5-1-2022

How to Estimate The Present Serviceability Rating of a Road Segment: Explanation of an Empirical Formula

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Comments:
Technical Report: UTEP-CS-22-60

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Abstract An accurate estimation of the road quality requires a lot of expertise, and there is not enough experts to provide such estimates for all the road segments. It is therefore desirable to estimate this quality based on the easy-to-estimate and easy-to-measure characteristics. Recently, an empirical formula was proposed for such an estimate. In this paper, we provide a theoretical explanation for this empirical formula.

1 Formulation of the Problem

Empirical formula. In pavement engineering, it is important to gauge the remaining quality of the road pavement based on its current status. The pavement quality is estimated by experts on a scale from 0 to 5. The corresponding expert estimate is known as the Present Serviceability Index (PSI). However, estimating the road quality requires a lot of expertise, a lot of experience, and there is not enough experts to gauge the quality of all the road segments. It is therefore desirable to estimate this value based on easy-to-observe and easy-to-measure characteristics. Such estimates of PSI are known as Present Serviceability Rating (PSR).

Several characteristics can be used to gauge the pavement quality. One of the most widely used characteristics if the Pavement Condition Index (PCI), which is

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a combination of values characterizing different observed and measured pavement faults. In principle, it is possible to provide a rough estimate of PSR based on PCI. However, to get a more accurate estimate for PSR, it is desirable to explicitly take into account values of the most important characteristics of the pavement imperfection.

In [1], an empirical formula was presented for estimating the Present Serviceability Rating (PSR) of a road segment based on the PCI and on the following three specific characteristics of the pavement:

- the mean rut depth of the pavement RD,
- the area of medium and high severity patching Patch, and
- the sum of the lengths of medium and high severity cracks LTCrk.

This formula has the following form:

$$\mathrm{PSR} = a_0 + a_{\mathrm{PCI}} \cdot \ln(\mathrm{PCI}) + a_{\mathrm{Patch}} \cdot \mathrm{Patch} + a_{\mathrm{Patch},2} \cdot \mathrm{Patch}^2 + a_{\mathrm{Patch},3} \cdot \mathrm{Patch}^3 +$$

$$a_{\mathrm{RD}} \cdot \mathrm{RD}^2 + a_{\mathrm{LTCrack}} \cdot \mathrm{LTCrack} \cdot \mathrm{RD}.$$

Problem. How can we explain this empirical formula? In other words, how can we answer the following questions – and similar other questions:

- Why there are up to cubic terms in terms of Patch and only linear terms in terms of the length of crack – which seems to indicate that terms of higher order in terms of this length did not lead to any statistically significant improvement of the resulting estimate?
- Why there are quadratic terms in terms of rut depth but only linear terms in terms of the crack length?

What we do in this paper. In this paper, we provide a theoretical explanation for this formula. This explanation provides answer to both above questions – and to several similar questions.

2 Our Explanation

How to explain dependence on PCI. In the above empirical formula, the Present Serviceability Rating (PSR) logarithmically deoends on the Pavement Condition Index (PCI).

In general, the logarithmic dependence is one of the basic dependencies corresponding to scale-invariance; see, e.g., [2]. So, such scale-invariance is the most probable explanation of the logarithmic dependence of PSR on PCI.

Remaining questions: dependence on other characteristics. The remaining questions are: how can we explain the dependence on other characteristics – the mean rut depth RD, the patching area Patch, and the cracking length LTCrk.

What is important is the area. The larger the area affected by a fault, the more this fault's effect on the traffic. Thus, in the first approximation, the effect is proportional to the area.

This means that if a fault is described by its length – as are cracks – or by its depth – as the rut depth – the effect should be, in the first approximation, proportional to the corresponding area – i.e., to the expressions which are quadratic in terms of these characteristics: RD^2, LTCrack^2, and $\text{LTCrack}\cdot\text{RD}$. From this viewpoint, in the first approximation, the important terms are terms which are linear in Patch, RD^2, LTCrack^2, and $\text{LTCrack}\cdot\text{RD}$.

To get a more accurate description, we may need to add terms which are quadratic, cubic, etc., in terms of these characteristics.

How faults appear: a reminder. Which of the possible terms are the most important? To answer this question, let us recall how faults appear.

- First, we have a pavement deformation – which is described by the rut depth.
- After some time, cracks appear.

How this affects the relative size of terms depending on crack length and rut depth. Since the cracks appear much later than the rut, they have less time to develop and thus, the effect of the crack size is, in general, much smaller than the effect of the rut depth: $\text{RD} \gg \text{LTCrack}$. This implies that $\text{RD}^2 \gg \text{RD}\cdot\text{LTCrack} \gg \text{LTCrack}^2$.

The largest term out of these three is RD^2, so we need to take this term into account. However, if we only take into account this term, we will completely ignore the effect of the cracks, and cracks are important. So, to take cracks into account, we need to consider at least one more term $\text{RD}\cdot\text{LTCrack}$. So, a reasonable idea is to consider terms which are linear in RD^2 and $\text{LTCrack}\cdot\text{RD}$.

What about patches? When the rut and depth drastically decrease the pavement quality, the pavement is patched. Current patching technology does not allow precise patching that would cover only the affected areas. As a result, the patch is not just covering the cracks and the rut, it covers a much larger area. As a result, the patches cover a much larger region. Thus, the patch area Patch is much larger than the terms RD^2, LTCrack^2, and $\text{LTCrack}\cdot\text{RD}$ describing the actual faults.

This explains the appearance of higher-order patch-related terms. Since the relative area covered by patches larger than the ratio of RD^2 to the pavement area, the terms quadratic and even cubic in terms of Patch are much larger than similar terms quadratic and cubic in terms of RD^2.

Thus, even those terms quadratic and cubic in terms of RD^2 can be safely ignored, it makes sense that much larger terms – quadratic and cubic in terms of Patch – cannot be ignored and have to be present in the estimation formula.

All this explains the above empirical formula.

Acknowledgments

This work was supported in part by the National Science Foundation grants 1623190 (A Model of Change for Preparing a New Generation for Professional Practice in Computer Science), and HRD-1834620 and HRD-2034030 (CAHSI Includes), and by the AT&T Fellowship in Information Technology.

It was also supported by the program of the development of the Scientific-Educational Mathematical Center of Volga Federal District No. 075-02-2020-1478, and by a grant from the Hungarian National Research, Development and Innovation Office (NRDI).

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