Louisiana DOTD's Issues Related to Faulting

5/6/2015

General Summary

Louisiana DOTD recognizes the extensive effort of the Federal team to review all of the potential options, to identify the most appropriate methodology for going forward, and the need to compromise the desired goal with the current practical reality.

Louisiana DOTD believes that in addition to determining the condition of the nation's pavement and bridge assets, a primary intent of MAP-21 is to advance and expand the concepts of full asset management for the nation's transportation infrastructure. Louisiana DOTD supports the intent of MAP-21 with respect to these concepts. Many states who were already moving in this asset management direction at varying speeds, will speed up their efforts, while for a few states, this may be a new important and expensive paradigm change.

This document is the result of several contributors. Any issues with this analysis, findings, or proposals will be the result of the limit of the researcher's ability to understand and convey the intended message of the contributors.

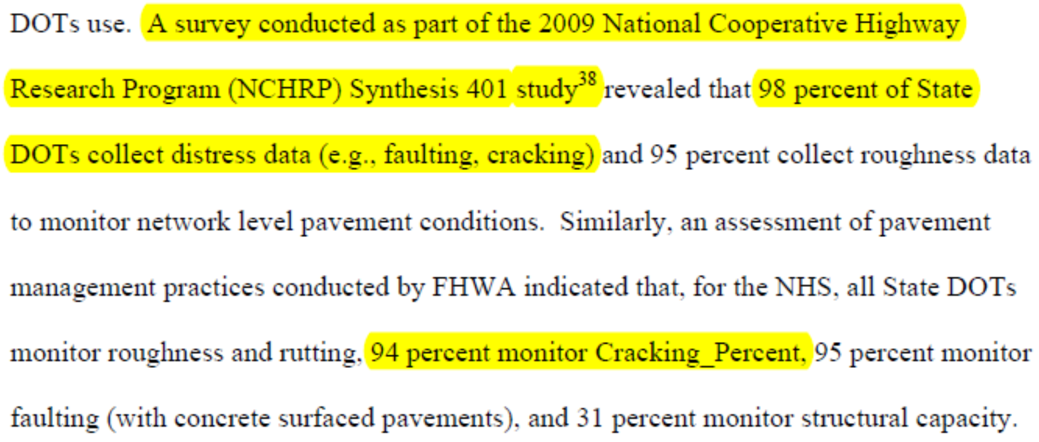
Louisiana DOTD has attempted to review all referenced documents relating to faulting and believes the analysis used to determine the proposed Faulting metrics are the results of a design based analysis and are consequently more theoretical focused. They also appear to be based on pre-2000 data, may be out-of-date and could be incorrect in setting the faulting thresholds identified throughout the proposed rule, ***2014-30085 federal register.pdf***.

While lower values for the proposed metrics would intuitively seem to provide a numerically better approach and would seem to result in superior data. A full review of the consequences of these proposed metrics might imply a different outcome. Basically, if the proposed faulting metrics remain as is, the calibration of data capture vehicles on some pavements might not be legitimately possible. Also it appears that, from our very limited data analysis, with respect to real world construction techniques and real world maintenance repairs, these metrics might not be achievable at this time. As it now stands, the proposed NPRM faulting metrics could effectively legislate jointed concrete pavement out of existence.

The federal regulation appears to allow for initial metrics to be set and reserves the right to adjust the metrics at a later date. Setting higher initial values would seem to provide the best opportunity for a full fundamental analysis of current real world data and of the consequences of the proposed metrics. It would also provide an opportunity to determine how these metrics can be refined to be support both Network Level Pavement Analysis and Project Level Pavement Management which would seem to more functionally support one of the primary intents of MAP-21 via the advancement and expansion of full asset management for the nation's transportation infrastructure.

Faulting Metrics and HPMS Data Submittals

On ***2014-30085 federal register.pdf*** page 39, we find that most states have faulting data.



DOTs use. A survey conducted as part of the 2009 National Cooperative Highway Research Program (NCHRP) Synthesis 401 study[38] revealed that 98 percent of State DOTs collect distress data (e.g., faulting, cracking) and 95 percent collect roughness data to monitor network level pavement conditions. Similarly, an assessment of pavement management practices conducted by FHWA indicated that, for the NHS, all State DOTs monitor roughness and rutting, 94 percent monitor Cracking_Percent, 95 percent monitor faulting (with concrete surfaced pavements), and 31 percent monitor structural capacity.

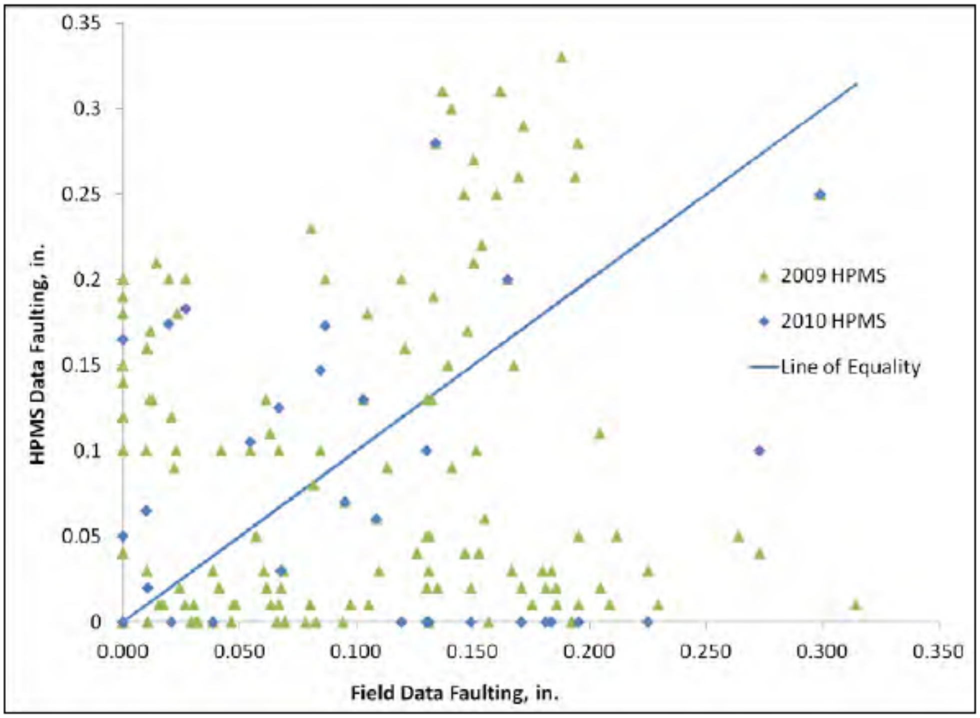
But then we find that on page 5-9 copied below, in the **July 2012, FHWA-HIF-12-049 "Improving FHWA's Ability to Assess Highway Infrastructure Health Pilot Study Report"** the following is indicated with respect to faulting. "The State DOT PMS faulting data were not collected to the same standard as the HPMS[12] data," with the footnote "12" indicating that *"methods used by each State to collect HPMS faulting data vary."*

Further, the analysis of the 2009 and 2010 HPMS faulting data submittals shows "poor correlation" from year to year. Then **FHWA-HIF-12-049** recommends that "faulting does not appear to be a good candidate for national condition assessment".

Faulting

Faulting data were included with the HPMS and field data sets. The State DOT PMS faulting data were not collected to the same standard as the HPMS[12] data, and consequently this review was limited to two data sets. Figure 5.8 illustrates the comparison between the HPMS and field collected faulting data.

Figure 5.8 Comparison of HPMS and Field Collected Faulting



Source: AMEC Environment & Infrastructure, Inc.

The correlation coefficient between the data sets in question was computed to be .10, which indicates a poor correlation. This lack of correlation is also readily observed from Figure 5.8. The temporal issues may describe some of the variability observed with these data. Further, faulting is also diurnal with changes occurring throughout the day. Regardless of the cause for the differences observed, faulting does not appear to be a good candidate for national condition assessment.

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[12] It should be noted that the methods used by each State to collect HPMS faulting data vary.

Louisiana DOTD agrees with the conclusions of **FHWA-HIF-12-049** as the NPRM is currently proposed; however, we believe that the FHWA is correct to move toward including this metric, but it must be done in a proper amount of time. Louisiana DOTD proposes the following numerous recommendations to provide a compromised method to navigate toward better correlation for faulting and allow this metric to go forward.

These proposals are strongly biased towards agencies that have automated data collection capabilities at their disposals. Consideration for other states must be factored into any implementation time line.

Summary of Louisiana DOTD's Proposals for Faulting

1. Louisiana DOTD Proposes that, since the US Government has decided not to convert to metric standards, the NPRM rules, the appropriate AASHTO Standards, the HPMS guide, etc. all be revised to English units of measure to be consistent and to eliminate the numerous Metric to English conversion rounding issues. The English units should be the primary units with the metric equivalent listed as well.
2. Louisiana DOTD Proposes that corrections be made to the NPRM, HPMS Guide, AASHTO Guidelines for a number of definitions, terms, proposed averages, proposed thresholds, etc. to sync these documents up and eliminate the conflicts.
3. Louisiana DOTD Proposes that the FHWA gather updated faulting data from various states for Interstate and NHS pavements and determine the faulting metrics from actual current data that includes the influence of truck traffic on faulting.
4. Louisiana DOTD Proposes that different performance metrics be identified for pavements that experience higher volumes of truck traffic, which requires an increase in traffic data capture along with vehicle classification counts for those pavements.
5. Louisiana DOTD Proposes that the FHWA evaluate all proposed metrics or any new proposed metrics with respect to data capture vehicle calibration capabilities and validate that standards can actually be developed and are reproducible to allow for calibrating automated data capture vehicles for the proposed metrics. The proposed metric measures do not appear to allow for data capture vehicle calibration.

6. Louisiana DOTD Proposes that the faulting performance metrics would be modified as follows; Good to be <0.2 inches, Fair to be between 0.2 to 0.4 inches, and Poor to be >0.4 inches to allow for states the option to use less expensive "real time" automated data capture.

7. In lieu of increasing the metric as proposed above, Louisiana DOTD Proposes that post processing, with no minimum fault threshold, and only manually identified straight line joints, be used for determining the faulting average. Forcing identification of straight line joints will assist preservation efforts by providing project level location data for high value faults.

8. Louisiana DOTD Proposes to adopt the Austroads term "Straight-Line Crack" for transverse joints, longitudinal joints, skewed joints and saw cut joints (which would include concrete patches). This allows for a correct differentiation between transverse cracks and designed joints.

9. Louisiana DOTD Proposes that the faulting average for a 0.1 mile segment include all straight line joint fault data for that segment, including the faults that have a 0.0 inch fault value.

10. Louisiana DOTD Proposes that only straight line joints be used in faulting determination and that other transverse cracks be captured via IRI and Percent Cracking measures. As it is, IRI will automatically capture strait line joints as well, and Percent Cracking will capture transverse cracks, so the DOTs will still receive a double penalty for faulting at straight line joints. There is no need to do the same for transverse cracks.

11. Louisiana DOTD Proposes that DOTs be given a phase-in period to allow them to develop or update data collection contracts that support these additional costly measures, during which the faulting measures would be based on real time data with a minimum threshold of 0.1 inch, and the performance metrics would be initially set to Good to be <0.2 inches, Fair to be between 0.2 to 0.4 inches, and Poor to be >0.4 inches during this phase-in period.

12. Louisiana DOTD Proposes that a future defined date, tied to a federal funding source for the additional cost, could be defined for implementation of the above proposed two future measures. This would give states the time to implement or update data collection contracts as well.

13. Louisiana DOTD Proposes that different performance metrics be identified for pavements that experience higher volumes of truck traffic.

14. Louisiana DOTD Proposed that HPMS be revised to capture all appropriate data for an appropriate analysis of faulting, i.e. faulting average, number of straight line joints, number of faults and a count of faults within a range of values.

15. Louisiana DOTD Proposes that the 1st data collection cycle to be used in performance analysis, be pushed back to a later data submittal. The current proposal indicates data being submitted in June 2015 will be used for these NPRM metrics. The large number of conflicts between HPMS, the AASHTO specifications, the FMIS requirements for HPMS and the proposed rules will not allow an “apples to apples” data comparison or analysis between the current year and future years, nor between states.

NPRM Proposed Faulting Metrics

The proposed rule, ***2014-30085 federal register.pdf***, sets the faulting metrics as summarized in Table 5 on pages 145-146.

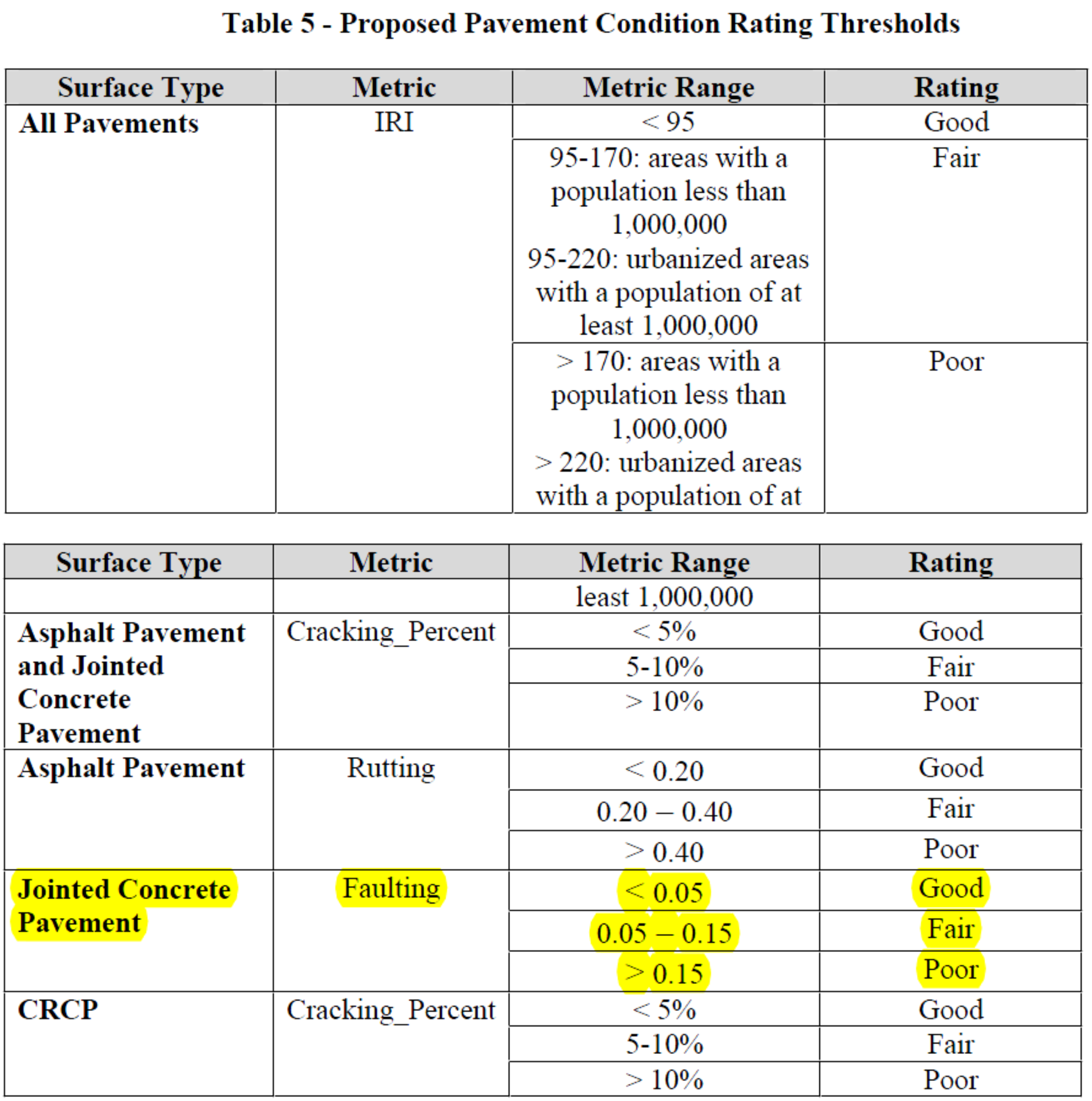


Table 5 - Proposed Pavement Condition Rating Thresholds

Surface Type	Metric	Metric Range	Rating
All Pavements	IRI	< 95	Good
		95-170: areas with a population less than 1,000,000 95-220: urbanized areas with a population of at least 1,000,000	Fair
		> 170: areas with a population less than 1,000,000 > 220: urbanized areas with a population of at least 1,000,000	Poor
Asphalt Pavement and Jointed Concrete Pavement	Cracking_Percent	< 5%	Good
		5-10%	Fair
		> 10%	Poor
Asphalt Pavement	Rutting	< 0.20	Good
		0.20 – 0.40	Fair
		> 0.40	Poor
Jointed Concrete Pavement	Faulting	< 0.05	Good
		0.05 – 0.15	Fair
		> 0.15	Poor
CRCP	Cracking_Percent	< 5%	Good
		5-10%	Fair
		> 10%	Poor

Also from *2014-30085 federal register.pdf* page 232,

For jointed concrete pavement:

(A) If the faulting value of a section is less than 0.05 inches, the faulting rating for the pavement section is Good;

(B) If the faulting value of a section is equal to or greater than 0.05 inches and less than or equal to 0.15 inches, the faulting rating for the pavement section is Fair; and

(C) If the faulting value of a section is greater than 0.15 inches, the faulting rating for the pavement section is Poor.

"Relative Coin Reference" for NPRM Proposed Faulting Metrics

If we analyze the proposed performance measure with a common relative "US coin size" reference, an observer can be easily visualized the relative "fault size" being proposed. It helps if you actually use coins for this consideration so we encourage the reader to acquire 8 dimes or 7 pennies before proceeding.

For the current proposed faulting metrics, No everyday US coin would represent a "Good" fault category.

Can a driver, in any current vehicle, ever feel a dime size fault on the pavement?

Can a driver, in any current vehicle, ever feel a fault 3 dimes thick on the pavement? Perhaps a driver could feel this fault size at stop and go traffic speeds, but certainly not at normal highway speeds.

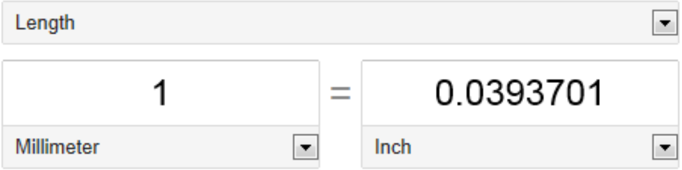
Fraction inch		decimal inch	NPRM Proposed Fault Range (decimal inch)		US money designation	US money thickness
1/64	=	0.0156	Good	0	paper dollar	0.0043
1/32	=	0.0313		<0.05		
3/64	=	0.0469	Fair	0.05	Dime	0.0531
1/16	=	0.0625			Penny	0.0598
5/64	=	0.0781			Quarter	0.0689
3/32	=	0.0938			Nickel	0.0768
7/64	=	0.1094				
1/8	=	0.1250				

9/64	=	0.1406		0.15		
5/32	=	0.1563	Poor	> 0.15	3 Dimes	0.1594
11/64	=	0.1719			2.6 Pennies	0.1556
3/16	=	0.1875			2.2 Quarters	0.1516
13/64	=	0.2031			2 Nickels	0.1535

Based on the numerous variables that contribute to faulting in joints, including ignoring the enormous effect truck traffic has on jointed concrete, these performance measures as proposed might, in reality, result in nearly 100% of the jointed concrete pavement being classified in "Poor" condition. The only pavement that might not be in "Poor" condition is new pavement; however, new pavement with these proposed measures in many cases will not be in "Good" condition either as we identify later with our limited real world data analysis.

