UNDERSTANDING NEW VEHICLE DYNAMICS: DEVELOPING RANGE STANDARDS FOR ELECTRIC BICYCLES

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Introduction

The physical effort required to travel by bicycle is a barrier to wider adoption of cycling for transportation. Electric-assist bicycles (e-bikes) provide a means to reduce the physical demands of cycling on the rider. E-bikes allow riders to travel at higher speeds and climb hills with less effort by providing additional propelling force through a motor drawing electrical energy from an on-board battery. Existing e-bikes are available to travelers in a range of styles and designs, ranging from vehicles very similar to conventional bicycles to what are essentially electric scooters(Rose, 2012).

E-bike use has steadily increased over the past decade, although the overall adoption is still fairly low in most countries and there is wide disparity in use around the world(Fishman & Cherry, 2016). On a microscale (sub-trip) level, e-bike riders typically travel faster than riders on conventional bicycles(Schleinitz, Petzoldt, Franke-Bartholdt, Krems, & Gehlert, 2017). Beyond average speed differences, there has been little investigation of the unique microscopic travel dynamics of e-bikes, and how they may differ from conventional bicycles. Speed dynamics (positive and negative acceleration), grade dynamics, and the interaction between the two are likely different between electric and conventional bicycles, assuming riders change their travel behaviour in response to the availability of motor power. Riders may choose to accelerate faster, to maintain a higher speed on ascents, or to take a hillier route, for example, if the perceived costs of acceleration, power, and ascents are lower (Bigazzi and Lindsey 2018).

E-bike "range" refers to the distance that can be travelled on a single battery charge. The range depends primarily on the battery capacity and state-of-charge, and the power demand from the cyclist (which in turn depends on the pedal assist level, speed, mass, grade, wind, and other factors). Various methods have been suggested to estimate e-bike range, but no widely-adopted standard method exists (Toll, 2018). Hence, there is no standard for measuring and reporting e-bike range to consumers, or for estimating energy consumption from e-bike usage. As one e-bike blogger stated, "it's pretty much still the Wild West when it comes to range claims" (Average Joe Cyclist, 2016). Some consumer advocates suggest assuming a conservative constant 12 Wh/km discharge rate (Paolo, 2014). Bosch, an e-bike motor manufacturer, provides an interactive web calculator to estimate range given an average speed, riding mode, mass, and other factors (Bosch, n.d.). A German vehicle association recently announced a voluntary testing standard, but it is not yet widely used or validated (Toll, 2018).

This research develops a method for e-bike range and energy factor estimates through the creation of e-biking schedules. 'Biking schedules' are archetypal riding patterns (speed, acceleration, and road grade)that can be generated from naturalistic travel data. Building on the methods used in macroscopic motor vehicle fuel consumption and pollution emissions models, we propose a framework in which archetypal e-biking schedules are developed as testing standards for various riding conditions.

E-Biking Schedules

Biking schedules are high-resolution speed-grade profiles that represent archetypal cycling patterns. The recently-introduced concept and techniques of biking schedules (Mohamed & Bigazzi, 2018) are derived from driving schedules (also known as driving cycles), which were developed and used

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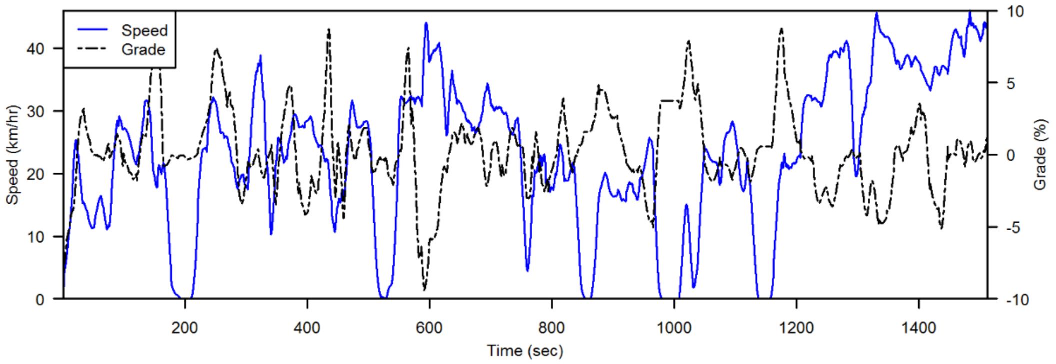
to represent typical driving behaviour for motor vehicle energy and emissions measurement and modeling (Tong & Hung, 2010). Biking schedules are inherently more complex than driving schedules because cycling speeds are more influenced by road grade and attributes of the vehicle and traveller.The main differences are that biking schedules include road grade (because of the relationships between cycling speed and road grade) and use a different set of cycling-relevant assessment parameters. For a detailed description of the biking schedule method see Mohamed & Bigazzi (2018).

