Carnegie Mellon University | UNIVERSITY of PENNSYLVANIA

FINAL RESEARCH REPORT

Contract No. DTRT-13-GUTC-26

Analysis of Effects of Tire Tread Deterioration on Safety Impacts from Analysis of Inspection Data

PI: H. Scott Matthews (ORCID: 0000-0002-4958-5981)

Carnegie Mellon University

DISCLAIMER

Problem Description

Unlike other countries, the United States does not have a single overall system for inspecting vehicles for safety problems. Instead, this responsibility is left to the 50 states to decide whether to require them, and if so at what level of rigor and for which vehicles and at what frequency. In the distant past, all states had inspection programs, but given the way this responsibility has been left to States, there are ongoing efforts across the US to eliminate inspection programs in order to "save people money". This has led to a patchwork system where more than half of states have no safety inspection program at all, and many of the states with inspection programs do not require all vehicles to be inspected every year.

The State of Pennsylvania in the United States has a requirement that all passenger vehicles undergo annual safety inspections by a trained and licensed inspector. These inspections occur in 'decentralized' facilities that are not managed directly by the state. Even Pennsylvania's program has been at risk of being eliminated due to legislative efforts in the past five years, but nonetheless, it remains intact. As with other efforts, the legislators tried to suggest that the inspection program is worthless since the failure rate of such inspections is low.

In prior research that considered millions of safety inspections in the state over time, we showed that the perception of "low failure rates" as had been suggested by legislators was false, and that the true failure rate was about 15-20%. This has had the effect of mitigating the attempts to eliminate the safety program in Pennsylvania.

Of the approximately twenty items inspected on each vehicle, we prioritized further work based on those items that most frequently lead to inspection failure., which include brake systems, tires, and headlamps. Given that we have access to the detailed reports for each inspection, we identified additional value-added research into what causes tires to fail. In short this is because the "tread level" is defined by regulation and all four tires must be above the minimum tread level, (i.e., 4/32 of an inch) else tires need to be replaced, at a cost of several hundred dollars. In this project, we sought to use data analytic methods to consider the deterioration rate of tire tread and also to consider the relationship between the inspection thresholds and the level of safety associated with tires.

Approach[1]

Our inspection data over time shows overall inspection results as well as dates, odometer readings, and specific tire tread values as measured by inspectors. With this data, we can track how tire tread deteriorates over time (i.e., how much tread depth is lost over what distance driven) for each vehicle and also aggregate across all vehicles or body types.

Another aspect of this research is to consider the interplay between the state-specified tire tread thickness needed to pass inspection and the average miles driven by vehicle between annual inspections. This is important because a car could pass an inspection as needed at its annual visit, but given its normal amount of driving, have tires that no longer would pass inspection shortly after the inspection (and thus the car would be driving for some part of the year with unsafe tires until the next inspection). By building models for each vehicle in the State, the deterioration rate for that car can be found, and normalized by its annual vehicle miles traveled (VMT) to determine the rate at which the tire tread would decrease, and the date at which the tread would be expected to be below the threshold. We do this for each vehicle, and create summaries of the overall results in terms of the percent of the fleet that is at risk for driving around on unsafe tires during the year. Our preliminary estimates are that tires deteriorate about 0.2/32 of an inch per 1,000 miles driven, and that about 15% of passenger cars would be expected to have unsafe tires before their next inspection.

The goal of our work is to work with policymakers to consider the current program where a single tire tread thickness is prescribed by law without consideration of how soon after the test we would expect the vehicle to be out of compliance, and to have either a more complex system for passing the tire tread component of the test that considers expected miles driven before the next inspection, or by increasing the regulated tread depth level (e.g., to 5/32" or 6/32") at time of inspection given the relatively high rates of average miles traveled. Either of these outcomes would reduce the number of unsafe cars traveling in the State, and presumably lead to less injuries and fatalities in the passenger transportation sector.

Method

To accomplish this research, we created a data analytics framework to maintain about 10 years worth of safety inspection data from passenger vehicles in Pennsylvania, including code to organize the data as well as to find deterioration rates of tire tread at the individual vehicle level. These individual vehicle level results were then aggregated to vehicle categories (e.g., sedans, SUVs, pickup trucks).

---

[1] Since we are including a submitted paper as an Appendix that gives all of the relevant detail of the approach, method, etc., we are providing relatively higher level introductions to these aspects of the project in this part of the report.

Given these deterioration rates, and the known inspection thresholds, we built a policy framework model that considered how changing (increasing) the inspection thresholds might allow for more of a safety factor to maintain safe tires in the fleet.

Findings

We found that the deterioration rate of tire tread for vehicles is approximately 0.2 32nd of an inch per 1000 miles driven. Thus, a vehicle driven the average of 10,000 miles per year would deteriorate 2 /32" of tread.

We also found that about 30% of vehicles are at risk of driving on unsafe tires in the year between inspection visits, and this risk would be significantly reduced if the inspection threshold were raised to 4/32"-6/32" to better compensate for the possibility that cars would drive under the threshold before the next inspection.

Conclusions and Recommendations

We believe that our results support increases in the thresholds used for inspections of tire tread, and that they should be increased in all states that do safety inspections.

We have communicated these results with the Pennsylvania Department of Transportation (PennDOT), which has convened a task force to consider changes to the safety inspection program and are in discussions with them about coming to present our findings to the task force.

The results of this research have also been written as a manuscript that has been accepted for presentation at the 2019 Transportation Research Board (TRB) conference and also provisionally accepted as a manuscript in Transportation Research Record. We have been in discussions with NHTSA about writing shorter summaries of the manuscript for use in NHTSA research result publications.

Project Outcomes

Attached is a manuscript accepted for presentation and publication at the 2019 TRB Conference.

Manuscript accepted for presentation at 2019 Transportation Research Board conference, and for publication in the journal Transportation Research Record – please do not re-distribute without permission.

Data-Driven Analysis to Support Revised Tire Tread Inspection Standards

Vinod Krishnappa[1], H. Scott Matthews[1,2], and Yi Liu[1]
Department of Civil and Environmental Engineering[1]
Department of Engineering and Public Policy[2]
Carnegie Mellon University

Abstract

Despite a long-term focus on passenger vehicle safety, there are still 38,000 vehicle-related fatalities annually. Some are the result of failure to maintain safety components of vehicles, such as brakes, tires, or headlights. Following NHTSA guidelines, 18 states have implemented periodic safety inspection programs where certified inspectors assess components, and owners are required to repair or replace deficient components.

In the case of tires, when a tire's tread depth falls to 2/32 of an inch, its stopping distance on a road becomes very high. Thus, this tread depth level was built into the safety inspection thresholds for tires. A social challenge is that in an annual vehicle inspection, if a tire passes at a level of 3/32", it may fall below the safe (2/32") threshold soon after the inspection. In an era of higher VMT and reduced attention to maintenance, perhaps the thresholds set for the safety inspections should be higher than the 'safe level' to provide a buffer.

Using 6 million safety inspection records from Pennsylvania from 2006-16 we calculate tread depth deterioration and annual VMT at the vehicle level. We estimate the 'percent of vehicles at risk of having unsafe tires before the next inspection' (using the 2/32" threshold) to be about 30%. We also estimate how that percent of 'at risk vehicles' decreases as the inspection thresholds are raised, and find an attractive threshold at about 5/32" where the percent of at-risk vehicles would be very low. Such changes could further reduce fatal and non-fatal accidents.

Introduction

In the US, safety of the passenger vehicle fleet has been a priority since nearly the birth of the automobile up to the present-day fleet of 190 million passenger vehicles. Despite this priority, there are still 38,000 road fatalities in the US per year, as well as 2.5 million non-fatal injuries (*1*). The causes of these crashes range from behavioral to technological, including vehicle features and components. Amongst the many activities undertaken to reduce these crashes are safety inspections of passenger vehicles. While safety inspections are included as a recommended part of NHTSA's Uniform Guidelines for State Safety Programs (*2*), they are not federally mandated, and thus are implemented voluntarily by states. Currently, only 18 of the 50 states have safety inspection programs – most of them requiring them annually - and the recent trend has been eliminating, not adding, such programs. Globally, many countries have safety inspections.

