

SMOOTH MOVING - it's a measure of quality

(1st of 3 articles)

HMA = Smoothness

The traveling public cares about smooth roads.

That was true in the early sixties, during the AASHO Road Tests, when drivers gave the highest approval ratings to roads that were the smoothest. And it was true again two years ago, during the National Highway Users Survey, when travelers ranked smoothness as the most important feature of the national highway system.

That's why the Pavement Serviceability Index (PSI) that came out of the AASHO tests was primarily pegged to smoothness, along with cracking, rutting, patching and pot holes. (See "Smoothness and PSI" article.)

Smoothness Saves Vehicle Operating Costs. The traveling public may be less aware, however, that smooth roads also save them money. Roughness has an adverse effect on vehicle operating costs such as fuel and oil consumption, tire wear, maintenance, and depreciation.

For example, fuel consumption will increase about 10 percent for cars and 15 percent for buses if the PSI drops from 4.5 to 2.5. Maintenance and tire costs can triple, and oil consumption will nearly double.

Taken all together, the total economic effect on vehicle operating costs is substantial adding 2.5-3 cents per mile or \$250-300 per 10,000 miles of driving. (See "Pavement Smoothness," Michael S. Janoff, NAPA publication IS 111, April 1991.)

Smoothness Saves Pavement Maintenance Costs. But how does smoothness relate to pavement performance and pavement life?

In his 1991 study, Michael Janoff shows a positive correlation between smoothness and long-term pavement performance. After collecting ten years' worth of data on 400 different sections of roadway, he concludes that "initial smoothness is related to both long-term roughness and long-term cracking; as initial pavement smoothness decreases (i.e. initial roughness increases), the roughness after 10 years increases and the percentage of cracking after 10 years similarly increases."

The reason for this is intriguing. It's obvious that rough roads jolt vehicles and their passengers. But those jolts, stresses, and strains transfer back to the vehicle's tires, which, in turn, distress the pavement. It's a circular dynamic, Janoff explains, not a one-way dynamic.

When Janoff next compared initial smoothness to annual maintenance costs, he found that, as expected, "Pavements that have higher 'initial smoothness also have lower average annual maintenance costs." Says Janoff, those savings in maintenance costs can total as much as \$1,200 per mile when initial PSI is increased from 4.0 to 4.5.

(see graph: " Initial Pavement Smoothness vs. Average Annual Maintenance Costs" following)

Managing Smoothness. Because they recognize the value of smoothness, most - if not all - contracting agencies include smoothness specifications in their contracts. And many include bonuses and incentives for better work. Even so "People don't manage pavement smoothness very well," says Larry Scofield, manager of transportation research for the Arizona Department of Transportation. "To make a smoother pavement, you have to increase the quality of the entire product." Quality product starts with proper design and specification, then requires the right equipment and construction techniques.

SMOOTHNESS AND PSI

The 1962 AASHTO Road Tests lead to creation of a "Pavement Serviceability Index" (PSI), which is a function of the "driveability" of a pavement. "Driveability" in turn, is a function of driver-perceived comfort.

This PSI is obtained from measurement of roughness and distress (e.g., cracking, patching, and rut depth). Roughness - the absence of smoothness is the dominant factor in estimating the PSI of a pavement.

The PSI scale ranges from 0 through 5, with 5 representing the highest level of serviceability. New pavements typically have PSI values between 4.0 and 4.5. Pavements typically need resurfacing when the PSI value drops to 2.0 - 2.5. At this level, there is a huge increase in the number of drivers/passengers who rate a road as "unacceptable," as shown by the following table:

PSI	% Rating Road as "Unacceptable" *
3.0	12%
2.5	55%
2.0	85%
* Source: AASHTO Pavement Design Guide, 1991	

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MAKING SMOOTH PAVEMENTS

(2nd of three articles)

Everyone who drives or rides in a vehicle over the surface of a highway pavement can subjectively judge the smoothness of the ride. In many states, however, the ride is also being judged objectively by new specifications which require the paving contractor to obtain a

predetermined level of smoothness when a pavement is constructed or resurfaced.

