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Assessing Energy Consumption of High-speed Trains Based on Mechanical Energy

Xujie Feng, Quanxin Sun*, Lu Liu, Minggao Li

MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing 100044, China

Abstract

Normally, not all the stopping sections of a high-speed rail (HSR) are long enough for a train to achieve the initially fixed target speed. By taking this crucial attribution of HSR into consideration, an assessment model for energy consumption of a high-speed train (HST) is established based on its mechanical energy. An example based on real data in China effectively demonstrates the model. It is found that both the target speed and stopping frequency have significant effects on HST energy consumption. If the target speed rises from 200 to 350 km/h, the increasing percentages of energy consumption are 133%, 140%, 149% and 153% respectively for HSTs of the four examined stop schedules: all-stop, skip-stop, large-stop and non-stop. The non-stop HST consumes the less energy whereas all-stop HST consumes the most under equivalent conditions. Moreover, the travel speed of an HST with high target speed and frequent stopping is not significantly higher than that of an HST with lower target speed and less frequent stopping, but the former's energy consumption is strikingly more than the latter's. The findings might help rail departments to make a more environmental-friendly HST operation scheme by integrating its target speed and stop schedule.

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Keywords: high-speed train; energy consumption; mechanical energy; target speed

* Corresponding author. Tel.: +86 10 51688623.
E-mail address: qxsun@bjtu.edu.cn.

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1. Introduction

Worldwide, the traffic section is a large energy consumer. The experience of developed countries illustrates that the ratio of energy consumed by traffic section to the total is highly positive correlated with the economic development level. Therefore, as expected, the ratio of energy consumed by China's traffic section to the total will probably grow as rapidly as her economy (Jia et al., 2010). Recently, China has invested enormously in HSRs. Till the end of 2012, over 9000 kilometers (km) of HSR has been put into operation in China, and by 2020 it is going to exceed 18000km. With such rapid development, how to control HSR energy consumption effectively has been a popular and great issue to scholars and policy-makers (Givoni, 2006). In order to answer this question, the estimation model for HST energy consumption should be established first of all, including finding the significant influence factors.

However, subjected to the financial and technical constraints, it is nearly impossible to pilot a large-scale energy use experiment on an operating HSR. As a result, many researchers have made efforts to estimate train energy use theoretically. The published findings are distinguished into two main categories according to their principles.

On one hand, a micro approach adopts computer-aided simulation to reproduce the train running process and evaluates the energy use based on electric current curve of locomotives. For example, Lukaszewicz (2001) develops a validated train model based on full scale testing, and the model is quite accurate as verified for the investigated trains. A number of operation factors are tested to improve the energy utilization efficiency in rail transit, including the target speeds (Feng, 2011), formation scales (Feng et al., 2012a) and stopping frequencies (Feng et al., 2012b). The third saving strategy for energy consumption of HST is the rational use of driving modes, including coasting control (Liu and Golovitcher, 2003) and regenerative brakes under variable line conditions. Although this micro approach is relatively more accurate, it has a stringent requirement for input conditions and fails without the electric current curve of locomotives.

On the other hand, a macro approach estimates train energy consumption by calculating its mechanical energy based on the energy conservation law. This approach also has a popular application owing to its fewer input requirements. For instance, Hickman et al. (1999) propose a calculation model for train energy use where the primary parameters include the average speed and stop frequencies of the train along the entire route as well as the maximum speed to which the train accelerates. However, the model is quite simplified and difficult to reflect the really more complicated running process. González-Franco et al. (2012) improve Hickman et al.'s model in consideration of more details of realistic train running process, and also estimate energy recovered from regenerative braking.

Most models of the above-referred macro approach are based on the parameter of the maximum speed, which is a fixed target speed when operating the train. However, a certain extent of HSR's stopping sections is not long enough to achieve the fixed target speed (Givoni and Banister, 2012). Ignoring this crucial attribution might result in over-estimated HST energy consumption. In the research, we divide the length of stopping sections into 2 categories: long enough to achieve the target speed and else. Then the HST running process in different categories is described and its energy consumption is modeled respectively. The paper is organized as follows: Next section sets up our theoretical model based on some necessary assumptions. In section 3, a numerical example based on real data is presented. Scenarios on its stop schedule, e.g. all-stop, skip-stop, large-stop and non-stop trains, are examined. The effects of accelerations and target speeds on HST energy consumption are evaluated. Finally, section 4 provides a brief conclusion and directions for possible future researches.

2. 2. Theoretical model

The running process and operation scheme of an HST on an HSR is described as follows, which also include parameter definitions and vital assumptions.

The HSR's length is defined as L and its passenger service stations are numbered as 1, 2, …, n from the original station to the terminal station. The length between the i-th station and its next adjacent station is marked by $R_{i,i+1}$, where $1 \leq i \leq n-1$.

The stop frequencies of the HST are s (including at the original and terminal stations, $2 \leq s \leq n$), and the series of