. They are cheaper than new tires.*

Greg Hansen WSDOT, TEF Fleet Administrator: *We have researched the literature available regarding tire debris and the thought that it is due primarily to retread tire failure. The literature seems to support that tread separation and failure on retread and new tires occur at about the same rate. Most say the vast majority of tire debris on the roads comes from tires that are insufficiently inflated causing them to overheat and fail. (He specifically referenced the "Commercial Medium Tire Debris Study" findings provided in response to question 1).*

OTHER SOURCES

Kara Steward, Washington State Dept. of Ecology, Waste 2 Resources Program: *Provided a links to:*

- *Tire Retread Information Bureau website. <http://www.retread.org/> Excerpted below.*
- *"Rubber on the Road: Issues and Answers" - specifically addresses to the "alligators" that DOT is asking about. According to the article, the blow-outs are due to improper tire pressure.... <http://www.retread.org/Rubber/index.cfm/Article/250.htm>*
- *To address improper tire pressure, California passed legislation this year that requires auto shops to check tire pressure when you take your car in for an oil change. <http://www.autoblog.com/2009/04/02/california-to-require-mandatory-tire-pressure-checks-at-automoti/>*

Information from the Tire Retread & Repair Information Bureau

Tire Retread & Repair Information Bureau – Frequently Asked Questions

Q. Where does rubber on the road come from?

A. The rubber pieces you see on the road come from both new and retreaded tires. It is important to note that most of the rubber on the road comes from truck tires and is caused mainly by under inflation, overloading, and tire abuse. See Rubber on the Road: Issues & Answers.

Q. Are retreaded tires really as safe as new tires?

A. Yes. Adjustment percentages of retreaded tires are about the same as with new tires. Statistics compiled by the U.S. Department of Transportation show that nearly all tires involved in any tire related accidents are underinflated or bald. Properly maintained tires, whether new or retreaded, do not cause accidents.

Q. Do any standards (federal or industry) control the quality and safety of retreaded tires?

A. Yes. Passenger, light pick-up, and 4x4 tires are retreaded according to standards established by the U.S. Department of Transportation and carry a code number (**) on the sidewall indicating where and when the tire was retreaded. Due in part to the standards established by the truck retread tire industry, the U.S. Department of Transportation has not developed regulations for manufacturing retreaded truck tires. The overall quality of retreaded truck tires has increased dramatically in recent years with the introduction of high technology, including the use of computers in manufacturing and non-destructive tire testing. As with passenger car tires, most problems with truck tires can be traced back to poor maintenance (primarily under inflation) and abuse (overloading).

<http://www.retread.org/Facts/index.cfm/ID/227.htm>

Tire Retread & Repair Information Bureau – Retread Facts

- Retreaded truck tires represent a savings of over \$3 billion dollars annually for truckers and trucking companies in North America.
- For most fleets, tires represent the second largest item in their operating budget, right after labor and fuel costs.
- The lowest possible cost-per-mile is achieved with a good tire management program that includes the use of quality retreads. (Hot Topic)
- Retreads are the replacement tire of choice for many truckers. Nearly half of all replacement truck tires are retreads.
- Retreads are not only cost effective, but they are also dependable, reliable, and safe. Retreads are used by truckers with scheduled delivery times, small package delivery companies with guaranteed delivery times, including the U.S. Postal Service, on commercial and military jets, by most school bus operators, taxis, and many other types of vehicles.
- Retreads are also environmentally friendly. Tires are basically petro-chemical products. It takes approximately 22 gallons of oil to manufacture one new truck tire. Most of the oil is found in the casing, which is reused in the retreading process. As a result, it takes only approximately 7 gallons of oil to produce a retread. Wide based truck tires save even more fuel.
<http://www.retread.org/Facts/index.cfm/ID/225.htm>

Literature Sources

Blowout Resistant Tire Study for Commercial Highway Vehicles

University of Michigan Transportation Research Institute (UMTRI)
Z. Bareket, D.F. Blower and C. MacAdam
April 2000

In this study a link was found between fatal crashes involving truck tire blowouts and front tire (steer axle) involvement. Improper tire maintenance is the major cause of blowouts according to this study. In addition to increasing safety, properly maintaining tires significantly increases their longevity and decreases operating costs. Data included files from the states of Michigan, North Carolina, Texas, and Washington. April 2000.

Highlights of Findings:

- Tire defects are the second most common vehicle defect noted on trucks in fatal crashes, behind brakes. Nevertheless, coded tire defects are rare — 0.87 percent of trucks involved in a fatal crash are coded with a tire defect.
- Crashes related to debris from truck tire blowouts in the roadway cannot be identified directly in any data, but using as a surrogate the more general category of object in the roadway, 0.16 percent of fatal crashes and 0.53 percent of all crashes are related to objects in the roadway. These percentages form the upper limit to the proportion of crashes caused by debris from tire blowouts. It is likely the true percentage from blowouts alone is much lower.
- Tire-failure crashes are very rare.
- Maintenance issues (e.g., under-inflation, overloading, tire mismatching, excessive wear, inadequate inspections, and associated matters leading to increased heat and tire operating temperatures) are the major causes of tire blowout.
- Road hazards are another contributing factor causing tire blowout.
- The surveyed industry views inadequate maintenance as the primary cause for tire blowout.
- Attempts to solve the problem are best accomplished by addressing the source.
- Significant effort goes into helping fleets develop proper maintenance procedures and driver education.
- The common view in the tire-manufacturing industry is that a properly maintained tire blows only upon impacting road hazards. Further, an alert and well-trained driver will not lose control of the rig when a front tire blows.

- Retreads are very widely used, primarily on non-steering, rear axle locations.
- Retread manufacturing processes do not appear to contribute significantly to tire blowouts.
- TACOM and a commercial partner are developing an inspection system based upon an infrared thermal imaging technology. The objective is to detect tire defects that can lead to tire failure.
<http://www.retread.org/PDF/umtris.pdf>

Vehicles/Transportation Retreaded Tires

Green California
Best Practices Manual

Retreaded tires are safe, dependable, and cost less than comparable new tires. Retreaded tires are safely used on the drive wheels of school buses, fire trucks, ambulances, and other emergency vehicles. In addition, approximately 80 percent of all aircraft tires in service in the United States are retreaded. [2] According to the United States Environmental Protection Agency (USEPA), retreaded tires are successfully used on Air Force One. [3] In North America, the trucking industry saves more than three billion dollars annually by using retreaded tires. [4]

When vehicle tires become worn, the tire casing can be reused with new tread. The retreading process bonds new tread to the tire body using a process similar to the manufacturing process of new tires.