Please note that while automated vehicles can measure faulting to this level, it would be nearly impossible for field maintenance staff to actually identify where the issue actually was, implement a possible treatment to correct to 1 mm or 0.04 inches or 5/128 of an inch, and then field measure and document the improvement. So the proposed metrics seem to be missing the project level awareness in favor of a system level approach.

Also when we investigate the origins of the "<0.05 inches" metric, we note the following metric to English conversion. So it appears this faulting metric may have originated elsewhere.



Length

1 = 0.0393701

Millimeter

Inch

NPRM Proposed Faulting Metrics Rounding & Averaging Issues

We also note that ***2014-30085 federal register.pdf*** starting on page 140 and continuing on 141,

> The FHWA proposes that partial slabs should contribute to the section that contains the majority of the slab length. In addition, FHWA proposes that the faulting metric would be computed as the average height, to the nearest 0.05 inch, of faulting between pavement slabs for the section.

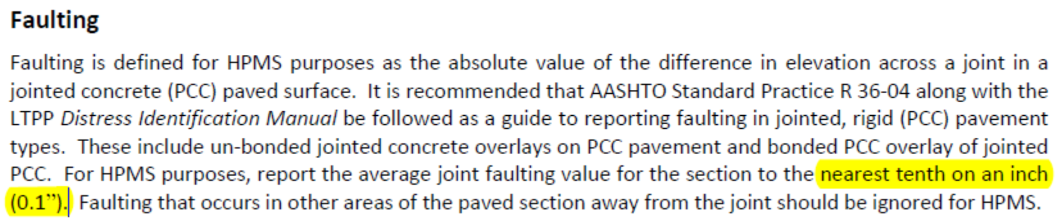
Also repeated on page 227.

> The faulting metric shall be computed as the average height, in inches to the nearest 0.05 inch, of faulting between pavement slabs for the section.

These "nearest 0.05 inch" averages directly conflict with the proposed metrics, since with this rounding requirement, you would be required to use either 0.0 or 0.05 inches for the measure, meaning you either don't have a fault or if you do, it automatically in a "Fair" condition. Note once again, the "Good" range is proposed to be from 0.0 to 0.04 (5/128 of an inch).

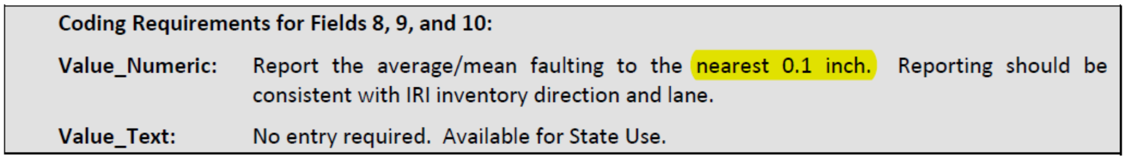
This faulting metric "averaging" requirement is completely different from setting a minimum threshold of 0.05 inch used to capture the data. Setting the minimum threshold to 0.05 inch might be a more valid approach if this metric becomes the final requirement, but there are several other reasons to change this value range including the inability to calibrate data collection vehicles.

The HPMS Field Manual in chapter 5.4 "Pavement Data Guidance" on page 5-11, calls for the average joint faulting value to be reported to the nearest "0.1 inch". This is also in conflict with the proposed measure. This is also the measure found on page 4-92 in the text box shown below.



Faulting

Faulting is defined for HPMS purposes as the absolute value of the difference in elevation across a joint in a jointed concrete (PCC) paved surface. It is recommended that AASHTO Standard Practice R 36-04 along with the LTPP *Distress Identification Manual* be followed as a guide to reporting faulting in jointed, rigid (PCC) pavement types. These include un-bonded jointed concrete overlays on PCC pavement and bonded PCC overlay of jointed PCC. For HPMS purposes, report the average joint faulting value for the section to the nearest tenth on an inch (0.1"). Faulting that occurs in other areas of the paved section away from the joint should be ignored for HPMS.



Coding Requirements for Fields 8, 9, and 10:

Value_Numeric:	Report the average/mean faulting to the nearest 0.1 inch. Reporting should be consistent with IRI inventory direction and lane.
Value_Text:	No entry required. Available for State Use.

Proposal Related to Referenced Research Materials

Louisiana DOTD Proposes that the FHWA gather current faulting data from various states for Interstate and NHS pavements and determine the faulting metrics from actual current data that includes the influence of truck traffic on faulting.

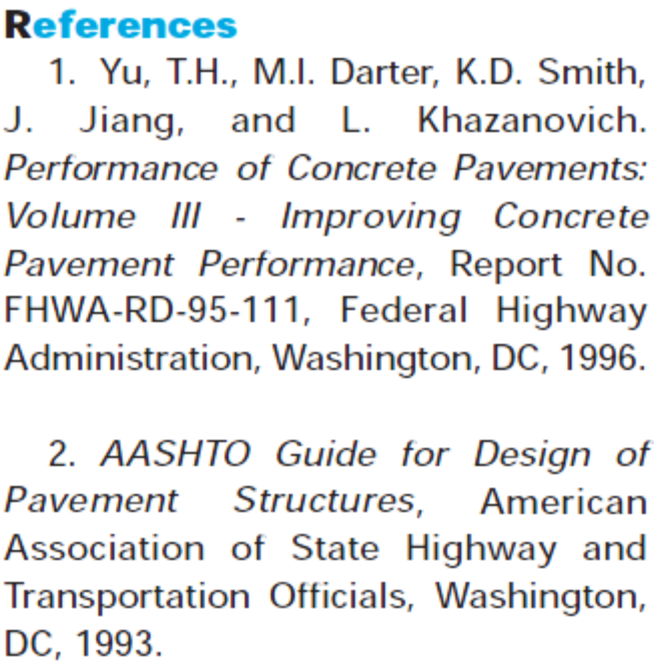
Louisiana DOTD Proposes that different performance metrics could be identified for pavements that experience higher volumes of truck traffic, which requires an increase in traffic data capture along with vehicle classification counts for those pavements.

Analysis of Referenced Research Materials

In reviewing the proposed metrics and the referenced documentation, there appears never to have been any real follow up with current real world data as time has progressed and truck loading has exponentially surged. All of the reference materials seem to point to data captured before the year 2000, and truck traffic exploded after that time frame.

From a design perspective, these measures seem to be realistic since they were based on design criteria, but it appears that these numbers have never been checked against the reality of actual field data. If we use design based criteria, or essentially use predictive models to determine the faulting metrics, and we don't perform a substantial analysis of the real world conditions and outcomes, then the metrics could be considered more theoretical than real.

From **TECHBRIEF, "LTPP Data Analysis: Frequently Asked Questions About Joint Faulting with Answers from LTPP"** references are shown here.



References

1. Yu, T.H., M.I. Darter, K.D. Smith, J. Jiang, and L. Khazanovich. *Performance of Concrete Pavements: Volume III - Improving Concrete Pavement Performance*, Report No. FHWA-RD-95-111, Federal Highway Administration, Washington, DC, 1996.

2. *AASHTO Guide for Design of Pavement Structures*, American Association of State Highway and Transportation Officials, Washington, DC, 1993.

The tech brief provides details, taken from these references above, with a specific note indicating that dowels and sub-drainage affect faulting. It should be noted that reference 1 appears to be out of date and is probably superseded by **FHWA-RD-98-117**, "Design and Construction of PCC Pavements, Volume II: Design Features and Practices That Influence Performance of Pavements" or **FHWA-RD-98-113**, Volume III: Improved PCC Performance Models which is very difficult to locate a copy of. In either case, they each reference the same data. Both "involve a detailed evaluation and analysis of the PCC pavement data in the Long-Term Pavement Performance (LTPP) database using statistical techniques to determine the design features and construction practices that have beneficial effect on long-term performance." This database appears to have been created in 1998 with a historical look at data prior to 1998 and as noted in the quote, is strictly based on a design and construction perspective.

FHWA-RD-98-117, appears to be using the same LTPP database, and uses a Canonical Discriminant Analysis which appears to provide a weighting mechanism to "find the highest possible multiple correlation with the groups" and allows for the "desire to statistically distinguish between two or more groups of observations." The initial example given identifies the following:

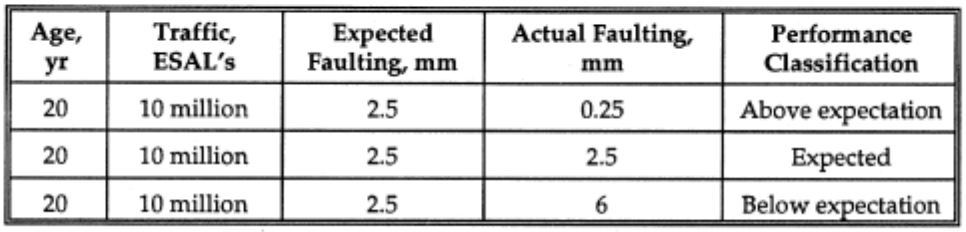
Group 1 – Pavements with faulting less than 10 mm (0.4 in)
Group 2 – Pavements with faulting more than 10 mm (0.4 in)

So the data appears to have values well outside the projected measures provided above that are focused on design and construction practices. The grouping breakdown, based on 0.4 inches, is a very curious cut off point for this analysis and we could find no information as to how that value was actually determined. It clearly shows values substantially higher than the proposed faulting metrics.

Also in that section of the document, you will find the following statement and table showing the results of the data analysis.

> “Using information from the LTPP database, performance models, and engineering judgment, the pavement sections in the LTPP database used for this study were classified as follows”

Table 2. Procedure of pavement performance evaluation.



Age, yr	Traffic, ESAL’s	Expected Faulting, mm	Actual Faulting, mm	Performance Classification
20	10 million	2.5	0.25	Above expectation
20	10 million	2.5	2.5	Expected
20	10 million	2.5	6	Below expectation

So the predictive analysis, in this particular example, is based on design parameters and a reflective analysis of the **pre-1998 data** and identifies an expected faulting of 2.5 mm (0.098 inches) or respectfully rounded will become 0.1 inches.

Length

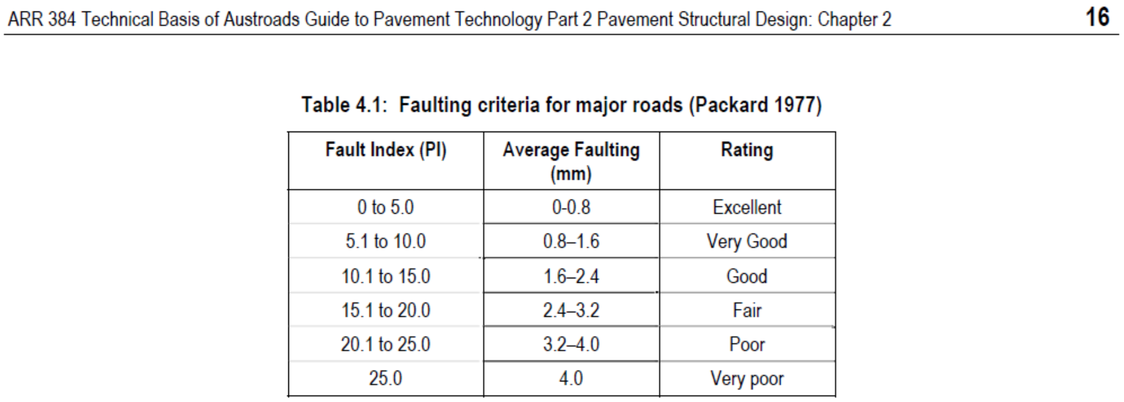
2.5 = 0.0984252

Millimeter

Inch

When we investigate the Austroads efforts in this area, we find similar results simply because they essentially referenced the same original US documents and findings. The following is taken directly from **“APR 384 Technical Basis of Austroads Guide to Pavement Technology Part 2 Pavement Structural Design: Chapter 2”**.

> “The erosion analysis follows a similar procedure to that of the fatigue analysis and is based on a suitable base thickness which will keep joint/crack deflections within safe limits by limiting the ‘erosion damage’ to 100%. This is determined by summing the individual erosion damage from each axle group load in the design load distribution. The 100% damage limit has been based on performance studies with limits placed on the serviceability index which correlates to limiting the faulting at transverse joints to the range of 3 to 6 mm at terminal conditions **(Packard and Tayabji 1985)**. Table 4.1 lists work by Packard **(Packard 1977)** to relate average faulting across joints to driver comfort conditions.”

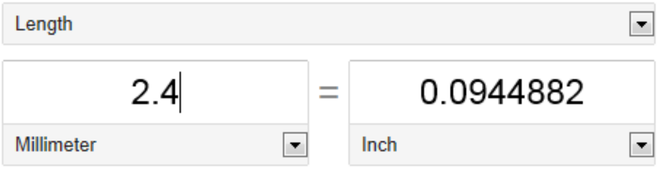


ARR 384 Technical Basis of Austroads Guide to Pavement Technology Part 2 Pavement Structural Design: Chapter 2 **16**

Table 4.1: Faulting criteria for major roads (Packard 1977)

Fault Index (PI)	Average Faulting (mm)	Rating
0 to 5.0	0-0.8	Excellent
5.1 to 10.0	0.8–1.6	Very Good
10.1 to 15.0	1.6–2.4	Good
15.1 to 20.0	2.4–3.2	Fair
20.1 to 25.0	3.2–4.0	Poor
25.0	4.0	Very poor

So the Austroads "Good" metric ends at 2.4 mm which is 0.094 inches or generously rounded will become 0.1 inches or 7/64 of an inch.

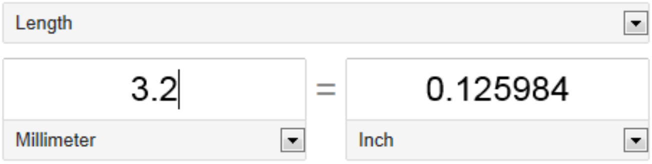


Length

2.4 = 0.0944882

Millimeter Inch

And the Austroads "Fair" metric ends at 3.2 mm or 0.126 inches or 1/8 of an inch.



Length

3.2 = 0.125984

Millimeter Inch

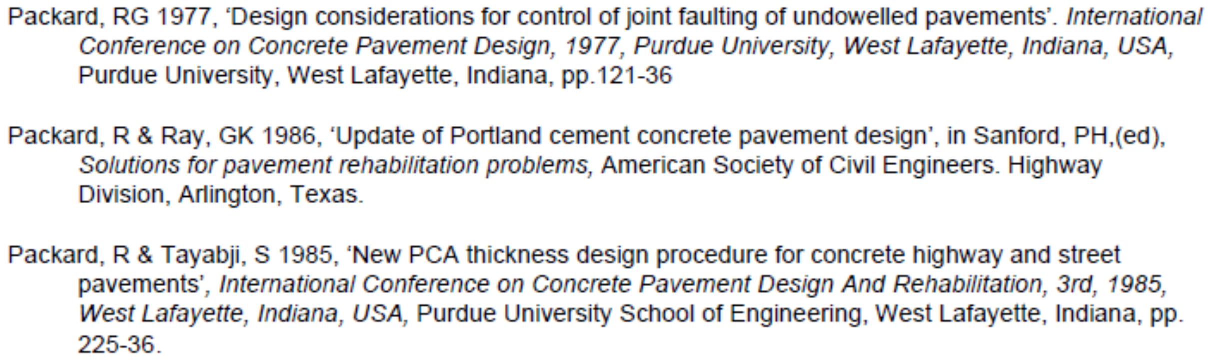
So should we adopt these measures instead? The Austroad's measures appear to be also based on the same data used for the NPRM proposed metrics, so our analysis of this source data should apply to the Austroad's metrics as well. The chart above is clearly identified in the document to be for "design criteria," but the information below is also included directly behind this Table 4.1 and is provided for review here.

> "The erosion criterion was suggested for use as a guideline and it was always the researchers' intention that it could be modified according to local experience since climate, drainage, local factors, and new design innovations may have an influence. To the authors' knowledge there have been no known cases in Australia where design engineers have amended the 100% erosion damage limit for a specific project."

It is interesting that the input that was expected from the "design engineers" never occurred. One needs to ask the next relevant question, what about the input from the field maintenance perspective? Or stated more succinctly, where is the correlation with real world data? So again, it would appear that the Austroads metrics are essentially based on predictive models and are theoretical since no substantial analysis of the real world outcomes have been performed.

Part of the purpose of MAP-21 is to bridge the long term disconnect between the design groups and the maintenance groups which historically have almost never communicated with respect to the impact of design decisions of the reality of field maintenance. There is hope that Life Cycle Cost will positively impact that relationship and decision process in a good way.

Following up on the source data used by Austroads and shown below, we find the data source went all the way back to **1977 for "driver comfort"** and **1985 for data analysis** leaving one to question the difference between those efforts and current realities. It should also be noted that driver comfort is already being addressed with the reporting and classification of the IRI.

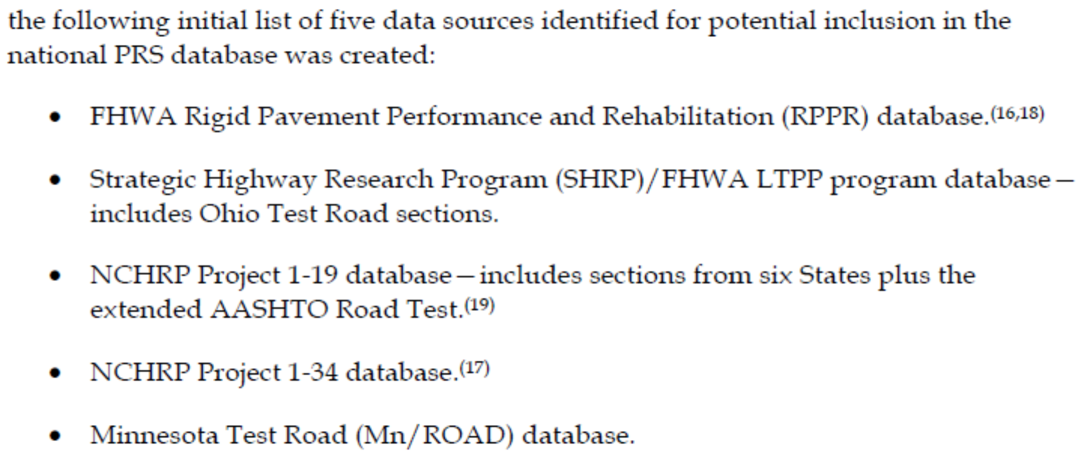


Packard, RG 1977, 'Design considerations for control of joint faulting of undowelled pavements'. *International Conference on Concrete Pavement Design, 1977, Purdue University, West Lafayette, Indiana, USA,* Purdue University, West Lafayette, Indiana, pp.121-36

Packard, R & Ray, GK 1986, 'Update of Portland cement concrete pavement design', in Sanford, PH,(ed), *Solutions for pavement rehabilitation problems,* American Society of Civil Engineers. Highway Division, Arlington, Texas.

Packard, R & Tayabji, S 1985, 'New PCA thickness design procedure for concrete highway and street pavements', *International Conference on Concrete Pavement Design And Rehabilitation, 3rd, 1985, West Lafayette, Indiana, USA,* Purdue University School of Engineering, West Lafayette, Indiana, pp. 225-36.

