The Effect of Road Surface Roughness to Recommended Speed of Vehicles

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Abstract

Road safety is one of the major concerns of the transportation system planners and managers in any nation. The principle goal of road safety is to reduce the frequency and severity of traffic accidents. The design and manufacturing of high-quality road directly play an important role in achieving better road safety. This research presents the model describing the relationship between road surface roughness with the vehicle’s recommended safe velocity. The result shows that the road surface roughness measured by the International Roughness Index (henceforth IRI) is indirectly proportional to the vehicle’s recommended safe velocity. In particular, if the recommended safe velocity is 100 km/h, the surface roughness IRI should not exceed 1.9 m/km. An implication of this is the possibility that using the simulation on MATLAB Simulink software should have the appropriate IRI concerning the designed speed.

Keywords: Road roughness, road safety, traffic speed

1. Introduction

Road safety is the combination of multiple parameters including geometry, vision distance, width, over operating conditions, pavement quality, road surface conditions, vehicle and driving behavior.

Of particular concern are deterioration of the road surface and the reduction of road safety. Road surface roughness is a parameter quantifying of the degradation of the road surface. Recent evidence suggests that the relationship between roughness with pavement life is being widely used in road surface management. Questions have been raised about the change in the estimated road life. It is now well established from a variety of studies, that the model also uses climatic conditions, initial structures, loads of vehicles involved in traffic and surface maintenance variables, [1].

To determine road surface roughness according to longitudinal sections, an existing standard ISO 8608 is used [2].

It is only since the work of Múčka (2018) that the study of road surface roughness has gained momentum. Analysis of 27 scientific papers simulated the road surface according to ISO 8608 such as that conducted by Múčka (2018) have shown that road layers were determined mainly for reference corner space-frequency $\phi = 1$ rad/m ($L_0 = 6.28$ m) and for angular frequency, $n_0 = 1/2\pi$ cycle/m ($L_0 = 6.28$ m) or $n_0 = 0.1$ cycle/m ($L_0 = 10$ m). The results showed a significant difference between the simulated lines and the spectral properties of the actual lines. Thus, a type-A road is proposed for good
or medium quality roads (highways). While types B and C are suitable for low-quality surfaces (grade 2, and grade 3 or local), [3].

To analyze the impact of the surface roughness of the vehicle's motion to the movement of the vehicle at different speeds, a simulation based on the automobile model was used to describe the contact of the tire with the road surface. The IRI and abnormal changes in road surface configuration are determined by dedicated road test equipment. The vehicle speed is closely related to road surface roughness and affects the dynamics of the suspension system and the stability of the movement, [4].

According to the Vietnam transportation standard, evenness of the road is checked and evaluated through the IRI. The experiment of the study is carried out using collecting, surveying designed enhancement, and constructing of automobile road data bank since it can forecast the investment in repairing and upgrading transportation roads [5]. The image of road surface roughness and pavement degradation is provided in Figure 1.

![Figure 1. Road surface roughness and pavement degradation](image)

The more the roughness index values increases, the more accident rates increases. Also, the number of car accidents is larger than that of cars accidents, but on the highway, the accident rate does not increase with roughness.

To date, the driver's driving behavior is governed by road rules in developed countries. Vietnam is one of the countries that gradually follow the driving rules. To overcome this problem, the rule is applied to limit the speed of the vehicles. Studying the effect of road safety, the driver's behaviour should be taken into account, especially limiting speed and being aware of the safety factors. Figure 2 presents the driver's behavior on IRI during the control of a series of routes to comment on driving comfort. It has been suggested that the lower IRI, the better the ride comfort [6].

![Figure 2. Results of investigation of the driver's behavior with road surface roughness](image)
As can be seen from Figure 2 above, the roughness of the road surface has a direct impact on vehicles collision. The braking distance increases with the specified speed of vehicles running from up to 50 km/h. Besides, longer wavelengths in vertical configuration have an impact on the ride quality of trucks compared to cars, [7].

2. Relation of the speed of movement with the coefficient of drag
The rolling resistance coefficient of the road surface depends on the movement speed of the car. When designing highways, rolling resistance coefficient is used as shown in formula (1).

\[ f_1 = f_0 \left[ 1 + 0.01(V - 50) \right] \] (1)

\( f_0 \) represents the rolling resistance coefficient at vehicle speed under 50 km/h, while it depends on the type of road surface. The \( f_0 \) is valued at 0.01 for concrete road, and the value of 0.3 is used for discrete sandy road. \( V \) is used to refer to the vehicle speed, km/h.

When designing natural soil roads (i.e. rural roads, forestry roads), rolling resistance coefficients are used as illustrated in the following formula (2).

\[ f_2 = \xi G \left( \frac{H}{D} \right) \] (2)

Where \( \xi \) is the coefficient that varies from 0.6 to 1, depending on the state of the soil. While \( H \) is the depth of the wheel track, and \( D \) is the wheel diameter.

3. The roughness of the road surface
Traditionally, it has been argued that the road surface roughness is widely accepted and used by road management agencies globally. It has been also acknowledged the roughness as deviation or irregularity of the intended longitudinal profile (called the real plane) of the road surface. The indicators of the road surface roughness is determined as current use rate (present serviceability rating as PSR), current usability (present serviceability index as PSI), number of turns (ride number as RN), and riding comfort index (RCI).