Both new and retreaded tires can fail. According to a study conducted by the Arizona Department of Transportation, the most common causes of tire failures in all types of tires - this includes new and retreaded tires - are under-inflation and damage due to roadway hazards and debris. [5]

<http://www.green.ca.gov/EPP/vehicles/RetreadedTires.htm>

Survey of Tire Debris on Metropolitan Phoenix Highways

Arizona DOT
Prepared in cooperation with the Governor's Office of Highway Safety
November 1999

This report was prepared to evaluate the impacts that tire debris on state highways produces in Arizona and the Phoenix metropolitan area. Estimates of debris collected in metro Phoenix were reported along with an analysis of the safety implications that roadway debris and tire defects have for Arizona motorists. In order to assess the causes of tire debris in metropolitan Phoenix, a sample of tires and tire fragments was taken at several ADOT maintenance yards in the metro area. These fragments were classified according to type of vehicle, retread, or original tire, and probable cause of failure.

The study revealed that, relative to the state as a whole, tire debris is a maintenance problem of greater magnitude in the Phoenix metropolitan area. However, roadway debris in general was not found to be a significant highway safety hazard in either the Phoenix metropolitan area or statewide. Tire defects and tire failures were also found to have a negligible effect on highway safety in terms of accidents reported in Arizona.

Truck tires, particularly retread tires, were found to be over-represented among the samples of tire fragments collected in metropolitan Phoenix. Tires for light trucks and sport utility vehicles were also overrepresented relative to these vehicles' configurations and share of travel. For all types of tires, under-inflation and damage due to roadway hazards and debris were the most common causes of tire failure.

Due to the minimal safety hazard posed by tire debris, the over-representation of different tire types in the Phoenix sample, and the attribution of most tire failures to driver negligence or infrequent maintenance, it is not recommended that a policy be adopted targeting specific types of tires at this time.

http://www.retread.org/PDF/Study_AZ.pdf

Roadside Alligators and the UMTRI Tire Debris Survey

John Woodroffe, MS
University of Michigan Transportation Research Institute
Oliver Page, Ph.D.
University of Michigan Transportation Research Institute
Resubmitted: 7 November 2008

TRB 2009 Annual Meeting CD-ROM Paper revised from original submittal.

Abstract: Roadside alligators (aka "tire debris") are those unsightly shreds or fragments of rubber that are occasionally found on the nation's highways. The typical road user misunderstands the nature, extent, and contributing factors precipitating its formation. During summer 2007, the University of Michigan Transportation Research Institute conducted a national tire debris survey that involved the collection of 85,000 pounds of rubber and that provided 300 casings and 1,196 debris items for subsequent failure analysis. This paper discusses tire debris within the context of roadside litter, presents the tire debris survey methodology, and finally discusses the survey results. Overall, where the original equipment/tread (OE)/retread status could be determined, there was a 60 / 40 percent split between OE and retread tire casings tested compared to a 21 / 79 percent split for tire fragments. There was also a strong similarity for these same tire items in the ranking of probable damage/failure causes. Road hazard or maintenance/operational reasons were two of the top three probable damage/failure causes. This result suggests that the majority of tire debris items found on the nation's highways is not as a result of manufacturing/process deficiencies. However, two primary challenges remain: firstly, increasing public awareness about the origins, characteristics, and impacts of tire debris, and, secondly, ensuring adherence to the highest standards in commercial driver truck operations and associated tire maintenance. Resolving these challenges has the potential to realize a significant reduction in roadside tire debris and to correct understanding of highway users about the origins of the roadside alligator. Key words: Tire Failure, Retread Tire, Roadside Debris. [PDF Attached](#)

Commercial Medium Tire Debris Study

National Highway Traffic Safety Administration, Washington DC
Authors: Woodroffe, J.F., Page, O., Blower, D., Green, P.E.
December 2008

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. <http://deepblue.lib.umich.edu/handle/2027.42/61517>

Laws and Executive Orders

Federal Executive Orders & Retreads

<http://www.retread.org/Government/index.cfm/ID/222.htm>

Department of Transportation (DOT) Required Markings for Retreaded Truck Tires

Tire Identification and Recordkeeping

The National Highway Traffic Safety Administration (NHTSA)

"Tire Identification and Recordkeeping Regulation" – Revision. Effective July 2, 2000, all tires used domestically must adopt the new 4-digit date code. January 1, 2000, was the effective date for tires used in Europe.

<http://www.retread.org/Government/index.cfm/ID/134.htm>

Motor Carrier Safety (*1087 Tire Condition and Use - applies to CA ONLY)

<http://www.retread.org/Government/index.cfm/ID/257.htm>

ROADSIDE ALLIGATORS AND THE UMTRI TIRE DEBRIS SURVEY

JOHN WOODROOFFE, MS
University of Michigan Transportation Research Institute
2901 Baxter Road
Ann Arbor
MI 48109-2150
Tel: 1 734 764 0248
Fax: 1 734 764 2640
email: jhfw@umich.edu

OLIVER PAGE, Ph.D.
University of Michigan Transportation Research Institute
2901 Baxter Road
Ann Arbor
MI 48109-2150
Tel: 1 734 647 4970
Fax: 1 734 764 2640
email: opage@umich.edu

Prepared for Presentation at the
88th Transportation Research Board Annual Meeting

Number of words: 4,985 (including Abstract)
Number of Figures: 2 (500 words)
Number of Tables: 8 (2,000 words)
Total Word Count: 7,485