Due to the NHTSA-provided system standards, many of the details of state safety inspection programs are similar. State programs inspect vehicle safety components, such as brakes, tires, and headlights, which can lead to crashes when not maintained in a safe condition. While those are some of the most popular components inspected, some programs also inspect less obvious safety components like wiper blades and the vehicle undercarriage. If a safety component problem is identified, it needs to be corrected before the vehicle passes the inspection. These problems may be assessed by simply adjusting or repairing the component (e.g., re-aiming headlights), but more likely by replacement (e.g., buying new tires), either of which increases user costs.

Vehicles often have safety problems identified at the time of inspection. Using a data driven analysis method of millions of state inspection records over time, Peck et al (*3*) found that when counting repairs or replacements necessary in order to pass an inspection, the failure rate for passenger vehicles in inspections in Pennsylvania ranges between 12-18% (i.e., this percent of vehicles 'would have failed' if the components had not been corrected). However, such aggregate analyses do not focus on the effects on any particular underlying safety component, or on assessing the utility of the standards used to test the level of safety of the components.

With respect to safety component-specific inspection activities, states have typically adopted system standards from NHTSA, including specific quantitative reference thresholds. For example, as part of the inspection of the safety of tires, NHTSA provides a way of measuring tire tread depth, and sets as a minimum safe level 2/32 of an inch (*2*), meaning that if the measured tread depth is less than or equal to 2/32", the tires are deemed unsafe and do not pass the inspection unless changed. This same tread depth has generally been used across the world for assessing tire safety. The 2/32" minimum tread depth threshold was set many years ago by NHTSA when studies assessed that there was a significant increase of stopping distance needed (a significant non-linear inflection point) at that depth.

Beyond tread depth, NHTSA and others have done various studies of when tires led to poor safety outcomes using fatality and accident data. NHTSA (*4*) estimated that about 400 out of the total 38,000 annual fatalities were the result of tire failures of all types (e.g., due to aging, underinflation, and tread depth). As part of that study, NHTSA also noted that between 1973 and 2004, tire tread life increased from 24,000 to 44,700 miles (*5*) while annual VMT increased from 10,000 to 12,500 miles (*6,7*). More recent research from NHTSA (*8*) notes that analysis of 2007-10 data showed a 50% reduction in fatalities (to 200 per year), partly due to improved tire performance standards (e.g., FMVSS No. 139) and also the introduction of Tire Pressure Management Systems (TPMS). However, a significant number of accidents and fatalities remain due to tire-related causes, which are in part due to owners being less diligent nowadays in maintaining safety components of vehicles, including the period (as relevant) between inspections (*9*).

Despite the longstanding global use of the 2/32" threshold for tire tread depth, various entities have called for increasing the minimum tread depth values. For example, the UK's Royal Society for Prevention of Accidents (RoSPA) in 2005 noted that at their legal minimum tire tread depth of 1.6 mm (about 2/32"), the stopping distance nonlinearly increased by 36.8% on hot rolled asphalt and 44.6% on smooth concrete compared to a reference depth of 4 mm (about 5/32") (*10*). Hence, RoSPA recommended that the minimum tire tread depth be changed to 3 mm (about 3.6/32”). Likewise, various manufacturers have recommended higher minimum tread depth levels in the same ranges, which is self-serving given the hundreds of dollars of additional revenue per vehicle that would be generated. However, that revenue is not wholly additional, it is just time-shifted by some short time period in the future when owners would need to change their tires.

Some challenges in maintaining safety components of vehicles cannot be fully addressed by safety inspection programs. That is because the periodic nature of the programs means that vehicles may be deemed safe at time of inspection, but could become unsafe in obvious or hard to observe ways before the time of next inspection. For example, a car could pass an inspection when all four tires have a tread depth level of 3/32” (which is above the threshold for being required to change them). But at such a low tread depth, a relatively modest amount of driving would deteriorate the tires down to the 2/32” ‘unsafe’ threshold depth, likely soon after the inspection and perhaps months (or years) before the next inspection which would force replacement of tires. This situation means that a significant number of cars could be at risk of driving on unsafe tires in the time between inspections, and is exacerbated by decreasing concern for preventive maintenance and also higher VMTs that accelerate tread deterioration. The same ‘time between inspection’ issues are true for other safety components. Independent of changing the unsafe tread depth level in policy (which should be set based on agreed science such as optimal stopping distance), a way to help reduce the number of vehicles at risk of driving on unsafe tires in the era of high VMT is to change the inspection threshold to a depth (e.g., 3/32” or 4/32”) that is above the commonly agreed unsafe tread depth (2/32”) to compensate for the likelihood that tread depth could deteriorate to the unsafe level before the time of the next inspection.

In this paper, we leverage data on Pennsylvania safety inspections that includes tread depth and odometer readings for one or more tires at the completion of a specific vehicle’s (by VIN) annual safety inspection. We use this data to create aggregate as well as vehicle-level estimates of the tread depth deterioration rate (as a function of VMT) to estimate the percent of vehicles that are at risk of driving with unsafe tires (defined as the current 2/32” depth threshold) at some point in time before the next inspection. The ‘at risk’ rate is then estimated as the tread depth inspection threshold is varied to higher depths than the current 2/32” standard. We do this to demonstrate how data analytic approaches to transportation policy can be achieved based on unexpected data sources such as safety inspections, and consider how other safety component standards could similarly be improved from such analyses.

Data Sources and Preparation

For the purpose of this analysis, data from two sources, namely E-Safety and CompuSpections, have been used. E-Safety is the official database of the State of Pennsylvania to maintain the records of the vehicles inspected, but use of the system is only voluntary and so only a sample of inspections are available. CompuSpections is a private company that sells record management software services to inspection stations and has a significant market share in the state. In both cases data was provided under a data sharing contract with the research team. About 6 million vehicle inspection records from 2006-16 were available spanning both data sources. The major difference in the data format from these two sources of data were that CompuSpections records had tire depth data for all four tires whereas the E-Safety database only requires a value for the lowest tire tread depth. Data from both sources had records that could not be used in this analysis for various reasons, and the various checks needed for a record to be deemed 'invalid' are listed below:

- Vehicle Identification Number (VIN) in the record is invalid
- Model year in the record does not match the model year determined using the VIN
- Odometer reading contains non-numeric characters
- Record does not have an inspection result
- Inspection type is not annual (meaning it refers to non-typical passenger vehicles)
- Tire tread depth is either below 2/32" or above 22/32" (which should not be possible)
- Duplicate records
- The body type of the vehicle is not for passenger car
- Either the tire tread depth values or the odometer reading is empty (note: for CompuSpections data, records without tire tread depth for all four tires)

Since the primary activity of our analysis was to estimate deterioration rates of tire tread at the individual vehicle level, we sought sequences of valid records associated with unique vehicles comprising least 3 inspection records. As a deterioration rate calculation requires two inspection records, the choice of requiring 3 records is in order to find two rates which can then be averaged for a vehicle. Table 1 summarizes the initial and valid records from both sources that were used in the analysis. It can be seen that 1.1 million records (associated with 273,000 unique VINs) from CompuSpections and 1.7 million records (associated with 422,000 unique VINs) from E-Safety, spanning over 7 and 9 years respectively, were used in the analysis.

