Research Record

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How Rough is Too Rough?

MSU and MDOT Create a New Index to Better Plan Pavement Preventive Maintenance

As every driver knows, when pavement deteriorates, it becomes rougher. What drivers may not realize is that the roughness they feel in the seat of their vehicles not only makes the drive less comfortable, but it also leads to a cycle of increasing deterioration rates with increasing roughness severity. To prevent this cycle of ever-increasing roughness and deterioration, engineers try to perform preventive maintenance before the pavement becomes too rough.

To help engineers determine when pavement becomes too rough, the Michigan Department of Transportation (MDOT) and Michigan State University (MSU) researchers sought to find a "hot spot" of roughness that marks the threshold where deterioration rates sharply accelerate. Once the roughness threshold is known, engineers can determine when to perform appropriate preventive maintenance to extend pavement life and keep a smoother ride.

The Michigan Department of Transportation (MDOT) regularly measures roughness and deterioration on all state trunklines in Michigan. From this data, MDOT assigns a roughness value called the Ride Quality Index (RQI) and a deterioration value called the Distress Index (DI) to 0.1 mile pavement sections. RQI indicates relative pavement roughness as felt in a passenger vehicle, and DI indicates the relative severity of pavement distress (e.g. cracks).

Pavement roughness leads to higher dynamic loads on localized pavement sections (Figure 1), which increases pavement deterioration at those locations. When pavement maintains a certain level of roughness and distress, engineers can calculate the pavement's remaining service life (RSL), which helps plan appropriate maintenance or reconstruction activities. The existing RQI and DI indexes are incorporated into pavement management systems (PMS) to determine RSL and guide maintenance or reconstruction planning.

The existing roughness index RQI (a Michigan index) measures roughness felt by passengers in cars. The International Roughness Index (IRI) focuses on how roughness affects passenger vehicles. However, engineers know that trucks accelerate pavement damage, so MSU and MDOT researchers tested the hypothesis that specific roughness profiles increase dynamic loading by trucks. Finding the roughness threshold that sharply increases dynamic truck loading would help identify when and where pavement deterioration would sharply accelerate.

To find the roughness threshold beyond which pavement deterioration sharply accelerates, researchers looked at the interaction between surface roughness, dynamic truck loading, and pavement damage. This research led to a new index, Dynamic Load Index (DLI), which measures the specific roughness profiles that excite truck suspensions and increase dynamic loading.

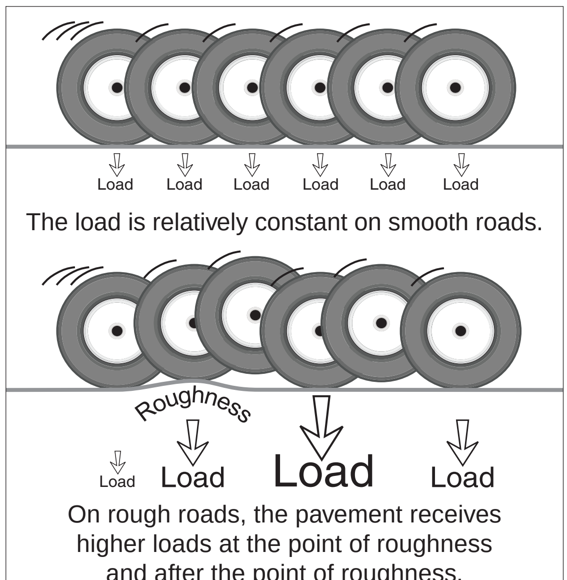

Figure 1. How pavement roughness generates dynamic load

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Correlating Surface Roughness, Dynamic Loading, and Pavement Distress

To show how distress and roughness data could help discern cases of load-related distress from other distress, researchers analyzed RQI and DI data from the existing MDOT database. While good statistical correlation between roughness and dynamic load-related distress accumulation existed, distress also existed in areas without significant dynamic loading. Therefore, researchers sought other relationships between roughness and distress.