Resubmitted: 7 November 2008

ABSTRACT

Roadside alligators (aka “tire debris”) are those unsightly shreds or fragments of rubber that are occasionally found on the nation’s highways. The typical road user misunderstands the nature, extent, and contributing factors precipitating its formation. During summer 2007, the University of Michigan Transportation Research Institute conducted a national tire debris survey that involved the collection of 85,000 pounds of rubber and that provided 300 casings and 1,196 debris items for subsequent failure analysis. This paper discusses tire debris within the context of roadside litter, presents the tire debris survey methodology, and finally discusses the survey results. Overall, where the original equipment/tread (OE)/retread status could be determined, there was a 60 / 40 percent split between OE and retread tire casings tested compared to a 21 / 79 percent split for tire fragments. There was also a strong similarity for these same tire items in the ranking of probable damage/failure causes. Road hazard or maintenance/operational reasons were two of the top three probable damage/failure causes. This result suggests that the majority of tire debris items found on the nation’s highways is not as a result of manufacturing/process deficiencies. However, two primary challenges remain: firstly, increasing public awareness about the origins, characteristics, and impacts of tire debris, and, secondly, ensuring adherence to the highest standards in commercial driver truck operations and associated tire maintenance. Resolving these challenges has the potential to realize a significant reduction in roadside tire debris and to correct understanding of highway users about the origins of the roadside alligator.

Key words: Tire Failure, Retread Tire, Roadside Debris.

INTRODUCTION

Roadside alligators (aka “tire debris”) are those unsightly shreds or fragments of rubber that are found on the pavement or hard shoulder areas of arterial or interstate highways. A perception among many highway users is that such tire debris is generated primarily by heavy trucks that are running on retread tires. Furthermore, this perception postulates that retread tires are less safe than new tires. This negative attitude toward tire debris is confirmed by Phelan (2007) where 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 prohibiting certain categories of retread tires. However, all these attempts to legislate retreads have been defeated. Currently, there are no nationally mandated manufacturing or performance standards for commercial medium- or heavy-duty tire retreads. During summer 2007, a national tire debris collection exercise was conducted by the University of Michigan Transportation Research Institute (UMTRI) to gain a better understanding of the tire debris issue.

PAPER OBJECTIVE

A better understanding of the tire debris issue may enable a reduction in the level of subjective responses (i.e., misguided perceptions) by highway users and safety advocates as to the causes and impacts of this type of roadside debris. The 2007 UMTRI Tire Debris Survey (TDS) adopted a scientific approach to clarify this issue. Through the reporting of the TDS, the objectives of this paper are to: 1) define a tire debris survey, 2) discuss tire debris within the context of roadside litter, i.e., its nature and extent, 3) Describe the TDS and the methodology followed, and 4) assess and discuss the potential significance of the TDS results. In achieving these objectives, this paper seeks to contribute to scientific knowledge and close the gap in our understanding of the tire debris that is occasionally found on the nation’s highways.

TIRE DEBRIS SURVEYS

The ongoing debate over the incidence and traffic safety impacts of tire debris has influenced the continued study of this issue since 1990. Several nationally or regionally focused tire debris studies conducted during the 1990s had the primary objective to determine the probable cause of tire failure and by so doing to validate or disprove whether a commercial medium- or wide-base truck tire’s retread status is a contributing factor in the formation of tire debris on the nation’s highways. (nb. Tire failure is a sudden and catastrophic failure of the tire resulting in the production of tire debris potentially impacting vehicle or highway safety). Indeed, some of these studies were driven by State Agencies requiring information on tire failure as input into proposed retread (commercial medium) truck tire legislation.

A tire debris survey would entail the collection of tire debris (e.g., casings and tire fragments) from the highway, trucks stops, or roadside debris storage sites (e.g., state highway maintenance yards) followed by the analysis of these specimens to determine the retread status and the probable cause of tire failure. Failure determination can be undertaken by microscope (e.g., microscopy/fractography, see Smith, 1997). However, typically a visual and/or tactile assessment by a qualified rubber forensic consultant is sufficient. Table 1 summarizes selected U.S. tire debris studies that have assumed importance in the understanding of tire debris generation and tire failure since 1990.

TABLE 1 U.S. Tire Debris Studies Since 1990

Study	Year	Survey Season	Location	Performing Organization	Pieces/Weight Collected	Sponsor
Rubber on the Road Study	1995	Summer	National	Technology Maintenance Council	1,720 tire items*	American Trucking Association
Rubber on the Road Study	1998	Summer	National	Technology Maintenance Council	2,200 tire items*	American Trucking Association
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

ROADSIDE DEBRIS/LITTER

The Disposal of Roadside Litter Mixtures study (Andres, 1993) is one of relatively few research projects that investigated the problem and extent of roadside debris. This study found that 4.4 million tons or 2.7 percent of discarded solid municipal waste in 1990 was derived from rubber and leather. However, the 2.2 volume-to-weight ratio of these materials was ranked first, the highest of all the 11 debris materials categorized using this ratio. This result suggests 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 by state agencies for its removal and disposal. Andres' study was also able to state that the environmental implications of rubber tires according to their difficulty of disposal ranked it in first place at 65 percent of the 50 U.S. states surveyed.

According to another study of roadside litter/debris (i.e., Keep America Beautiful Campaign (KAB, 2008)), trucks are listed as one of the seven primary sources of roadside litter. However, this is with respect to their uncovered loads and not to tire debris that may be generated through tire failure. A Visible Litter Survey (VLS) performed in the state of Florida in 2002 listed vehicle and tire debris as the top source of litter (14 percent) by proportion of items collected (R.W. Beck, 2007). Andres (1993) also goes on to indicate that "rural interstate roads and expressways generally offer less opportunity for litter deposits [i.e., deliberately dumped] because of the high speed nature of the roadway and a lack of access to commercial establishments." However, it is the opportunity of high speeds and the predominance of long distance traffic that makes rural arterial or interstate highways the prime location where roadside alligators (i.e., tire debris) are found.

The collection and disposal of tires often necessitates additional sorting of any roadside debris collected (as some landfills do not accept casings or tire shreds), the disposal of which negatively impacts municipal finances. If left on the roadway, tires continue to produce negative environmental impacts as they can be a source of lead and zinc in highway runoff, develop into potential breeding sites for mosquitoes, or conceal harmful creatures such as snakes. Highway maintenance crews are caught in a cycle where the continuous effort required for tire debris collection and disposal is constantly weighed against the potential negative highway safety and local ecosystem impacts if such debris is left uncollected.