If we go back to the US efforts and investigate the **September 2000, FHWA-RD-00-130, "Improved Prediction Models for PCC Pavement Performance-Related Specifications, Volume 1: Final Report"** used to develop the **PaveSpec 3.0 software**, on page 16 we find the following list of data base sources for this software upgrade.

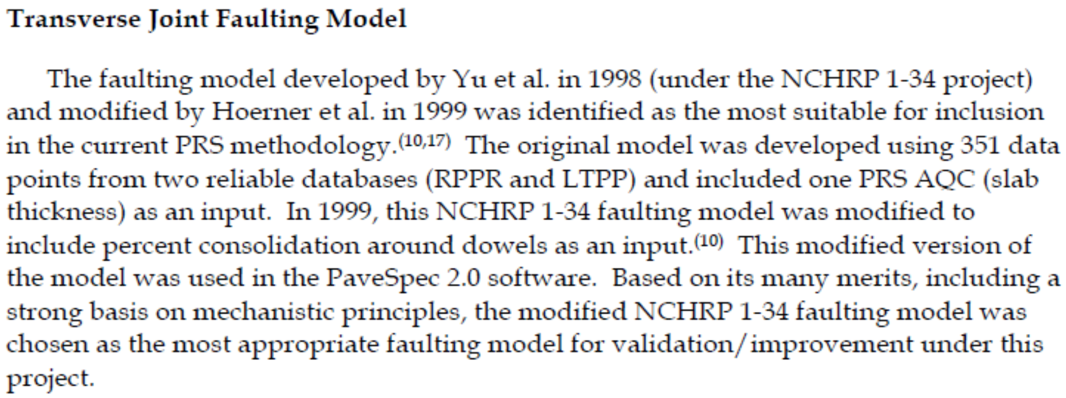


the following initial list of five data sources identified for potential inclusion in the national PRS database was created:

- FHWA Rigid Pavement Performance and Rehabilitation (RPPR) database.(16,18)
- Strategic Highway Research Program (SHRP)/FHWA LTPP program database—includes Ohio Test Road sections.
- NCHRP Project 1-19 database—includes sections from six States plus the extended AASHTO Road Test.(19)
- NCHRP Project 1-34 database.(17)
- Minnesota Test Road (Mn/ROAD) database.

The **FHWA RPPR database** appears to use data from 1987 and 1992 respectively, the **LTPP database** is discussed above and appears to use pre-1998 data, **NCHRP 1-19** appears to use 1984 data, **NCHRP 1-34** appears to use 1996 data that was updated in 1999 and **Mn/ROAD** appears to use data from 1994 through 1998.

On page 29 in **FHWA-RD-00-130** we find that it appears that the **1999 version of NCHRP 1-34** data for the faulting model in **PaveSpec 3.0.**



Transverse Joint Faulting Model

The faulting model developed by Yu et al. in 1998 (under the NCHRP 1-34 project) and modified by Hoerner et al. in 1999 was identified as the most suitable for inclusion in the current PRS methodology.(10,17) The original model was developed using 351 data points from two reliable databases (RPPR and LTPP) and included one PRS AQC (slab thickness) as an input. In 1999, this NCHRP 1-34 faulting model was modified to include percent consolidation around dowels as an input.(10) This modified version of the model was used in the PaveSpec 2.0 software. Based on its many merits, including a strong basis on mechanistic principles, the modified NCHRP 1-34 faulting model was chosen as the most appropriate faulting model for validation/improvement under this project.

On page 22 in table 6 we see that **NCHRP 1-34** used estimated ESAL's and did not identify truck loading.

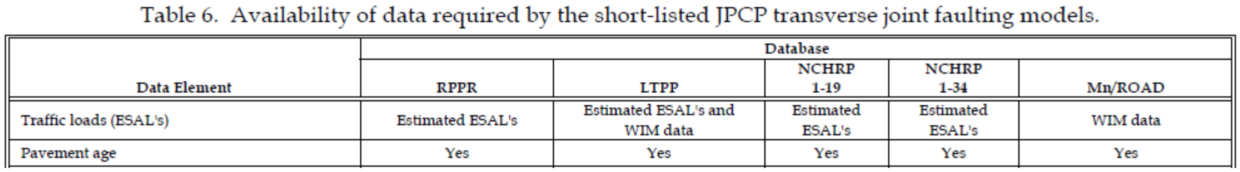


Table 6. Availability of data required by the short-listed JPCP transverse joint faulting models.

Data Element	Database				
	RPPR	LTPP	NCHRP 1-19	NCHRP 1-34	Mn/ROAD
Traffic loads (ESAL's)	Estimated ESAL's	Estimated ESAL's and WIM data	Estimated ESAL's	Estimated ESAL's	WIM data
Pavement age	Yes	Yes	Yes	Yes	Yes

Then on page 29 in **FHWA-RD-00-130,** we find the Maximum cumulative EASL's were set at 20,000,000, which by today's standards seems low.

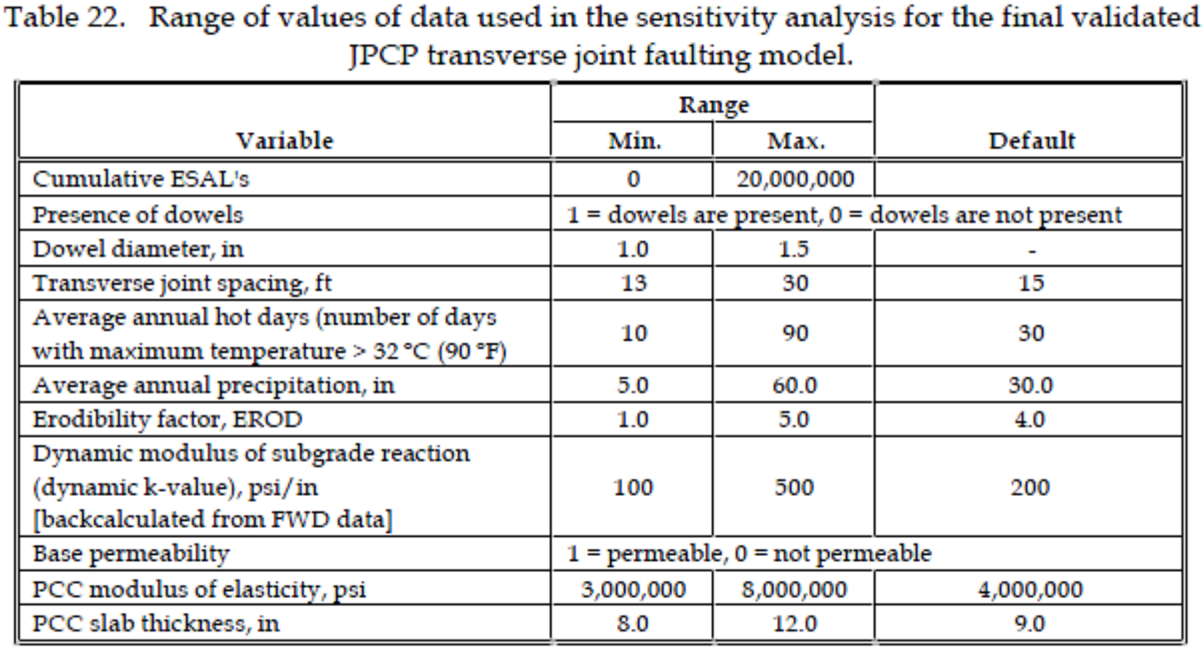
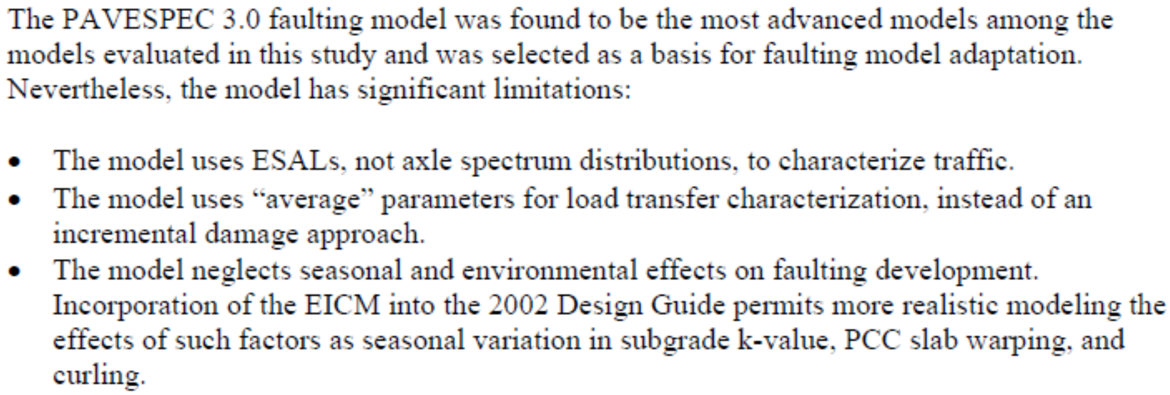


Table 22. Range of values of data used in the sensitivity analysis for the final validated JPCP transverse joint faulting model.

Variable	Range		Default
	Min.	Max.	
Cumulative ESAL's	0	20,000,000	
Presence of dowels	1 = dowels are present, 0 = dowels are not present		
Dowel diameter, in	1.0	1.5	-
Transverse joint spacing, ft	13	30	15
Average annual hot days (number of days with maximum temperature > 32 °C (90 °F)	10	90	30
Average annual precipitation, in	5.0	60.0	30.0
Erodibility factor, EROD	1.0	5.0	4.0
Dynamic modulus of subgrade reaction (dynamic k-value), psi/in [backcalculated from FWD data]	100	500	200
Base permeability	1 = permeable, 0 = not permeable		
PCC modulus of elasticity, psi	3,000,000	8,000,000	4,000,000
PCC slab thickness, in	8.0	12.0	9.0

Then on page 23 in the **2003 "Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures"** we find the PaveSpec 3.0 faulting model was update for the Mechanistic-Empirical Design. Complaints included the use of ESALs instead of "axle spectrum distributions" which appears to knock the lack of detail truck loading, and the update included the move to an "incremental damage" approach.



The PAVESPEC 3.0 faulting model was found to be the most advanced models among the models evaluated in this study and was selected as a basis for faulting model adaptation. Nevertheless, the model has significant limitations:

- The model uses ESALs, not axle spectrum distributions, to characterize traffic.
- The model uses "average" parameters for load transfer characterization, instead of an incremental damage approach.
- The model neglects seasonal and environmental effects on faulting development. Incorporation of the EICM into the 2002 Design Guide permits more realistic modeling the effects of such factors as seasonal variation in subgrade k-value, PCC slab warping, and curling.

We find on page 52 in the **Mechanistic-Empirical Design,** several charts that identify a "sensitivity analysis of faulting prediction to dowel diameter and different edge support conditions" for Illinois, North Dakota, Florida and Arizona. These charts clearly predict that that Jointed Concrete Pavements with dowels spend a large part of their existence below the faulting level of **0.05 inches**.

Perhaps this is where the lower metric value originates; however, we note on page 51 shown below, it would appear that this analysis is using a relatively low number of total **ESALs, 19,000,000,** a number that would certainly have been reasonable before the year 2000. The analysis also appears to be using the 1987 and 1992 respectively data from **FHWA RPPR database** and the pre-1998 data from the **LTPP database**.

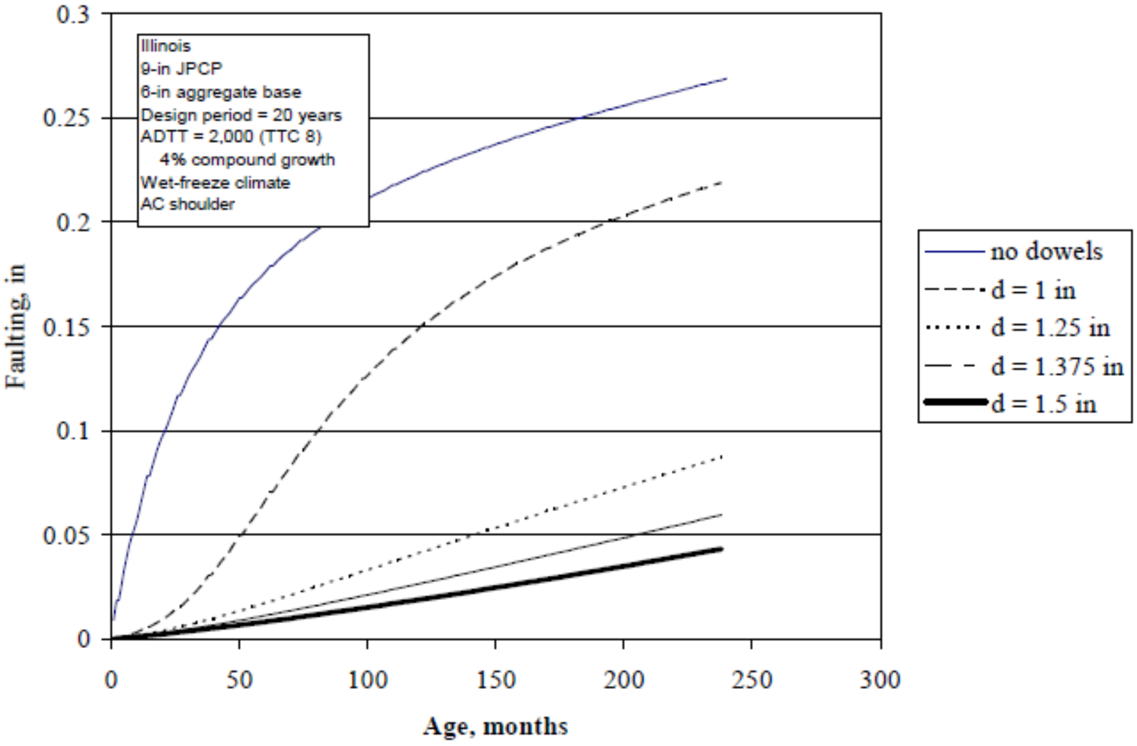
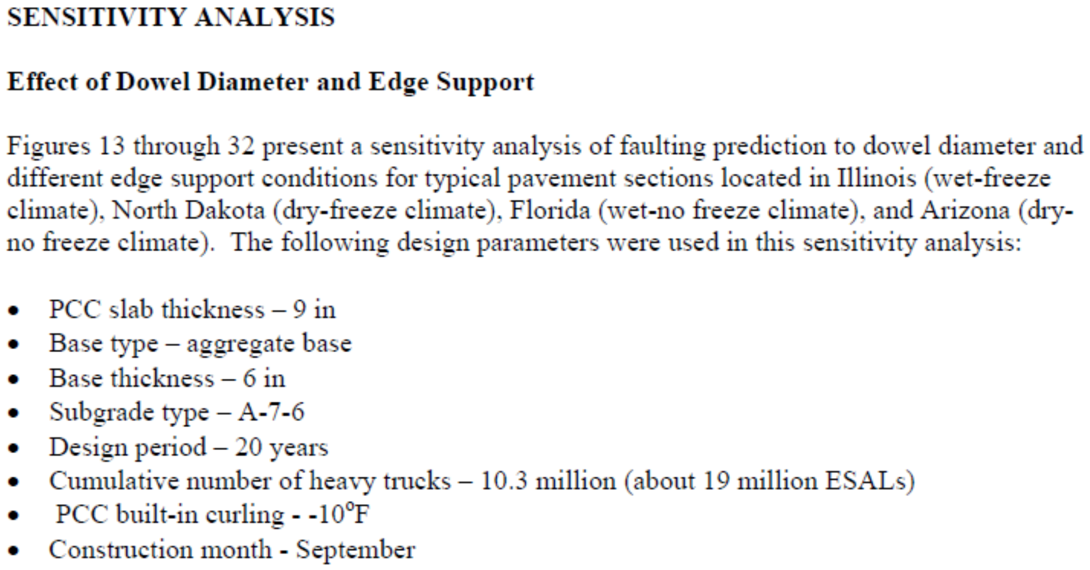


Figure 13. Faulting prediction for Illinois sections. AC shoulder.



SENSITIVITY ANALYSIS

Effect of Dowel Diameter and Edge Support

Figures 13 through 32 present a sensitivity analysis of faulting prediction to dowel diameter and different edge support conditions for typical pavement sections located in Illinois (wet-freeze climate), North Dakota (dry-freeze climate), Florida (wet-no freeze climate), and Arizona (dry-no freeze climate). The following design parameters were used in this sensitivity analysis:

- PCC slab thickness – 9 in
- Base type – aggregate base
- Base thickness – 6 in
- Subgrade type – A-7-6
- Design period – 20 years
- Cumulative number of heavy trucks – 10.3 million (about 19 million ESALs)
- PCC built-in curling - -10°F
- Construction month - September

Review of Truck Traffic & Other Data Issues

The following statement, found ***2014-30085 federal register.pdf*** on page 147, appears to erroneously purport that traffic has no effect on pavement condition.

> “Traffic levels were not included in the computation of pavement conditions except as implied by location as either urbanized or non-urbanized areas. Although traffic is an important consideration for the design of pavements, it is not considered a measure of the existing pavement condition. For this reason, the proposed rating system described in paragraphs (b) through (e) was designed without weightings or other prioritization related to anything other than the physical characteristics of the pavement structure.”

This fundamental statement seems to completely ignore the actual reality that truck traffic is the primary factor negatively influencing the long term structural viability of the nation’s pavements and bridges.

We must note that our staff research professor in this field argues that the authors could not have meant this literally, but that they probably meant that traffic data is not considered when pavement analysis data is captured. He may be correct, but we still need to make the case that there is substantial evidence against this NPRM statement which is documented below. In fact, it would seem plausible that if different ranges for

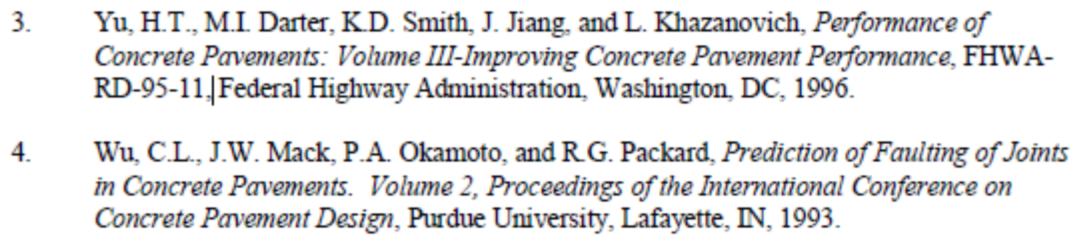
IRI are considered for large urban areas, then the proposed rules might also consider providing different ranges of faulting for areas that experience high truck traffic.

FHWA-RD-98-117, Appendix B, "Review of Factors that Influence Performance of PCC Pavements" clearly contradicts the NPRM assessment as we see a clear identification that "traffic loading plays a key role in the performance of all types of pavements." Further it states,

> "All these reasons make the evaluation of the effect of traffic loading on the performance of PCC pavements very critical, especially since traffic volumes continue to increase steadily. In addition, truck loads continue to get heavier, and the increased use of new types of multiple axle configurations and tire types, including super-singles and singled-out duals, have resulted in existing pavements being subjected to loadings far in excess of what was originally anticipated."