	CompuSpections	**E-Safety**
Date Range	2006 - 2013	2007 - 2016
Total # of records	2,217,335	4,010,714
# Valid records	2,140,193 (1,094,967 Vehicles)	3,548,239 (1,884,104 Vehicles)
# Records associated with Vehicles with at least 2 records	1,519,920 (474,694)	2,458,765 (794,630)
# Records associated with Vehicles with at least 3 records	1,116,960 (273,214 Vehicles)	1,714,731 (422,613 Vehicles)

Table 1: Data from both CompuSpections and E-Safety

Since we seek valid and useful sequences of data on tire tread depth, we need to ensure that spurious records are not included. To illustrate how the data on tire tread depths in the inspection records is affected by our data validation and cleaning activities, the distribution of tire depths of the records from both the sources at various stages of cleaning described above is shown in Figure 1 and 2. While the initial dataset has some very high depth outliers, the valid and 'set of three' subsets have reasonable ranges of tread depth and that are similar across the two datasets. New tires typically have a tread depth of 10/32" - 12/32", but some off-road tires have 15/32" or higher (*11*). A previous study conducted by Thiriez and Subramanian (*12*) shows a similar distribution as our valid records, suggesting that we have a reasonable sample of the fleet of passenger vehicles.

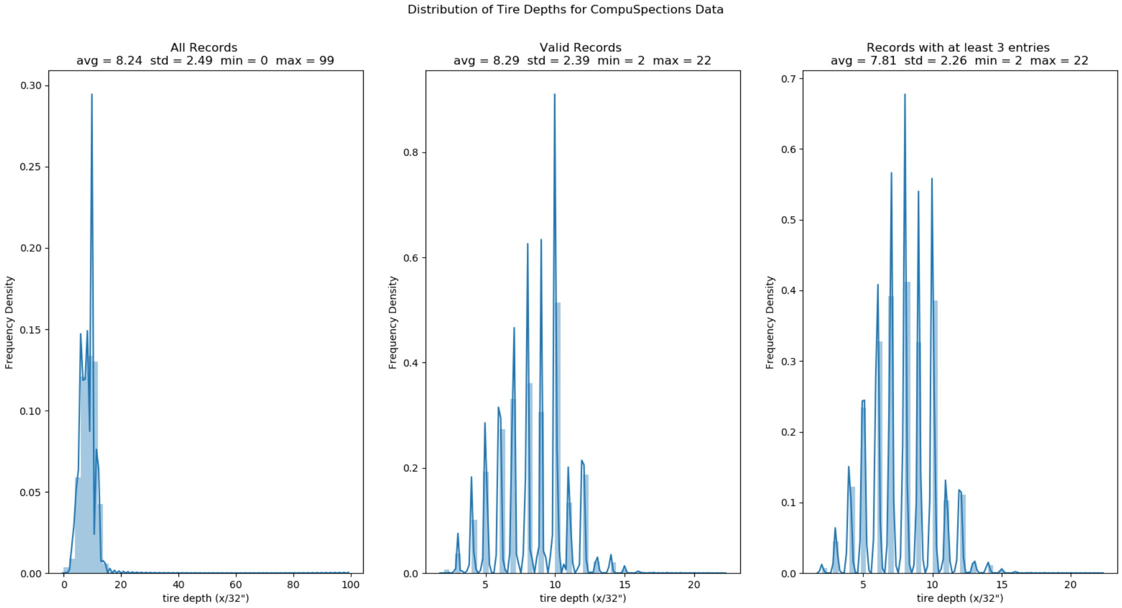


Figure 1: Distribution of tire tread depth of the records from CompuSpections data source at various stages of data cleaning

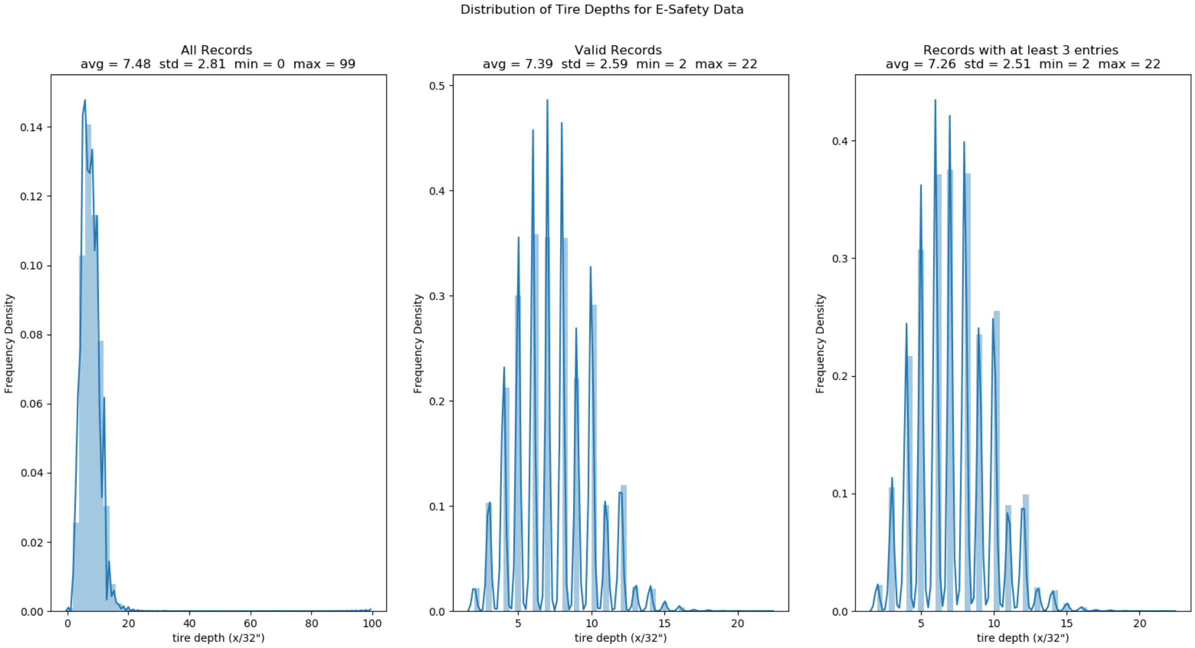


Figure 2: Distribution of tire tread depth of the records from E-Safety data source at various stages of data cleaning

Estimation of Vehicle Miles Travelled

Out of the valid 1.1 million CompuSpections and 1.7 million E-Safety records retained after initial validation checks, only records which showed an increase in odometer reading were used to calculate the average annual VMT. Only about 15,000 data points in E-Safety were lost due to negative change in odometer reading or constant odometer reading. Some outlier treatment was conducted to avoid the influence of large values recorded potentially due to data collection error (for example the raw data showed odometer increases of more than 360,000 miles in a year, or about 1,000 miles per day). The distribution of annual VMT, in miles, for different percentiles of outlier treatment is shown in Figures 3 and 4.

Removing 1% of outliers on both ends of the distribution for CompuSpections, the average annual VMT is calculated as 10,200 miles. For E-Safety, 2% of data were removed on both ends of the distribution and average mileage is determined as 9,000 miles/year. These outlier settings were based to balance removing extreme values while preserving the mean and standard deviation. According to NHTS 2017, the average annual mileage per vehicle for Pennsylvania is 11,300 (*13*), and although our results differ slightly, considering we are conducting analysis using different methods (some of which do not utilize average VMT value), our results should not be drastically different from reality.