According to consulting engineer, Jim Scherocman, the process of achieving smoothness is the same whether Hot Mix Asphalt (HMA) is being delivered directly from the haul truck, from a windrow in front of the paver, or from a material transfer device into the paver hopper.

Achievement of smoothness requires a return to the basics in the operation of the paving machine.

Forces on the Paver Screed (see diagram following)

Four primary forces act on the paver screed and affect smoothness.

Elevation of the tow point on the paver where the screed is attached - The change in the elevation of the tow point is transferred back to the screed through the tow arms on each side of the paver, causing the angle of attack of the paver screed to change. As the angle of attack changes, more or less mix is passed under the screed. This process is known as the "free floating screed" principle. In order for the paver to produce a smooth pavement layer, it is necessary for the tow point to move with the paver tractor unit. When the tow point moves in this way, the screed places more mix in the low spots in the underlying pavement surfaces and less mix over the high points in that surface.

Forward speed of the paver - When the paver increases speed, the angle of attack of the screed decreases, thus reducing the thickness of the layer being placed. When the speed of the paver decreases, the angle of attack increases and a thick pavement layer is constructed. In order to build a smooth pavement, therefore, it is necessary for the paver operator to maintain a constant paving speed.

Head of material -- When the amount of mix being carried in front of the screed - the head of material - changes, the angle of attack of the screed also changes. An increase in the amount of HMA in the auger chamber in front of the screed causes the angle of attack to increase and a thicker mat to be placed. If the head of material in front of the screed decreases, the angle of attack of the screed decreases, and a thinner mat is constructed. For a smooth mat, it is critical for the paver operator to maintain a constant head of material in front of the screed at all times.

Thickness Control Screw - When the paver screed operator manually changes the setting of the thickness control screws, up or down, the angle of attack of the screed, and thus the thickness of the HMA mat, also changes. For mainline paving work, on a state highway, county road or city street, the smoothest mat will be constructed when the screed operator does not attempt to "help" the paver and lets the free-floating screed principle provide the necessary leveling action.

If the paver operator can maintain a constant paver speed, can maintain a constant head of material in front of the screed, and the screed operator can resist from making manual changes in the setting of

the thickness control screws, the angle of attack of the paver screed will be controlled by changes in the elevation of the tow point. Thus, the paver will place a smooth mat.

Trading Haul Trucks

It is common practice for paver operators to attempt to keep the paver moving at all times. When the haul truck delivering HMA into the paver hopper is empty or when the end of a windrow is reached, the operator slows the paver down gradually to avoid stopping. At the same time, the operator may run the paver hopper empty, hoping the next truck will arrive and place mix either directly into the paver hopper or into the windrow before he has to stop the laydown machine. Often the paving operation stops anyway, with the paver hopper empty, waiting for the next truck to arrive.

When the paver is slowed down gradually during this process and the amount of mix in front of the screed is reduced, the combined result of these two forces acting on the free floating screed is a decrease in the thickness of the HMA mat being placed - a dip in the pavement surface. When the next truck delivers mix into the paver hopper or into the windrow, the paver operator may overflow the auger chamber with mix in front of the screed and go back to normal paving speed quickly. The net effect of these two actions is a significant increase in the angle of attack of the screed when the paver starts moving again - a bump is built into the pavement surface.

Thus, every time the paver slows down gradually or stops because the hopper is empty, a dip and a bump are constructed in the surface of the new mat.

To build a smooth pavement, it is much better to operate the paver on a "rapid stop, rapid start" basis. If the truck delivering mix into the paver hopper is empty or if the paver reaches the end of the windrow, the paver operator should shut the paver down quickly - from paving speed to dead stop. This will reduce the effect of the change in speed on the angle of attack of the screed. The operator should also stop the paver with the hopper about half-full of mix in order to keep the head of material in front of the screed constant. These two steps will prevent a dip from being constructed in the pavement surface at the paver stopping point.