According to the June 2000 **FHWA-RD-00-076, "Preliminary Evaluation and Analysis of LTPP Faulting Data – Final Report"** with respect to truck volume, we find the following

> "Traffic data are one of the most important factors affecting joint faulting [3, 4]. Good quality traffic data over the whole pavement life is very important for the study of the effect of cumulative traffic on faulting. Available traffic data were obtained from the IMS table TRF_MONITOR_BASIC_INFO for the sections under study. An analysis of monitoring traffic data revealed that data were missing for a number of sections, and the available ESAL data represented only a few years in pavement life, with large differences in values between different years. Some of the sections with missing monitoring information had estimated information available. Comparison of the ESAL values for the sections that have both monitoring and estimated information showed large differences between the two.
>
> Since the traffic data obtained from the LTPP IMS database were available only for a few years, the traffic data for the remaining years were backcasted to the year when the pavement was opened to traffic and forecasted to the year of the latest faulting survey in order to estimate the cumulative traffic. Traffic data for the latest monitored year were assumed to be most accurate and, therefore, were used in backcasting and forecasting procedures. In this study, a constant growth factor of 2 percent was assumed for all the sections. The use of the 2 percent growth factor was considered conservative, as it results in a high level of cumulative traffic loading."
>
> References 3 and 4 from this quote are included for review.



3. Yu, H.T., M.I. Darter, K.D. Smith, J. Jiang, and L. Khazanovich, *Performance of Concrete Pavements: Volume III-Improving Concrete Pavement Performance*, FHWA-RD-95-11. Federal Highway Administration, Washington, DC, 1996.

4. Wu, C.L., J.W. Mack, P.A. Okamoto, and R.G. Packard, *Prediction of Faulting of Joints in Concrete Pavements. Volume 2, Proceedings of the International Conference on Concrete Pavement Design*, Purdue University, Lafayette, IN, 1993.

We've already noted above that on page 52 in the **Mechanistic-Empirical Design,** the knock against the PaveSpec 3.0 faulting model for the use of ESALs instead of "axle spectrum distributions, to characterize traffic"

So one of the, if not the most important, primary wild card factors in the design of pavements, and especially the subsequent pavement performance, is the loading caused by truck traffic. Clearly the limited LTPP data is further compromised by the extremely limited traffic data as acknowledged by the study above. So it appears that the enormous influence of truck traffic is being missed in the current analysis of this data. **FHWA-RD-00-076** goes on further to challenge the validity of the traffic data in the LTPP database.

> "Validity of the available traffic data was assessed through comparison of historical and monitoring ESAL data and by comparison of calculated truck factors for each section to an acceptable range (0.5 to 2.5). Analysis of the ESAL values for the sections that have both monitoring and historical ESALs showed that the quality and quantity of the available historical and monitoring traffic data vary considerably. Sections with questionable data were defined as those that showed unusually high or low values (ESALs or truck factors) or major discrepancies between the surveys. A list of sites with questionable data is given in table 13, and an example of a questionable trend between historical and monitoring ESAL data is presented in figure 8. The historical trend for this section indicates a substantial increase in truck loads, whereas the trend for monitoring data is declining. Particularly disturbing is the decline in ESALs per truck between 1992 and 1997. An opposite trend is expected, especially for recent years, because of increased competitiveness in the trucking/shipping industry and advances in wireless communications."

If the current proposed measures were based on these findings, then we are being asked to rely on potentially incorrect assessments of what could be dated material. When we include the fact that the data is pre-1998 data, we further note that there were inherent limitations within that data that have led to these measures identified above. For instance in **FHWA-RD-98-117,** "Table 2. Procedure of Pavement Performance Evaluation" previously shown above, the analysis results in predicted design faulting measures based on historical data using only 10 million cumulative ESALs (CESALs) for the evaluation. One would venture to say that 10 million CESALs would be a valid number for very few current pavement design efforts and probably never for Interstates and some of the high volume NHS pavements. In fact, an existing current pavement design for I-10 in southwest Louisiana using DARWin Pavement Design and Analysis System, calculates the 20 year design using **87,449,472 18-kip ESALs**.

Further in **FHWA-RD-00-076**,

> "Figure 26 shows the distribution of CESALs with age. There is a general trend of higher CESALs for older pavement sections; however, no strong correlation can be established. This can be explained by different road functionalities that result in lower or higher ESALs per year. Attempts were made to correlate faulting values with CESALs, but no meaningful relations were achieved.
>
> The quality of the traffic data used is very questionable, as was addressed in chapter 2 of this report. There is a strong need for a systematic procedure/ guideline for traffic backcasting applicable to all LTPP sections. This procedure should account for differences in traffic stream (vehicle distribution by class) and growth rates specific to different road functional classes and geographical regions. Available historical and monitoring data need to undergo QC analysis to resolve conflicts between historical and monitoring traffic trends."

So **FHWA-RD-00-076** absolutely questions the validity of the data and then insists that traffic data be captured and included in these efforts. Perhaps the comment about lack of correlation between faulting and CESALs confuses the situation; but, at this low level of traffic, with no intelligence indicating the percent truck traffic, no real correlation does exist. Would that be the case for current truck loadings, which is the basis for the "vehicle distribution by class" suggestion noted above?

We again want to mindful that **FHWA-HIF-12-049** concludes that there is "poor correlation" from year to year between the 2009 and 2010 HPMS faulting data submittals.

In this case, CESALs are the cumulative ESALs since traffic opening date to the time of faulting survey. Figure 26 is provided here to show the limited amount of data over 10 million CESALS.

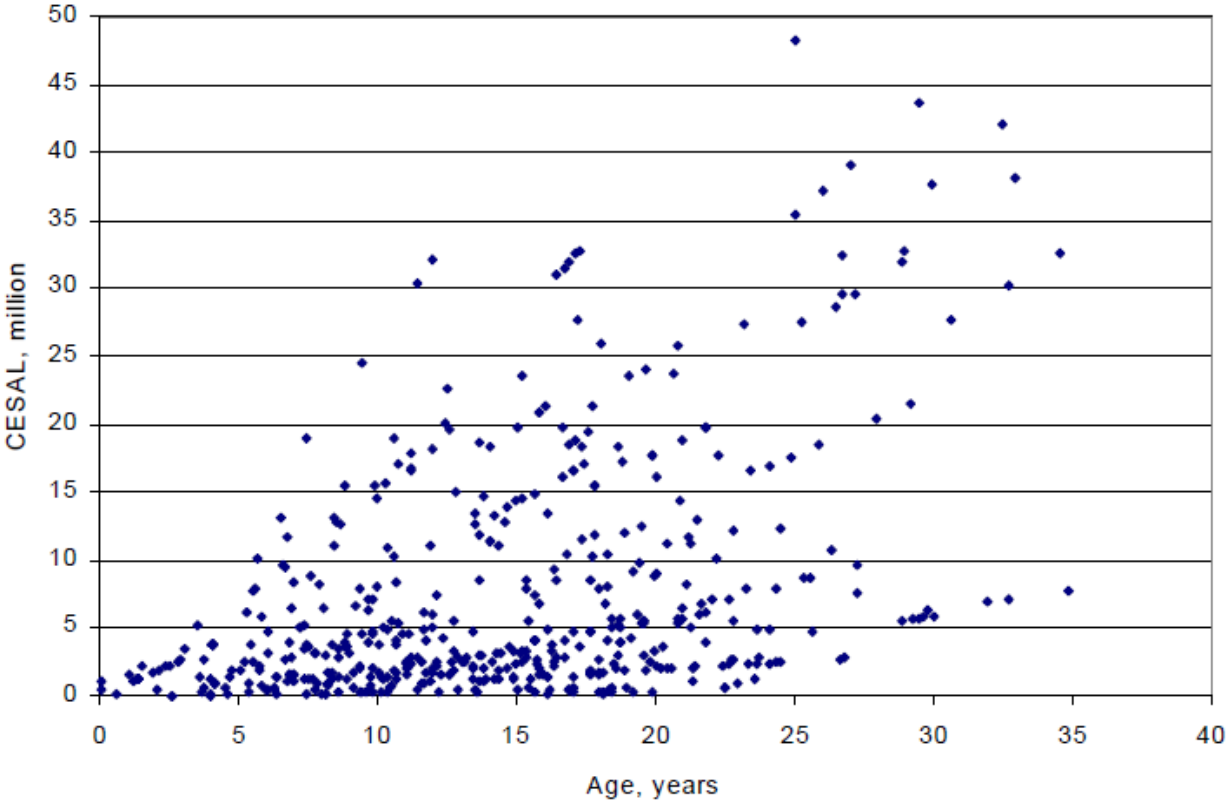


Figure 26. Distribution of CESALs with age.

Oddly enough, if one takes a shortcut and only reads **chapter 5, "Summary"** or **chapter 6, "Recommendations for Future Research" in FHWA-RD-00-076**, the reader will find no mention of the truck influence what so ever; however, the authors clearly define and discuss the data limitations and issues in great detail within the document. Then they perform the analysis as if there were no issues with truck traffic and disappointingly these issues are completely ignored in chapters 5 and 6.

Furthermore, according to **FHWA-RD-00-076**,

> "In this study, a constant growth factor of 2 percent was assumed for all the sections. The use of the 2 percent growth factor was considered conservative, as it results in a high level of cumulative traffic loading."

So this June 2000 document indicates that a 2 percent traffic loading growth factor would result in a higher than probable traffic loading and that this would result in very conservative design as a result.

Perhaps the use of the 2 percent growth factor might not have been as conservative as predicted. The following table found in **Report No. FHWA/TX-05/0-4169-1, "Rural Truck Traffic and Pavement Conditions in Texas,"** clearly documents in October 2003, that truck traffic volumes exploded not long after the LTPP database was created.

Table 3.1 Percent Growth in Average Annual Daily Truck Traffic Volumes in Rural Texas

District	Average Annual Daily Growth in Truck Traffic (1997 to 2001)	District	Average Annual Daily Growth in Truck Traffic (1997 to 2001)
Paris	3.12	Austin	13.00
Forth Worth	7.34	San Antonio	4.72
Wichita Falls	7.85	Corpus Christi	4.91
Amarillo	3.04	Bryan	5.76
Lubbock	3.65	Dallas	5.91
Odessa	7.38	Atlanta	3.65
San Angelo	5.85	Beaumont	3.64
Abilene	6.23	Pharr	6.87
Waco	6.41	Laredo	6.06
Tyler	5.51	Brownwood	5.18
Lufkin	4.57	El Paso	10.38
Yoakum	3.99	Childress	4.96

(Source: Texas Department of Transportation, 2003)

When we look at the data for further review, **FHWA-RD-97-131,"Common Characteristics of Good and Poorly Performing PCC Pavements",** which also appears to reference the LTPP database, the study once again identifies the shortfalls of the data.

> "this study contains faulting data for 176 JPCP and JRCP sections. The total number of observations is 368. For some sections, time series data contain up to 10 observations over 5 years. Other sections have only one performance record in the data base."

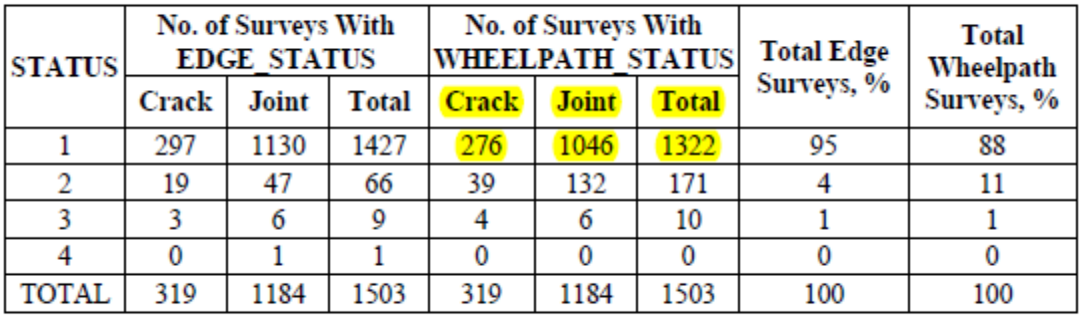
FHWA-RD-00-076, "Preliminary Evaluation and Analysis of LTPP Faulting Data – Final Report" also provides a clear documentation as to the limitations of the "faulting data availability" noting that this faulting data included both outside pavement edge joints and wheel path joints.

> "Data for 422 JCP sections were available in the IMS database at the time of the study. Out of 422 sections, only 307 sections had records in the faulting data table MON_DIS_JPCC_FAULT, for a total of 24,108 records. The number of faulting surveys for these sections ranged from one survey to nine, with 31 percent of sections having only one survey in the database. This magnitude of missing data is considered very serious because faulting is one of the key distress types associated with jointed concrete pavements. Future efforts should be focused on ensuring that faulting data are collected as required."

The study further reported on the Faulting Data Quality with a series of points outlining deficiencies.

> "Available faulting data were also evaluated in terms of usefulness for faulting trend analysis. It was found that less than 45 percent of sections had faulting data available from three or more surveys. Therefore, trend analysis reported in this report is to be viewed as "limited" or "preliminary." It is recommended that more extensive trend analysis be conducted as more data become available. The lack of faulting measurements over time must be corrected in the future if the LTPP program is to provide significant findings on ways to reduce faulting."

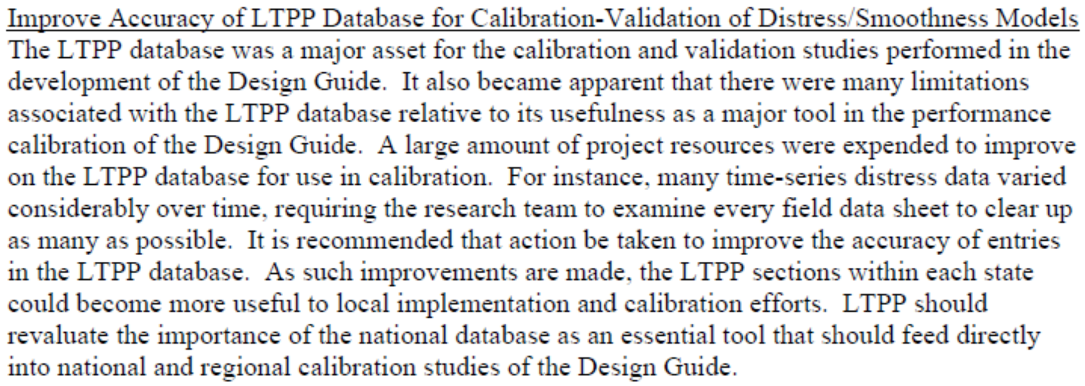
As identified in **Table 18. "Summary of the status of faulting data",** the entire wheel path faulting analysis is based on 1322 faults with 276 identified as cracks and 1046 as joints. Please note that in the column "Status", values 2 through 4 indicate rejected faulting data due to one reason or another.



STATUS	No. of Surveys With EDGE_STATUS			No. of Surveys With WHEELPATH_STATUS			Total Edge Surveys, %	Total Wheelpath Surveys, %
	Crack	Joint	Total	Crack	Joint	Total		
1	297	1130	1427	276	1046	1322	95	88
2	19	47	66	39	132	171	4	11
3	3	6	9	4	6	10	1	1
4	0	1	1	0	0	0	0	0
TOTAL	319	1184	1503	319	1184	1503	100	100

So it appears that not only are "Key" factors missed in the current analysis of this data, but in fact the data is pre-1998 data, there is a very limited amount of data that was used in the analysis, and there are inherent limitations within that data that have led to the proposed faulting metrics.

We also find on page "v" in the **"Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures"** the following excerpt that indicates the limitations and the need to improve the accuracy of entries in the LTPP database with respect to its "usefulness as a major tool in the performance calibration of the Design Guide."

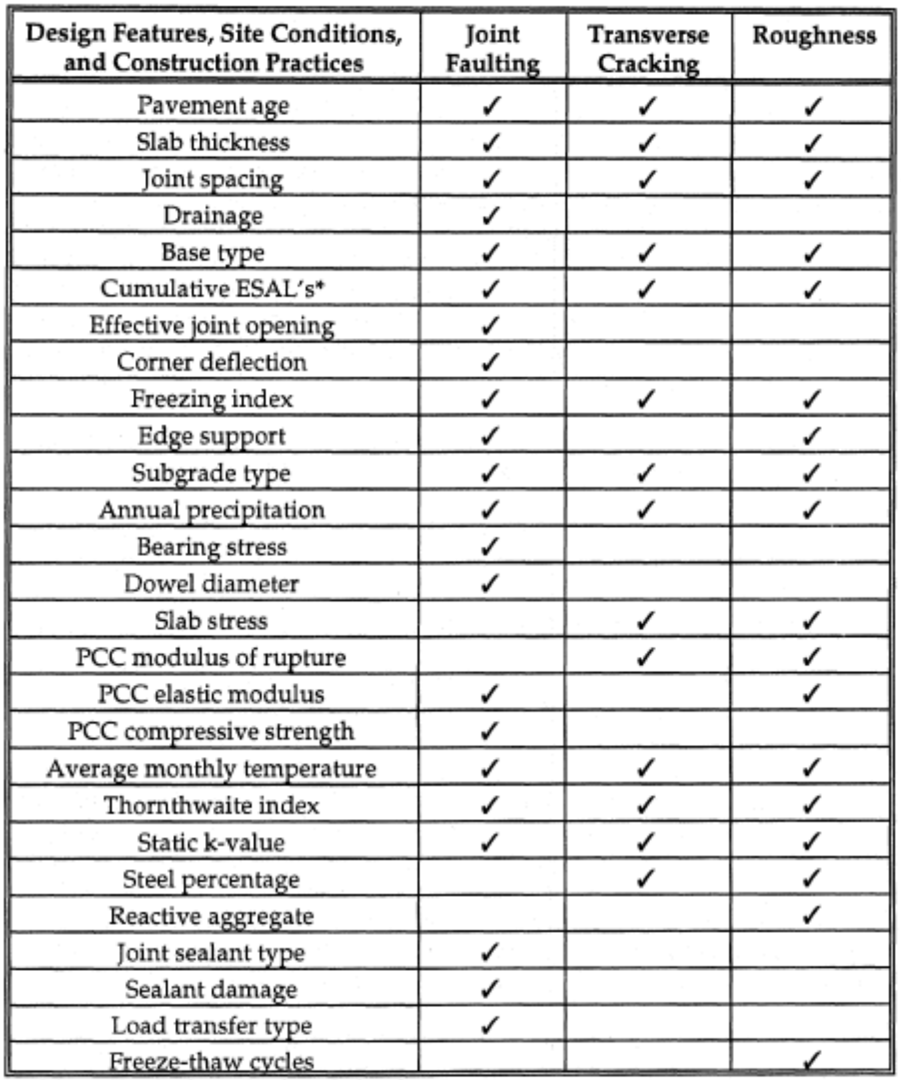


Improve Accuracy of LTPP Database for Calibration-Validation of Distress/Smoothness Models

The LTPP database was a major asset for the calibration and validation studies performed in the development of the Design Guide. It also became apparent that there were many limitations associated with the LTPP database relative to its usefulness as a major tool in the performance calibration of the Design Guide. A large amount of project resources were expended to improve on the LTPP database for use in calibration. For instance, many time-series distress data varied considerably over time, requiring the research team to examine every field data sheet to clear up as many as possible. It is recommended that action be taken to improve the accuracy of entries in the LTPP database. As such improvements are made, the LTPP sections within each state could become more useful to local implementation and calibration efforts. LTPP should revaluate the importance of the national database as an essential tool that should feed directly into national and regional calibration studies of the Design Guide.

From **FHWA-RD-98-117** page 4, the following table identifies all the variables that affect Joint Faulting and Transverse Cracking, which we note to be separate measures here. The document goes to great length to identify how all these variables affect pavement design and by reference performance. This table reflects the many potential variables that can contribute to joint faulting and transverse cracking opportunities.