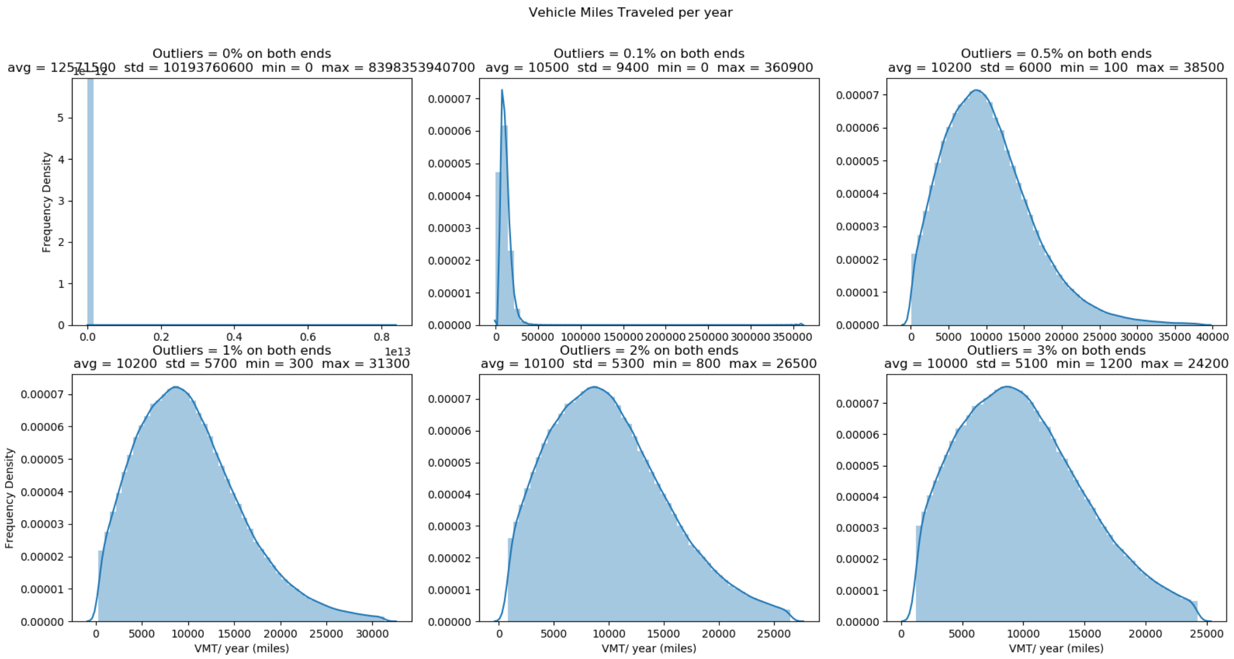


Figure 3: Annual VMT (miles) for different percentiles of outliers (CompuSpections data)

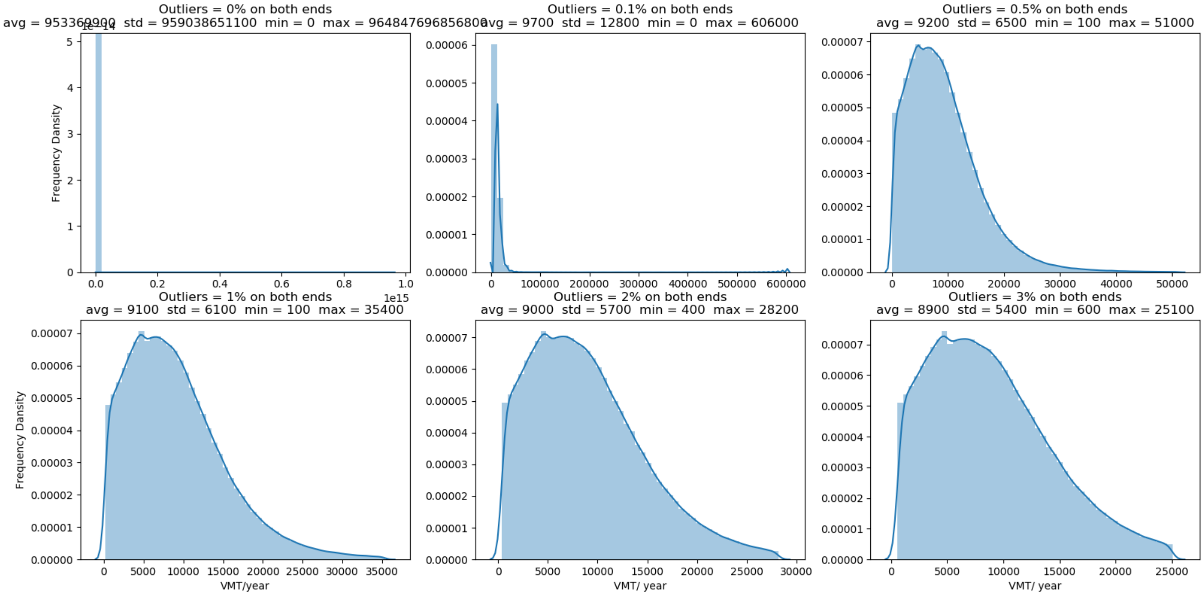


Figure 4: Annual VMT (miles) for different percentiles of outliers (E-Safety data)

Estimation of Tire Tread Deterioration Rates and Timing of Tire Changes

After the initial validation checks, for the calculation of tire tread deterioration, only inspection records which were less than 400 days apart (including a slight buffer) were considered for calculation of tire tread deterioration rate (TDR), as a longer date difference may not be able to capture tire changes between inspections.

Similarly, records needed to show a decreasing value of tire tread depth for all of the recorded tires. Since they are non-decreasing, they are excluded from the TDR calculations, but are used for analysis below. Other exclusions occurred due to identified data collection errors, duplicate records, etc., but removed only a few thousand records. Out of 1.1 million CompuSpections records, there were more than 550,000 data points and out of 1.7 million E-Safety records, there were about 600,000 data points which passed these additional conditions to be used to find deterioration rates.

The TDR is calculated as the ratio of decrease in tire tread depth to the increase in odometer reading across the paired records. After examining the distribution of vehicle-specific TDRs, some outlier treatment was deemed necessary due to various extreme or hard to believe values. This was to ensure that a very small percentage of large values either due to recording error or any other reason did not skew the average TDR used for further analysis. The TDR (per 32 of an inch) per 1,000 miles driven for different percentiles of outlier treatment is shown in Figures 5 and 6. In the end, the average TDR for passenger vehicles is found to be -0.3 to -0.4 per 1,000 miles driven (or about 3/32”- 4/32” deterioration per 10,000 miles driven). Lacking any literature sources on TDRs, we attempted to validate the results. Given that new tires have 10/32” to 12/32” of tread depth, the TDR results seem to intuitively match tire warranties and other stated facts that say tires should last 2-3 years.

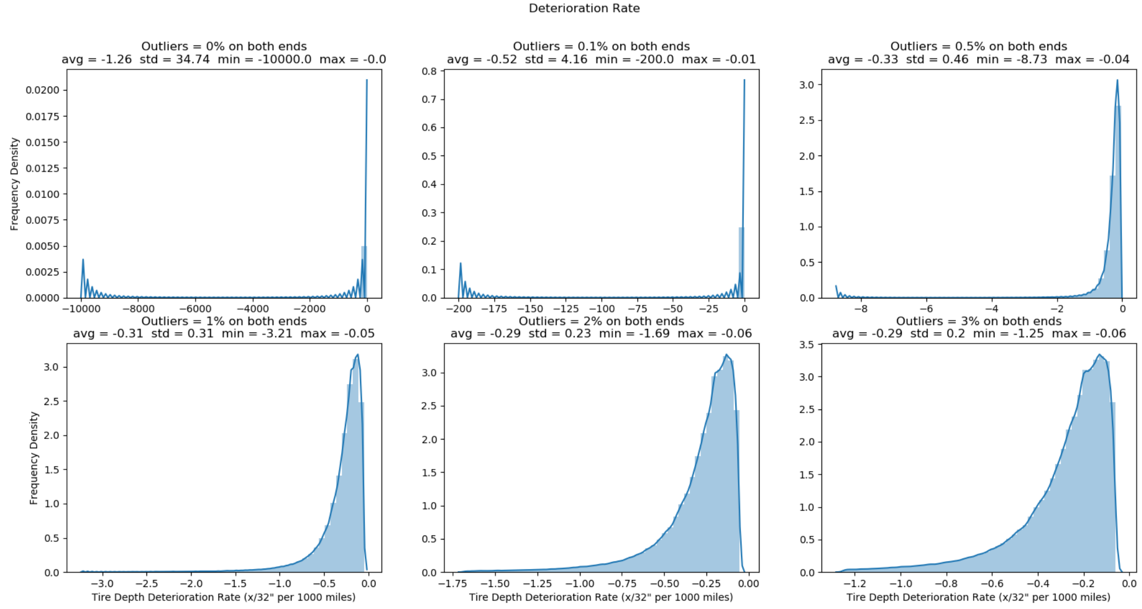


Figure 5:Tire tread depth deterioration rate for various percentiles of outliers for CompuSpections data

