Smoothness Matters:

The Influence of Pavement on Fuel Consumption

By Howard Marks, PhD, MPH

Vehicle emissions are major contributors to greenhouse gases, and one of the keys to reducing emissions is reducing consumption of fuel used by cars and trucks on our roadways.

While auto makers continue to make progress on improving fuel efficiency of the engines in the vehicles they manufacture, researchers and state transportation agencies are looking at additional ways to reduce emissions. One area of study is the influence that pavement characteristics have on vehicle fuel consumption. Since slight changes in vehicle fuel economy may have dramatic effects when amassed over a state, country or time frame, slight changes in pavement characteristics could result in meaningful improvements in fuel economy.

While auto makers continue to make progress on improving fuel efficiency of the engines in the vehicles they manufacture, researchers and state transportation agencies are looking at additional ways to reduce emissions.

This article reviews findings from the majority of studies on this subject available in the literature. One compelling tenet has remained the same for over 30 years: Smoothness is a determinant of vehicle fuel economy. The smoother the pavement, the lower a vehicle's fuel consumption.

There are generally three pavement characteristics that are being explored in an effort to reduce vehicle fuel consumption: pavement-tire rolling resistance, pavement stiffness or viscoelasticity, and pavement texture or smoothness.

Pavement-Tire Rolling Resistance

Rolling resistance, or the loss of a vehicle's energy due to contact between the tires and the pavement, has been cited as affecting vehicle fuel economy. However, this loss of energy pales in comparison to losses of energy from other non-pavement factors such as engine and drive-train inefficiencies and internal vehicle friction. These include energy dissipation due to shock absorbers and losses of energy from aerodynamic drag, tire deformation and other factors. The best estimate of the contribution of pavement-tire rolling resistance to overall energy loss is 4.2 percent (California Energy Commission, 2009). Further complicating matters, changes in rolling resistance do not have a direct relationship with changes in fuel consumption. It is estimated that a 5 to 7 percent reduction in rolling resistance increases automobile fuel efficiency by a mere 1 percent.

Pavement Stiffness or Viscoelasticity

It has been suggested that a pavement's stiffness (or viscoelasticity) could have an influence on vehicle fuel economy, all else being equal – including smoothness, subsurface structure, and texture. Over the years, a number of studies have attempted to show that pavement viscoelasticity is a determinant of vehicle fuel consumption. However, the majority of these studies failed to account for other factors, particularly smoothness. In a recent review, Perriot (2008) re-analyzed many of these pavement studies and concluded that in those studies that purported to show the greatest effect of pavement influence on vehicle fuel economy (changes up to 20 percent fuel consumption), the pavement's stiffness or viscoelasticity accounted for between 0.005 percent to 0.5 percent difference in fuel consumption, depending on the vehicle type (e.g., automobile vs. tractor-trailer). Because these are very low estimates based on theoretical calculations, and have no statistical significance, the very small potential impacts of pavement viscoelasticity on vehicle fuel consumption are highly suspect. Any greater reported values should be considered unreliable at best.

Pavement texture or smoothness

Pavement texture or smoothness affects rolling resistance by influencing the energy loss due to friction

Research at the National Center for Asphalt Technology (NCAT) in Auburn, Alabama has showed that heavily loaded trucks driven on rough pavements consume more fuel than the same trucks driven on smooth pavements.

between the tire and pavement. The most authoritative work looking at this issue was conducted by the Federal Highway Administration (FHWA) during the WesTrack study (Sime et al., 2000). Results from this study indicated that trucks running on slightly smoother pavement could reduce fuel consumption by 4.5 percent.