Table 1. Proposed variables to be investigated for each prediction model.



Design Features, Site Conditions, and Construction Practices	Joint Faulting	Transverse Cracking	Roughness
Pavement age	✓	✓	✓
Slab thickness	✓	✓	✓
Joint spacing	✓	✓	✓
Drainage	✓		
Base type	✓	✓	✓
Cumulative ESAL's*	✓	✓	✓
Effective joint opening	✓		
Corner deflection	✓		
Freezing index	✓	✓	✓
Edge support	✓		✓
Subgrade type	✓	✓	✓
Annual precipitation	✓	✓	✓
Bearing stress	✓		
Dowel diameter	✓		
Slab stress		✓	✓
PCC modulus of rupture		✓	✓
PCC elastic modulus	✓		✓
PCC compressive strength	✓		
Average monthly temperature	✓	✓	✓
Thornthwaite index	✓	✓	✓
Static k-value	✓	✓	✓
Steel percentage		✓	✓
Reactive aggregate			✓
Joint sealant type	✓		
Sealant damage	✓		
Load transfer type	✓		
Freeze-thaw cycles			✓

* ESAL = Equivalent single axle load.

Also remember that some technical documents reference a "user comfort level" with those numbers appearing to originate in the **1977 RG Packard publication "Design considerations for control of joint faulting of undowelled pavements"**. It is most likely time to abandon this research document when we understand that vehicle suspension systems have clearly advanced since 1977.

If this analysis is correct, and these proposed metrics are based on the pre-2000 historical faulting data, which ignores the significant increase in Truck traffic, and is very limited in size and scope as document above, then the pre-2000 data could very well portray an incorrect picture while seeming to support the NPRM proposed metrics.

Since no one could have predicted the greatly increased truck volumes and increased loads that have occurred, a review of current faulting data, using updated values, would seem appropriate before finalizing these proposed faulting metrics.

Also it would seem appropriate to seek the necessary traffic data to analyze exactly how truck traffic affects infrastructure conditions in the US.

Data Capture & Vehicle Calibration

Perhaps Louisiana DOTD's biggest concern about the proposed faulting metric range would be the threat posed to the ability to calibrate data capture vehicles.

Louisiana DOTD Proposes that the FHWA evaluate all proposed metrics or any new proposed metrics with respect to data capture vehicle calibration capabilities and validate that standards can actually be developed and are reproducible to allow for calibrating automated data capture vehicles for the proposed metrics.

Analysis for Data Capture Vehicle Calibration - Effects of Temperature & Wheel Path

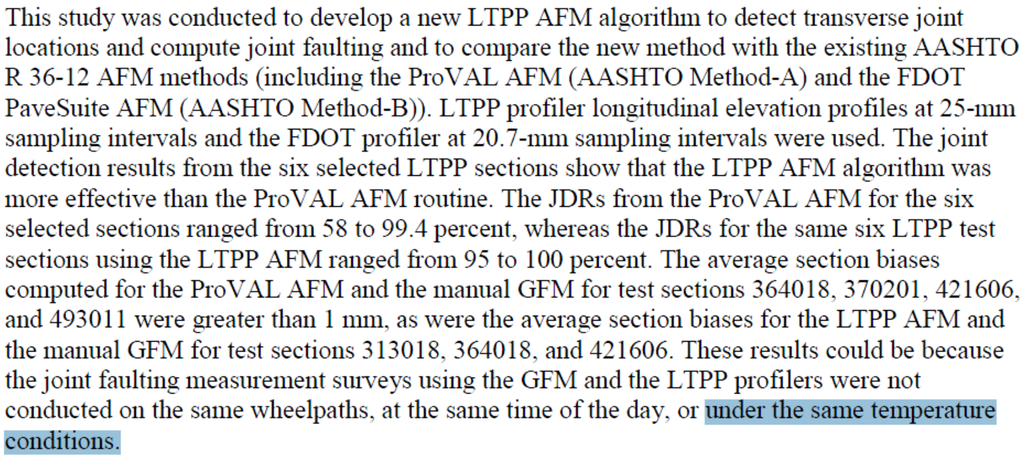
The following analysis considers the impact of the 1 mm (0.04 inches or 5/128 of an inch) proposed faulting metric on the ability to calibrate data capture vehicles and produce reliable and repeatable data capture efforts.

We find on the Penn State University web page, http://www.engr.psu.edu/ce/courses/ce584/concrete/library/cracking/thermalexpansioncontraction/thermalexpcontr.htm that in a 20 foot section of concrete, with a temperature change of 100 degrees, the length of the concrete section can expand by 0.13 inches, so a corresponding real world temperature change can have a proportional influence on joint expansion/contraction and subsequent faulting measures made on the same day.

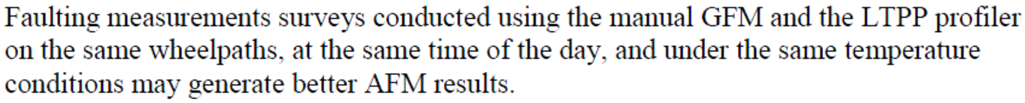
According to **FHWA-HRT-14-092, "Long Term Pavement Performance Automated Faulting Measurement"** shown below, temperature certainly makes a difference in faulting measures.

Wheel paths also make a difference. For our calibration sites, the wheel path can't be exactly the same on each run, so great effort is currently required to calibrate and certify the vehicle. For the NPRM proposed range of measures, validation could almost never be performed, as the various runs could vary significantly. The range of measures for the proposed metric could have the calibrated sites range from Good to Poor on back to back runs.

We note from **FHWA-HRT-14-092** below, that the "average section biases … were greater than 1 mm" for the analysis performed, with the wheel path and temperature listed as the primary culprits. If we are interpreting this terminology correctly, we believe it means that for calibration runs, apparently occurring at different times on different days, on the same pavement resulted in deviations greater than 1 mm which equals the "Good" proposed metric of 0.04 inches or 5/128 of an inch.



This study was conducted to develop a new LTPP AFM algorithm to detect transverse joint locations and compute joint faulting and to compare the new method with the existing AASHTO R 36-12 AFM methods (including the ProVAL AFM (AASHTO Method-A) and the FDOT PaveSuite AFM (AASHTO Method-B)). LTPP profiler longitudinal elevation profiles at 25-mm sampling intervals and the FDOT profiler at 20.7-mm sampling intervals were used. The joint detection results from the six selected LTPP sections show that the LTPP AFM algorithm was more effective than the ProVAL AFM routine. The JDRs from the ProVAL AFM for the six selected sections ranged from 58 to 99.4 percent, whereas the JDRs for the same six LTPP test sections using the LTPP AFM ranged from 95 to 100 percent. The average section biases computed for the ProVAL AFM and the manual GFM for test sections 364018, 370201, 421606, and 493011 were greater than 1 mm, as were the average section biases for the LTPP AFM and the manual GFM for test sections 313018, 364018, and 421606. These results could be because the joint faulting measurement surveys using the GFM and the LTPP profilers were not conducted on the same wheelpaths, at the same time of the day, or under the same temperature conditions.



Faulting measurements surveys conducted using the manual GFM and the LTPP profiler on the same wheelpaths, at the same time of the day, and under the same temperature conditions may generate better AFM results.

Louisiana DOTD requires the contractor to conduct initial and periodic calibrations on selected actual pavements. Currently we calibrate on (4) four asphalt pavements, (4) four JCP pavements, (4) four composite pavements and (1) one CRC pavement with "low", "medium" and "high" severity condition levels on each pavement type. When referring to the "wheel path" in a calibration effort, our experience is that a driver can experience great difficulty trying to match the same wheel path on the same pavement for the required minimum of (3) three consecutive runs. Calibration is sometimes difficult to achieve, for our current metric ranges, on pavements with "medium" and "high" severity levels at our calibration sites.

A recent fault analysis by Fugro Roadware's new 3-D data capture system, experienced large differences from one measurement to another as it moved across a single full joint and clearly showed that states will definitely get single wheel path variations of 1 mm or more on the same joint.

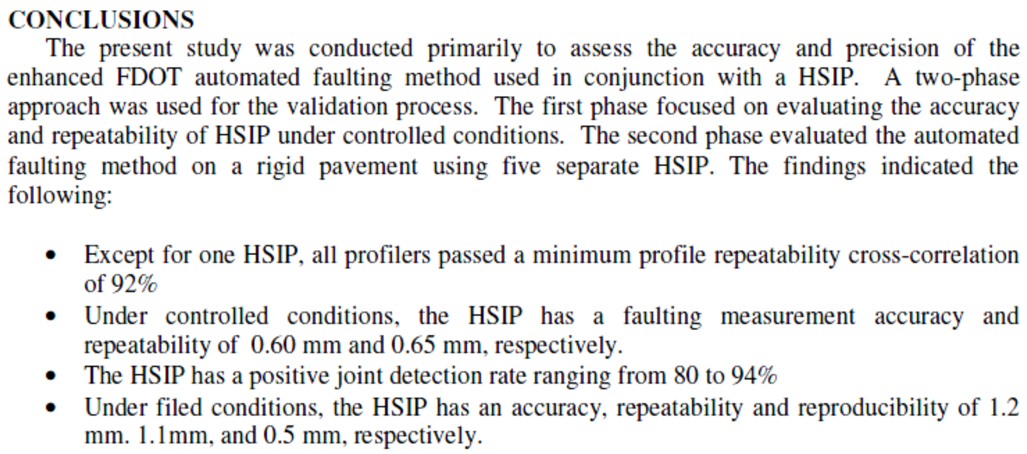
If we review the **Florida DOT, March 2010 "Alternative Validation Practice of an Automated Faulting Measurement Method,"** which was conducted to compare the difference between the Georgia Fault Meter and high speed inertial profilers (HSIP), we find that under "controlled" conditions on the Gainesville Speedway racetrack, a faulting measurement accuracy and repeatability of 0.60 mm and 0.65 mm, respectively, was obtained.

The **Florida DOT** field condition phase of the study was conducted on a 2,000 ft (609.6m) test section closed to traffic, the section included a 500 ft (152.4m) lead-in and lead-out, and a 1,000 ft (304.8m) effective test length spanning over 49 concrete slabs. The slabs were 20 ft (6.1m) long by 12 ft (3.7m) wide with a relatively smooth surface finish. The study section was a "two-lane joint plain concrete pavement (JPCP) and was selected for its proximity to the FDOT State Materials & Research Office, the relatively low vehicular traffic volume and operating speed, and the relative ease for setting up traffic control." So the analysis appears to have been performed on a pavement that would most likely be classified in "Good" to "Fair" condition and certainly with "low" severity.

In the results, an inexperienced driver reduced joint detection rate down to 74% compared to peers rates of 80 to 94%.

The average difference between the Georgia Fault Meter and the high speed inertial profiler (HSIP) or "accuracy" was estimated at 1.2 mm. The average difference in estimated faulting between any two independent runs of a single HSIP, or "repeatability" was estimated at 1.1mm. The maximum difference in estimated faulting between two different HSIP or "reproducibility" was estimated at 0.5 mm.

Again we note that the intent of **Florida DOT** analysis was not to identify valid faulting ranges, nor to certify calibration of the HSIPs, so the use of a relatively "low" severity pavement or a pavement in good condition was certainly within the norm. We must point out, however, that we would certainly expect to see much larger "accuracy" issues with "medium" severity and certainly with "high" severity faulted pavements. In light of this, doubling the accuracy number to 2.4 mm or 0.1 inches or 7/64 of an inch would be a more reasonable minimum threshold; however, the metric ranges should still be evaluated against reasonable field data, including identifying the ability to field locate joints with faults at the metric range transitions values between "Good" and "Fair".



CONCLUSIONS

The present study was conducted primarily to assess the accuracy and precision of the enhanced FDOT automated faulting method used in conjunction with a HSIP. A two-phase approach was used for the validation process. The first phase focused on evaluating the accuracy and repeatability of HSIP under controlled conditions. The second phase evaluated the automated faulting method on a rigid pavement using five separate HSIP. The findings indicated the following:

- Except for one HSIP, all profilers passed a minimum profile repeatability cross-correlation of 92%
- Under controlled conditions, the HSIP has a faulting measurement accuracy and repeatability of 0.60 mm and 0.65 mm, respectively.
- The HSIP has a positive joint detection rate ranging from 80 to 94%
- Under filed conditions, the HSIP has an accuracy, repeatability and reproducibility of 1.2 mm. 1.1mm, and 0.5 mm, respectively.

It now becomes clear, the proposed faulting metric range starting at 1 mm (0.04 inches or 5/128 of an inch) will most likely result in the **very significant unintended consequence of preventing the calibration of data capture vehicles from being legitimately possible on some pavements.**

It also becomes clear that the proposed metric ranges and thresholds will not allow for reliable measures, which are repeatable, for any given pavement due to variability caused by a combination of random factors including equipment, operator experience, pavement texture and vehicle wander. Again we note that most of these issues, for this project, were greatly reduced under the "controlled field conditions." We also note that care was taken by **Florida DOT** to isolate the temperature variable by collecting data in the middle to late afternoon for two consecutive days. The weather was mostly fair on both days with partly cloudy skies.

Faulting Metric Adjustment Proposals Based on Data Analysis

Louisiana DOTD Proposes that the faulting performance metrics would be modified as follows; Good to be <0.2 inches, Fair to be between 0.2 to 0.4 inches, and Poor to be >0.4 inches to allow for states to consider using the less expensive "real time" automated data capture.

In lieu of increasing the metric as proposed above, Louisiana DOTD Proposes that post processing, with no minimum fault threshold, and manually identified joints, be used for determining the faulting average. Forcing identification of straight line joints will assist preservation efforts by providing project level location data for high value faults.

Louisiana DOTD Proposes that the faulting average for a 0.1 mile segment include only straight line joint fault data for that segment, and include the faults that have a "0.0 inch" value for the "post processed, no minimum fault threshold" data.

Louisiana DOTD Proposes to adopt the Austroads term "Straight-Line Crack" for transverse joints, longitudinal joints, skewed joints and saw cut joints (which would include concrete patches). This allows for a correct differentiation between transverse cracks and designed joints.

Louisiana DOTD Proposes that only straight line joints be used in faulting determination and that other transverse cracks be captured via IRI and Percent Cracking measures. As it is, IRI will automatically capture strait line joints as well, and Percent Cracking will capture transverse cracks, so the DOTs will still receive a double penalty for faulting at joints. There is no need to do the same for transverse cracks.

Louisiana DOTD Proposes that DOTs be given a phase-in period to allow them to develop or update data collection contracts that support these additional costly measures, during which the faulting measures would be based on real time data with a minimum threshold of 0.1 inch, and the performance metrics would be initially set to Good to be <0.2 inches, Fair to be between 0.2 to 0.4 inches, and Poor to be >0.4 inches during this phase-in period.

Louisiana DOTD Proposes that a future defined date, tied to a federal funding source for the additional cost, could be defined for implementation of the above proposed two future measures. This would give states the time to implement or update data collection contracts as well.

Analysis of Data for Faulting Metric Adjustment Proposals

Issues with Determining Faulting Values

The NPRM sites the use of AASHTO R36-13 as the method to determine faulting. This standard contains 2 optional methods for measuring the fault depth, both of which are solely dependent on the longitudinal profile measured by the inertial profiler systems, also used to measure pavement roughness. This standard has changed dramatically since the 2013 release of the AAHSTO standards and becomes a problem since it has no equivalent standard in the American Society for Testing and Materials (ASTM).

When this process is applied to smooth roads or new pavements, with isolated areas of faulting, measurement issues are often seen. Without reference to known locations for straight line joints, the number of measured 'faults' according to the standards is often far less than the true number of straight line joints. As such, only the significant (ie. higher) fault measurements are recorded and are available to be averaged. This skews the results, for example, if a single joint is detected with a 0.20 inch fault, as currently described in the NPRM 490.311(a)(4)(iii), the faulting average for that 0.1 mile segment would be 0.20 inches. Since no process is currently defined to account for the additional smooth joints/cracks which are not detected by the process outlined in the standard, this grossly overstates the pavement condition in a very penal manner. If all additional straight line joints are included over this 0.1 mile section, the faulting average for just a few faults justifiably becomes almost non-existent.

In addition, newer 3D data collection technologies are now becoming available that greatly exceeds the accuracy and repeatability of the AASHTO R36-13 standard, but would not be acceptable for use as currently proposed. Ironically these 3D capabilities outline the variability in faulting data along a single joint as detailed in the data capture vehicle calibration issue.

In the next section we will look at how lower the faulting threshold can increase the number of false positives. A false positive would be a fault that gets detected that is not caused by a straight line joint and could be the result of a distress crack or debris on the road. Post processors try to minimize the number of false positives by removing faults that are too close together.

Analysis of Real Faulting Data for an Older Industrial Corridor and Older Interstate Pavements

The following table is a snap shot of data from an older heavy industrial corridor in Louisiana. The table is fault color coded with green equaling the <0.05 inch "Good" category, blue equaling the 0.05 to 0.15 "Fair" category, and red equaling the >0.15 inch "Poor" category of faulting proposed by the NPRM.

To aid the field data capture crew in managing the ongoing validity of the data capture, the data collection contractor captures real time faulting measures with a 0.1 inch minimum threshold. Setting the real time threshold any lower that 0.1 inches defeats the intended ability to quickly identify and rectify data capture technology failures.

Many states use this real time data for their faulting measures, because it is the least expensive data to obtain. Unfortunately, in the case of this particular industrial corridor, the real time faulting measure results in 99.2% of the pavement being classified as "Poor" with respect to the currently proposed NPRM faulting metrics. The reason this is happening is because you are ignoring faulting values between -0.1 inches and +0.1 inches, so the average fault value must be significantly higher.

Further analysis indicates a significant difference in real time verses post processed data. Post processing provides the ability to look at the profile a little bit deeper and has a more refined ability to remove false positives (ie. if it finds 2 faults within a few feet of each other, it can evaluate which one is more likely true). It is still not yet in these cases tied to the identified straight line joint locations, but it does follow our contractor best guess interpretation of AASHTO R 36-13 and just uses the longitudinal profile data. See "Issues with AASHTO R36-13" later in this document.