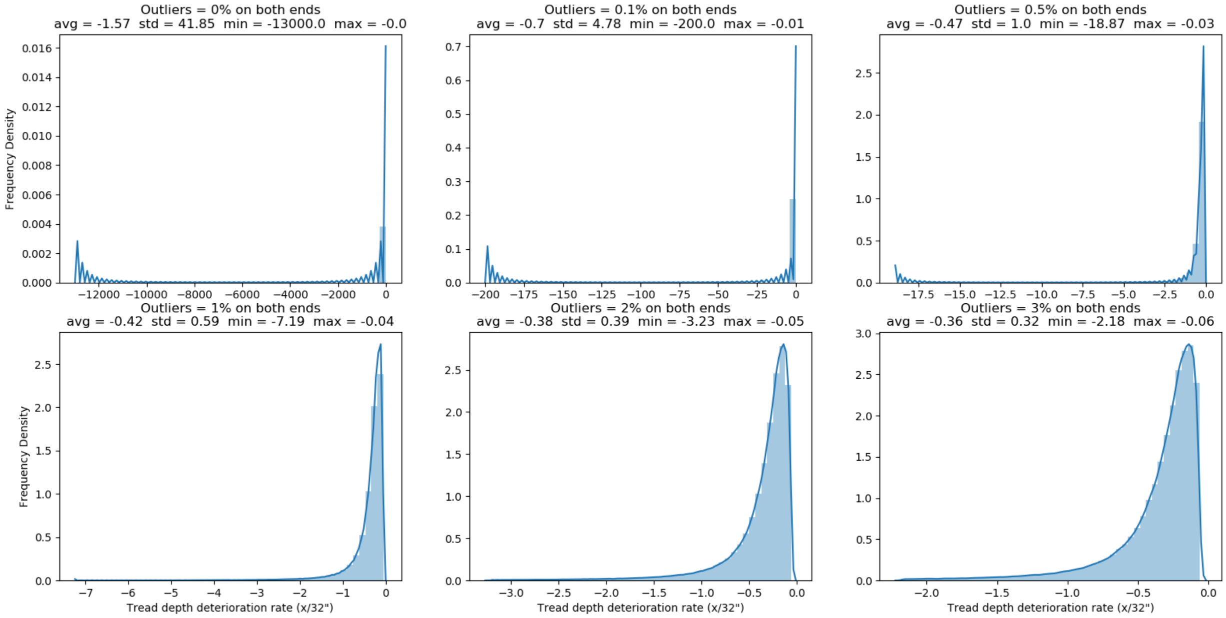


Figure 6: Tire tread depth deterioration rate for various percentiles of outliers for E-Safety data

While not a core focus of this study, we performed an initial analysis of the number of data points that showed an *increase* in tread depth or had a constant tread depth between two inspections, which was 330,000 in CompuSpections and 400,000 in E-Safety. Since our records are generated at the time of an annual inspection, with limited text comment fields for descriptions of repair activities, we considered two categories for managing the large numbers of records identified above where tire tread *increased* between consecutive inspections: first, tires changed at the time of inspection, and second, tires preventatively changed in between inspections. Identifying additional insights from either category can help to inform the broader challenge of avoiding unsafe tires.

For the first category, the data were further analyzed to see when inspection record fields noted that tires were changed during the inspection. For the E-Safety data, out of the 400,000 affected records, 30,000 vehicles met this criteria, about 8% of the subset. A similar analysis was not yet possible with the CompuSpections data but is expected to be similar. While this part of the study is only a preliminary analysis, future work could explicitly track the vehicles identified as likely to have unsafe tires before the next inspection period to see which get tires before the inspection and which wait until the inspection. The analysis could also predict the timing of when tires would need to be changed to try to assess how long the tires remained unsafe before being changed. The goal would be to find the percentage of drivers with ‘unsafe tires’ waiting until the time of the inspection to change the tires.

Thus, for the second category, the maximum tread depth for each vehicle was identified and assumed as the tread depth of a new tire. If there was an increase in tread depth, but the new value recorded was less than the maximum value, then the tire change was categorized as between the two annual inspections. E-Safety records showed that there were about 130,000 tires changed during inspection and

270,000 tires changed between two annual inspections. Since E-Safety just collects the data point for the tire with the lowest tread depth, there may be more changes which cannot be determined by E-Safety data alone. There were about 105,000 vehicles (350,000 tires) that had at least one of the tires changed during inspection and about 207,000 vehicles (620,000 tires) had at least one of the tires changed between two inspections according to CompuSpections data. From both CompuSpections and E-Safety data, it can be seen that about 67% of the vehicles change their tires preventively, but the remaining 33% wait to change during inspection. This has big implications on the status quo inspection threshold of 2/32", and considerations of changing it, since waiting for drivers to proactively change tires between inspections could lead to more unsafe vehicles on the road. With both the TDR and VMT for each vehicle, we can consider better data-driven models to estimate the percentages of at-risk vehicles at times between inspections in support of alternative inspection thresholds.

Method

In order to consider whether the tread depth inspection level is keeping up with modern vehicle maintenance and use, and whether it is sufficiently identifying the prospect of having a vehicle with unsafe tread levels between inspections, we constructed a model to estimate the percent of cars likely to fall below the safe tread level at some period in time between inspections.

To do this, we define two similar but distinct values that are critical to this analysis. First, the "unsafe tread depth level", which is assumed to be fixed at 2/32", in line with current NHTSA standards and safety inspection programs in the US, and otherwise deemed to be the level where tires are no longer effective as measured by stopping distance. Second, the "inspection threshold", which is what is used by inspectors to assess tire tread depth compliance. These state safety inspection threshold levels for tread depth are currently also 2/32", but as suggested above since the two values are the same, it raises the prospect that tires slightly above threshold may pass a current inspection, but drop below the safe level at some point in time before the next inspection. This leads to vehicles being at risk of unsafe tread. Thus, increasing the inspection threshold would provide "headroom" against getting to an unsafe level.

In order to predict the number and percent of vehicles that could fall below the safe level (and thus be at risk of having unsafe tires), we use the vehicle level TDR and VMT values found above. We seek the number of vehicles who pass a current inspection, but whose vehicle-specific TDR and VMT could lead to an expected tread depth (td) that is below the safe level before the time of the next inspection, as expressed in Equation 1.

$$\text{predicted td} = \text{current td} + \text{VMT} * \text{TDR} \qquad (1)$$

The percentage of vehicles which have currently passed the inspection, but are at risk of failing the inspection within the next year if tires are not changed (the "at risk %"), is calculated as the ratio of the number of vehicles which would be predicted to have tread depth below 2/32" (and fail inspection next year) to the number of vehicles which have passed the current inspection.

Even though we have vehicle specific data, we create several parallel models to assess the ability to use simpler aggregated data instead in support of better safety policy. By aggregated, we mean for example the average values across the fleet of vehicles for which we have data. This will be important as clarified below because while data may be vehicle-specific, a modified policy might need to be based on aggregate considerations. For example, if we were to suggest an informed policy that considers all information about a vehicle (tire tread depths, historic TDR, historic VMT, etc.) when determining its allowed inspection threshold, the policy could be very complex. On the other hand, if the policy were set based on data-driven averages of TDR and VMTs of all vehicles in the fleet (e.g., those reported above like -0.3/1000 miles and 10,000 miles driven), the policy would be easier to implement (but, perhaps not improve safety for vehicles whose own values varied significantly from the average). Our goal is thus to create an ensemble of similar policy models that all seek to identify percentages of at-risk vehicles, to then assess how detailed the policy might need to be in order to be effective.

