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The use of Bayesian statistics to predict patterns of spatial repeatability

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Abstract

Statistical spatial repeatability (SSR) is an extension to the well known concept of spatial repeatability. SSR states that the mean of many patterns of dynamic tyre force applied to a pavement surface is similar for a fleet of trucks of a given type. A model which can accurately predict patterns of SSR could subsequently be used in whole-life pavement deterioration models as a means of describing pavement loading due to a fleet of vehicles. This paper presents a method for predicting patterns of SSR, through the use of a truck fleet model inferred from measurements of dynamic tyre forces. A Bayesian statistical inference algorithm is used to determine the distributions of multiple parameters of a fleet of quarter-car heavy vehicle ride models, based on prior assumed distributions and the set of observed dynamic tyre force from a 'true' fleet of one hundred simulated models. Simulated forces are noted at 16 equidistant pavement locations, similar to data from a multiple sensor weigh-in-motion site. It is shown that the fitted model provides excellent agreement in the mean pattern of dynamic force with the originally generated truck fleet. It is shown that good predictions are possible for patterns of SSR on a given section of road for a fleet of similar vehicles. The sensitivity of the model to errors in parameter estimation is discussed, as is the potential for implementation of the method.

Keywords: Weigh-in-motion; Statistical spatial repeatability; Bayesian; Pavement; Impact factor

1. Introduction

Spatial repeatability is the phenomenon that the pattern of dynamic force applied truck axles to a road pavement is similar for repeated runs at similar speeds. This effect results in a concentration of high dynamic tyre forces at specific locations on a pavement surface and has been observed by several authors both experimentally (Ervin, 1983; Mitchell, 1987) and in numerical studies (Huhtala et al., 1992). This opposes the

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Nomenclature

c_{b}	vehicle damping coefficient
G_{d}	pavement spectral density
$G_{\mathrm{d}}(n_0)$	constant related to pavement surface roughness
g	acceleration due to gravity
IF	impact factor
$\mathrm{IF}^{\mathrm{o}}_{nm}$	observed impact factor for truck n at location m
K	mean suspension stiffness of fleet
K_{t}	mean tyre stiffness of fleet
k	suspension stiffness
k_n	suspension stiffness of truck n
k_{t}	tyre stiffness
$k_{\mathrm{t}n}$	tyre stiffness of truck n
M	number of sensors
m_1	unsprung mass
m_2	sprung mass
m_{2n}	sprung mass of truck n
N	number of vehicles
n	wavenumber
P	static vehicle load
$R(t)$	vehicle tyre force
$r(t)$	road profile height at time t
t	time
v	vehicle velocity
w	constant related to pavement surface roughness
y_1	displacement of unsprung mass
y_2	displacement of sprung mass
Z	mean lateral approach position of fleet
z	lateral approach position
z_n	lateral approach position of truck n
σ^2_{IF}	unknown error in IF
σ^2_k	variance in suspension stiffness
$\sigma^2_{k\mathrm{t}}$	variance in tyre stiffness
σ^2_z	variance in lateral approach position

traditional assumption that applied dynamic tyre loads are randomly distributed along a pavement length, suggesting that the pavement is uniformly susceptible to damage along its length.

Cole and Cebon (1992) performed a numerical investigation of spatial repeatability using an experimentally validated two-dimensional articulated vehicle model. They generated a fleet of 37 leaf sprung vehicle models with similar geometry and eight varying parameters relating to the ride characteristics, identifying repeatable patterns of dynamic tyre forces. The relationship between vehicle velocity and level of repeatability was highlighted. A further experimental study, involving measurement of heavy vehicle tyre forces on a major national route in the UK, was conducted (Collop et al., 1996) which confirmed theoretical predictions of the influence of speed on spatial repeatability of tyre forces.

O'Connor et al. (2000) proposed the concept of 'statistical spatial repeatability' (SSR). Using data from a multiple-sensor weigh-in-motion (MS-WIM) site in France, they showed that the mean pattern of impact factors is similar for many trucks of the same type. This is illustrated in Fig. 1. Similar patterns were found for different types of truck and even for trucks with different numbers of axles.