A number of other studies, before and after the WesTrack study, have identified similar or greater fuel economy on smoother pavements – fuel consumption reductions up to 10 - 20 percent (Laganier and Lucas, 1990; Sandberg, 1990; Zaniewski et al., 1979; Zaniewski, 1982; Zaniewski, 1983; Ross, 1981; Amos, 2006). A number of studies have documented that smoother pavements reduce rolling resistance (Christophe, et al., 1993; Zaniewski et al., 1979; and Ross, 1981). But because rolling resistance itself only accounts for a fraction of fuel economy savings, it is pavement smoothness, and its associated factors, that is determinative of both rolling resistance and vehicle fuel consumption.

Not only do smoother pavements reduce fuel consumption, but they also reduce vehicle operating costs and driver fatigue by minimizing tire bounce and load impacts. According to figures developed by The Road Information Program (TRIP), driving on rough roads costs our nation's motorists $23 billion annually in extra vehicle operating costs (Asphalt Pavement Alliance, 2009). Some experts estimate that increasing pavement smoothness by 25 percent results in almost a 10 percent increase in pavement longevity.

There is no doubt that substantially reduced fuel consumption is well-documented in vehicles traveling on smoother roads. Smoothness matters.

Studies That Do Not Account for Pavement Smoothness

Because 94 percent of America's roadways are paved with asphalt, it becomes difficult to directly compare pavement type (asphalt vs. concrete) when smoothness metrics are not held constant.

Swedish study

One of the more recent studies was published in Sweden (Jonsson and Hultqvist, 2009) where researchers tried to compare vehicle fuel consumption on asphalt and concrete roads. Although there was a 1.1 percent difference in fuel consumption on different pavements, the study concluded that it was pavement texture or smoothness, not necessarily pavement type, which was determinative of the fuel consumption difference.

Cement Association of Canada-sponsored study

Since 1998, the Cement Association of Canada has partnered with the National Research Council of Canada (NRCC) to sponsor a number of studies that attempt to identify the effect of pavement type (concrete vs. asphalt) on fuel consumption. From 1998 until 2005, those studies produced limited information. The most recent report (Taylor and Patten, 2006) states with regard to the earlier research efforts that "it was determined that a more thorough statistical model would allow for better interpretation of the results" [p.1], and that was the reason for the final research to be conducted and eventually published in 2006. A critique of the earlier NRCC study is provided by the Asphalt Pavement Alliance (2009).

The final research report (Taylor and Patten, 2006) indicates that there are differences between fuel consumption when comparing different pavement types. The report does note that various test sections were matched, first for smoothness and then for grade, in order to eliminate bias. However, a thorough review of the report reveals that even though pavement types were matched for smoothness, the data obtained from the roughest sections of concrete were discarded due to grade restrictions (see Table 3-2, Taylor and Patten, 2006). Further, the longest sections of asphalt pavement studied, representing approximately one-half of the total length tested, had no smoothness grade listed, other than that they were identified as having International Roughness Indicator (IRI) scores between 1 and 2 (see p. 13, Taylor and Patten, 2006). In IRI scoring, 1 to 2 is a wide range indeed, and lumping these pavements together increases the potential for serious bias.

Taking into consideration the mismatch between pavement sections on roughness, it is unclear how the report's findings can identify any fuel economy difference between pavement types. As a side note, the report also states that under certain circumstances the passenger vehicle consumed less fuel on asphalt roads than on concrete roads, but the difference was not statistically significant.

NRMCA-sponsored study

Another recent study, sponsored by the National Ready Mixed Concrete Association (NRMCA), attempts to compare vehicle fuel economy on asphalt and concrete pavements in an urban setting (Ardekani and Sumitsawan, 2009). Although their preliminary findings indicated that fuel consumption on concrete pavements was lower than on asphalt pavements, their

