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How comfortable are your cycling tracks? A new method for objective bicycle vibration measurement

Michal Bíl *, Richard Andrášik, Jan Kubeček

CDV Transport Research Centre, Brno, Czech Republic

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ABSTRACT

Cycling comfort consists of several factors. Their relevant values are important in the process of bicycle facility planning. Poor surface pavement quality manifests itself in terms of vibrations of a bicycle. This strongly influences the perception of a cycle track, general cycling comfort and the route choice as well. We introduce dynamic comfort index (DCI) which is capable of objectively describing the vibration properties of surface pavement on a track. The DCI is derived from data gathered when riding a bicycle equipped with a GPS device and an accelerometer. The most common types of devices were selected to make the DCI widely applicable. We tested DCI values on various bicycles and surface pavements. DCI values on individual cycling tracks were compared with the subjective feelings of 43 cyclists via questionnaires. A strong correlation (−0.94) was obtained between the objectively measured DCI values and the subjectively assessed evaluations. This makes the DCI approach transferable to any other environment. This method has been applied to an entire road network within the historical center of the city of Olomouc (Czech Republic). It can further be used by bicycle track administrators to monitor surface quality, by planners to obtain relevant surface pavement values, and by individual cyclists for optimal route choice.

1. Introduction

Planning, construction and management of bicycle facilities are demanding and expensive processes. To ensure that cyclists will make use of such facilities, reliable data are needed. Cyclist's route choice is often surveyed (e.g., Hunt and Abraham, 2007; Kang and Fricker, 2013) and it is generally accepted that cycling comfort consists of several factors: environmental, mechanical and biomechanical factors, and physiological factors (Ayachi et al., 2015). Environmental factors (e.g., traffic conditions, path width, road geometry and surrounding conditions) significantly influence cyclists' evaluations of the comfort of bicycle lanes and shared roads (Li et al., 2012).

Bicycle tracks and roads designated for cyclists should also be safe and undemanding. Cyclists omit long ascending tracks, particularly when commuting to work (Milakis and Athanasopoulos, 2014). Every day bicycle commuters usually use the fastest routes, because they are experienced riders (Menghini et al., 2010). Certain road surfaces may be difficult to ride on a bicycle and along with other factors may discourage people from using their bicycles. Comfortable cycling requires smooth rolling at the lowest possible energy input (Hölzel et al., 2012). The surface pavement type (e.g., Walker, 2002) is often included (along with other factors, such as traffic volumes and road width) in the assessment of optimal routes for cyclists, which is part of bicycle network analyses (e.g., Rybarczyk and Wu, 2010).

* Corresponding author.

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Optimal cycling routes are usually planned by the Bicycle Level of Service (BLOS) approach. An example of such a methodology is the approach of Landis et al. (1997) who used 5 levels of surface quality (very poor, poor, fair, good, and very good) for the surface pavement type. They made a valid point stating that the pavement condition is frequently dismissed by some practitioners as being insignificant. The response to real-time stimuli captured in their study does confirm that pavement condition plays an important role in cyclists' assessment of roadway environment. A common system of surface pavement quality evaluation is, however, subjective (e.g., Walker, 2002). Objective road quality for cyclists is usually not part of the indices used to predict bicyclists' perceptions of a specific roadway environment, e.g., the bicycle compatibility index (Harkey et al., 1998).

Older people, women and experienced cyclists, as demonstrated by Bergström and Magnussen (2003) or by Stinson and Bhat (2005), attach more importance to a smooth surface. A poor road surface is thus a discouraging factor which strongly affects the supply side in the bicycle transportation planning process. Actual pavement surface condition is thus one of the variables influencing the route choice of a cyclist (Landis et al., 1997).