Development of Network-level RQI-DI Relationships

To test the hypothesis that dynamic loading and subsequent pavement deterioration sharply accelerates at a critical roughness level, researchers looked for a relationship between RQI and DI. Investigators reviewed data from the MDOT pavement management system (PMS) database for all pavement types and selected three independent data sets of 97 projects (1,437 half-mile sections) with different ages, distress indexes, and roughness indexes (RQI).

Analysis results from the first data set showed transverse cracking with associated distress were prevalent in relatively rough pavement of all types. In relatively rough, rigid pavements, investigators most frequently found transverse joint deterioration, delamination, and patch deterioration. However, results from the second and third data sets did not correspond with the results from the first data set and dynamic load-related distress types could not be isolated.

The correlation between distress index (DI) and roughness (RQI) for rigid pavements had the highest accuracy, followed by composite and then flexible pavements (Figure 2). However, for flexible pavements, the RQI-DI relationship is not predictable because of the high scatter (variation) in the data.

To find critical roughness values, researchers conducted probability analysis on DI-RQI curves to look for the likelihood of a certain roughness with a corresponding distress index. Critical roughness values varied greatly, which is likely due to the varied failure factors which exist in pavement besides axle load. In addition to poor DI-RQI correlations for some pavement types, these critical values also only represent the overall behavior of pavements at the network level, and may not be applicable for a particular pavement project.

Development of Relationships between RQI and Dynamic Load

In order to isolate a critical roughness value at which pavement deterioration sharply increases, researchers looked for relationships between dynamic load and RQI. If a critical roughness level increased dynamic load sharply, researchers expected to find corresponding sharp increases in pavement deterioration rates.

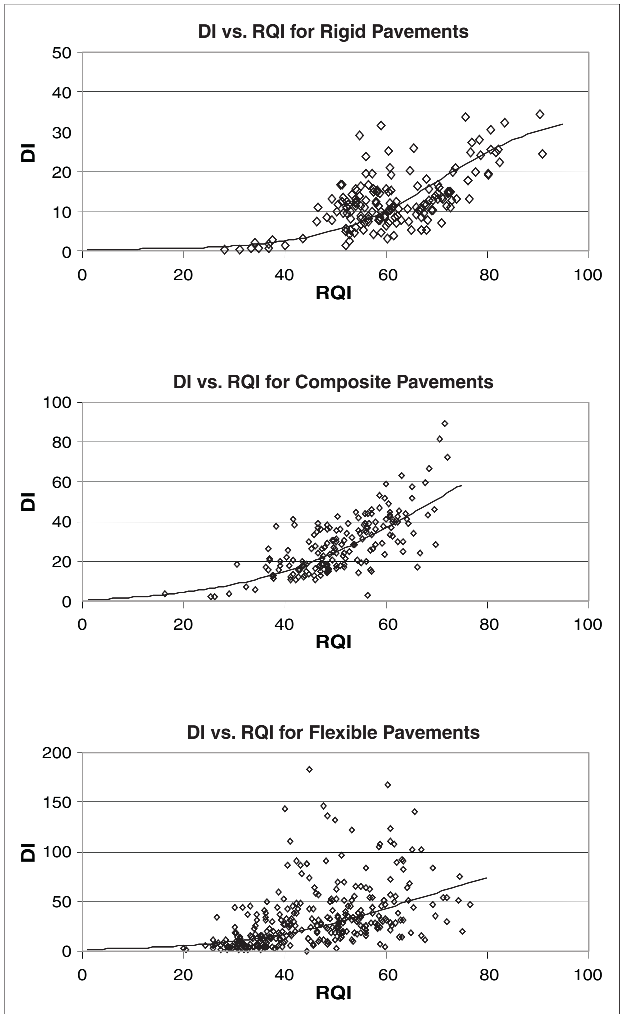

Figure 2. Distress Index (DI) vs. Ride Quality Index (RQI)

For this analysis, researchers simulated dynamic truck loading by inputting actual surface profiles of 333 in-service pavement sections (0.l-mile long) from thirty-seven projects in Michigan into the TruckSim truck simulation program. The software simulated two, three, and five axle trucks, which represents 85% of the truck traffic on the tested road segments.