We define and summarize these nine ensemble models in Table 2. As shown, we model each of the two key variables in equation 1 (VMT and TDR) in three alternative ways for each of the two datasets. VMT can be modeled as: (1) any assumed value (which from the data suggests it is in a range between 1,000 and 30,000 miles) (2) average of each vehicle's historical VMT based on odometer readings from inspection records; and (3) predicted vehicle VMT using linear regression to incorporate possible increasing or decreasing trend. Similarly, TDR can be modeled as: (1) overall average rate over all vehicles in the data; (2) average rate for specific "body type" (Passenger Car, Pick-up Truck, etc.); (3) average of each vehicle. The at-risk percentage at the current inspection standard of 2/32" (the status quo) for the different methods and data sources are tabulated and averaged in the final column of Table 2. Note that for comparability, the "Assumed VMT" values used for the results shown in the table are 10,000 for CompuSpections and 9,000 for E-Safety (complete results for all mileage bins shown below).

Table 2: Percent of vehicles at risk of driving on unsafe tires before next inspection (at current inspection standard of 2/32") for different methods

			At Risk Percentage	
VMT Method	**Tread Deterioration Method**	**Model Name**	**CompuSpections**	**E-Safety**
Arbitrary value assumed as overall average annual VMT for all vehicles	Overall Average	Model1	26%	28%
	Body Type Specific Average	Model2	21%	28%
	Vehicle Specific Average	Model3	31%	36%
Vehicle Specific Historical Average	Overall Average	Model4	23%	31%
	Vehicle Specific Average	Model5	26%	26%

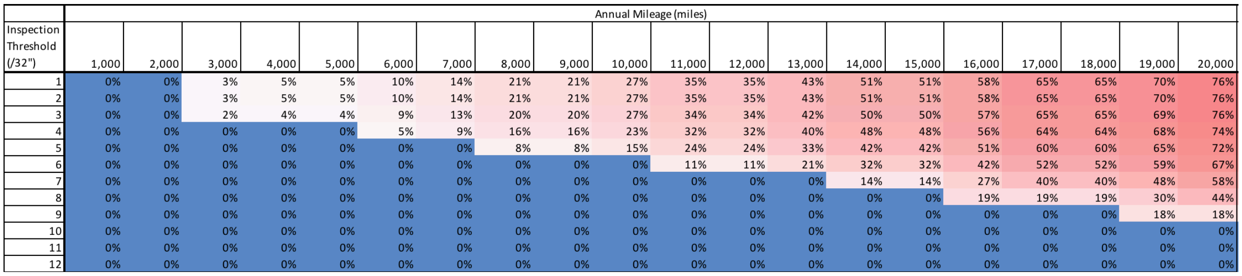
	Body Type Specific Average	Model6	25%	31%
Vehicle Specific Predicted	Overall Average	Model7	25%	28%
	Vehicle Specific Average	Model8	28%	33%
	Body Type Specific Average	Model9	21%	28%
	Average of all the methods		**25%**	**30%**
	Overall Average from both sources		**28%**	

These results tell us that across all nine models and two data sources, on average about 28% of vehicles which pass a current inspection would be expected to fail their next annual inspection due to tire tread depth without a proactive decision by the owner to replace their tires before that time. There is not a significant variation in results across the eighteen values presented – about 21 to 36%. If we attempt to leverage the results above that suggest that 67% of the vehicles change their tires preventively, then out of these 28% of vehicles, 18.5% of vehicle owners might change the tires before it goes below the safe depth of 2/32", but the other 9.5% of the vehicles would be using the unsafe tires until the inspection.

The tire tread inspection thresholds aren't about the number itself but about taking the opportunity at time of inspection to identify vehicles whose tire-related safety might be at risk. And since these mandatory inspections only happen on an annual basis, this once a year opportunity could be informed by knowledge of driving levels as well as behavior which tends to only respond to problems as they happen. As motivated above, we next thus consider the inspection threshold to be variable. While Table 2 shows the results for different models of VMT and TDR at the *current* inspections standards (which are equal to the NHTSA safe tread level), we also estimate how the "at risk percentage" varies if the inspection standards were changed in order to better appreciate the fact that vehicles are being driven more and owners are generally paying less attention to safety components like tires. Specifically, we consider increases in the inspection standard (e.g., to 3/32") to try to reduce the number of vehicles at risk of driving on unsafe tires. Raising the inspection standard would mean that there would be less vehicles whose expected tread depth at the next inspection would be below the unsafe level, due to the increased headroom compared to the unsafe level.

An initial analysis to determine the variation of "at risk percentage" with variation of inspection standards and annual VMT was conducted by using the overall average TDR (Model1 from Table 2, i.e., -0.3 and -0.4/1000 miles from CompuSpections and E-Safety). The average "at risk percentage" computed across both data sources, for a particular combination of inspection standard and arbitrary VMT applied to all cars in the fleet, are shown in Figure 7. The figure is color scaled where blue represents an expectation of 0% of vehicles are at risk (or 100% of vehicles are safe) until the next annual inspection and red indicates a maximum number of vehicles are at risk (in this case, 76% vehicles in top right corner).

Figure 7: Percent of at-risk vehicles calculated using overall average tire tread deterioration rate and VMT (Model1). Average over both data sources



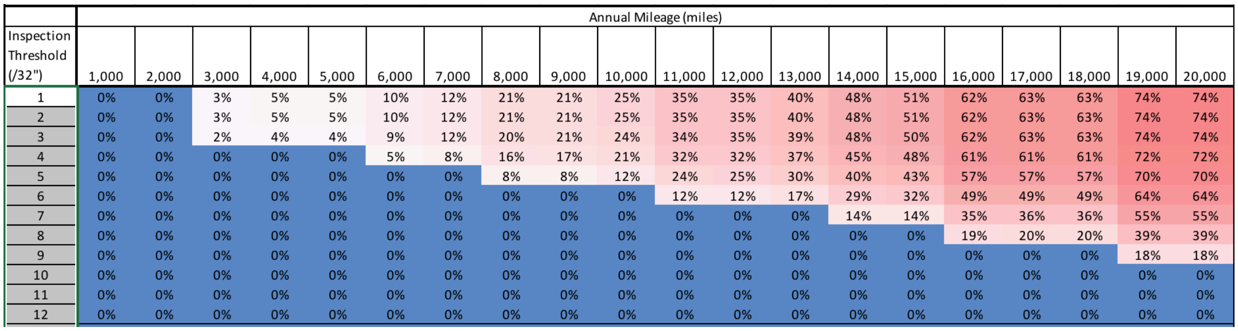
	Annual Mileage (miles)																			
Inspection Threshold (/32")	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
1	0%	0%	3%	5%	5%	10%	14%	21%	21%	27%	35%	35%	43%	51%	51%	58%	65%	65%	70%	76%
2	0%	0%	3%	5%	5%	10%	14%	21%	21%	27%	35%	35%	43%	51%	51%	58%	65%	65%	70%	76%
3	0%	0%	2%	4%	4%	9%	13%	20%	20%	27%	34%	34%	42%	50%	50%	57%	65%	65%	69%	76%
4	0%	0%	0%	0%	0%	5%	9%	16%	16%	23%	32%	32%	40%	48%	48%	56%	64%	64%	68%	74%
5	0%	0%	0%	0%	0%	0%	0%	8%	8%	15%	24%	24%	33%	42%	42%	51%	60%	60%	65%	72%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	11%	11%	21%	32%	32%	42%	52%	52%	59%	67%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	14%	27%	40%	40%	48%	58%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%	19%	19%	30%	44%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	18%	18%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

The results show that for low VMT (1-2,000 miles per year), the inspection threshold has no meaningful effect on safety, as expected. But even as VMT is modest and much lower than average, from 3,000 to 6,000 VMT, we expect about 5% of the fleet would be driving on unsafe tires even if the inspection threshold were raised to 3/32". At higher levels of VMT, we see increasing expected percentages of at-risk vehicles even with much higher inspection thresholds. For example, the value in the cell corresponding to the inspection standard of 2/32 on the y-axis and 10,000 VMT on the x-axis represents the average of the model1 result in Table 2. Visually, much of the lower half has 0% at-risk vehicles.

