Introduction

The relationship of tire tread depth to wet traction has been a subject of technical research and discussion since at least the mid 1960s. Now, nearly 50 years on, these discussions continue, and disagreements regarding the importance of improving wet traction also continue.

During this time, bias-ply tires have been replaced by radial construction and, in the USA, highway speeds have increased; miles driven have approximately tripled.

This Paper reviews research that strongly suggests an increase in minimum tire tread depth requirements would significantly and positively affect highway safety.

Historical Data

Radial tire wet frictional performance is compared to bias-ply tire performance in Figure 1, taken from [1], a 1967 Paper. Since radial tires comprise almost all passenger car tires in use, any conclusions relating to tire performance based upon bias-ply tires probably no longer are valid. In these braking tests of fully-treaded tires, water depth was controlled at ¼ inch.

As an example of increased highway speeds, posted speed limits of 70 mph on “Interstate System and non-interstate system routes” changed in the USA from zero miles so posted in 1994 to 40,897 miles in 2000. [2]
Figure 1 – Radial vs Bias Ply Tires
Braking Coefficients, ¼ Inch Water Depth, 1967

Figure 2 shows the estimated total miles driven on all USA roads per year from 1971 through 2013. [3] From approximately 1.1 trillion miles in 1971, total miles driven reached a peak of approximately 3 trillion miles in 2008 and then decreased to approximately 2.95 trillion miles in 2013.

Based upon these increases in vehicle speed and miles driven, wet traction performance should be of increasing concern.

Early Research (1960 – 2000)

At the start of any discussion of wet traction, it is well to keep in mind this early (1967) admonition: “In spite of all that may be done by the tire or highway engineer toward the improvement of (wet) skid (resistance), the most significant step which can be taken is completely within the control of each individual driver – reduce speed.” [1]
It was recognized early (1968) that “...the radial tire is better (than the bias-ply) for cornering (wet) traction...”, and it was asserted that this was “...due to its higher cornering stiffness.” [4] Recent research (19) suggests that a laterally-stiffer tire, due to age or low aspect ratio, will have a lower effective* cornering stiffness and lower lateral friction development on a wet surface than a younger or higher-aspect ratio tire.

Also, it has been known for some time that “...the coefficient of friction between tires and wet roads decays with (increasing) speed, due to difficulties in displacing the water from the ground contact zone.” This is stated in [5], a Paper from 1968.

* See footnote 3.
Figure 3, also from [5], gives the earliest results found for the effects of tire wear on wet traction in braking tests of radial tires. The water depths in these tests were in the range of 0.04 inches to 0.06 (2/32) inches, or 1.0 to 1.5 mm.

It is this decrease in friction before hydroplaning occurs that is the most significant wet traction issue, since hydroplaning is a relatively rare event. It has been recognized, at least since 1970, that “…aquaplaning¹ … contrary to popular belief, is not a major cause of skidding on wet roads.” [6]

Figure 3 – Braking Coefficient vs Tread Wear, 1968

In another Report from 1970 [7], field test results for bias-ply tires of various tread depths, on minimally-wet surfaces (generally less than 1/32 in. or 0.8 mm water depth), found a

¹ “Aquaplaning” is the British term for hydroplaning.
marked decrease in braking force coefficient for tread depths less than 1 to 2 mm
(approximately 2/32 in.)\(^2\), on a “smooth concrete” surface.

Figure 4 is from [8], a 1983 Paper. These lateral force coefficient results are for an evenly
worn 155SR13 tire of approximately 9/32 inches (7 mm) tread depth. Although the data are
not available for direct quantitative comparisons, the shapes of the lateral friction versus
speed plots, for various water depths, are similar to recent research results.

It is asserted in [8] that, for these wet-surface tests, “…tread depth values (are) …the single
greatest variable dominating other differences associated with tires from different
manufacturers.”

