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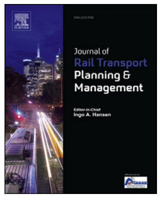

Energy-saving train scheduling diagram for automatically operated electric railway

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ABSTRACT

Interest in energy-saving railway scheduling and operations is growing because of environmental concerns. Saving energy on both the hardware and software sides is an ever-increasing interest and challenge. Railway scheduling is closely related to the energy consumption of rolling stock. Energy consumption decreases when running time is increased because running curves can include considerable coasting time. However, the running time between two adjacent stations is determined for scheduling, and this running time is adhered to very strictly in Japan. Power-limiting brakes, which use regenerative braking without mechanical braking, are very useful in energy-saving operations. However, power-limiting brakes have some drawbacks, such as slow deceleration and the difficulty of notch operation. How to use power-limiting brakes effectively on schedule remains a research problem.

We propose a method for developing an energy-saving schedule based on automatic train operation (ATO), which offers exceptional control notch performance and is easier to apply to an optimised schedule than manual train operation. In the proposed method, running time distribution is optimised based on energy savings between stations by keeping the total running time constant. Only the running time is optimised, so that additional timetabling strategies for energy-saving can be applied, such as reducing dwell and turnaround times and increasing running time margins. Practical considerations are included, such as determination of running times as integer values. The results of this study show that energy-saving efficiency is increased when the running time distribution between stations is optimised.

1. Introduction

1.1. Railways as a key to solving environment problems

The world is facing significant environment problems, including global warming and worldwide energy concerns. The Fifteenth Session of the Conference of Parties to the United Nations Framework Convention on Climate Change (COP15) was held in Denmark in 2009 and global warming countermeasures were discussed by over 80 ministers. In Europe, the European Rail Research Advisory Council (ERRAC) projects were initiated to decrease CO_2 emissions to 50% by 2050, compared with

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those in 1990 (Chéron et al., 2011). Railways have received considerable attention recently as green vehicles. Fig. 1 shows CO_2 emissions of various transportation systems based on the primary energy source in Japan in 2012 (MLIT). Railways are better for the ecology than other types of transportation. Because of its outstanding ecological properties, various railway projects have been considered, such as the Shift 2 Rail project (Shift2Rail). Railways are in demand because they contribute to energy savings and reduce CO_2 emissions, compared with other types of transportation.

Some technologies have been developed to achieve energy savings in operating an electric railway. The West Japan Railway Company has surveyed its regenerative energy practices and studied its effective utilisation (Yamashita et al., 02 2009). The Railway Technical Research Institute develops on-board storage devices to stock regenerative energy without regeneration cancellation in Japan (Ogasa, 2009). Storage devices consisting of batteries and supercapacitors have been installed in a substation in Korea (Lee et al., 2011). Software technologies have also been proposed, such as driving operation (Albrecht, 2014). Energy-saving operation, which is considered to mean fully use of electric brakes has been tested by some railway companies (Hamazaki, 2012; Izeki, 2013).

1.2. Purpose of this study

The purpose of this study was to develop a software-based approach to achieving energy savings in railway operations by less costly means than through hardware enhancements. Previous studies have proposed the use of power-limiting brakes (Watanabe et al., 2013a, 2013b). The energy-saving efficiency of this braking method has been demonstrated. However, the performance of this braking method has been limited by the difficulty of notch operation by a driver, even if an operation assistance system has been installed (Watanabe and Koseki, 2014; Watanabe et al., 2014). For this reason, the use of automatic train operation (ATO) systems has been proposed as means to achieve better performance and energy-saving efficiency from power-limiting brakes.

In this paper, we propose an energy-saving operation scheme and a method for designing an optimised railway line schedule for ATO. The use of power-limiting brakes with ATO and the utility of its use on ATO railroad are discussed in Section 2. Our optimisation of a schedule based on ATO with power-limiting brakes and the method for determining an optimal schedule are described in Section 3. The optimisation procedure seeks to minimise the energy consumption of rolling stock so that the running time distribution based on energy saving driving between all stations is optimised while the total running time is kept constant. Practical scheduling concerns, such as the need to determine running times as integer values, are considered in the calculation procedure. Based on the optimisation procedure, we compared running curves and schedules from the point of view of energy savings, as described in Section 4. A basic schedule and an optimised schedule were compared and evaluated in terms of the total energy consumption of each.

2. Energy-saving operation for ATO

2.1. Running curve with optimisation

In terms of software applications, driving methods have been widely studied in railway research. Previous research has suggested that railway operation involves a trade-off between the energy consumption of rolling stock and running time (Bocharnikov et al., 2010). The energy consumption of rolling stock can be calculated using a running curve. For this reason, in the past, optimisation of running curves was studied for energy-saving operation purposes (Ko et al., 2005; Miyatake, 2011;

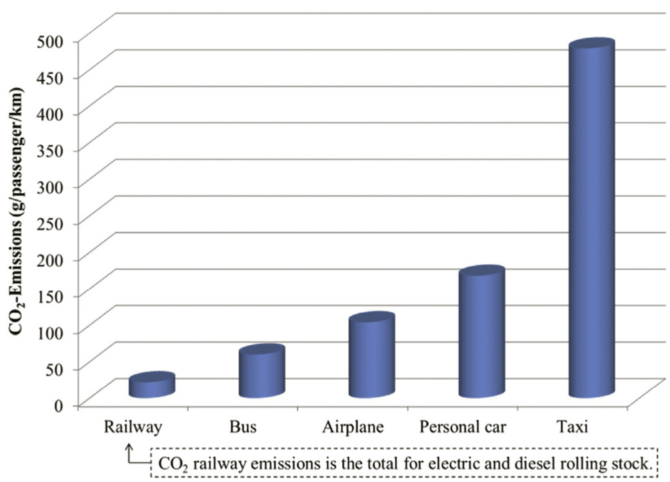

Fig. 1. CO_2 emissions of various types of transportation based on the primary energy source in Japan in 2012 (MLIT).