Similarly, if the inspection standard were doubled to 4/32" with the assumption that all cars were being driven 10,000 miles per year, we would still predict 23% of them to be at risk of having unsafe tires before the next inspection. And at 5/32", only about 15% of the 10,000 VMT vehicles would be at risk. We would need to increase the standard to 6/32" to eliminate vehicles with unsafe tires. While these are aggressive measures, they are in line with the recent literature from RoSPA and others calling for these increases. Further, we do not mean to imply that the threshold needs to be raised to the level to completely eliminate the potential for unsafe tires, as achieving "0%" is difficult, but policymakers could discuss an acceptable level of at-risk vehicles, such as 5%, for the inspection threshold increase. These results are highlighted first because they use the most aggregate assumptions and considerations, which of course would be most accessible to policymakers considering changes to the inspection thresholds.

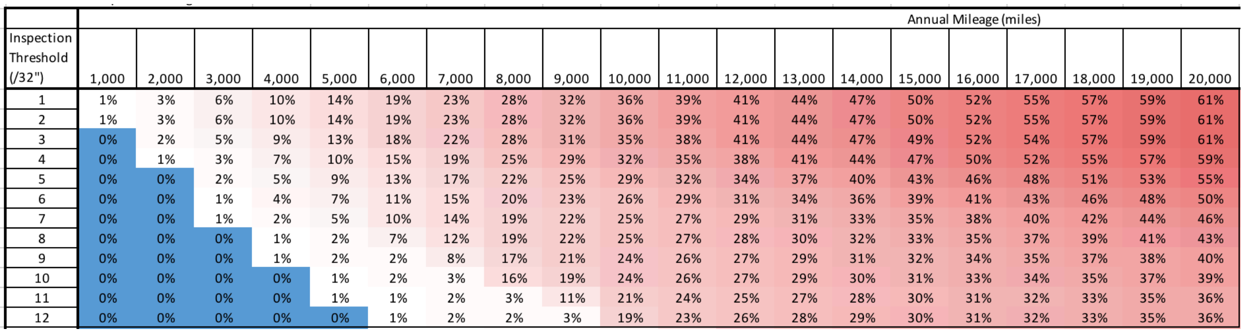
Following this template, Figure 8 and Figure 9 show results for Model2 and Model3, which use body type specific TDR and vehicle-specific TDR respectively, but still the arbitrary-binned VMT columns, the cells again showing the average of "percent vehicles at risk" from the two data sources.

Figure 8: Percent of at-risk vehicles calculated using body type specific deterioration rate and overall annual mileage(Model2)



	Annual Mileage (miles)																			
Inspection Threshold (/32")	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
1	0%	0%	3%	5%	5%	10%	12%	21%	21%	25%	35%	35%	40%	48%	51%	62%	63%	63%	74%	74%
2	0%	0%	3%	5%	5%	10%	12%	21%	21%	25%	35%	35%	40%	48%	51%	62%	63%	63%	74%	74%
3	0%	0%	2%	4%	4%	9%	12%	20%	21%	24%	34%	35%	39%	48%	50%	62%	63%	63%	74%	74%
4	0%	0%	0%	0%	0%	5%	8%	16%	17%	21%	32%	32%	37%	45%	48%	61%	61%	61%	72%	72%
5	0%	0%	0%	0%	0%	0%	0%	8%	8%	12%	24%	25%	30%	40%	43%	57%	57%	57%	70%	70%
6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	12%	12%	17%	29%	32%	49%	49%	49%	64%	64%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	14%	14%	35%	36%	36%	55%	55%
8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	19%	20%	20%	39%	39%
9	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	18%	18%
10	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
12	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Figure 9: Percent of at-risk vehicles calculated using vehicle specific deterioration rate and overall annual mileage (Model3)



	Annual Mileage (miles)																			
Inspection Threshold (/32")	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	12,000	13,000	14,000	15,000	16,000	17,000	18,000	19,000	20,000
1	1%	3%	6%	10%	14%	19%	23%	28%	32%	36%	39%	41%	44%	47%	50%	52%	55%	57%	59%	61%
2	1%	3%	6%	10%	14%	19%	23%	28%	32%	36%	39%	41%	44%	47%	50%	52%	55%	57%	59%	61%
3	0%	2%	5%	9%	13%	18%	22%	28%	31%	35%	38%	41%	44%	47%	49%	52%	54%	57%	59%	61%
4	0%	1%	3%	7%	10%	15%	19%	25%	29%	32%	35%	38%	41%	44%	47%	50%	52%	55%	57%	59%
5	0%	0%	2%	5%	9%	13%	17%	22%	25%	29%	32%	34%	37%	40%	43%	46%	48%	51%	53%	55%
6	0%	0%	1%	4%	7%	11%	15%	20%	23%	26%	29%	31%	34%	36%	39%	41%	43%	46%	48%	50%
7	0%	0%	1%	2%	5%	10%	14%	19%	22%	25%	27%	29%	31%	33%	35%	38%	40%	42%	44%	46%
8	0%	0%	0%	1%	2%	7%	12%	19%	22%	25%	27%	28%	30%	32%	33%	35%	37%	39%	41%	43%
9	0%	0%	0%	1%	2%	2%	8%	17%	21%	24%	26%	27%	29%	31%	32%	34%	35%	37%	38%	40%
10	0%	0%	0%	0%	1%	2%	3%	16%	19%	24%	26%	27%	29%	30%	31%	33%	34%	35%	37%	39%
11	0%	0%	0%	0%	1%	1%	2%	3%	11%	21%	24%	25%	27%	28%	30%	31%	32%	33%	35%	36%
12	0%	0%	0%	0%	0%	1%	2%	2%	3%	19%	23%	26%	28%	29%	30%	31%	32%	33%	35%	36%

The results from Model2 show only modestly different results to Model1, i.e., that the percentage of vehicles at risk drop to 0 when the mileage is equal to average annual mileage, and the inspection standard is increased to at least 6/32”. Thus, the use of body-type specific TDRs does not have a pronounced differential effect on the at-risk results.

However, the results from Model3 show how our expectations of at-risk vehicles begin to differ significantly when able to consider vehicle-specific TDRs. In general, even for the same overall average VMT assumptions, the percent of vehicles at-risk generally increases across the board, and more importantly, increases even at inspection thresholds that are much higher than the 5 or 6/32” referenced above. Visually, small percentages of at-risk vehicles occupy much of the lower triangle of the figure. This is because, in reality, some vehicles in the dataset have TDRs much higher than the average (perhaps because the owners are very aggressive in terms of acceleration and braking and wear out their tires far more quickly than the average). This shows that there are small but not insignificant numbers of cars in the fleet that even much higher inspection thresholds would not completely eliminate unsafe tires. This result also reinforces our earlier comment that achieving “0%”unsafe tires is likely impossible and thus should not be the policy goal.

While similar result figures were created for all nine models, the remaining results are summarized in a tabular fashion to conserve space. The results of the analysis using vehicle specific mileage (Models 4-6) and predicted mileage based on vehicles’ data (Models 7-9) are tabulated in Table 3 and Table 4, respectively. For historical VMTs, percentage of vehicles at risk is calculated for historical average as well as minimum and maximum annual mileage for specific vehicles. As above, the results shown are the averages of both data sources. Instead of the arbitrary VMT bins, all vehicles are using their own historical or predicted VMTs.