Vehicle stability is influenced significantly by the cornering characteristics of the tires.
Cornering stiffness tends to increase with tire wear under dry conditions, but “effective”\(^3\)
cornering stiffness falls once water is present. Since cornering stability is crucial for vehicle
control and accident prevention (even more so than stopping ability at highway speeds), the
emphasis in this discussion is on the effects of tread wear, water depth and speed on
effective cornering stiffness and lateral friction, rather than on braking friction. This is
recognized by the industries’ “best tread on the rear” guideline.

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\(^2\) This value, 2/32 inches or 1.6 mm, is the most common legal minimum tread depth requirement, both in
Europe and in the U.S.A.
\(^3\) Cornering stiffness is considered a tire property that is unaffected by water on the surface, but “effective”
cornering stiffness is the property needed for handling analysis on wet surfaces.
With water present, the lateral force coefficient decreases with water depth and speed, the fall being rapid when a tread depth of 1 to 2 mm (approximately 2/32 inches)\(^4\) is reached [8].

![Figure 4 – Lateral Coefficient vs Water Depth, 1983](image)

Tread Depth = 9/32 inches (7 mm)

The earliest direct industry notification found, of the significance of new tire placement on vehicle stability, is dated February 22, 1974 (40 years ago!) from Sears Roebuck and states, in part, “When mounting two new tires, regardless of the type of tires on the vehicle or the type of new tires, the new tires must always go on the rear axle” [9]. That reference is not readily available, but the same caution is stated (nine years later) in [8]: “Replacing worn rear tires usually improves vehicle stability. However, the replacement of regularly worn front tires can cause instability if there is less than about 3 mm (~ 4/32 inches) of tread remaining on the rear tires.”

\(^{4}\) See previous footnote 2.
Results described as “produced by the Dunlop Company in the 1960s” are shown in Figure 5 taken from [10]. The water depth was reported as 2.5 mm, or 3/32 (0.094) inches. No information on tire size or other details of the tests was given, but the shapes of the “adhesion” versus speed plots again are similar to recent tests.

As of this writing (February, 2014), tire manufacturers’ websites do not agree on the minimum tread depth at which tires should be replaced. Recommendations vary from 2/32 inches (the “Lincoln-head penny test”) to 4.0 mm (5/32 inches) for winter tires. [11, 12, 13, 14, 15] Manufacturers do agree on the importance of placing two new tires on the rear wheels when only two new tires are purchased.

Figure 5 – Braking “Adhesion” vs Tread Wear, Water Depth 2.5 mm, Circa 1960
Legislation

A survey completed in 2003 [16] gave information on legal requirements for minimum tire tread depth state-by-state in the U. S. A., most of which require 2/32 inches minimum. It also was noted that the European Union, since 1989, and the United Kingdom, since 1992, require 1.6 mm (2/32 inches). Some states in the U. S. A. have no requirement and California and Idaho require 1/32 inch minimum tread depth. No rational basis for these legal requirements is known, although 2/32 inches historically has been the minimum tread depth at which tire warranties usually apply.

Significance of the Issue

Research presented at ITEC in 2012 [17] concluded that approximately 360 deaths and 30,800 injuries, in 2009 in the U. S. A., could be attributed to loss of wet-road traction. Of the accident cases suggesting loss of wet traction (109 cases out of 6,949 accidents reviewed, or 1.57 percent), it was concluded that 80 percent of them occurred when the average tread depth on all tires was less than 4/32 inches. An unpublished review of 1,016 dry road cases (not the full set available) was completed in an attempt to determine if loss of traction was an initiating cause. It was concluded that confounding factors such as steering input and tire pressures (which were, of course, measured post-impact) prevented a clear conclusion of the possible roll of traction loss on dry roads.

Recent Research (2000 – 2013)

Research presented in 2002 verified and extended that of Williams and Evans [8], and
illustrated that tread depths less than 4/32 inches (3 mm) have significant loss of longitudinal and lateral friction on wet test surfaces at highway speeds. Figure 6 is from [18] and shows results for the lowest water depth tested in that investigation. Also investigated was the effect of tire placement, with the conclusion that the deepest tread depth rubber should be on the rear of passenger cars, regardless of vehicle configuration, to address vehicle handling on wet surfaces and avoid dangerous oversteer conditions.