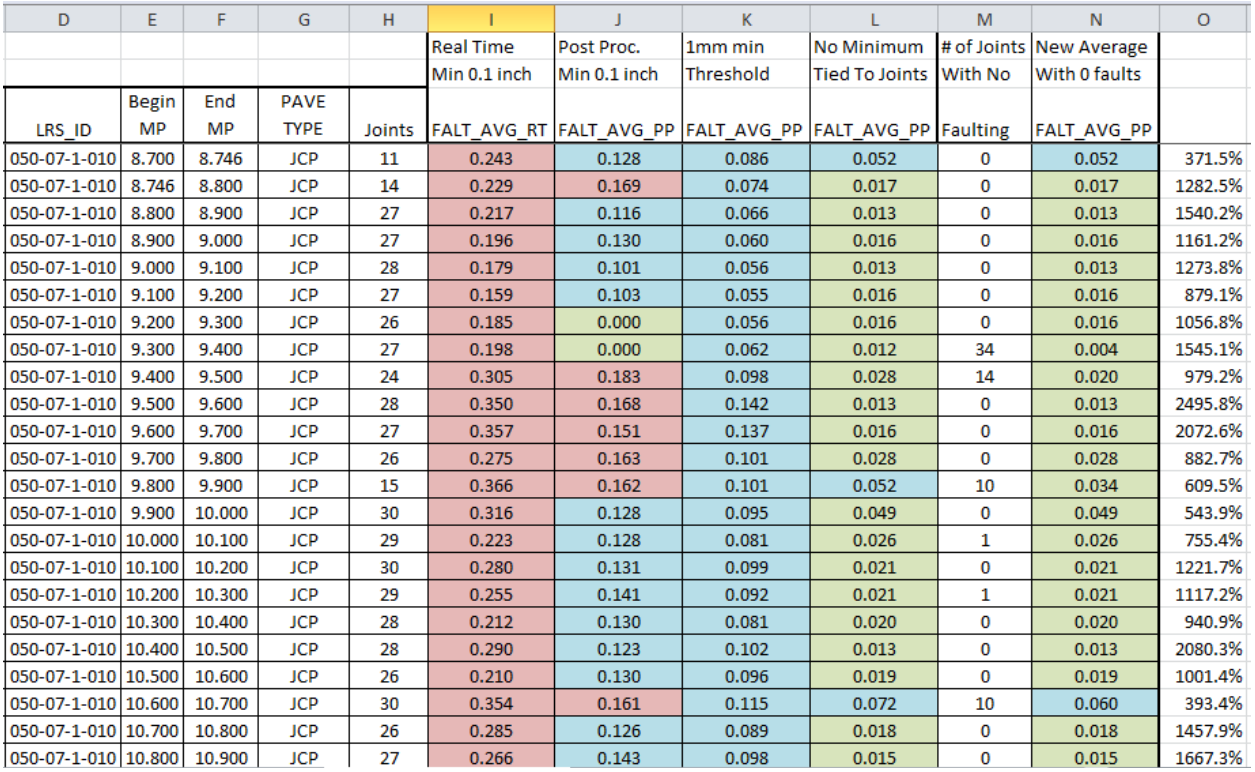
Unfortunately, based on the current NPRM, in both the real time and post processed data, the fault height reported is still only an average of what is actually measured. So if only (1) one fault is found, that one fault would be the average faulting value reported for the 0.1 mile section, which pretty much singularly defeats any real value in capturing the data, with respect to defining the actual pavement condition.

Each of the columns that follow the real time measure, represent post processed values. As we lower the minimum threshold from 0.1 inches to 1 mm(0.04 inches), we discover another interesting anomaly, the average faulting values mostly decrease when the threshold is reduced, or removed, because there are now so many more potential faults identified. On the surface, this would appear to be reasonable and fairly accurate for this older corridor; however, in many cases, these are not only real straight line joint faults, but also could include false positives from transverse cracking, patching, and other rough pavements which will already be double counted against the states with cracking percent and IRI metrics.

If we take a profoundly different approach and we force the post processing to only consider manually identified straight line joints for faulting, we begin to focus only on real faulting values. For instance, in a segment with 10 joints, the system would expect to find a fault for each wheel path, or 20 faults. By forcing the use of pre-identified straight line joints, we can eliminate the software algorithm guesswork and also completely remove the "minimum" threshold used in previous analysis. This analysis also eliminates any potential false positives since it only focuses on Straight Line "cracks" such as joints and saw cuts. In this analysis, the "No Minimum, Tied to Joints" column still does not factor in faults with "0.0 inch" values.

We find in the column, "# of Joints with No Faulting", which is a count of faults with "0.0 inch" values. In a large number of cases, no "0.0 inch faults" are found, as one would expect on an older industrial corridor. In cases where a number of "0.0 inch" faults are found, the column "New Average with 0 Faults" averages these values in to the faulting average for that 1.0 mile segment. This methodology, using pre-identified straight line joints with no "minimum" threshold, also appears to better support the data needed for mechanistic-empirical pavement design. Taking this one step further, and averaging in all “0.0 inch” faults, gives the most reproducible and accurate average faulting measure for the 0.1 mile segment.

The final column below shows the (%) percent difference between the “post processed pre-identified joint with no minimum threshold” verses the “real time capture with a 0.1 inch minimum threshold.” These large percentages clearly identify the significant potential faulting differences between how these measures could be captured and post processed. The other minimum threshold post processed columns included here also identify significant differences between how these values are determined, clearly define the effect of setting higher or lower threshold values, and serve to quantify some of the potential issues with the current proposal.



D	E	F	G	H	I	J	K	L	M	N	O
					Real Time Min 0.1 inch	Post Proc. Min 0.1 inch	1mm min Threshold	No Minimum Tied To Joints	# of Joints With No	New Average With 0 faults	
LRS_ID	Begin MP	End MP	PAVE TYPE	Joints	FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
050-07-1-010	8.700	8.746	JCP	11	0.243	0.128	0.086	0.052	0	0.052	371.5%
050-07-1-010	8.746	8.800	JCP	14	0.229	0.169	0.074	0.017	0	0.017	1282.5%
050-07-1-010	8.800	8.900	JCP	27	0.217	0.116	0.066	0.013	0	0.013	1540.2%
050-07-1-010	8.900	9.000	JCP	27	0.196	0.130	0.060	0.016	0	0.016	1161.2%
050-07-1-010	9.000	9.100	JCP	28	0.179	0.101	0.056	0.013	0	0.013	1273.8%
050-07-1-010	9.100	9.200	JCP	27	0.159	0.103	0.055	0.016	0	0.016	879.1%
050-07-1-010	9.200	9.300	JCP	26	0.185	0.000	0.056	0.016	0	0.016	1056.8%
050-07-1-010	9.300	9.400	JCP	27	0.198	0.000	0.062	0.012	34	0.004	1545.1%
050-07-1-010	9.400	9.500	JCP	24	0.305	0.183	0.098	0.028	14	0.020	979.2%
050-07-1-010	9.500	9.600	JCP	28	0.350	0.168	0.142	0.013	0	0.013	2495.8%
050-07-1-010	9.600	9.700	JCP	27	0.357	0.151	0.137	0.016	0	0.016	2072.6%
050-07-1-010	9.700	9.800	JCP	26	0.275	0.163	0.101	0.028	0	0.028	882.7%
050-07-1-010	9.800	9.900	JCP	15	0.366	0.162	0.101	0.052	10	0.034	609.5%
050-07-1-010	9.900	10.000	JCP	30	0.316	0.128	0.095	0.049	0	0.049	543.9%
050-07-1-010	10.000	10.100	JCP	29	0.223	0.128	0.081	0.026	1	0.026	755.4%
050-07-1-010	10.100	10.200	JCP	30	0.280	0.131	0.099	0.021	0	0.021	1221.7%
050-07-1-010	10.200	10.300	JCP	29	0.255	0.141	0.092	0.021	1	0.021	1117.2%
050-07-1-010	10.300	10.400	JCP	28	0.212	0.130	0.081	0.020	0	0.020	940.9%
050-07-1-010	10.400	10.500	JCP	28	0.290	0.123	0.102	0.013	0	0.013	2080.3%
050-07-1-010	10.500	10.600	JCP	26	0.210	0.130	0.096	0.019	0	0.019	1001.4%
050-07-1-010	10.600	10.700	JCP	30	0.354	0.161	0.115	0.072	10	0.060	393.4%
050-07-1-010	10.700	10.800	JCP	26	0.285	0.126	0.089	0.018	0	0.018	1457.9%
050-07-1-010	10.800	10.900	JCP	27	0.266	0.143	0.098	0.015	0	0.015	1667.3%

In the summary table below, for the 11.8 miles or 119 segments (0.1 mile segments), on this industrial corridor, for the “post processed no minimum threshold tied to manually defined joints” we find the faulting measures to have 39.5% in the “Good” category, 60.5% in the “Fair” category, and 0% in the “Poor” category based on the proposed NPRM metrics. This is significantly different from the real time 99.2% in the “Poor” category found in the real time data which many states are currently using.

An important point now has to be made about comparing the results from these different columns in the tables provided. Effectively the 99.2% “Poor” in the “Real Time

0.1 inch minimum" column is the same data that is the 2.5% "Poor" in the "Post Processed 1 mm minimum" column. The 2.5% is simply watered or averaged down by all the data below 0.1 inch and above 1 mm.

The real question that needs to still be answered is does this lowering or elimination of the minimum data capture threshold provide any real value. We will try to answer that later.

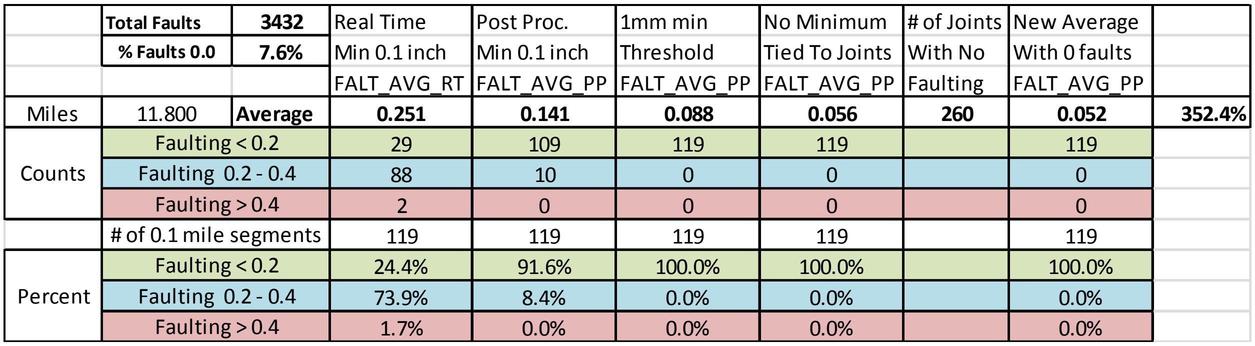
It is significant to note that a "joint repair/joint replacement/patching" project occurred just a few years ago on this pavement segment and we actually consider the pavement to be in "Fair" condition, which the real time analysis would not seem to support. This joint repair project also answers the question one might have as to why you would find any number of "0.0 inch" faults on an older industrial corridor as noted in the table above.

Most importantly, for states that don't want to pay extra for post processed data, it provides a "statistical point of contention" factoring against the proposed metrics with respect to older pavements.

If these proposed metrics are approved, State DOTs could come to the realization that joint repair/joint replacement/patching preservation projects might not be a good investment strategy. The "unintended consequence" of these proposed metrics would be that these types of preservation treatments would be forsaken if they proved to provide very limited extension of life cycle value towards meeting the metric, as this analysis would seem to indicate. This would also appear to defeat the move away from "worst 1st to preservation" movement.

	Total Faults	**3432**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**7.6%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
Miles	11.800	**Average**	**0.251**	**0.141**	**0.088**	**0.056**	**260**	**0.052**	**352.4%**
Counts	Faulting < 0.05		0	7	1	47		50	
	Faulting 0.05 - 0.15		1	70	115	72		69	
	Faulting > 0.15		118	42	3	0		0	
	# of 0.1 mile segments		119	119	119	119		119	
Percent	Faulting < 0.05		0.0%	5.9%	0.8%	39.5%		42.0%	
	Faulting 0.05 - 0.15		0.8%	58.8%	96.6%	60.5%		58.0%	
	Faulting > 0.15		99.2%	35.3%	2.5%	0.0%		0.0%	

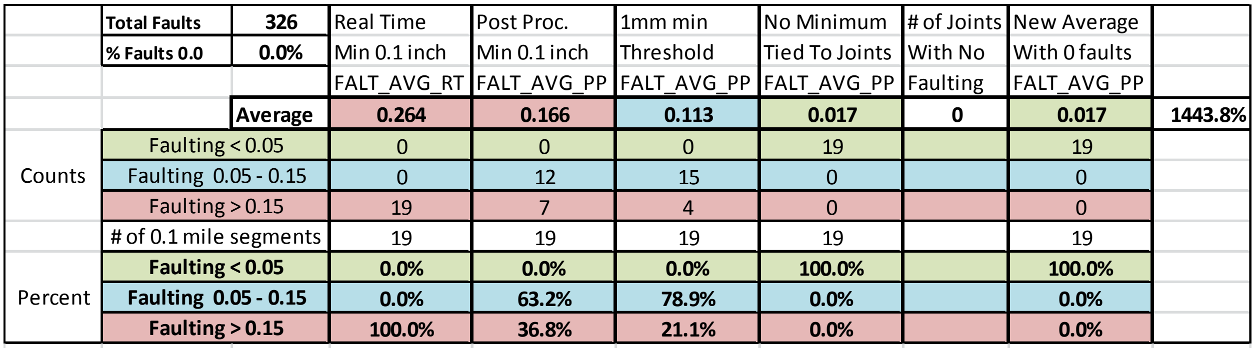
When we adjust the faulting metrics to match the proposed "rutting metrics" we find the much more palatable result shown below. Again the most accurate measure is the "post processed pre-identified joint with no minimum threshold" but these metrics might allow states to consider continuing their use of the real time data.



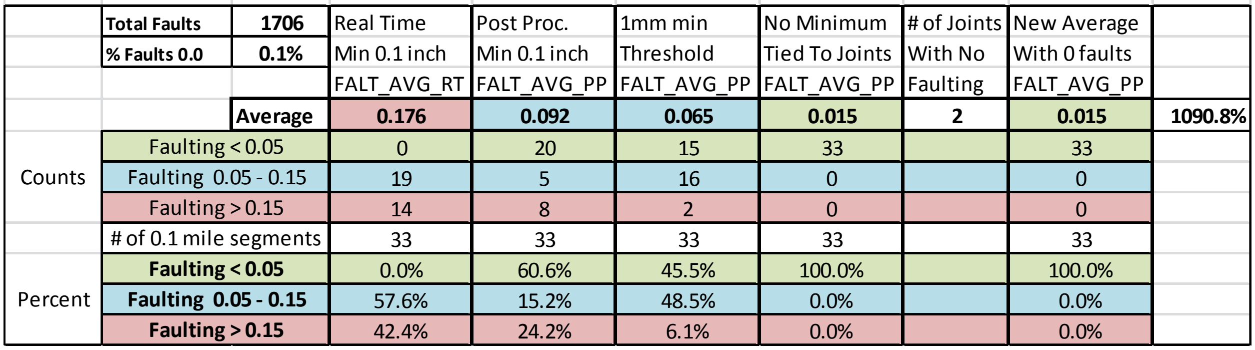
	Total Faults	**3432**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**7.6%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
Miles	11.800	**Average**	**0.251**	**0.141**	**0.088**	**0.056**	**260**	**0.052**	**352.4%**
Counts	Faulting < 0.2		29	109	119	119		119	
	Faulting 0.2 - 0.4		88	10	0	0		0	
	Faulting > 0.4		2	0	0	0		0	
	# of 0.1 mile segments		119	119	119	119		119	
Percent	Faulting < 0.2		24.4%	91.6%	100.0%	100.0%		100.0%	
	Faulting 0.2 - 0.4		73.9%	8.4%	0.0%	0.0%		0.0%	
	Faulting > 0.4		1.7%	0.0%	0.0%	0.0%		0.0%	

When we looked at two (2) additional older interstate pavements shown in the table below, we note that no “joint repair” projects have been conducted on these pavements, as evidenced by the very low number of joints with “0.0 inch” faults. Again we note the color coded “Good”, “Fair”, and “Poor” values defined above.

We find once again that forcing the software to use only identified straight line joints with no minimum threshold provides a much more accurate picture, and in this case, a 100 percent different picture, from real time data capture. This table also shows the significant differences from “Poor” to “Fair” verses “Good” for other post processed data captures with defined minimum thresholds.



	Total Faults	**326**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**0.0%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
		Average	**0.264**	**0.166**	**0.113**	**0.017**	**0**	**0.017**	**1443.8%**
Counts	Faulting < 0.05		0	0	0	19		19	
	Faulting 0.05 - 0.15		0	12	15	0		0	
	Faulting > 0.15		19	7	4	0		0	
	# of 0.1 mile segments		19	19	19	19		19	
Percent	**Faulting < 0.05**		**0.0%**	**0.0%**	**0.0%**	**100.0%**		**100.0%**	
	Faulting 0.05 - 0.15		**0.0%**	**63.2%**	**78.9%**	**0.0%**		**0.0%**	
	Faulting > 0.15		**100.0%**	**36.8%**	**21.1%**	**0.0%**		**0.0%**	



	Total Faults	**1706**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**0.1%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
		Average	**0.176**	**0.092**	**0.065**	**0.015**	**2**	**0.015**	**1090.8%**
Counts	Faulting < 0.05		0	20	15	33		33	
	Faulting 0.05 - 0.15		19	5	16	0		0	
	Faulting > 0.15		14	8	2	0		0	
	# of 0.1 mile segments		33	33	33	33		33	
Percent	**Faulting < 0.05**		0.0%	60.6%	45.5%	100.0%		100.0%	
	Faulting 0.05 - 0.15		57.6%	15.2%	48.5%	0.0%		0.0%	
	Faulting > 0.15		42.4%	24.2%	6.1%	0.0%		0.0%	

When we looked at these two (2) older interstate pavements and we again adjust the faulting metrics to match the proposed “rutting metrics” we find the much more palatable result shown below. Again the most accurate measure is the "post processed pre-identified joint with no minimum threshold" but these metrics would allow states to consider continuing their use of the real time data.

	Total Faults	**326**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**0.0%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
		Average	**0.264**	**0.166**	**0.113**	**0.017**	**0**	**0.017**	**1443.8%**
Counts	Faulting < 0.2		0	15	19	19		19	
	Faulting 0.2 - 0.4		19	4	0	0		0	
	Faulting > 0.4		0	0	0	0		0	
	# of 0.1 mile segments		19	19	19	19		19	
Percent	**Faulting < 0.2**		**0.0%**	**78.9%**	**100.0%**	**100.0%**		**100.0%**	
	Faulting 0.2 - 0.4		**100.0%**	**21.1%**	**0.0%**	**0.0%**		**0.0%**	
	Faulting > 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**		**0.0%**	

	Total Faults	**1706**	Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	
	% Faults 0.0	**0.1%**	Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	
		Average	**0.176**	**0.092**	**0.065**	**0.015**	**2**	**0.015**	**1090.8%**
Counts	Faulting < 0.2		26	25	32	33		33	
	Faulting 0.2 - 0.4		5	7	1	0		0	
	Faulting > 0.4		2	1	0	0		0	
	# of 0.1 mile segments		33	33	33	33		33	
Percent	**Faulting < 0.2**		**78.8%**	**75.8%**	**97.0%**	**100.0%**		**100.0%**	
	Faulting 0.2 - 0.4		**15.2%**	**21.2%**	**3.0%**	**0.0%**		**0.0%**	
	Faulting > 0.4		**6.1%**	**3.0%**	**0.0%**	**0.0%**		**0.0%**	

The proper method to handle Patching, with respect to faults, should be addressed in the NPRM as well. Should a Patch at a joint be considered 3 straight line joints each with a respective set of faulting measures, or should only the original straight line joint be analyzed for faulting? This analysis is based only on the original straight line joint.

Analysis of Faulting Data on New Pavement

When we further analyze new pavements with minimum or no cracks, we find the following summary details in the table shown below. It appears that when we successfully force the faulting to only consider "manually identified joints with no minimum threshold", we get respectably valid results that every state could accept.

If we use any other method shown in the table below, it appears we are either not capturing all the straight line joints and are determine the faulting average with only the bad joints, or we are potentially processing numerous false positives, which essentially penalize the state by capturing duplicate Cracking Percent values or pavement roughness values (IRI) or both in the "0.1 inch" and "1 mm(0.04 inch)" post processed columns. It would be curious to investigate if the software algorithms have been evaluated for accuracy on brand new pavements as well.