Using the simulation software, researchers found very good correlations between RQI and dynamic loading (Dynamic Load Coefficient, DLC, and 95th percentile dynamic load) and between RQI and pavement damage (Figure 3). The relative damage from the 95th percentile dynamic load and the corresponding reduction in pavement life at different RQI levels were calculated. Based on these relationships, the critical RQI-values where the reduction in RSL sharply accelerates were determined for rigid, flexible, and

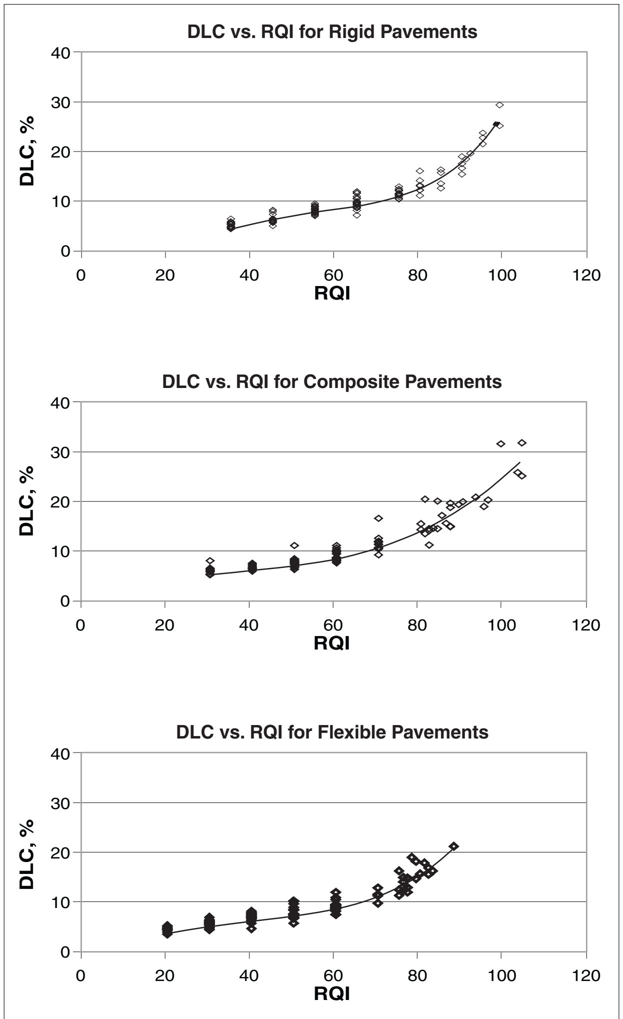

Figure 3. Dynamic Load Coefficient (DLC) vs. Ride Quality Index (RQI)