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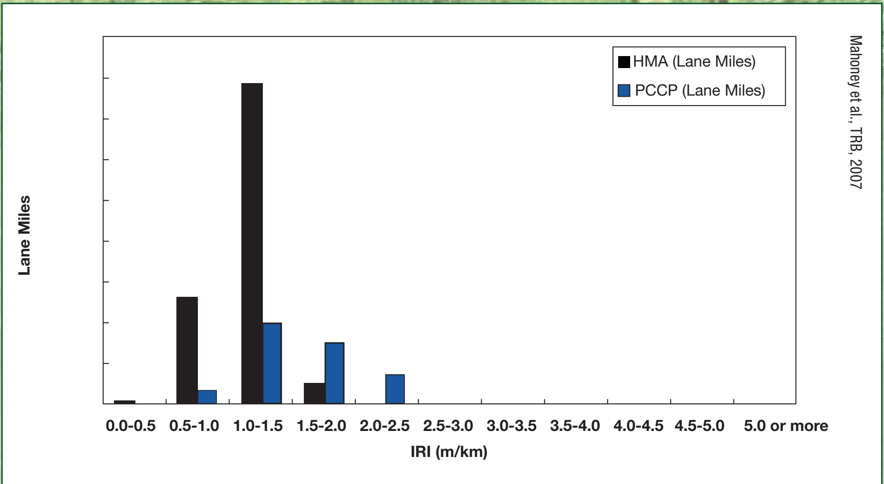
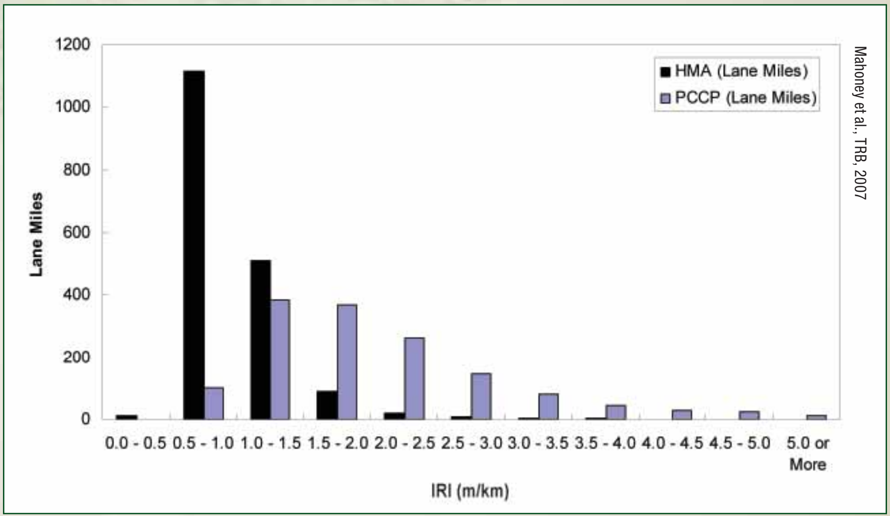
analysis indicates that the results are not statistically significant. Further, questions about the smoothness and substructure of each road go unanswered. From the pictures provided in the reference, the concrete road appears to be a four-lane thoroughfare, while the asphalt road appears to be an unmarked rural side street. Pavement substructure, i.e. base thickness, is known to have an effect on pavement stiffness and therefore to be another factor which may contribute to vehicle fuel economy. The study also fails to take this factor into consideration.

Although the three above studies are intended to compare pavement type, they fail to hold constant some of the most influential pavement characteristics, such as smoothness. The studies sponsored by the cement and concrete industries do not identify smoothness (or roughness) as a bias in their findings. The Swedish study reports that even though there were observed differences in vehicle fuel consumption on asphalt vs. concrete pavements, the differences were attributed to pavement smoothness.

Upon further review of these studies, it is quite evident that the findings of these recent studies are similar to the previous 30 years of research in this area: when looking solely at pavement characteristics, smoothness is the determinative factor in vehicle fuel economy.



Figures 1 and 2: Smoothness data from Oregon (top) and Washington DOTs shows that the asphalt pavements in both states are smoother than the concrete pavements.