ROADSIDE TIRE/RUBBER DEBRIS ESTIMATION

In his assessment of tire debris in the Phoenix, AZ area, Carey (1999) developed a methodology to estimate the proportions of roadside tire debris generated according to vehicle type, e.g., passenger car, light truck, and medium/heavy truck. This method (see Table 2) incorporates the proportions of annual vehicle miles traveled (VMT) by vehicle type 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. The resulting adjusted shares reflect the proportions of tires/wheels by type that pass over a given stretch of highway, and it is further assumed that any generated tire debris ideally should reflect these proportions.

TABLE 2 Share of Travel versus Estimated Roadside Share of Debris

Tire Type	Share of Tire Travel on U.S. Highways			
	VMT Share	Average # Tires ¹	Adjustment ²	Adjusted Share ³
Passenger Auto & Light Truck ⁴	90.0%	4	0.036	75.0%
Medium/Heavy Truck	10.0%	12	0.012	25.0%
Total	100.0%		0.048	100.0%

1) Average number of tires by vehicle configuration. 2) Adjustment made by multiplying share of VMT by number of tires. 3) Adjusted share equals "Adjustment" by type divided by sum of adjustment values. 4) Includes two axle-six-tire SUV/trucks. Source: Carey (1999).

The example presented in Table 2 indicates VMT shares of 90 percent and 10 percent for passenger vehicles/light trucks and medium/heavy trucks, respectively (column #2). The VMT shares are multiplied by the average number of tires per vehicle type (column #3). The adjusted shares (column #5) represent the proportions of VMT (column #4) with respect to the number of tires according to vehicle type. For example, the 10 percent VMT for medium/heavy trucks (i.e., individual vehicles) increases to 25 percent when incorporating the higher average number of tires for this vehicle type. Carey then postulates that volumes of tire debris (generated by different vehicle types) that exceed their estimated adjusted shares indicate an overrepresentation.

Figure 1 revisits Carey's method through simultaneously adjusting the VMT shares (in 10 percent increments) and the average number of tires per vehicle. The maximum average number of tires per medium/heavy truck (i.e., 18) is a figure based on the particulate emission estimation work of the Environmental Protection Agency (1995). This figure can be compared to the average of 12 tires per truck as originally used in Carey's method (see Table 2) that is based on work by Smit (quoted in Carey (1999)). Point A (in Figure 1) represents the estimated adjusted share of 25 percent (on the Y axis) where 10 percent of VMT is attributable to medium/heavy trucks with an average of 12 tires per vehicle (see Table 2). The Technical Maintenance Council (TMC) tire debris surveys of 1995 and 1998 (see Table 1) concluded that 64 percent of tire debris collected originated from medium/heavy trucks (B in Figure 1) (Laubie, 1999). Despite

the lack of VMT information for the TMC studies, it is apparent that the proportions of medium/heavy truck tire debris collected were significantly higher (i.e., an overrepresentation) than their estimated adjusted shares at most levels of medium/heavy truck VMT proportions (assuming an average of 12 tires per medium/heavy truck). It is evident from Figure 1 that the extent of overrepresentation of deposited tire debris according to vehicle type is dependent on the share of total VMT and the average number of tires per medium/heavy truck, factors which will vary by type of roadway and location.

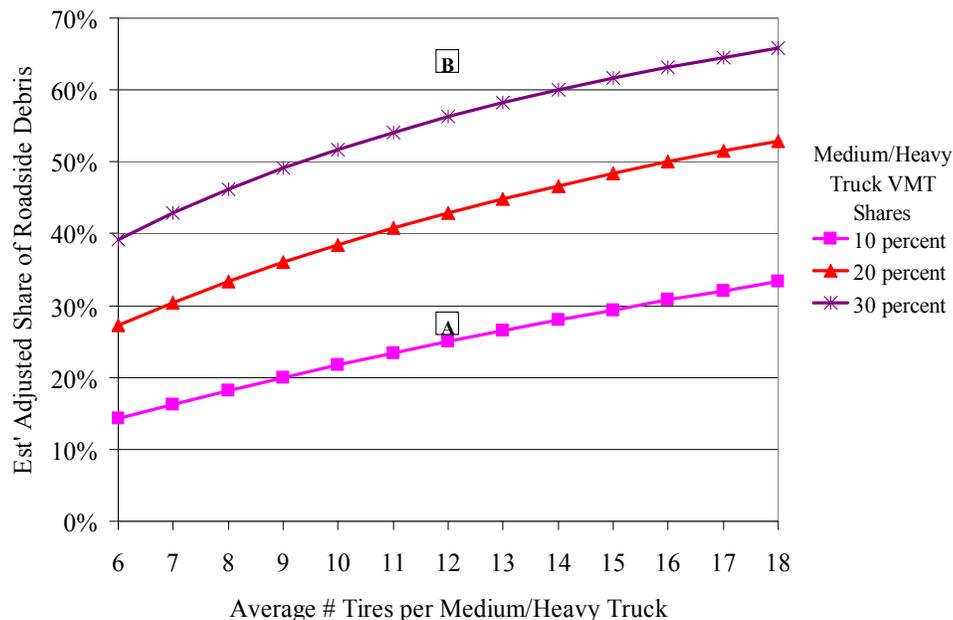


FIGURE 1 Estimated Shares of Roadside Tire Debris According to Truck VMT Percentage

THE UMTRI TIRE DEBRIS SURVEY - METHOD

Debris Study Objective and Selection of Survey Sites

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 ($n = 1,700$) and casings ($n = 300$) for subsequent analysis in order to determine the original equipment/tread (OE) (i.e., new) or retread status, the probable cause of failure, and whether there was a higher incidence of retread versus OE tire debris items in the sample. Five collection sites around the U.S. were selected according to average annual daily truck traffic (AADTT) interstate volumes. The sites selected were: I-75 in Gainesville, FL (South); I-65, I-94, and I-80 in Gary, IN (Midwest); I-5 in Taft, CA (West); I-10 in Tucson, AZ (Southwest); and I-81 in Wytheville, VA (Mid-Atlantic). At each of the five survey sites, a truck stop and a state highway maintenance yard were identified as debris collection points (see Table 3).

