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Research on Traction Energy Cost Intensity and Passenger Transport Efficiency of a Metro Train

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Abstract

Metro takes the most part of energy consumption in urban public service systems and lots of researchers force on the energy-efficient methods for the unban rail transport. Based on train traction calculations and computer-aided simulations, this research studies the transports of a metro train on a certain metro line in city B to analyze the relationship between the target speed and formation of this train and its traction energy cost intensity and passenger transport efficiency. The Comprehensive Evaluation Index (CEI) is proposed to analyze integrated optimization strategies of urban rail transport by calculating the traction energy cost and the technical operation time. It is found that the target speed should be set with the consideration of the attribute of the line and the formation scale of the trains may also be determined by the passenger volume. What's more, the ratio of the motor cars of a metro train operating on a rail line in off-peak hours prefers 0.50 for both saving traction energy and ensuring a relatively high passenger transport efficiency. Finally, this research optimizes the transport plan of the trains running on the studied metro line according to the passenger travel demands in different daily operation time periods to decrease the general traction energy cost on the premise of a reasonable efficiency of passenger transport.

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Keywords: urban rail transport; traction energy cost intensity; passenger transport efficiency; computer-aided simulation

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1. Introduction

Owing to the characteristics of big carrying capacity and high transport efficiency, urban rail transit has become into an important transport means for the relief of urban traffic congestion. Reducing the intensity of traction energy cost for metro trains on the premise of a certain passenger transport efficiency is not only able to improve the benefit of the urban rail transit operation enterprise but also good for the establishment of an energy-efficient urban transport system.

Statistics in China show that more than half of the electric power supplied to an urban rail transit system is consumed by the tractions of its trains to overcome their resistance in their transports from the track (Song, 2009). Some studies focus on the track conditions of a rail line. Hoang et al. (1975) have analyzed the relationship between the location of gradient change point of a track and the train traction energy consumption. A heuristic method employing a direct search algorithm is used in the trajectory optimization. Kim and Schonfeld (1997) have set dipped track profiles between rail transit stations and have assessed the energy costs and travel time of alternative scenarios. Liu et al. (2007) have used the computer-aided simulation to give a sensitivity analysis of track curves and slope, which get their quantitative relationships to train traction energy consumption.

As for train operation control, mathematical models have been established to solve the optimization problems. Firpo and Savio (1995) have used the Simplex method to get optimal values for such as acceleration and cruising speed of a train to minimize its energy consumption. Chang and Sim (1997) have put forward a GA algorithm to explore the optimum coasting program on the basis of the evaluating the punctuality, riding comfort and energy consumption of a train. Hwang (1998) has utilized the fuzzy clustering and a GA hybrid scheme for determining an economical running pattern to optimize travel time and energy cost of a train. Kim et al. (2010) have developed a time-driven train performance simulation model considering train traction, track alignment and train control. Special attention has also been paid to rail transport management. With the use of computer-aided simulation, the traction energy saving effect of target speed, acceleration, load factor, formation scale, traction capacity, stop-spacing, etc. has also been discussed respectively (Uher et al, 1984; Ding and Sen, 2009; Kim et al, 2011; Feng, 2011).

This study analyzes the transports of a metro train operating on a certain urban rail transit line in city B and attempts to get the relationship between the target speed, formation scale and traction capacity of this train and its traction energy cost intensity and passenger transport efficiency in quantificational manners. Considering the characteristics of the passenger volumes in working days, the formation scale and traction capacity of each metro train are changed to decrease the intensity of its traction energy cost without paying more transport time.

2. Data

The population of City B is about 19.61 million. Its GDP is 1,377.79 billion Yuan RMB and the annual growth rate is 10.20%. The metro line connects a developing zone and a function expansion zone of the city. The resident population and the population density of the developing zone are 1.66 million and 1.23 thousand people/km2 respectively, and the ones of the function expansion zone are 3.28 million and 7.61 thousand people/km2 respectively (National Bureau of Statistics of China, 2010).

The length of the studied urban rail transit line is 21.24 km. There are seven stations along this rail line. Its maximum gradient is 18.00‰ and the minimum curve radius is 350 m. The studied train currently consists of four motor cars (35.00 tons/car) and two trailer cars (30.00 tons/car). The abbreviation of 4M2T here is used to represent the studied train. M represents motor car and T represents trailer car. The top-speed of the studied train is 100.00 km/h and its length and passenger capacity are respectively 120.00 m and 1,460 persons which are assumed to be fully used in this research. The average weight of each passenger is 60.00 kg (General Administration of Quality Supervision, Inspection and Quarantine of China, 2004) in this study.

3. Simulation and evaluation

3.1 Train operation simulation