Impacts of poor cycling track surfaces or road surfaces in general on the decision of a cyclist to use a particular route have not been widely studied thus far (Heinen et al., 2010; Joo et al., 2015). We could only presume that if cyclists would have a choice they would select the smoother routes. The study of Landis et al. (1997) is among the few works which explicitly states that surface quality is an important decision factor for cyclists when choosing a cycling route. The vibration of a bicycle is often a prominent consequence of poor cycling track quality. Cyclists perceive bicycle vibrations negatively (Landis et al., 1997; Torbic et al., 2003) and therefore the direct measurement of vibration should be applied to the cycling network. This is particularly needed if such a network consists of sections of various surface pavements and age.

1.1. Vibrations and cycling comfort

Cyclists perceive surface quality by way of bicycle vibrations which are among the important causes of discomfort (Thibauldt and Champoux, 2000; Giubilato and Petrone, 2012). As vibration increases, comfort decreases (Torbic et al., 2003). The main reason for vibrations is an uneven road pavement (Olieman et al., 2012). Hölzel et al. (2012) studied the effects of four different road surfaces (asphalt, concrete slabs, cobblestones, self-binding gravel) on vertical acceleration, including less used and worn surfaces. They conclude that the most comfortable were asphalt surfaces and the least worn concrete slabs. They also found that cycling comfort decreases with higher velocities. Giubilato and Petrone (2012) studied the response of various wheel models to surface roughness. Their results indicate that the ranking between comfort properties of different wheels varies with the road surface roughness and the cruising speed considered.

Although bicycle designers are attempting to improve cycling comfort through various technical innovations (e.g., Vanwallenghem et al., 2012), an objective mapping of vibrations along cycling tracks and roads used by cyclists is still needed in any efforts to achieve higher quality in the cycling network or to localize problematic places.

Inertial sensors (accelerometers) are deemed ideal candidates to serve as pavement sensors for wide-area instrumentation (Levenberg, 2014). Joo and Oh (2013) used GPS and an accelerometer mounted onto a bicycle to derive Bicycle Monitoring Index (BMI). They combined data about vibrations and speed. They computed the probability of the suitability of a road segment for cycling. Their BMI has two aspects: mobility and safety. It is bicycle speed which limits the suitability of the road segment from the mobility point of view. If it is below 5 km/h, then the road segment is not suitable. The safety is then related to the acceleration level, which is approximated from Weibull distribution. The results presented by Joo and Oh (2013) are single numbers for the entire road segments, but without identification of places with local extremes.

Bicycles equipped with an accelerometer are often used for cycling track vibration mapping. Mohanty et al. (2014) present a review of current Instrumented Probe Bicycle (IPB) technology and research. IPBs are common bicycles equipped by several technologies which measure both bicycle position and acceleration (e.g., Joo and Oh, 2013). The sensors used often include, for example, a potentiometer to measure hand-brake depression (Lee et al., 2014), a lateral distance sensor (Yamanaka et al., 2013), a laser pointer (Angel-Domenech et al., 2014) or a camera (Dozza et al., 2013; Yamanaka et al., 2013). Measurement by means of such an IPB provides an abundance of data about cycling tracks, but it can be complicated to reproduce the results by other researchers.

1.2. Cycling comfort mapping in the Czech Republic

Strong support for cycling as an alternative to other modes of transportation was provided by the Czech government in the form of the National Cycling Strategy adopted in 2004. Since then various regional agencies have supported building cycling tracks and the construction of a supplementary cycling infrastructure. Approximately 39,000 km of marked cycling tracks are recorded by individual regions (Bíl et al., 2012). At present, the main effort is to standardize the entire network data, because they are administered with varying systems of data recording.

A new method for cycling-track mapping (Bíl et al., 2012) has been applied to approximately 15,000 km of the Czech cycling trails. Data is collected directly in the field riding a bicycle. One parameter describes the type of surface pavement (e.g., asphalt, cobblestones). Another parameter is the subjective estimate of the bicycle type which is suitable for the road section (e.g., mountain bike, touring bicycle or a racing/regular bicycle). Problems which have been documented in connection with this mapping lie in the fact that the same type of surface may be of varying quality or age. The mappers can also