Tire Debris Collection Program and Schedule

In order to maximize the collection of tire debris, the summer season was selected as the time to conduct the collection exercise. Several tire debris studies have shown that the summer season has the highest potential of tire debris generation (see Table 1). At each site, both the highway

TABLE 3 Survey Site Collection Agency and Timeframes

Collection Site	Highway Maintenance Agency	Truck Stop	Debris Collection Period
Gainesville, FL	Florida Department of Transportation (FDOT)	Petro Shopping Center - Riddick, FL	Tuesday 14 to Tuesday 28, August 2008
Gary, IN	Indiana Department of Transportation (INDOT)	TravelCenters of America - Lake Station, IN	Monday 6 to Monday 20, August 2008
Taft, CA	California Department of Transportation (CALTRANS)	TravelCenters of America - Wheeler Ridge, CA	Thursday 6 to Thursday 20, September 2008
Tucson, AZ	Arizona Department of Transportation (AZDOT)	Triple 'T' Truck Stop - Benson Highway, AZ	Monday 10 to Monday 24, September 2008
Wytheville, VA	VMS Inc.	TravelCenters of America - Peppers Ferry, VA	Thursday 9 to Thursday 23, August 2008

maintenance agency and the associated truck stop collected debris and casings simultaneously over a two-week period (see Table 3). Members of the study team were not directly involved in the collection of roadside debris. However, study team members were able to go out with state highway maintenance teams to observe the roadside debris collection process. Each collection site followed a pre-determined collection program where the primary tasks were to designate a collection receptacle (e.g., trailer, dumpster, or open space), collect and deposit the tire/rubber debris, and finally permit the transportation the collected items for failure analysis. A 53-foot drop-frame trailer was positioned at the designated truck stop for loading with tire casings. At the end of the collection period, the trailer was taken from the truck stop to the highway maintenance agency yard for loading of the tire shreds/casings (i.e., collected by the highway agency) and then hauled to the tire/rubber forensic consultant's testing facility.

Debris collection guidelines were given to managers at each truck stop/highway maintenance agency. These guidelines were to ensure uniformity in the type of debris collected (only debris or casings from medium/heavy trucks were required), to enhance environmental safety, and to minimize any unforeseen logistical challenges. The guidelines given were:

- Only casings or shreds from large trucks were required. The size of tire shreds were preferably a minimum 2 feet (0.6 meters) in length and 4 inches (10.16 cm) in width.
- Tire casings were to be stacked one on top of one another starting from the front of the trailer.
- Any casing collected must be rimless.
- If casings have been sitting in the open air and collected any water (or other debris), removal of such debris is required before placing casing in the trailer.
- Deliberately dumped casings found along interstates are not required.

Tire Debris Failure Determination

Collected tire debris from the five survey sites was transported to a tire/rubber forensic consultant for failure analysis. 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, which eliminated the potential for samples from one geographic region to be intermingled with those from elsewhere.

Tire failure analysts employed the industry-accepted and validated, scientific “observations to conclusions” methodology. This involved visual and tactile means as a practical method for determining the cause, or causes, of tire failure. Simple tools (e.g., tread depth gauge, jeweler’s loupe and tape measure) were also used in the tire failure analysis exercise. The failure analysis methodology applies equally to whole tires, tire casings, or fragments of tires. A purpose-specific inventory system was developed in order to assure complete tracking of each specimen and its accompanying data. Physical characteristics of each specimen examined were also recorded, in order to determine the most likely category in which to place the sample. Additionally, a database of the various characteristics of the sampled tire debris was created. Seven general damage (i.e., failure) categories were utilized, five of which contained further sub-categories. However, 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. The damage/failure categories are presented in Table 4.

TABLE 4 Damage/Failure Determination Categories

Damage/ Failure Category	Explanation (i.e., damage resulting from)
Excessive Heat	Operation of a tire while underinflated, overloaded, or at excessive speeds
Excessive Intra-Carcass Pressurization	Compromise of the inner liner as the result of a road hazard, mounting damage, or by some other means resulting in pressure entering the tire’s structure at excessively high levels. This excessive intra-carcass pressure can separate the tire’s individual manufactured components and/or separate rubber from the reinforcement material (steel or fabric).
Indeterminate Cause	The non-availability of sufficient pieces of the casing/fragment or other information in order to reach a conclusion as to a damage category assignment
Maintenance/Operational	Improper repairs, excessive wear, incorrect tire or wheel mounting or dismounting, locked brake skid damage, and by contact with some part of the vehicle upon which the tire is operating
Manufacturing/ Process Issues	Original tread or retreading process manufacturing issues that could be expected to contribute to the tire’s disablement
Overdeflected Operation	The internal steel reinforcement material (steel radial sidewall ply) sustaining sufficient cyclic flex fatigue or the occurrence of belt/belt package detachment
Road Hazard	Punctures, cuts, and the striking of objects such as curbs, potholes, etc.

THE UMTRI TIRE DEBRIS SURVEY - RESULTS

Volumes of Tire Debris and Casings Collected

Table 5 presents details of the tire debris and casings collected and sampled from each site. Overall, more than 85,000 pounds of rubber was collected from the five collection sites over the survey period, ultimately providing 1,496 samples. Despite the casing and debris size guidelines given to the highway maintenance teams and truck stops when collecting items for this study, debris and casing items from light trucks and passenger cars were inadvertently collected. Indeed, the size of a debris item is not a definitive guide to the vehicle type of origin. The tire failure analysts were tasked only to test commercial medium/heavy truck debris items. After items belonging to this category were sampled, the balance of the tire debris items collected was isolated (i.e., put back into a trailer) resulting in the examination of 300 casings and 1,196 tire fragments that met the study criteria. Nevertheless, it was estimated that 60 percent of the tire debris items collected originated from medium/heavy trucks and the balance from passenger cars and light trucks.