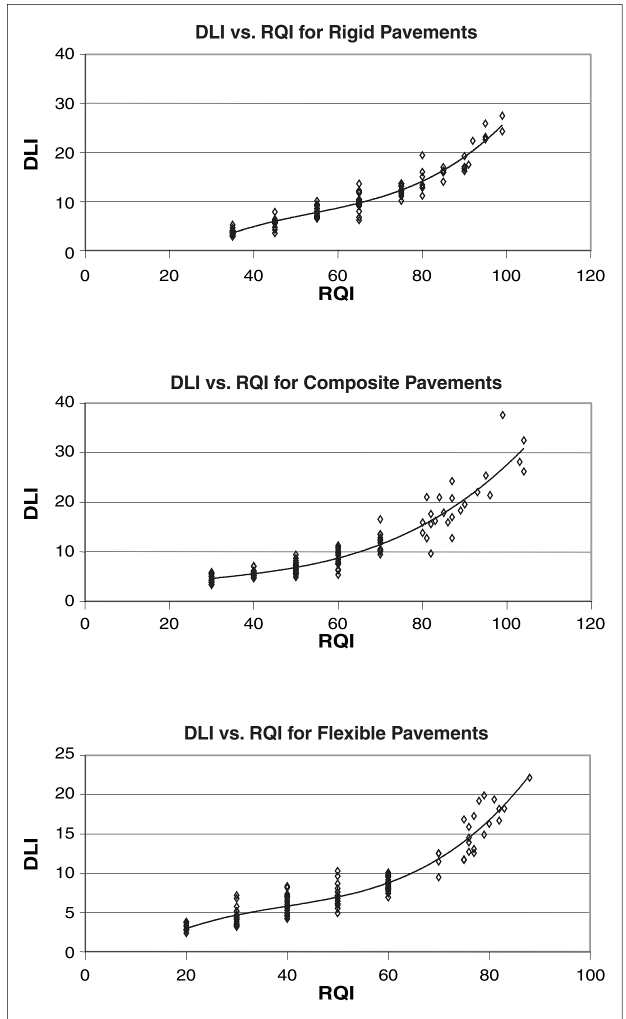

Figure 4. Dynamic Load Index (DLI) vs. Ride Quality Index (RQI)

composite pavements. Pavement damage began near RQI levels of 61, 50 and 47 for rigid, composite and flexible pavements, respectively. Pavement damage accumulated at the highest rate near RQI levels of 77, 70 and 66 for rigid, composite, and flexible pavements, respectively. The lower values agree better with the field-derived, DI-based values, as can be expected since distress accumulation should start some time after increased loading.

Development of a New Roughness Index for Predicting Dynamic Loads

Having found a good correlation between load and roughness, the researchers sought to narrow their analysis to find out how dynamic truck loading affects pavement life. The result of this narrower focus is a new index, called Dynamic Load Index (DLI). The new index is a better indicator of dynamic axle loading than the existing roughness indices RQI and IRI (International Roughness Index). RQI and IRI show roughness in a broad frequency range and is intended to represent the roughness that the driver of a passenger vehicle feels. DLI is intended to measure roughness in a narrower frequency range, specifically that range which increases dynamic truck loading. DLI is calculated as a weighted index of pavement profile elevation changes in the frequency ranges 1.5-4 Hz and 8-15 Hz. The first frequency range corresponds to truck body bounce, while the second frequency range corresponds to axle bounce.

Analysis showed a very good correlation between DLI and dynamic load and can be used in lieu of a truck simulation program (Figure 4). More importantly, the new index can also differentiate between profiles that generate high dynamic loads and those having the same RQI but generating low dynamic loads. The DLI value allows engineers to better gauge whether a particular pavement with a given surface profile needs smoothing to reduce pavement deterioration rates.

Project-level Roughness Thresholds for Predicting Increased Dynamic Loads

Having created a relationship between DLI and pavement deterioration rates, researchers focused on the application of DLI for preventive maintenance planning. To do this, relationships between DLI and predicted pavement deterioration levels were developed using a mechanistic approach. Researchers then generated tables for determining what extensions of pavement Remaining Service Life (RSL) would be possible at a given DLI value (Figure 5). The tables would make simple reference tools for regional personnel to help them decide when to perform preventive smoothing maintenance.