Figure 7 is from [19], published in 2013, wherein shallower water depths were investigated regarding their effects on lateral friction, lateral friction being considered more significant for loss of control than braking friction. The same conclusion regarding tread depth versus friction at highway speeds was demonstrated as previously, namely that tread depths below 2.74 mm (approximately 4/32 inches) lost significant lateral wet traction capability as compared to deeper tread depths.

Figure 6 – Braking Coefficient vs Tread Wear, 2002
In [20], a 2013 Paper, it is stated that “...in regards to accident causation, it is not statistically significant which axle has the deepest tread. What is significant is that a tread depth at or below 4/32 of an inch anywhere on the vehicle leads to an increased rate of accidents.” Thus, although there is industry agreement that the best-treaded tires should be on the rear of the vehicle, there still is some controversy in the research community. Also, although there is general agreement in the research community that tread depths below 4/32 of an inch lead to an increased rate of loss of lateral control, there has been no action on the need for increased minimum tread depth standards in the industry and in the legislative arenas.

Recent Industry Innovations

*Michelin North America Inc.* has introduced its Premier A/S passenger car tire that features “EverGrip” technology [21, 22]. This tire has (1) a tread that reveals new grooves and tread
blocks in the outer tread blocks as it wears, (2) tread grooves that widen (as opposed to narrowing) as the tread wears, and (3) a “...high-traction compound featuring ‘extreme amounts’ of silica and sunflower oil...” that is claimed to increase wet traction.

![Figure 8 – Michelin “EverGrip” Tread; Tread Groove Shape](image)

Of course, the widening grooves, as the tire wears, do not increase the water channel size; it still decreases, but not as much as a narrowing groove (see Figure 8). The “emerging” grooves in the outer tread blocks do provide for increased drainage (Figure 9), but may lead to other performance compromises, since there is a reduction of the amount of contact available between the tire tread and the contact surface.

Michelin has done laboratory and test track research on these tires, but, of course, that work is proprietary.
Bridgestone advertizes many wet-traction enhancements [23]. These include (1) 3-D zig zag sipes “to increase the number of biting edges while enhancing block stiffness”, (2) a computer optimized component system (CO-CS), which “provides the appropriate combination of tread design, casing shape, materials and construction”, (3) a tread block design that “provides consistent surface contact to reduce irregular wear,” (4) dual layer tread which “exposes high grip rubber as the tire wears,” (5) high angle grooves to “improve drainage of excess water from the rib area into the main groove for hydroplaning resistance,” (6) hydro evacuation surface, HES, which “reduces flow resistance of water along groove walls”, (7) high sipe density and key hole sipes which expose wider sipes as the tire wears, (8) silica, to “improve traction in wet conditions by increasing the flexibility of the tread compound,” (9) Super EPC, “special compound additives that counteract the effects of heat to maintain wet performance as the tire wears,” and (10) tapered leading tread elements “to help channel water.”
It would be very useful if, for these tires, tests similar to those described in References 18 and 19 were available for comparison. These new tread designs may have a significant effect on the need to increase minimum legislated tread depths.

Conclusions

1. Research has shown, consistently, that passenger car tires with tread depths below about 4/32 inches (3 mm) develop significantly less friction on laboratory test surfaces in the presence of water depths as low as 0.02 inches (0.51 mm), at highway speeds, than do tires of greater tread depth.

2. The research community is in general agreement that tread depths at or below 4/32 inches (3 mm) lead to an increasing rate of loss of control on wet roads.

3. Industry guidelines and legislation regarding minimum tread depth do not address the information contained in conclusions 1 and 2 above.

4. Recent innovations in tread design may affect, and improve, the wet traction performance of passenger car tires, but do not reduce the need for increased minimum tread depth in the general population of tires. Comparative public-domain testing is needed.

5. Arguments against deeper tread depth minimum requirements, such as reduced tire operating life and higher average rolling resistance, must be weighed against safety considerations.

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Bibliography