TABLE 5 Weights of Collected Tire Debris and Casings

Collection Site	Truck Stop	Highway Maintenance Yard	Total Weight Collected	# Casings Tested	# Tire Fragments Tested	Total Items Tested
Gainesville, FL	15,040 lbs	3,380 lbs	18,420 lbs	60	198	258
Gary, IN	25,780 lbs	4,280 lbs	30,060 lbs	60	259	319
Taft, CA	8,140 lbs	6,700 lbs	14,840 lbs	60	328	388
Tucson, AZ	8,300 lbs	5,328 lbs	13,628 lbs	60	161	221
Wytheville, VA	7,400 lbs	1,680 lbs	9,080 lbs	60	250	310
Total	64,660 lbs	21,368 lbs	86,028 lbs	300	1,196	1,496

Casings and Tire Fragments Retread Status

Table 6 summarizes information with respect to the retread status of the tire debris items (casings or fragments) assessed. Approximately 127 (42 percent) of the 300 casings analyzed were retreads and 169 (56 percent) were original tread casings (the balance was categorized as “unknown”). Of the 1,196 tire fragments that were analyzed, approximately 214 (18 percent) were from original tread tires, approximately 812 (68 percent) were from retreaded tires, and in approximately 170 (14 percent) of the examinations, no determination as to original tread or retread could be made.

TABLE 6 Tire Casings and Fragments Original Tread/Retread Status*

Collection Site	Tire Casings						Tire Fragments					
	Original Tread		Retread		Unknown		Original Tread		Retread		Unknown	
	#	%	#	%	#	%	#	%	#	%	#	%
Gainesville, FL	34	56.7%	25	41.7%	1	1.7%	40	20.2%	125	63.1%	33	16.7%
Gary, IN	34	55.7%	27	44.3%	0	0.0%	38	23.6%	114	70.8%	9	5.6%
Taft, CA	30	50.8%	26	44.1%	3	5.1%	41	16.4%	164	65.6%	45	18.0%
Tucson, AZ	44	73.3%	16	26.7%	0	0.0%	61	18.6%	219	66.8%	48	14.6%
Wytheville, VA	27	45.0%	33	55.0%	0	0.0%	34	13.1%	190	73.4%	35	13.5%
Total	169	56.3%	127	42.3%	4	1.3%	214	17.9%	812	67.9%	170	14.2%

* The percentages represent the proportions of tire items tested originating from a specified location, e.g., 57 percent of tire casings collected in Gainesville were original tread compared to 20 percent of tire fragments for the same location.

Damage/Failure Condition Categorization according to Casing or Tire Fragment Status

The probable cause of damage/failure determined for the 300 casings and 1,196 fragments assessed according to their OE, retread, or unknown status is presented in Tables 7 and 8.

TABLE 7 Tire Casings Damage/Failure Category Determination*

Tire Status	Damage/Failure Category**													
	1		2		3		4		5		6		7	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
OE (i.e., new)	20	11.8	4	2.4	51	30.2	70	41.4	8	4.7	11	6.5	5	3.0
Retread	21	16.5	7	5.5	45	35.4	20	15.7	15	11.8	13	10.2	6	4.7
Unknown	2	50.0	0	0.0	1	25.0	0	0.0	0	0.0	1	25.0	0	0.0
Total	43	14.3	11	3.7	97	32.3	90	30.0	23	7.7	25	8.3	11	3.7

* The percentages represent the proportions of tire casings tested according to their OE/retread status, e.g., 20 (or 12 percent) of all OE tire casings assessed failed due to overdeflected operations compared to 21 (17 percent) of retread casings.

** Damage/Failure Categories are: Category 1 – Overdeflected Operation, Category 2 – Excessive Heat, Category 3 – Road Hazard, Category 4 – Maintenance/Operational, Category 5 – Manufacturing/Process, Category 6 – Indeterminate, and Category 7 – Excessive Intra-Carcass Pressurization

TABLE 8 Tire Fragments Damage/Failure Category Determination*

Tire Status	Damage/Failure Category**													
	1		2		3		4		5		6		7	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%
OE (i.e., new)	6	2.8	43	20.1	46	21.5	42	19.6	9	4.2	66	30.8	2	0.9
Retread	7	0.9	150	18.5	206	25.4	36	4.4	82	10.1	329	40.5	2	0.2
Unknown	6	3.5	27	15.9	29	17.1	28	16.5	7	4.1	73	42.9	0	0.0
Total	19	1.6	220	18.4	281	23.5	106	8.9	98	8.2	468	39.1	4	0.3

* The percentages represent the proportions of tire fragments tested according to their OE/retread status, e.g., 66 (or 31 percent) of all tire fragments originating from OE tires assessed were classified as Indeterminate compared to 329 (41 percent) of retread fragments.

** Damage/Failure Categories are: Category 1 – Overdeflected Operation, Category 2 – Excessive Heat, Category 3 – Road Hazard, Category 4 – Maintenance/Operational, Category 5 – Manufacturing/Process, Category 6 – Indeterminate, and Category 7 – Excessive Intra-Carcass Pressurization.

Casings and Tire Fragments Failure/Damage Condition

Approximately 275 (91.7 percent) of the 300 tire casings that were examined 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 percent) were categorized as indeterminable. The 300 casings were analyzed and assigned to the various categories as follows: excessive heat – 11 items, excessive intra-carcass pressurization – 11 items, indeterminable – 25 items, maintenance/operational – 90 items, manufacturing/process – 23 items, overdeflected operation – 43 items, and road hazard – 97 items. Of the 1,196 tire fragments examined, 728 (61 percent) provided sufficient information for the tire failure analysts to categorize the most likely reason that the tire containing the fragment had become unserviceable. The remaining 468 of the tire fragments examined were categorized as indeterminable. The analyses of the 728 tire fragments were assigned to the damage/failure categories as follows: excessive heat – 220 items, excessive intra-carcass pressurization – 4 items, indeterminable – 468 items, maintenance/operational – 106 items, manufacturing/process – 98 items, overdeflected operation – 19 items, and road hazard – 281 items. The resulting percentages of the 275 casings and 728 tire fragments examined (excluding the indeterminate category) according to their determined damage/failure category are presented graphically in Figure 2 (overleaf).