When the paver hopper is refilled with HMA, either directly from the next haul truck or from the newly placed mix in the windrow, the operator should go back to paving speed quickly, minimizing the effect of the change in speed on the angle of attack of the screed. Since the paver hopper is kept half-full between truckloads, the amount of mix in the auger chamber and the head of material do not change. So the thickness of the mat being placed stays constant - and smooth. The "rapid stop, rapid start" process greatly improves the smoothness of the pavement being constructed.

Material Transfer Devices

A number of different equipment manufacturers currently supply material transfer devices which are used as a "go between" for delivering HMA from the haul truck to the paver hopper. One purpose of these units is to keep the paver moving at a constant speed, with the transfer unit acting like a mobile surge bin. Depending on the capacity of the transfer unit (how many tons of HMA can temporarily be held), however, it is often still necessary to stop the paver if the next haul truck does not arrive at the paving site in a timely manner.

When mix is not available in the transfer device, the paver operator should again practice the "rapid stop, rapid start" paving procedure. The paver should be shut down quickly and with the paver hopper half-full of mix. When mix is once again delivered from the transfer device to the paver hopper, the paver operator should return to paving speed quickly. This process will result in the construction of a smooth mat behind the paving machine.

Keep It Simple

Paving contractors looking to build smoother pavements need to keep it simple, according to Scherocman. "At first, the procedure of rapid stop, rapid start seems too simple to be a solution to the problem of constructing a smoother HMA pavement," he says. "But it really is just that simple. And the benefits are significant."

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HOW SMOOTH IS SMOOTH?

(3rd of 3 articles)

As we've noted in the first two parts of our series on smoothness, drivers want smooth roads. Yet it hasn't always been easy to measure smoothness objectively, especially in the early years with limited tools and knowledge. But over the last few decades mechanization and technology have provided increasingly precise tools. That's important for a number of reasons. With the new incentive/disincentive specifications, the contractor's terms of payment are based on the measured smoothness test results. The owner may pay a bonus for a pavement that's smoother than required, or impose a penalty for a ride that doesn't meet the specification. Clearly measurements must be accurate, repeatable, and hopefully related to what we feel when we drive the road.

Historically Speaking. Road smoothness measuring tools and measurement indices have been around since the turn of the century. One of the earliest methods, deviations on a straight edge, consisted of laying a straight edge on the pavement and measuring the gaps. Specifications called for a maximum allowable deviation from a straight line, typically 0.02 feet in the 12 foot straight edge. Even though

this procedure is a reasonable measure of paving quality, it is possible to meet the specification with a road that "feels" rough when driven.

Progress to Profilographs. Deviations on a straight edge gave way to a rolling straight edge design, from which modern profilographs were developed. These devices have wheels at both ends, supporting a frame that acts as a straight edge. A measuring wheel is mounted on the frame. The wheel measures the road's longitudinal profile -- the bumps and dips in the pavement surface. The accumulated total of the measured deviations is expressed in an inches-per-mile rating. A rating of 5 to 7 inches per mile generally means a smooth riding pavement.

The profilograph has been used successfully for many years, however it is labor intensive, and measures at walking speeds.

Humming Buicks, the Mother of Invention. In the late 1950s, after discovering a problem with harmonic vibration in some models of Buicks, GM began to investigate the measurement of road roughness. Inertial profilometry was born. By using accelerometers to compensate for the motion of the vehicle body, these instruments directly measure road surface profile.