Clearly for the proposed metrics, with respect to this new pavement data analysis, any method used other than "manually identified joints with no minimum threshold" results in very contentious data for new pavements that would be very difficult for State DOTs to accept.

Another interesting statistic is that using field construction techniques, that impose IRI mandates and restrictions, don't appear to result in a significant number of faults with "0.0 inch" values on new pavements, as identified in the column "# of Joints with No faulting." In fact, the data indicates that the number of "0.0 inch" faults on new pavements is "statistically irrelevant." It appears that IRI may not be able to index certain aspects of faulting, because faults are too 'localized' (sudden and short duration); however, a certain curiosity its tweaked in trying to understand the nature of pavements with lots of faults, and very few other visible defects, that also have correspondingly high IRI values.

What really turns up the heat against the proposed faulting metrics is clearly identified when we compare the "1 mm(0.04 inch)" threshold data against the "manually identified joints with no minimum threshold". The number of 0.1 mile segments that result in Fair or Poor measures on new pavements, using the "1 mm(0.04 inch)" threshold post processed data, finds that 40% of the 25 segments, 80% of 15 segments, 80% of 20 segments, 64% of 200 segments, and 54.8% of 62 segments are in Fair or Poor condition. Based on the proposed metrics, this would be considered a complete failure in construction technique and is completely unacceptable.

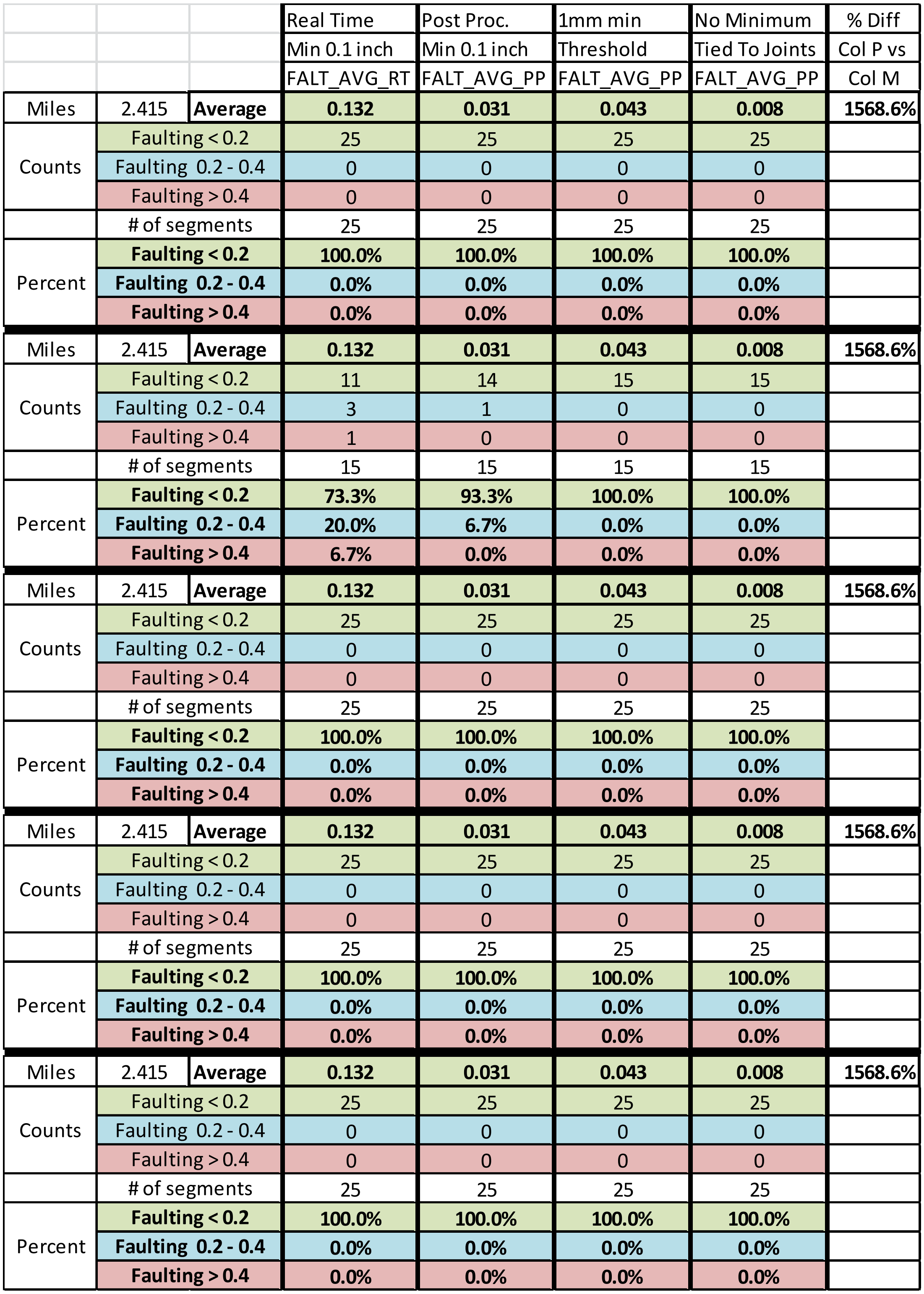
We clearly see that the faulting metrics are either not reasonable and need to be revised upward, or that every joint must be included in the faulting average calculation as shown in "manually identified joints with no minimum threshold" column to more closely capture valid real world conditions. This would also prevent the continued use of real time data by some states. This also identifies that setting the minimum data capture threshold does not necessarily always correlate with the faulting metric and they appear to be somewhat different things.

		Real Time	Post Proc.	1mm min	No Minimum	# of Joints	New Average	% Diff
		Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	With No	With 0 faults	Col G vs
		FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Faulting	FALT_AVG_PP	Col D
2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**0**	**0.008**	**1568.6%**
Faulting < 0.05		1	19	15	25		25	
Faulting 0.05 - 0.15		17	5	10	0		0	
Faulting > 0.15		7	1	0	0		0	
# of segments		25	25	25	25		25	
Faulting < 0.05		4.0%	76.0%	60.0%	100.0%		100.0%	
Faulting 0.05 - 0.15		68.0%	20.0%	40.0%	0.0%		0.0%	
Faulting > 0.15		28.0%	4.0%	0.0%	0.0%		0.0%	
1.546	**Average**	**0.149**	**0.050**	**0.073**	**0.009**	**2**	**0.009**	**1557.7%**
Faulting < 0.05		3	10	3	15		15	
Faulting 0.05 - 0.15		5	3	11	0		0	
Faulting > 0.15		7	2	1	0		0	
# of segments		15	15	15	15		15	
Faulting < 0.05		20.0%	66.7%	20.0%	100.0%		100.0%	
Faulting 0.05 - 0.15		33.3%	20.0%	73.3%	0.0%		0.0%	
Faulting > 0.15		46.7%	13.3%	6.7%	0.0%		0.0%	
1.952	**Average**	**0.170**	**0.091**	**0.065**	**0.027**	**30**	**0.026**	**527.8%**
Faulting < 0.05		1	9	4	19		19	
Faulting 0.05 - 0.15		7	5	16	1		1	
Faulting > 0.15		12	6	0	0		0	
# of segments		20	20	20	20		20	
Faulting < 0.05		5.0%	45.0%	20.0%	95.0%		95.0%	
Faulting 0.05 - 0.15		35.0%	25.0%	80.0%	5.0%		5.0%	
Faulting > 0.15		60.0%	30.0%	0.0%	0.0%		0.0%	
22.200	**Average**	**0.140**	**0.048**	**0.058**	**0.013**	**173**	**0.012**	**1020.2%**
Faulting < 0.05		37	139	72	200		200	
Faulting 0.05 - 0.15		84	33	124	0		0	
Faulting > 0.15		79	28	4	0		0	
# of segments		200	200	200	200		200	
Faulting < 0.05		18.5%	69.5%	36.0%	100.0%		100.0%	
Faulting 0.05 - 0.15		42.0%	16.5%	62.0%	0.0%		0.0%	
Faulting > 0.15		39.5%	14.0%	2.0%	0.0%		0.0%	
6.057	**Average**	**0.105**	**0.028**	**0.048**	**0.011**	**58**	**0.011**	**833.7%**
Faulting < 0.05		24	52	28	62		62	
Faulting 0.05 - 0.15		22	7	32	0		0	
Faulting > 0.15		16	3	2	0		0	
# of segments		62	62	62	62		62	
Faulting < 0.05		38.7%	83.9%	45.2%	100.0%		100.0%	
Faulting 0.05 - 0.15		35.5%	11.3%	51.6%	0.0%		0.0%	
Faulting > 0.15		25.8%	4.8%	3.2%	0.0%		0.0%	

With respect to real time data, if we modify the evaluation for the new pavements identified in the table above, we find in the table below that if we use the proposed rutting metric values for faulting, (Good <0.2 inches, Fair 0.2 to 0.4 inches, and Poor >0.4 inches) the analysis provides a more reasonable result for the real time data capture that many states are using.

With respect to new pavements, while this might not be the ideal situation, as the real time data cannot filter anything out, it does seem to provide a somewhat reasonable measure that DOTs could live with until they could update or implement data collection contracts to include straight line joint identification and fault categorization.

However, using this approach and setting the minimum threshold to 0.1 inches appears to interfere with the analysis efforts of mechanistic-empirical pavement design and that would need to be considered as well.



			Real Time	Post Proc.	1mm min	No Minimum	% Diff
			Min 0.1 inch	Min 0.1 inch	Threshold	Tied To Joints	Col P vs
			FALT_AVG_RT	FALT_AVG_PP	FALT_AVG_PP	FALT_AVG_PP	Col M
Miles	2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**1568.6%**
Counts	Faulting < 0.2		25	25	25	25	
	Faulting 0.2 - 0.4		0	0	0	0	
	Faulting > 0.4		0	0	0	0	
	# of segments		25	25	25	25	
Percent	**Faulting < 0.2**		**100.0%**	**100.0%**	**100.0%**	**100.0%**	
	Faulting 0.2 - 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
	Faulting > 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
Miles	2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**1568.6%**
Counts	Faulting < 0.2		11	14	15	15	
	Faulting 0.2 - 0.4		3	1	0	0	
	Faulting > 0.4		1	0	0	0	
	# of segments		15	15	15	15	
Percent	**Faulting < 0.2**		**73.3%**	**93.3%**	**100.0%**	**100.0%**	
	Faulting 0.2 - 0.4		**20.0%**	**6.7%**	**0.0%**	**0.0%**	
	Faulting > 0.4		**6.7%**	**0.0%**	**0.0%**	**0.0%**	
Miles	2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**1568.6%**
Counts	Faulting < 0.2		25	25	25	25	
	Faulting 0.2 - 0.4		0	0	0	0	
	Faulting > 0.4		0	0	0	0	
	# of segments		25	25	25	25	
Percent	**Faulting < 0.2**		**100.0%**	**100.0%**	**100.0%**	**100.0%**	
	Faulting 0.2 - 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
	Faulting > 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
Miles	2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**1568.6%**
Counts	Faulting < 0.2		25	25	25	25	
	Faulting 0.2 - 0.4		0	0	0	0	
	Faulting > 0.4		0	0	0	0	
	# of segments		25	25	25	25	
Percent	**Faulting < 0.2**		**100.0%**	**100.0%**	**100.0%**	**100.0%**	
	Faulting 0.2 - 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
	Faulting > 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
Miles	2.415	**Average**	**0.132**	**0.031**	**0.043**	**0.008**	**1568.6%**
Counts	Faulting < 0.2		25	25	25	25	
	Faulting 0.2 - 0.4		0	0	0	0	
	Faulting > 0.4		0	0	0	0	
	# of segments		25	25	25	25	
Percent	**Faulting < 0.2**		**100.0%**	**100.0%**	**100.0%**	**100.0%**	
	Faulting 0.2 - 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	
	Faulting > 0.4		**0.0%**	**0.0%**	**0.0%**	**0.0%**	

Network verses Project Level Analysis

So once again we ask the question, does this lowering or elimination of the minimum data capture threshold provide any real value?

While lowering the proposed metrics would intuitively seem to provide a numerically better approach, and result in superior data, the proposed metrics are also strongly focused on Network Level Analysis and don't favor the Project Level Analysis needed to support preservation and maintenance decisions.

Louisiana DOTD and other states have historically set the minimum data capture threshold at 0.2 inches for faulting and we use the values (Good <0.2 inches, Fair 0.2 to 0.4 inches, and Poor >0.4 inches) for the performance metric. At this higher threshold, ignoring all faulting between +0.2 and -0.2, the faulting average values are significantly higher, as would be expected. Please understand, our goal of measuring faulting is not to just to define network pavement condition, it is to identify where realistic project level field treatments can be implemented to improve the condition of the pavement.

In this case, for the older industrial corridor documented above, the overall faulting average for the "post processed 0.2 inch" threshold is actually 48.6% higher (0.376 inches verses 0.253 inches) than the "real time 0.1 inch" threshold and 149.0% higher (0.376 inches verses 0.151 inches) that the "post processed 0.1 inch" threshold.

The most important thing to note here is that the faulting average alone is not enough information to decide on a project level treatment. We must also know the number of faults above this threshold or we must have a count of the faults within different ranges. If a significant number of faults above the threshold are found, or within different ranges, preservation treatments can be triggered for joint repair. For those segments with a limited number of faults, in-house maintenance staff would need to address the larger faults on segments that don't rise to the preservation project level due to a limited number of faults, or multiple pavement segments within a jurisdiction would have to be combined to generate a project that would be feasible for contractors to bid on.

The real point of this discussion is that when we lower the data capture threshold, without defining the actual number of straight line joints, we will get a more representative view of the likely faulting average, but it will provide no real value with respect to actual pavement management efforts. Also it appears from our limited data analysis, with respect to real world construction techniques and real world maintenance repairs, that the NPRM proposed metrics can't be achieved at this time.

If we can define the actual straight line joints, and capture the actual fault values at the straight line joints, then we can capture real repeatable average faulting, but this apparently might not be possible at the proposed metric values due to the variability in wheel path and temperature issues defined in the calibration section.

So when we get to the point where we can define the actual joints, and capture all the fault values at each joint, then we must also require the vendor to provide the count of faults in various ranges for a 0.1 mile segment, (i.e. 2 @ <0.2 inch, 85 @ >0.2<0.4, 35 @ >0.4) to provide both Network Level and Project Level value in this data.

Any proposed metrics also should also determine if the vendors can actually calibrate their data collection vehicles on various pavements with different levels of distress using the proposed metrics. Data evaluation should determine it construction, preservation and maintenance techniques can actually support them.

"Relative Coin Reference" for Louisiana DOTD's Proposed Faulting Metrics

The following table identifies these proposed faulting metrics, (Good <0.2 inches, Fair 0.2 to 0.4 inches, and Poor >0.4 inches) with respect to our earlier "relative coin reference". In this proposal, a straight line joint fault would fall out of the "Good" range at 4 dimes thick and fall out of the "Fair" range at 8 dimes thick.

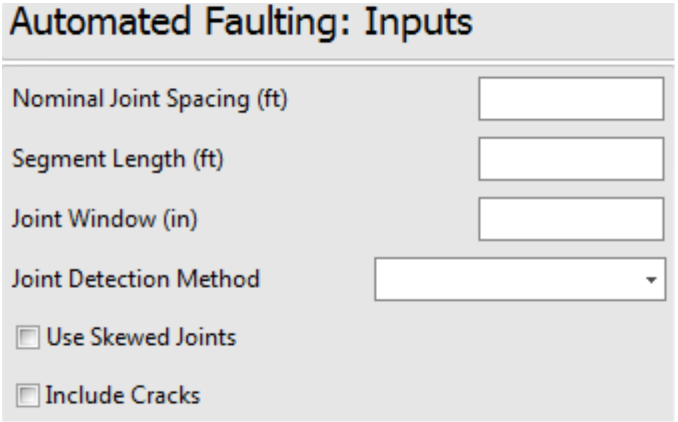
	LADOTD Proposes	fraction inch		decimal inch	US money designation	US money thickness
Good	0	1/64	=	0.0156		
		1/32	=	0.0313		
		3/64	=	0.0469	Dime	0.0531
		1/16	=	0.0625	Penny	0.0598
		5/64	=	0.0781	Quarter	0.0689
		3/32	=	0.0938	Nickel	0.0768
		7/64	=	0.1094		
		1/8	=	0.1250		
		9/64	=	0.1406		
		5/32	=	0.1563		
		11/64	=	0.1719		
	0.2	3/16	=	0.1875		
Fair	> 0.2	13/64	=	0.2031	3.8 Dimes	0.2018
		7/32	=	0.2188	3.3 Pennies	0.1973
		15/64	=	0.2344	2.9 Quarters	0.1998
		1/4	=	0.2500	2.6 Nickels	0.1996
		17/64	=	0.2656		
		9/32	=	0.2813		
		19/64	=	0.2969		
		5/16	=	0.3125		
		21/64	=	0.3281		
		11/32	=	0.3438		
		23/64	=	0.3594		
		3/8	=	0.3750		
	0.4	25/64	=	0.3906		
Poor	> 0.4	13/32	=	0.4063	7.5 Dimes	0.3983
		27/64	=	0.4219	6.7 Pennies	0.4007
		7/16	=	0.4375	5.8 Quarters	0.3996
		29/64	=	0.4531	5.2 Nickels	0.3992

Analysis of ProVAL

For an older segment of jointed concrete pavement, we used ProVal to analyze a 144 foot section of pavement with 18 straight line joints (spaced about 20 feet apart), no skewed joints and 1 crack and minimal truck traffic.

In the 1st data run, we used only the ProVal joint metrics, and do not check the “include skewed joints” or “include cracks”. The output captured 4 faults at an average spacing of 36.1 feet with an average faulting value of 0.092 inches. While the average fault spacing is nearly a meaningless measure, since we know the joint spacing to be approximately 20 feet, the faulting average seems to be reasonable since the pavement remains in good condition.

When we turned on the “Include Cracks” function, we captured 17 faults with an average fault spacing of 8.02 feet with an average fault value of 0.058 inches. The number of faults and the average fault value would lead you to believe these are valid numbers; however, the fault spacing raises a serious question with the results. The joint spacing is never less than 18 feet in that pavement, there is only 1 crack in the segment and the joint only run only found 4 faults. This raises concerns with respect to false positives for faulting in ProVAL.



Automated Faulting: Inputs

Nominal Joint Spacing (ft)

Segment Length (ft)

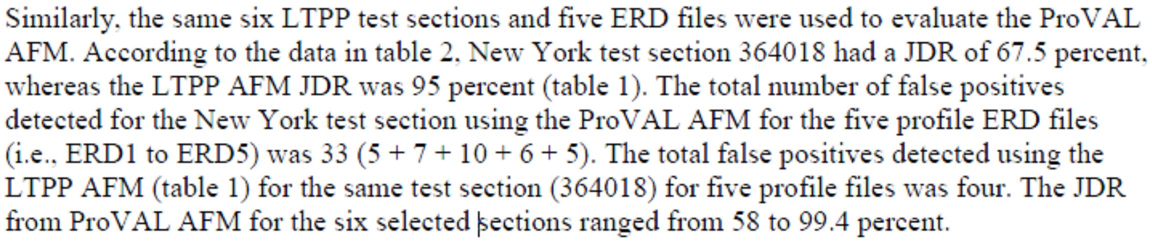
Joint Window (in)

Joint Detection Method

☐ Use Skewed Joints

☐ Include Cracks

On March 31, 2015, we obtained a copy of **FHWA-HRT-14-092, “Long Term Pavement Performance Automated Faulting Measurement”**. On page 21 of this document we find issues with joint detection rates and false positives in the analysis of ProVAL. Clearly a joint detection rate that could be as low as 58% might be a concern.