The biking schedule method was applied to naturalistic GPS data collected from conventional and electric bicycle trips in Vancouver, Canada. The GPS data were collected in summer and fall of 2017 from a pool of 260 recruited participants. Each participant recorded 1-second GPS data for walking and cycling trips over a 1-week period using a smartphone application. In total, 14,961 km of travel data were obtained from more than 2,314 trips (8% by e-bike). Separate biking schedules were created to represent the dynamics of conventional and electric bicycle trips. The e-biking schedule is illustrated in Figure 1. In addition, because the context of the conventional and electric bicycle trips were different, a matched-sample conventional biking schedule was created, matched to the age, gender, trip purpose, and terrain characteristics of the e-bike trips. A comparison of the dynamics of the electric and matched-conventional bicycle trips revealed significant differences, supporting the need for vehicle-based differentiation of assumed (archetype) bicycle dynamics (Mohamed & Bigazzi, Forthcoming).

Figure 1: Example E-Biking Schedule



Use of Driving Schedules in Motor Vehicle Modeling

As stated above, driving schedules were developed to represent typical driving patternsand provide information about expected fuel consumption and emissions. For example, the U.S. Environmental Protection Agency (EPA) developed regulatory driving schedules for vehicle testing to be used in labelling (i.e., the “city” and “highway” fuel economy labels)(U.S. Environmental Protection Agency, 2009a). The EPA also developed a much large library of driving schedules for motor vehicle emissions modeling in the MOVES emissions model (U.S. Environmental Protection Agency, 2009b). For emissions estimates in which detailed (second-by-second) vehicle activity data are unavailable, MOVES and other macroscopic emissions models base emissions estimates on an assumed set of vehicle dynamics (i.e., driving schedules). MOVES specifically retrieves driving schedules from its internal library to match the vehicle type (light, medium, or heavy duty vehicles), average speed, and facility type of the modeled activity.

Proposed E-Bike Range Test Standard

Analogous to the application of driving schedules for motor vehicle fuel and emissions estimation, e-biking schedules can be used for e-bike range estimates and testing standards. The key factor is that the e-biking schedules must be broadly representative of typical e-bike use. The dataset applied above to generate an e-bike schedule for Vancouver, Canada has insufficient spatial coverage to be broadly applicable. Hence, the first requirement toward development of a comprehensive e-bike range test standard is to *compile a multi-city dataset of 1 Hz speed and a road grade data from naturalistic e-bike trips*.

The biking schedule construction method described above can then be applied to generate representative testing schedules for the entire dataset or for segments of interest with the dataset. For motor vehicle driving schedules, consumer information is derived from a binary “city” and “highway” segmentation, whereas emissions modelling is based on a three-dimensional segmentation across vehicle type, facility type, and average speed bins. The most relevant segmentation of the data (and test schedules) for e-bikes depends on 1) the factors that differentiate e-bike power consumption and range, and 2) the factors of interest for consumers or modellers. Hence, the second requirement toward development of a comprehensive e-bike range test standard is *determination of the most appropriate segmentation for e-biking schedules*. As an initial step, we propose the following potential factors for segmentation, in decreasing hypothesized importance:

1. Motor assist type (pedal/throttle) and level,
2. Terrain (level, rolling, mountainous), and
3. Riding style (mild, aggressive).

Other potential factors include traveller demographics (age, gender), trip purpose (commute, leisure, exercise), and bicycle type (mountain, hybrid, tricycle).

In future work, after compiling a multi-city dataset, these factors should be tested by 1) consultation with e-bike customers and retailers about the factors of interest relevant to purchase decisions, and 2) statistical testing of significant differences in cycling dynamics based on these segmentations. The proposed approach would provide a broadly representative test schedule standard which could be used in both laboratory testing and simulation modelling to provide e-bike range and energy consumption estimates. This would lead to better information for consumers in the e-bike market, and for analysts investigating the energy and environmental impacts of e-bikes.

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