DISCUSSION

Volumes of Tire Debris and Casings Collected

Initially it was intended that the tire forensic consultant analyze 300 casings and 1,700 tire fragments. In the aggregate, significantly more than the required numbers of tire fragments were provided to meet the numerical requirement. However, when sorted to the standards of the project, a number of fragment samples could not be included as they were determined to originate from either passenger-vehicle or light-truck tires. It is probable that the distribution of the collected tire debris according to vehicle type (estimated at 60 percent for medium/heavy trucks and the balance originating from passenger vehicles/light trucks) was reflective of the adjusted VMT shares at each of the five collection locations. Indeed, the importance of this distribution indicates that there may not be a significant overrepresentation of medium/heavy-truck tires as the model developed by Carey (1999) might suggest.

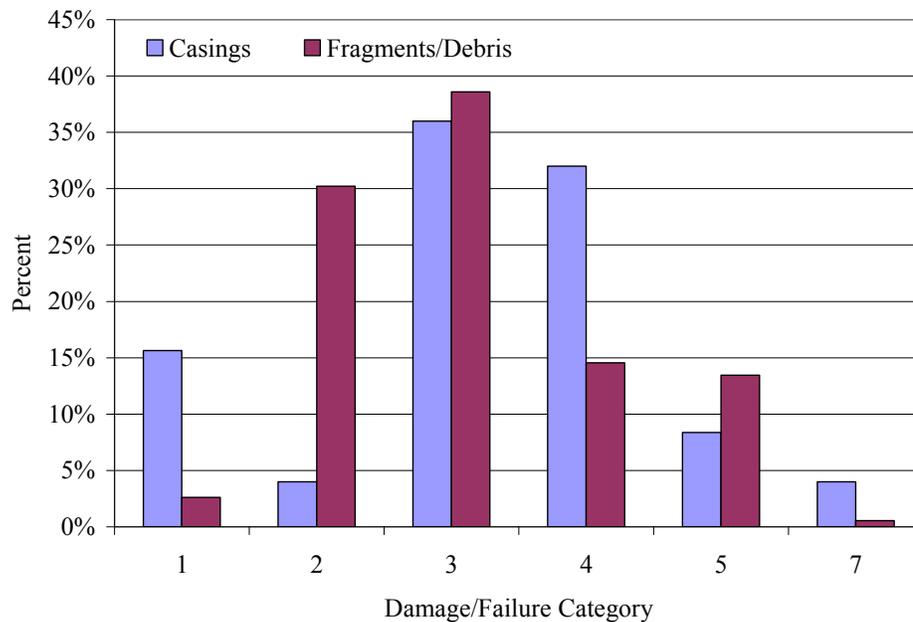


FIGURE 2 Tire Casings & Fragments Damage/Failure Category Determination (Excluding Indeterminate Category).

Damage/Failure Categories:	Category 4 – Maintenance/Operational
Category 1 – Overdeflected Operation	Category 5 – Manufacturing/Process
Category 2 – Excessive Heat	Category 6 – Indeterminate (excluded)
Category 3 – Road Hazard	Category 7 – Excessive Intra-Carcass Pressurization

Casing/Tire and Fragment Retread Status

Overall, there was a 60 / 40 percent split between OE and retread tire casings tested (see Table 6). Indeed, discussions with tire and trucking fleet industry stakeholders confirmed this relationship by indicating the following: 1) Current U.S. trucking industry practice discourages the use of retreads on steer axles, 2) Typically up to 50 percent of the drive tires in a trucking fleet may be running on retreads. However, there are many fleets that do not run retread drive tires, 3) For the trailer fleet, the proportion of retread tires may increase to between 70 and 100 percent; and 4) Retreads tend to go to trailers. Therefore, in a typical 18 wheeler, if all tires had an equal chance of failure (or withdrawal from service), the probability of a tire being a non-retread (i.e., an OE) would be higher for any of the 10 steer/drive axle tires when compared to the remaining eight trailer axle tires.

Of the 1,196 tire fragments tested, the OE/retread status could be determined for only 1,026 (86 percent). Of these, approximately 214 (21 percent) were from original tread tires and 812 (79 percent) were from retread tires. 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, VA, to a high of 24 percent Gary, IN. However, the retread fragment percentages were more closely aligned, ranging from 63 percent in Gainesville, FL, to 73 percent in Wytheville, VA (see Table 6).

Damage Condition Categorization according to Tire/Fragment Status

The top three reasons that tire casings were removed from service were (refer to Table 7) road hazards – 97 casings (32 percent), maintenance/operational factors – 90 casings (30 percent), and

overdeflected operation – 43 casings (14 percent). However, the majority of casings collected in TDS originated from truck stops and it may be expected that such casings will have a slightly higher percentage of causes for removal relating to road hazard, maintenance, and underinflation, as these removals are generally unplanned. Casings failing due to manufacturing- or process-related factors only accounted for less than 8 percent (i.e., $n = 23$) of the sample assessed. Of this proportion (i.e., the 8 percent), further failure analysis by the tire forensic consultant revealed that the vast majority appeared to be retreading process issues, such as casing selection and repair, or tread rubber application issues. Indeed, the majority of casings collected in the TDS was removed from service for road hazard, maintenance/operational issues, and overdeflected operation, as would be expected for both original tread casings and retreads. The importance of this result implies that possibly the majority of tire debris items (irrespective of OE/retread status) found on the nation's highways is not as a result of manufacturing/process deficiencies but other factors, notably, road hazard and belt separation/overdeflection. Comparable results are evident in other tire debris studies, e.g., Laubie (1999) and Carey (1999).