> Similarly, the same six LTPP test sections and five ERD files were used to evaluate the ProVAL AFM. According to the data in table 2, New York test section 364018 had a JDR of 67.5 percent, whereas the LTPP AFM JDR was 95 percent (table 1). The total number of false positives detected for the New York test section using the ProVAL AFM for the five profile ERD files (i.e., ERD1 to ERD5) was 33 (5 + 7 + 10 + 6 + 5). The total false positives detected using the LTPP AFM (table 1) for the same test section (364018) for five profile files was four. The JDR from ProVAL AFM for the six selected sections ranged from 58 to 99.4 percent.

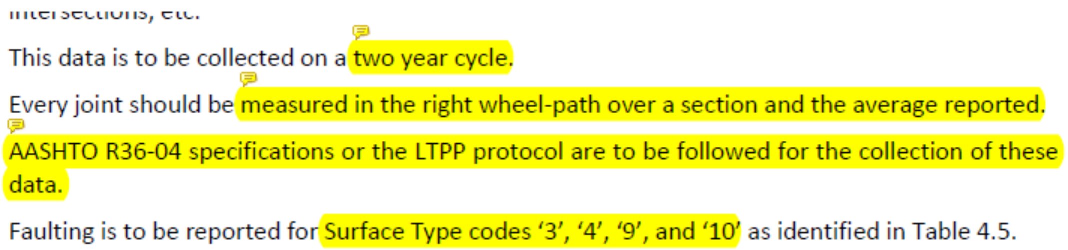
We are not sure if ProVAL will allow post processing with pre-defined straight line joints at this time.

Issues with AASHTO R36-13

Wheel Path Definition Consistency

R 36-13 has a definition for “outside wheel path” but not for “inside wheel path”. On page R36-3 in “4.4” it identifies the manual method to use “outside wheel path” but on page R 36-4 in “5.2.6” it identifies that “Profile data should be collected for both left and right wheel paths.”

By the way, HPMS requires faulting to be reported only for the right wheel path.



intersections, etc.

This data is to be collected on a two year cycle.

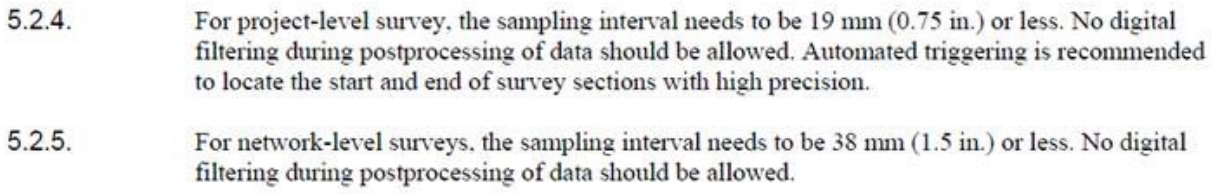
Every joint should be measured in the right wheel-path over a section and the average reported.

AASHTO R36-04 specifications or the LTPP protocol are to be followed for the collection of these data.

Faulting is to be reported for Surface Type codes ‘3’, ‘4’, ‘9’, and ‘10’ as identified in Table 4.5.

Digital Filtering Question

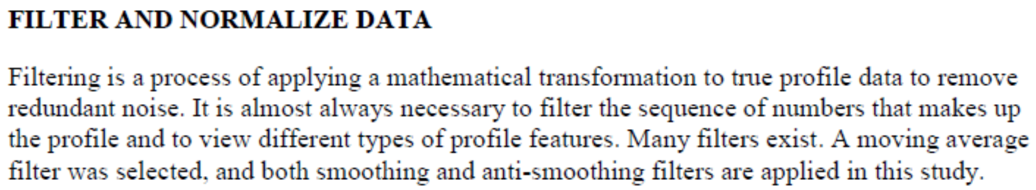
When we further investigate R36-13, we find the following snippets need further explanation. The concept of “no digital filtering during post processing” identified below in “5.2.4” and “5.2.5”.



5.2.4. For project-level survey, the sampling interval needs to be 19 mm (0.75 in.) or less. No digital filtering during postprocessing of data should be allowed. Automated triggering is recommended to locate the start and end of survey sections with high precision.

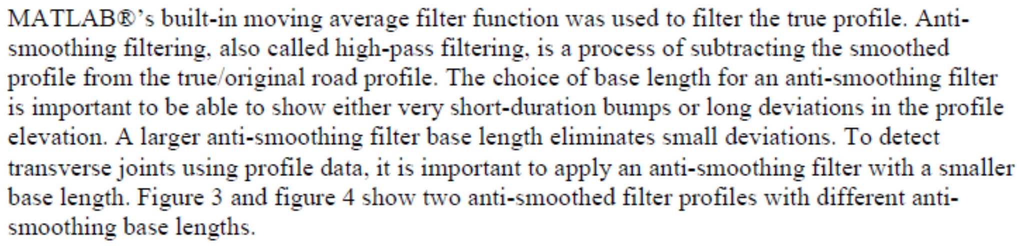
5.2.5. For network-level surveys, the sampling interval needs to be 38 mm (1.5 in.) or less. No digital filtering during postprocessing of data should be allowed.

In FHWA-HRT-14-092, Long Term Pavement Performance Automated Faulting Measurement”, from pages 9 and 10, we find the excerpts below outlining the advanced amount of filtering required to create a profile. One would have to interpret this “no digital filtering during post processing” to mean there is no additional smoothing of the longitudinal profile prior to applying the AASHTO process for identifying joints/faults. This could be more definitively stated.



FILTER AND NORMALIZE DATA

Filtering is a process of applying a mathematical transformation to true profile data to remove redundant noise. It is almost always necessary to filter the sequence of numbers that makes up the profile and to view different types of profile features. Many filters exist. A moving average filter was selected, and both smoothing and anti-smoothing filters are applied in this study.



MATLAB®'s built-in moving average filter function was used to filter the true profile. Anti-smoothing filtering, also called high-pass filtering, is a process of subtracting the smoothed profile from the true/original road profile. The choice of base length for an anti-smoothing filter is important to be able to show either very short-duration bumps or long deviations in the profile elevation. A larger anti-smoothing filter base length eliminates small deviations. To detect transverse joints using profile data, it is important to apply an anti-smoothing filter with a smaller base length. Figure 3 and figure 4 show two anti-smoothed filter profiles with different anti-smoothing base lengths.

Sampling Interval Proposal

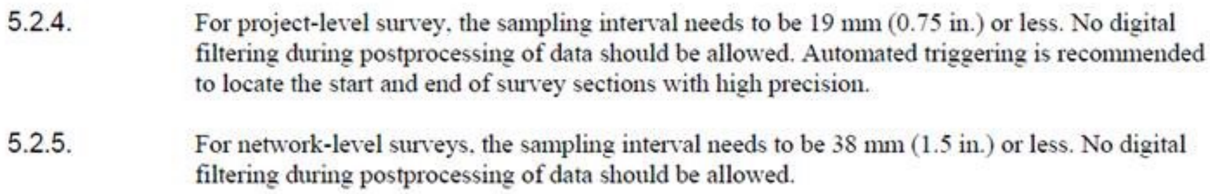
Louisiana DOTD Proposes that a 1 inch sampling interval be used to determine the faulting measure at a straight line joint.

Analysis of Sampling Interval

For "Automated Fault Measurement" in R36-13, the sampling interval "5.2.4 and 5.2.5" is again shown below and are set to 0.75 inches and 1.5 inches.

We need to note that a 1 inch sampling interval provides 36 points with which to determine the fault location at a straight line joint while the 0.75 inch sampling give you 45 points. Using 45 points doesn't currently appear to provide an improvement in fault validity and appear to be data capture overkill. It should be noted that some high speed laser profilers cant' report samples at rates greater than 1.0 inch, so at this time 0.75 inch sampling might be a technical stretch.

Perhaps once again we are just running into a metric to English conversion situation, 19 mm = (0.75 in), that could go away with the English unit being the primary measure and the conversion being provided towards metric measures.



5.2.4. For project-level survey, the sampling interval needs to be 19 mm (0.75 in.) or less. No digital filtering during postprocessing of data should be allowed. Automated triggering is recommended to locate the start and end of survey sections with high precision.

5.2.5. For network-level surveys, the sampling interval needs to be 38 mm (1.5 in.) or less. No digital filtering during postprocessing of data should be allowed.

Other Questions

In R 36-13 “6.2.1.1” shown below, the choice of wording, “anti-smoothing filtering”, seems to provide a conflict within the same sentence since a moving average filter definitely smooths a profile.

R 36-13 “6.2.1.3” begins the discussion of identifying joints and cracks. Avoidance of multiple hits within 0.5m or (1.64 ft) is reasonable, except it would seem important to identify which of the multiple hits should be identified as the false positive. Our data collection contractor typically removes the smaller measurement since the odds are the higher value is real, but it needs to be defined. We also use 6 feet as the measure for avoiding multiple hits as skewed joints will become an issue with the proposed 0.5 m (1.64 ft) and you won’t typically expect 2 faults within half a slab length. Again predefining straight line joints could alleviate this situation as a skewed straight line joint would be identified.

R 36-13 “6.2.1.4” and “6.2.3.4” appears to allow for identification of the difference between straight line joints and cracks; but, it requires a manual identification. Most states don’t currently pay for that extra manual identification from their data collection contractor, but the results are significantly different when faults are tied to joints as identified in the Louisiana DOTD data analysis provided in this document.

The R 36-13 “6.2.3.3” minimum faulting starting threshold of 3 mm (0.12 inches) (1/8 inch) is in direct conflict with the NPRM and again points out the issues with the metric to English conversion.

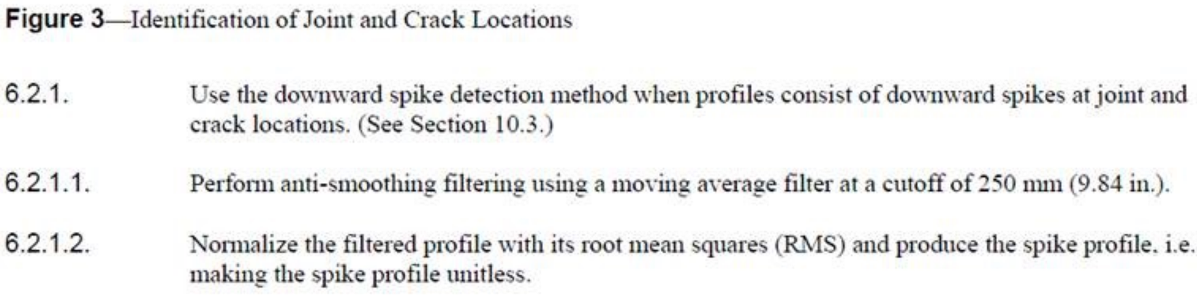
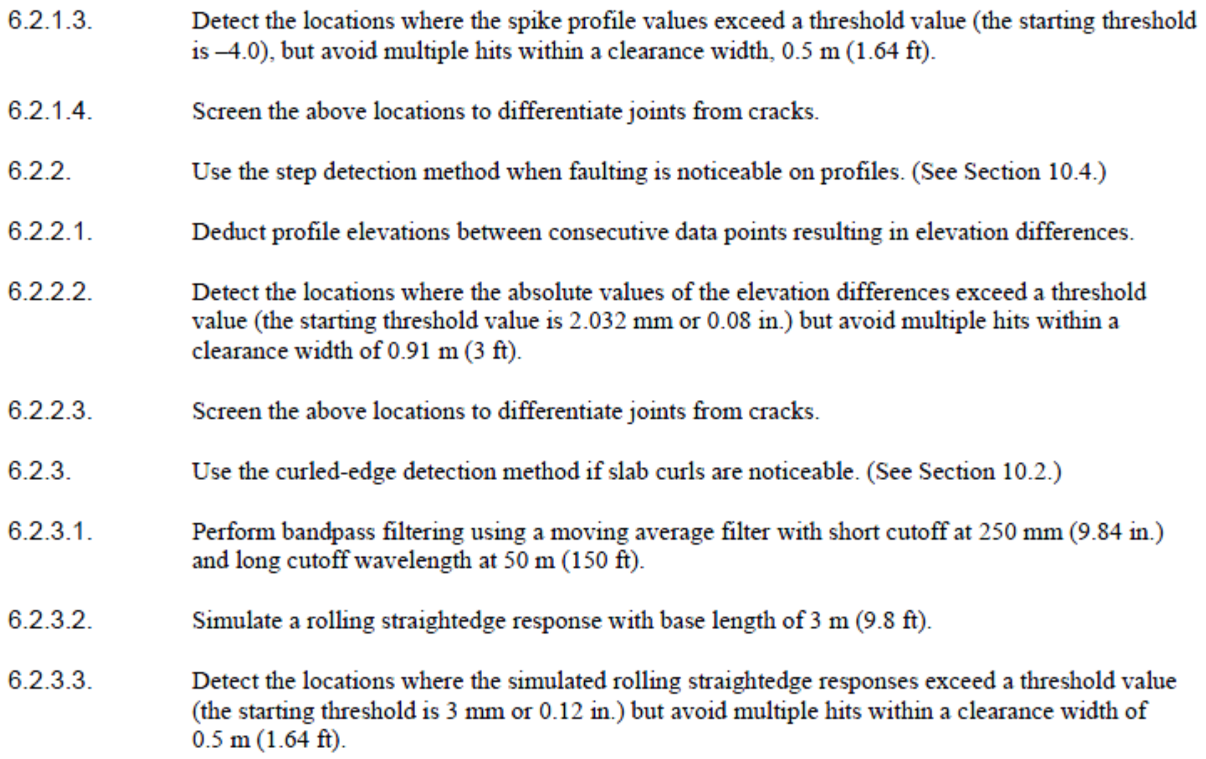


Figure 3—Identification of Joint and Crack Locations

6.2.1. Use the downward spike detection method when profiles consist of downward spikes at joint and crack locations. (See Section 10.3.)

6.2.1.1. Perform anti-smoothing filtering using a moving average filter at a cutoff of 250 mm (9.84 in.).

6.2.1.2. Normalize the filtered profile with its root mean squares (RMS) and produce the spike profile. i.e., making the spike profile unitless.



6.2.1.3. Detect the locations where the spike profile values exceed a threshold value (the starting threshold is –4.0), but avoid multiple hits within a clearance width, 0.5 m (1.64 ft).

6.2.1.4. Screen the above locations to differentiate joints from cracks.

6.2.2. Use the step detection method when faulting is noticeable on profiles. (See Section 10.4.)

6.2.2.1. Deduct profile elevations between consecutive data points resulting in elevation differences.

6.2.2.2. Detect the locations where the absolute values of the elevation differences exceed a threshold value (the starting threshold value is 2.032 mm or 0.08 in.) but avoid multiple hits within a clearance width of 0.91 m (3 ft).

6.2.2.3. Screen the above locations to differentiate joints from cracks.

6.2.3. Use the curled-edge detection method if slab curls are noticeable. (See Section 10.2.)

6.2.3.1. Perform bandpass filtering using a moving average filter with short cutoff at 250 mm (9.84 in.) and long cutoff wavelength at 50 m (150 ft).

6.2.3.2. Simulate a rolling straightedge response with base length of 3 m (9.8 ft).

6.2.3.3. Detect the locations where the simulated rolling straightedge responses exceed a threshold value (the starting threshold is 3 mm or 0.12 in.) but avoid multiple hits within a clearance width of 0.5 m (1.64 ft).

Other Broad Points to Consider

- There are new FMIS requirements that affect data submittal requirements to HPMS and HPMS may have to be updated to support those requirements.
- Per NPRM, Current Standard Practice for Evaluation Faulting of Concrete Pavements is AASHTO Designation: R36-13 as identified in document. The current HPMS guide contradicts the new proposed rules by referring to the AASHTO R36-04 specification.
- No definition is given for a transverse crack in R36-13, the HPMS guide or the Publication No. FHWA-RD-03-031 "Distress Identification Manual for the Long-Term Pavement Performance Program."
- The NPRM, the HPMS guide and R36-13 do not agree with respect to Transverse cracks. Transverse Cracks are reported in HPMS as Item 53, Cracking_Length which is the "Estimate of relative length in feet per mile (what about 0.1 mi) of transverse cracking for AC pavements and reflection transverse cracking for composite pavements where AC is the top surface layer. There is no mention of Transverse cracks in other measures for concrete pavement surfaces.

- The HPMS summary of Field Manual Edits, February 2015, eliminates Item 53, Cracking_Length from the "data items to be reported."

- R36-13 "… recommended that a precision for faulting be established such that it is calculated to the nearest 1 mm (0.04 in.)" or <= 5/128 inch. These automatically conflict because the NPRM proposed metric 1st measure since it matches the smallest unit of measure obtained, with the consequential effect of either having no fault or a measured fault in "Fair" condition.

- Faulting is not a "Safety" issue like "Rutting", but the proposed faulting metrics are much more stringent than rutting.

- Faulting is automatically double counted by IRI for measuring ride comfort.

- The current HPMS guide contradicts the new proposed rules by requiring this data to be collected on a 2 year cycle with no differentiation for Interstates and NHS sections.

- The current HPMS guide contradicts the new proposed rules by using only sample sections.

- The Summary of Field Manual Edits, February 2015, for the HPMS guide does not address any of the NPRM rules.

- When published, **NCHRP 01-57 [RFP] - Standard Definitions for Comparable Pavement Cracking Data**, may result in new recommendations for this measure.

- Louisiana DOTD Proposes that the 1st data collection cycle to be used in performance analysis, be pushed back to a later data submittal. The current proposal indicates data being submitted in June 2015 will be used for these NPRM metrics. The large number of conflicts between HPMS, the AASHTO specifications, the FMIS requirements for HPMS and the proposed rules will not allow an "apples to apples" data comparison or analysis between the current year and future years, nor between states.

- Louisiana DOTD Proposes that the NPRM rules, the appropriate AASHTO Standards, the HPMS guide, etc. be revised to all English units of measure to be consistent and to eliminate the numerous Metric to English conversion rounding issues. The English units should be the primary units with the metric equivalent listed as well.

- Note that the HPMS guide states in Appendix F that the data must be submitted in English units.

Appendix F. Metric-to-English Soft Conversion Procedures

The HPMS software requires the States' data to be submitted in English units. States that maintain their data in metric units are required to apply a soft conversion factor to their data for HPMS submittal purposes. A soft conversion is a computation which involves the application of a conversion factor to an initial value for the purpose of producing a converted value. The converted value must then be rounded in accordance with the requirements for the specific data field or data item, as applicable.

Table F-1 provides a list of factors to be used when performing a Metric-to-English soft conversion:

Table F.1 Metric-to-English Conversion Factors

Conversion Type	Conversion Factor
Kilometers to Miles	1 / 1.609344
Meters to Feet	1 / 0.3048
Meters per Kilometer to Inches per Mile	63.36
Millimeters to Inches	1 / 25.4
km/h to MPH	1 / 1.609344

The following shows an example of how this procedure would be applied for the purpose of converting units of meters to feet:

3.9624 meters * (1 feet / 0.3048 meters) = 13 feet