DLI	Remaining Service Life (years)														
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
5.0	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8
6.0	0.7	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2.0	2.1	2.2	2.3	2.4
7.0	0.9	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.5	2.7	2.8	**3.0**
8.0	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	2.6	2.8	2.9	**3.1**	**3.3**	**3.5**
9.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5	2.7	2.9	**3.1**	**3.3**	**3.5**	**3.7**	**3.9**
10.0	1.3	1.5	1.7	2.0	2.2	2.4	2.6	2.8	**3.0**	**3.3**	**3.5**	**3.7**	**3.9**	**4.1**	**4.3**
11.0	1.4	1.7	1.9	2.1	2.4	2.6	2.9	**3.1**	**3.3**	**3.6**	**3.8**	**4.0**	**4.3**	**4.5**	**4.8**
12.0	1.6	1.8	2.1	2.3	2.6	2.8	**3.1**	**3.4**	**3.6**	**3.9**	**4.1**	**4.4**	**4.7**	**4.9**	**5.2**
13.0	1.7	2.0	2.2	2.5	2.8	**3.1**	**3.4**	**3.6**	**3.9**	**4.2**	**4.5**	**4.8**	**5.0**	**5.3**	**5.6**
14.0	1.8	2.1	2.4	2.7	**3.0**	**3.3**	**3.6**	**3.9**	**4.2**	**4.5**	**4.8**	**5.1**	**5.4**	**5.7**	**6.0**
15.0	1.9	2.3	2.6	2.9	**3.2**	**3.6**	**3.9**	**4.2**	**4.5**	**4.8**	**5.2**	**5.5**	**5.8**	**6.1**	**6.5**
16.0	2.1	2.4	2.8	**3.1**	**3.5**	**3.8**	**4.1**	**4.5**	**4.8**	**5.2**	**5.5**	**5.9**	**6.2**	**6.6**	**6.9**
17.0	2.2	2.6	2.9	**3.3**	**3.7**	**4.0**	**4.4**	**4.8**	**5.1**	**5.5**	**5.9**	**6.2**	**6.6**	**7.0**	**7.4**
18.0	2.3	2.7	**3.1**	**3.5**	**3.9**	**4.3**	**4.7**	**5.1**	**5.5**	**5.9**	**6.2**	**6.6**	**7.0**	**7.4**	**7.8**
19.0	2.5	2.9	**3.3**	**3.7**	**4.1**	**4.5**	**5.0**	**5.4**	**5.8**	**6.2**	**6.6**	**7.0**	**7.4**	**7.8**	**8.3**
20.0	2.6	**3.0**	**3.5**	**3.9**	**4.4**	**4.8**	**5.2**	**5.7**	**6.1**	**6.5**	**7.0**	**7.4**	**7.8**	**8.3**	**8.7**

Figure 5. Sample table of life extension for various RSL and DLI levels

To create the tables, RSL-values were calculated for 0.5-mile sections using actual distress index growth over time from the first data set. The results showed that for rigid pavements, 17% of sections with DLI between 7 and 11, and 51% of sections with DLI between 11 and 15 would have life extensions of more than three years. For composite pavements, none of the sections would have life extensions of 3 years or more. For flexible pavements, 9% of sections with DLI between 7 and 11, and 34% of sections with DLI between 11 and 15 would have life extensions of more than 3 years. These results indicate that preventive maintenance smoothing action is best suited for rigid pavements.

Determining Optimal Timing for Smoothing Preventive Maintenance Action

To find the most appropriate time frame for applying preventive maintenance, investigators developed a reliability-based model that predicts roughness growth over time. The model uses DLI-growth rates to generate reliability tables showing expected roughness X years in the future for a given roughness at year N. The model gives engineers a tool to predict when future maintenance could best be applied without using expensive and complex simulation programs.

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Conclusions

The research in this study supports the hypothesis that a certain level of roughness can predict a sharp increase in dynamic load and accelerated pavement deterioration. The steps taken that support this conclusion included:

1. Identifying empirical relationships between roughness and distress using RQI for roughness and DI for distress from in-service pavements.
2. Developing relationships between surface roughness and theoretical pavement damage using the mechanistic approach.

Finding the relationships among roughness, dynamic load, and pavement damage helped determine the critical RQI-value ranges that signal accelerating pavement deterioration. Researchers found reasonable agreement between theoretically-derived and empirically-derived RQI-value ranges for predicting deterioration rates, but the predictability is too unreliable at the project level. The researchers therefore concluded that RQI was not suitable for predicting dynamic truck loading on specific pavement profiles at the project level.

To better predict pavement deterioration using only RQI data, researchers created a new DLI roughness index for identifying the specific pavement roughness profiles that create dynamic load from trucks. This new index gives maintenance engineers the data necessary to predict when smoothing maintenance will offer the greatest increase in service life for certain pavement types.

After further testing and refinement, DLI may become an integral part of MDOT's statewide pavement management system. DLI may prove to be a valuable tool for more accurately predicting optimal preventive maintenance treatments, delaying costly reconstruction, and giving Michigan motorists a smooth ride no matter what kind of vehicle they are in.

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