The top three probable cause of failure reasons for fragments examined were (refer to Table 8): indeterminable category – 468 fragments (39 percent), road hazard – 281 fragments (23 percent), and excessive heat – 220 fragments (18 percent). However, if the indeterminate category is removed, the ranking is as follows (see also Figure 2): road hazard – 281 fragments (39 percent), excessive heat – 220 fragments (30 percent), and maintenance/operational – 105 fragments (14 percent). The significant percentage of tire fragment items categorized as indeterminate 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. Indeed, the more of the tire that is available for examination the better in terms of reaching the most complete conclusion. The percentage of fragments demonstrating road hazard damage in Figure 2 was approximately the same as the percentage of road hazard damage among the casing population examined (approximately 38 percent and 36 percent, respectively). This result corroborates the preponderance of tire debris to be a direct consequence of road hazard.

Overrepresentation of Retreads

Of particular interest in the TDS was whether there was an overrepresentation of retread tires in debris items collected. With respect to the tested tire casings, the majority of these were removed from service at truck stops. At this location a significant proportion of tires removed would be from the long-distance trucking fleet with its corresponding OE/retreads split between steer/drive and trailer wheels. Accepting these relationships and the higher probability that steer/drive tires will be new compared to their trailer counterparts, the OE/retread split of 56 percent and 42 percent (see Table 6) is in the same range as the steer/drive and trailer wheel proportions (i.e., 10 versus eight) of a typical 18-wheeler tractor-trailer. This result suggests that the retread casings tested were not overrepresented in the sample.

With respect to tire fragments earlier in this paper, it was alluded that there was an increased probability that trailer axle tires will be running on retreads when compared to steer/drive axles. Taking this issue further with tire and truck fleet stakeholders, it was also acknowledged that 1) A significant proportion (i.e., 60%+) of commercial medium-base tires running in the U.S. are retreads, 2) Tires positioned on trailer axles often receive the least maintenance, and 3) The generation of tire fragments is the result of the continued operation of an incapacitated tire, i.e., the longer an incapacitated tire is run along the ground increases the generation of shreds. Accepting the distance between the truck operator and trailer axles in a

typical 18 wheeler, a failure of a trailer axle tire while in service may go unnoticed by the operator. Indeed, failure of a steer/drive axle tire may not generate an excessive volume of fragments due to the immediate awareness of the failure (and subsequent defensive driving action) by the truck operator. However, if more than 60 percent of trailer wheels are retreads and a failure occurs (unnoticed) in any of these tires, it is likely that the majority of shreds found on the roadsides will be derived from trailer tires that in all probability will be retreads. The significant percentages of retread tire fragments collected from all five collection sites (see Table 6) support this hypothesis. This result also suggests that the retread tire fragments tested were not overrepresented in the sample.

CONCLUSIONS

Misunderstandings by the typical road user have incorrectly attributed the nature, extent, and contributing factors precipitating the formation of the roadside alligator. In clarifying this issue, several tire debris studies conducted since 1990 have sought to determine the probable cause of tire failure and to validate or disprove whether a commercial medium- or wide-base truck tire's retread status is also a contributing factor. The TDS was one of such studies. Executed during summer 2007, this survey involved the collection of 85,000 pounds of rubber that provided approximately 1,500 truck tire samples for subsequent failure analysis.

The TDS results suggest that the proportions of commercial medium tire debris collected according to adjusted VMT shares may not be significantly overrepresented if localized traffic flow characteristics are taken into account. Indeed, the OE versus retread proportions of the collected tire debris broadly correlated with accepted industry expectations. There was a strong similarity between casings and tire fragments with respect to probable damage/failure cause where the OE/retread status was known. In these cases, road hazard or maintenance/operational reasons were two of the top three probable damage/failure causes. The importance of this result suggests that the majority of tire debris items found on the nation's highways is not a result of manufacturing/process deficiencies. Indeed, similar findings are corroborated in earlier studies of tire debris that also prove the direct link between deficient tire maintenance and inflation pressures and premature tire failure.

U.S. trucking industry practices have strongly influenced the OE/retread tire mix on the typical 18-wheeler tractor-trailer combination (described in paragraphs #1 (page 9) and #4 (page 10)). Insulation of the driver's cab from the steer/drive versus trailer axle tires has also contributed to the extent that a failure in any tire may go unnoticed by the driver while the vehicle is in operation (discussed in paragraph #4 (page #10)). These two factors, we believe, suggest that the retread tire fragments tested were not overrepresented in the debris items collected. With respect to the tire and truck fleet industry stakeholders, there is the possibility that the TDS results confirm accepted beliefs. In any given location roadside alligators often represent tire debris from all vehicle types as inadequate tire inflation pressure has the potential to precipitate tire failure for all types of tire (i.e., OE and retread) and not just the commercial medium. However, two primary challenges remain: firstly increasing public awareness about the origins, characteristics, and impacts of tire debris, and, secondly, ensuring adherence to the highest standards in commercial driver truck operations and associated tire maintenance. Resolving these challenges has the potential to see a significant reduction in roadside tire debris, correct the understanding of all highway users regarding the origins of the roadside alligator and sustain the attention of all vehicle operators about the importance of maintaining correct tire inflation pressures.

REFERENCES

- Andres, D.L. (1993). Disposal of Roadside Litter Mixtures. *NCHRP Synthesis of Highway Practice 184*. Washington, D.C.: National Academy Press.
- Carey, J. (1999). *Survey of Tire Debris on Metropolitan Phoenix Highways*. Report No. ATRC-99-11. Phoenix, AZ: Arizona Department of Transportation.
- Environmental Protection Agency. (1995). Appendix: Particulate Emission Factors for Mobile Sources as Calculated in the Model Part5. 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.
- Keep America Beautiful. (2008). *KAB's Seven Primary Sources of Litter*. Retrieved May 31, 2008, from http://www.kab.org/site/PageServer?pagename=litter_sevensources.
- 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.
- 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.
- Smith, R.W. (1997). The Microscopy of Catastrophic Tire Failures. *Rubber Chemistry and Technology*. American Chemical Society. Volume 70. Issue 2. pp.283-293

ACKNOWLEDGEMENTS

The authors gratefully acknowledge funding from the National Highway Traffic Safety Administration (NHTSA) in the execution of the 2007 UMTRI Tire Debris Survey. Thanks also go out to Arik Svenson NHTSA Program Manager; and Mike Bair, Richard Loesh and Tom Dodson of Smithers Scientific Services for their invaluable contributions to the study.