The IRI index is defined as the surface roughness with a wavelength of 0.5 m to 50 m in the longitudinal section. It is also measured by recording the movement of the axle and suspension during the vehicle moves at a constant speed. In the industry-standard (22TCN-277-01), the IRI is defined more specifically since the surface roughness reflects the longitudinal roughness of the pavement with a wavelength of specific amplitude. Also, the IRI appears to affect the dynamic characteristics of the vehicle, driving quality, drainage conditions and causes of dynamic loads impact on the road.

The roughness is first calculated with an IRIqc wheel on a track using a single-track model and is then determined by averaging the two IRIqc values of each wheel on the rear axle with two dual wheels.

In the national standard TCVN 8865: 2011, the method of measuring IRI by the indirect method is given in formula (3) with a vehicle speed of 30 km/h.

\[ IRI = 0.1268 \times (\text{Shockiness}) - 0.3905; (R^2 = 0.9396) \] (3)

IRI is calculated in formula (4) with vehicle speed of 45 km/h

\[ IRI = 0.1302 \times (\text{Shockiness}) - 1.1044; (R^2 = 0.9625) \] (4)

The relationship between the roughness of the road and the risk of collision is given in the equation (5) below [see 8].

\[ \text{Crash rate} = 0.0049 \times (\text{Ro})^2 - 0.4948 \] (5)

It should be noted that the Crash rate (CR) is the collision rate, and the Roughness (Ro) is the average value of roughness in length (kilometre).
4. Relationship of the roughness with the speed of the vehicle

Figure 3 provides an experimental study that causes accident rates to increase at 50 km/h and 70 km/h [8].

![Figure 3. The relationship of roughness with the speed of movement of the vehicle through the number of accidents](image)

As shown in Figure 4, the relationship with speed depends on the type of vehicle, the difference between a car and heavy truck (HV) when running on the same surface roughness [9].

![Figure 4. Relation of vehicle speed and roughness according to vehicle type](image)

Figure 5 illustrates the limit of the roughness given for each speed. It indicated that the lower rate of IRI, the speed is being decreased. Therefore, for high speeds (100 km/h) the road surface must have a higher quality level than the lower speed zone (50 km/h).
5. Examine the surface movement [9]
In the previous section, the measurement results were adopted to determine the exact surface roughness. The two methods used in this study involved direct and indirect measurement. Measurements were selected for their specialized agency about public transport.

In most recent studies, the application of software has been developed and can simulate virtual alternative to the experiment, which still gives reliable results. This study used Matlab Simulink tool to simulate in the module called sldemo_VariableTransportDelay as an assisted application.

The model of the vehicle and the road is provided in Figure 6. Hi (t) is the bumping at the front wheel over time (Front wheel vertical displacement). And, Ho (t) is the bumping at the rear wheel or if determined by displacement which is rear wheel vertical displacement.

![Figure 6. Vehicle-road model and survey parameters](image)

The block diagram of the simulation module is shown in Figure 7. The purpose of the simulation is to determine the "bumping" of the wheel in the formula when moving at different speeds 15, 30, 50, 70, 80, 90, 100 and 120 km/h with different IRI indicators on the road.
Figure 7. Block of Simulink model “sldemo_VariablenTransportDelay”

In particular, the vehicle speed and the IRI are the parameters set, moving vertically of the front or rear wheel is the parameter definition in the simulation. As can be seen in Figure 8, the frequency of "bumping" increases when the vehicle speed increases. The more increase of the simulation time with the longer the actual distance, the more increase in the number of measurement points. In this stage, we cannot count manually, since we can also use the meter to record the results and counting the analysis of the number of "bumping" of the wheels.
At speed 80 km/h

At speed 90 km/h

At speed 100 km/h

At speed 120 km/h

Figure 8. Simulation results determine the "shockiness" of the wheel

6. Conclusion

This study has shown that the vehicle’s speed is the main parameter used in conjunct with the change of the roughness of the road surface. It has argued that these two parameters will indicate the driving behavior. The analysis of two parameters in the "Driver-Vehicle-Road" relationship supported by the current findings. These experiments confirmed that road surface roughness may benefit to road safety. One of the more significant findings to emerge from this study is that driving to the environment that has the roughness changes, the driving speed and driving concentration might have been reduced. Hence, the roughness will have been challenging in the operation. In general, therefore, it seems that the roughness could be one of the factors that can adjust the speed limit in-vehicle control.

The results of this investigation show that the roughness value is in the range of 0 to positive numbers but there is no upper limit. However, it will be limited according to road use requirements. In a highway, the study revealed that the IRI is 1.9 m/km maximum. It has been suggested from the study that the sections should be longer than 500 m with the results of the IRI between 4.2 and 5.3 m/km to create the feel for drivers.

The findings will be of interest to use the existing modules of Matlab Simulink software to simulate the determination of the "bumping" of the wheels and it will make the study reliable and time-saving. More research using applications regarding these similar problems and real experiments should be carried out, in particular of public transport research.
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