Transportation Research Part D 51 (2017) 276–289

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Big data driven dynamic driving cycle development for busses in urban public transportation

R. Günther, T. Wenzel, M. Wegner, R. Rettig *

University of Applied Sciences Hamburg, Faculty of Engineering and Computer Science, Berliner Tor 7, 20099 Hamburg, Germany

A R T I C L E I N F O

Article history:
Available online 10 February 2017

Keywords:
Dynamic driving cycles
Reference driving cycles
Testing
Validation
Public transportation
Busses

A B S T R A C T

Field-relevant reference driving cycles, equivalent to real-life operation, are a prerequisite for the consistent development and testing of vehicles, their components, and control algorithms. Furthermore they are the basis for certification and type testing. However, a static cycle can easily be detected during vehicle testing, so that optimized control parameters could be used to obtain improved emission results under test conditions. In this paper, a novel method is described and applied to generate a dynamic driving cycle that statistically matches the real-life operation of a vehicle. The analysis is performed based on an extensive field data set obtained during an automated measurement campaign of public busses for more than a full year with 27,365 h of operation and 315,583 km driven in the city of Hamburg (Germany). The data collected is statistically compared to the static reference cycles New European Driving Cycle (NEDC) and Worldwide harmonized Light Vehicles Test Procedure (WLTP). Two micro trip models with increasing complexity are described and fit to the data set. All models are quantitatively compared to the measured data set applying a Quality of Fit (QoF) indicator. Based on the highest consistency to field data, a non-deterministic driving cycle generator is developed and its output is statistically compared to the original measurement. In contrast to the existing reference cycles, the dynamic output of the non-deterministic driving cycle generator presented in this paper is statistically proven to be consistent with real-life operation of public busses in the urban environment of Hamburg.

1. Introduction

To replicate real-life conditions during vehicle development, testing, certification, and type approval, reference cycles like the New European Driving Cycle (NEDC) (UNECE, UN) or Worldwide harmonized Light Vehicles Test Procedures (WLTP) (Tutuianu et al.) have been developed. They consist of a sequence of data points of vehicle speed versus time. However, existing cycles suffer from certain disadvantages:

- They represent an obviously artificial sequence that cannot be found in real-life operation (UNECE, UN; Tutuianu et al.).
- Others represent a specifically measured single sequence of defined length (Gao et al., 2015; Lai et al., 2013; Nesamani and Subramanian, 2011; Covaciu et al.; Hung et al., 2007; Esteves-Booth et al., 2001).
- They statistically do not reflect the parameters of real-life operation of a vehicle.

* Corresponding author.
E-mail address: Rasmus.Rettig@haw-hamburg.de (R. Rettig).

http://dx.doi.org/10.1016/j.trd.2017.01.009
1361-9209/

- They are fully deterministic and thus easily detectable, e.g., during emission tests.

Thus the development of real-life, data-driven, non-deterministic driving cycles is of significant relevance. Besides of overcoming the identified gaps, it can

- support the standardized development of vehicles and their application to local environments.
- improve the development of control algorithms and driving strategies, e.g., for minimizing CO_2 emissions or for the charging and discharging of electrically driven vehicles (Duvall).
- support the development of standardized testing cycles for components like batteries.
- provide a basis for the setup of recharging infrastructure when moving from combustion engines to electrically propelled vehicles.

The literature generally distinguishes transitory and modal cycles (Covaciu et al.). Transitory cycles consist of many changes in speed, whereas modal cycles include longer periods of cruising at constant speed. The NEDC, which is currently the common reference for passenger cars in Europe, is an example for a modal driving cycle (Fig. 1). Transitory cycles, like the WLTP (Fig. 2), are generally considered to be more realistic. Both cycles are static, limited in length, and thus do not replicate the variations and the complexity of real-life operation.

Further activities include the development of city- or region-specific, static driving cycles for public busses: Gao et al. (2015) construct the Dalian driving cycle for a single electric bus line by dissecting their measurements into kinematic sequences followed by a cluster analysis and a comparison to results obtained in the city of Zhuzhou and a typical Chinese city. Lai et al. (2013) analyze in total 223 h of operation of fourteen bus routes in the city of Bejing. The authors distinguish between bus rapid transfer (BRT) lines, express, and regular lines and create type specific, static driving cycles. Nesamani et al. perform a similar analysis for the city of Chennai (Nesamani and Subramanian, 2011) and propose a static driving cycle. Further investigations (Covaciu et al.; Hung et al., 2007; Esteves-Booth et al., 2001) propose city-specific, static driving cycles for public busses. The International Association of Public Transport (UITP) proposes three different, fixed 'Standardized

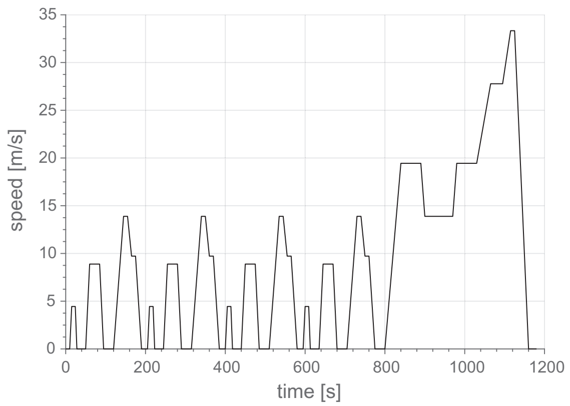

Fig. 1. Speed profile of the New European Driving Cycle (NEDC) (UNECE, UN).

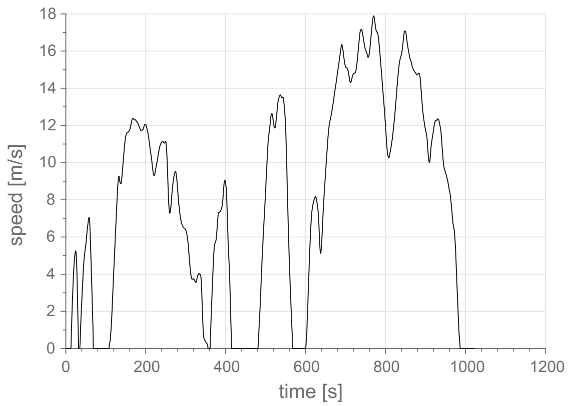

Fig. 2. Speed profile of the Worldwide harmonized Light Vehicles Test Procedures (WLTP class 1) (Tutuianu et al.).