Asphalt Pavements Are Smoother Than Concrete Pavements

Because 94 percent of America's roadways are paved with asphalt, it becomes difficult to directly compare smoothness of different pavement types while matching for traffic load and pavement age. In a 1999 report to Congress, the General Accounting Office (GAO) noted that "Concrete roads may produce rougher (smoothness) readings than asphalt roads, even if the concrete road is of very high quality. Features such as joints between sections can contribute to the roughness of concrete highways." (Asphalt Pavement Alliance, 2009).

An even more recent analysis (Mahoney et al., 2009) compared pavements in the Northwest from state DOT smoothness data. In this report, a good example can be found on Figures 1 through 3 (Mahoney et al., 2009). Both Oregon and Washington DOT smoothness data (Figures 1 and 2, respectively) clearly show the majority of interstate asphalt pavements are smoother than concrete pavements. Data from Washington DOT (Figure 3) shows that the majority of interstate asphalt pavements in these states are older than concrete pavements. This documents that older asphalt pavements retain higher levels of smoothness than newer concrete pavements.

Ensuring and Maintaining Smooth Pavements to Reduce Fuel Consumption

Keeping a road smooth begins with a well-engineered foundation and pavement structure. In other words, Perpetual Pavement is the beginning of fuel efficiency through smoothness. It is to this nation's advantage that so many of our existing asphalt pavements meet the

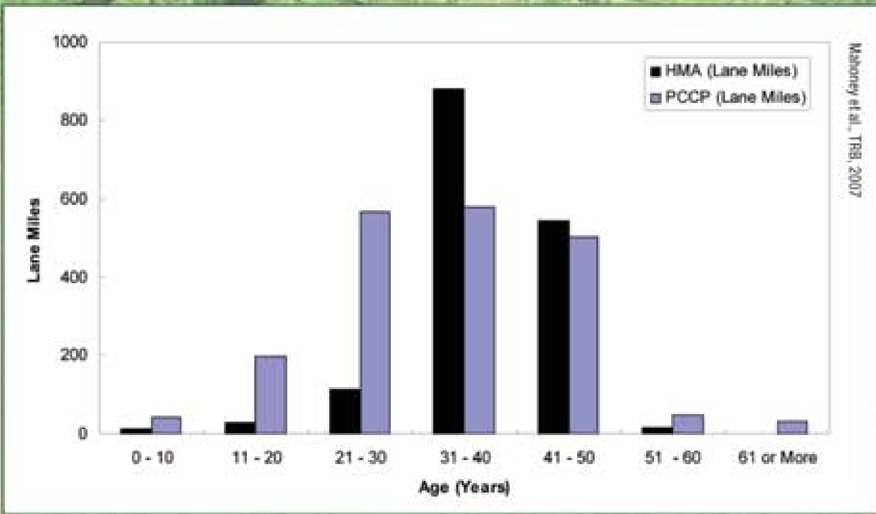


Figure 3: The asphalt pavements in Washington and Oregon tend to be older than the concrete pavements in those states.

definition of perpetual. They can remain in place for the long haul, with only periodic replacement of the pavement surface to eliminate distresses and restore the ride quality. Premium materials should be used on high-volume pavement surfaces to provide the longest and highest-performing roadway without disruption. Studies have shown that stone-matrix asphalt and other modern asphalt mixes can provide surfacings that will last in excess of 20 years. Restoring ride quality can be achieved quickly and simply through milling the surface for recycling, then overlaying with asphalt. These periodic improvements in ride quality will have a significant impact in improving the fuel mileage of vehicles traveling these roads.

Conclusions

After closely examining the available research and investigating a variety of different factors, one thing is clear: of all characteristics of pavement, smoothness is the major determinant of fuel economy. A small number of researchers have focused on pavement flexibility as a factor in fuel economy, but those studies failed to properly control for pavement smoothness and their results do not stack up with thirty years of research findings. Simply stated, the smoother the pavement, the less fuel consumed by the vehicle. HMAT

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