Table 3: Percent of vehicles at risk calculated using vehicle specific mileage and different deterioration rates (Models 4-6)

	Tire Tread Deterioration Rate (TDR) Model								
	Overall Average TDR			**Vehicle Specific TDR**			**Body Type Specific TDR**		
	Mileage			**Mileage**			**Mileage**		
Inspection Threshold (/32")	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**	**Min**	**Avg**	**Max**
1	22%	29%	36%	19%	25%	31%	22%	28%	36%
2	22%	29%	36%	19%	25%	31%	22%	28%	36%
3	21%	28%	35%	18%	24%	30%	21%	28%	35%
4	18%	25%	32%	15%	21%	27%	18%	25%	32%
5	13%	19%	27%	11%	16%	22%	13%	19%	27%
6	8%	13%	20%	10%	13%	18%	8%	12%	19%
7	5%	8%	13%	9%	12%	15%	5%	8%	13%
8	2%	4%	8%	9%	12%	15%	2%	4%	8%
9	1%	2%	5%	9%	11%	14%	1%	2%	5%
10	1%	1%	3%	9%	11%	14%	1%	2%	3%
11	0%	0%	1%	8%	10%	12%	0%	0%	2%
12	0%	0%	1%	7%	9%	12%	0%	0%	1%

Table 4: Percent of vehicles at risk calculated using predicted mileage and different models of deterioration rate (Models 7-9)

	Tire Tread Deterioration Rate (TDR) model		
Inspection Threshold (/32")	**Overall Average**	**Vehicle Specific**	**Body Type Specific**
1	27%	31%	25%
2	27%	31%	25%
3	26%	30%	24%
4	23%	27%	21%
5	15%	24%	13%
6	3%	21%	3%
7	2%	20%	2%
8	1%	20%	1%
9	0%	20%	0%
10	0%	19%	0%
11	0%	14%	0%
12	0%	10%	0%

These tables show comparable results as above, but visually emphasize that the combination of vehicle specific values for both VMT and TDR reveal fairly significant percentages of the fleet that could have unsafe tires even with aggressively set inspection thresholds. In short, possessing the additional vehicle-specific information allows an analyst to better appreciate the numbers of vehicles that we would expect to have unsafe tires across the board. But, as first mentioned above, we would not expect or recommend that the policies actually be individually tailored to specific vehicles (e.g., with a highly targetable algorithm for each vehicle similar to using Equation 1). Aside from the technical challenges in achieving that, there would be social equity issues associated with having different thresholds. Instead, we would expect an agreeable state agency in charge of transportation to take a more pragmatic approach that utilizes the available distributions and averages and sets an inspection threshold that considers all of the factors above, but does not try to achieve “zero” at-risk vehicles. The 5 or 6/32” inspection thresholds would likely have big benefits in terms of promoting safety, but would leave some highly driven, high deterioration rate vehicles still at risk.

Conclusions

Maintaining the safety of the passenger vehicle fleet is a relevant and ongoing activity by government, as unsafe components such as brakes, tires, or lights can lead to fatal and non-fatal accidents. Potentially unsafe conditions can be identified and corrected via mechanisms like vehicle safety inspections. While past studies considered overall failure rates, none were identified that considered effects of specific safety components or considered whether the existing thresholds were appropriate.

This study considered how the inspection thresholds used to determine the road-worthiness of tire tread on passenger vehicles might be modified in order to consider the fact that cars are driven more (and preventive maintenance seems less common). We assumed that NHTSA’s currently used 2/32” tread depth – used as the basis for defining when tires become unsafe – remains true, but considered higher inspection thresholds to maintain tire safety given the time between inspections. While we propose that the fleet would be safer by such changes, we did not attempt to actually model safety or performance of the tires.

We analyzed the relative proportions of the fleet that might be at risk to having unsafe tires (i.e., less than 2/32” of tread) between inspections by finding underlying TDRs and annual VMT at the vehicle level using data from Pennsylvania safety inspections over a 10 year period. Even though we had vehicle-specific data for tires and VMT, we also aggregated the TDR and VMT to find fleet average levels to simulate the types of values we would expect to be used as the basis of policy design. We find that across most of the models, the *minimum* inspection standard to maintain safe driving conditions is 5/32”, but in specific conditions it may be better to determine the minimum tire tread depth for a specific vehicle, such as for cars with very high VMT relative to the average (we note that the same effect could be achieved if such cars were required to be inspected more frequently).

While the effect of increasing the inspection threshold means potentially more vehicles needing to replace tires, this is not an additional cost to owners, just a time-shifted cost in that such tire replacements may have otherwise been deferred by several months with a lower inspection threshold.

We are encouraged by the level of safety data-driven analytics that are possible from the inspection data. Future studies could consider parallel investigations into the appropriate thresholds or effectiveness of other components such as brakes or lights. Such studies could also benefit from the increasing use of telematics, such as available from connected vehicle platforms, to assist with data collection, monitoring, and assessments of such programs.

Acknowledgments

This research was supported by the US DOT Grant No. DTRT-13-GUTC-26, through Technologies for Safe and Efficient Transportation (T-SET), a University Transportation Center. The authors take full responsibility for all errors or opinions expressed herein. We also acknowledge the assistance of Yi (Vickie) Liu of CMU for research assistance, and Prithvi Acharya of CMU for editorial assistance. Finally, we acknowledge Bernie Elder of CompuSpections for the project idea and other advisory assistance.

References

1. Highway Statistics 2016. Federal Highway Administration (FHWA). https://www.fhwa.dot.gov/policyinformation/statistics/2016/pdf/vm1.pdf. Accessed July 15, 2018.
2. National Highway Transportation Safety Administration. *Uniform Guidelines for State Safety Programs*. https://icsw.nhtsa.gov/nhtsa/whatsup/tea21/tea21programs/. Accessed July 15, 2018.
3. Dana Peck, H. Scott Matthews, Paul Fischbeck, and Chris T. Hendrickson. An Analysis of Vehicle Safety Inspection Data in Pennsylvania: Expected Failure Rates. *Transportation Research Part A,* Volume 78, August 2015, Pages 252-265, 2015. DOI: 10.1016/j.tra.2015.05.013
4. NHTSA, Research Report to Congress on Tire Aging, August 2007.
5. Tire Service Life. February 2005. *Tire Business Databook*, Goodyear Corporation.
6. Highway Statistics, 1973," Annual publication of the Federal Highway Administration, 1974.
7. Highway Statistics 2004, FHWA, Table VM-1, http://www.fhwa.dot.gov/policy/ohim/hs04/htm/vm1.htm. Accessed July 15, 2018.
8. Tire Aging: A Summary of NHTSA's Work, U.S. Department of Transportation National Highway Traffic Safety Administration, March 2014
9. American Automobile Association (AAA). Preventive Maintenance Fact Sheet. 2015. https://newsroom.aaa.com/wp-content/uploads/2015/10/Preventive-Maintenance-Fact-Sheet.pdf. Accessed July 15, 2018.

10. Royal Society for the Prevention of Accidents. Tyre Tread Depth and Stopping Distances. August 2005. https://www.rospa.com/rospaweb/docs/advice-services/road-safety/vehicles/tyre-tread-depth.pdf. Accessed July 15, 2018.
11. Tire tread depth: why it matters and how to measure it, via https://resources.tireamerica.com/research/how-to-measure-tire-tread-depth. Accessed July 15, 2018.
12. Kristin Thiriez, Rajesh Subramanian. *Tire Pressure Special Study: Tread Depth Analysis.* NHTSA Research Note. DOH HS 809 359. October 2001.
13. National Household Travel Survey 2017. Table Designer. https://nhts.ornl.gov/. Accessed July 25, 2018.