The Benefits of Inertial Profilometers. One of the most accurate and efficient tools available for measuring smoothness, profilometers can accurately obtain continuous measurements of the road profile at highway speeds. The first generation of profilometers was developed for network level, pavement management work. However, new low-speed/light-weight versions have been developed to support the growing smoothness specification demand. The low-speed version can travel approximately 10 to 24 mph with highly repeat-able measurement results. Another advantage of profilometers is that the data can be used to compute many different indices, including the PSI (Present Serviceability Index), the IRI (International Ride Index), and the profilographs inches per mile profile. This allows an easy transition from profilograph specifications to profilometers.

The profilometer is rapidly gaining respect as a cost-effective, accurate device. Recently the Federal Highway Administration has moved to recommend a change to profilometers to measure pavement smoothness.

Improving on Specifications. While measuring tools and indices have become more sophisticated, there is still much to know and learn about setting road smoothness specifications.

The current specifications were developed for high speed highway applications with "multiple opportunities" for the contractor to improve an existing rough ride.

Before we are able to apply these types of specifications more broadly, we need to understand the relationship between initial road roughness, "number of opportunities," and expected final smoothness. Some states have already begun to develop these data (see sidebar; "specifications

becoming science", following) and to reap the benefits of improved smoothness on a wide range of roadways.

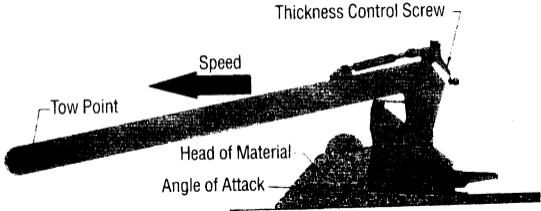
Smooth Moving Forward. The next decades should bring us further in our quest to create smooth roads. Technical innovations, process improvements, compilations of historical data, human ingenuity - all will bring us closer to the ultimate in smooth roads.

SPECIFICATIONS BECOMING SCIENCE

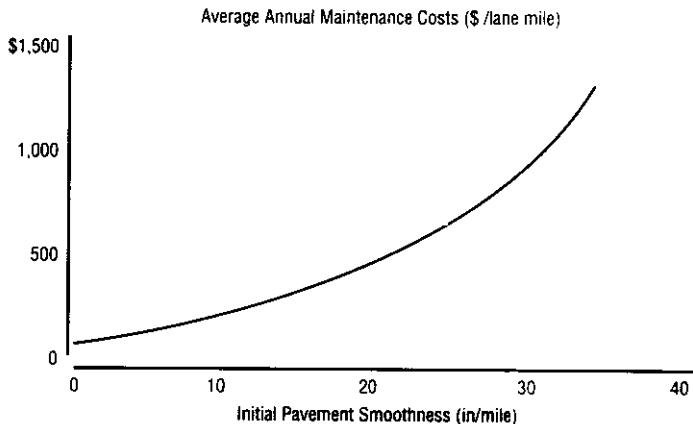
In an ideal world we would like to be able to relate the effect of each construction activity (i.e. mill & fill, overlay, wearing course, etc.) to the final ride quality. If this were possible we could perform a "roughness design" in addition to the structural design that is currently the standard in reconstruction projects. Roughness designs are not yet in practice, but the Arizona Department of Transportation (ADOT), is bringing us closer.

ADOT believes in incorporating historical and current road smoothness data into specifications for reconstruction projects. "You need to know how much you can realistically improve the smoothness of a road before you set your specifications," says Larry Scofield, Research Engineer for ADOT.

ADOT considers the number of opportunities the contractor has to improve smoothness (i.e. one lift of overlay, two lifts of overlay, etc.) in the specification limits. This provides an equitable means of establishing smoothness specifications that consider both the existing condition of the road and the specific design.



Initial Pavement Smoothness vs. Average Annual Maintenance Costs*



This chart shows that, as initial pavement roughness increases, so does the average annual maintenance cost.

* Source: Janoff 1991, in NCHRP 1-31, March 1997, page 42. Available for review at <http://www.nap.edu/readingroom/reader.cgi?auth=free&label=ulbook.NI7001>.