Hindawi Publishing Corporation
Mathematical Problems in Engineering
Volume 2013, Article ID 643274, 7 pages
http://dx.doi.org/10.1155/2013/643274

Research Article

Rational Formations of a Metro Train Improve Its Efficiencies of Both Traction Energy Utilization and Passenger Transport

Xuesong Feng,[1] Haidong Liu,[1] Hanxiao Zhang,[1] Baoshan Wang,[1] and Qipeng Sun[2]

[1] *MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, No. 3 Shangyuancun, Haidian District, Beijing 100044, China*
[2] *School of Economics and Management, Chang'an University, Nan Er Huan Zhong Duan, Xi'an 710064, China*

Correspondence should be addressed to Xuesong Feng; charles.x.feng@gmail.com

Received 4 July 2013; Revised 31 July 2013; Accepted 1 August 2013

Academic Editor: Wuhong Wang

Copyright © 2013 Xuesong Feng et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Based on simulations of passenger transports of two representative types of metro trains in China, this study analyzes efficiencies of energy consumption and passenger transport of a metro train in the effect of its target speed, formation scale (FS) (i.e., length and mass of the formation), relative traction capacity (RTC) (i.e., ratio of the motoring cars to all its cars), and so forth. It is found that increasing energy cost efficiency of a metro train with decreasing its target speed is evidently accelerated with reducing its RTC below 0.50 at the expense of obviously lowering its passenger transport efficiency. Moreover, if the passenger capacity of the train is sufficiently utilized, increasing its FS for the same RTC is easy to have its passenger transport efficiency improved significantly even for a meanwhile much decreased target speed with consuming energy less intensively. Therefore, metro trains in peak hours may take comparatively big FSs, relatively high target speeds, and RTCs over 0.50 to meet usually urgent and large-scale travel demands in such time. In contrast, trains in nonpeak hours ought to have small FSs, relatively low target speeds, and RTCs smaller than 0.50 for mainly avoiding energy waste.

1. Introduction

Urban traffic congestion commonly happens in China today. The urban traffic networks are characterized by slow travel speeds, long trip time, and increased vehicle queuing, which adversely affects urban mobility [1]. As a result, the urban rail transit (URT) networks have been rapidly developed in different cities of China. Till the end of 2011, the total length of the URT lines in operation has been increased from only about 500.00 kilometers (km) in 2006 to approximately 1,714.00 km in China, and by 2050 it is going to exceed 13,000.00 km [2]. With such a rapid development, issues for both energy saving and transport efficiency improvement arise on, for example, how to reasonably decide the target speed, formation Scale (FS) (i.e., length and mass of the formation), relative traction capacity (RTC) (i.e., proportion of the motoring cars to all the cars), stop frequency, and so forth of a URT train.

Many studies have been made by scholars and practitioners to improve the passenger transport efficiencies of trains as well as to decrease their energy consumption. One of the main categories of the efforts is the optimization work through determining driving control point(s) for the transport of a train. For instance, Liu and Golovitcher [3] develop an algorithm by utilizing the optimal control theory to tell the control change points of a train in its transport process for the most energy-efficient trip in the required travel time. Wong and Ho [4] compare the capacities of different methods for searching the most suitable coasting point(s) to regulate the train service and find that transport distance between neighboring stops plays a decisive role on their convergence speeds. Kim and Chien [5] take advantage of the simulated annealing algorithm to find the optimal control patterns of a train under various track alignments for the minimum energy cost of its transport adhering to the time schedule. Ignacio and Alberto [6] mathematically proved that increasing the speed of a train on downward slopes has positive effect upon not only decreasing travel time but also reducing energy consumption for the whole trip. In contrast, another kind of the achievements tries to interpret the effect of controlling some specific factors of a train on the improvement of its energy utilization efficiency in consideration of passenger transport time. Such factors include driving strategy [7], total mass of the cars [8], stop frequency [9], or, in other words, transport distance between neighboring stops [10], acceleration and braking performance [11], mass distribution [12], power distribution between independent engines [13], passenger boarding rate [14], target speed at each time [15], and formation scale [16, 17]. Furthermore, research on incorporating optimal driving controls and timetable adherence of multitrains to minimize their total energy consumption has been attached much importance in recent years. For example, with the aid of an event-based model, a dynamic programming method is applied by Wong and Ho [18] to devise an optimal set of dwell times and run times of trains for their energy saving and service regulation. Acikbas and Soylemez [19] propose an approach with the utilization of artificial neural networks and genetic algorithms to optimize the coasting points of trains to minimize the energy consumption for their target travel times. A genetic algorithm integrated with simulation is designed by Yang et al. [20] to seek the approximate optimal coasting control strategies of trains for the optimization of energy cost and travel time on a rail network. Cucala et al. [21] use a fuzzy linear programming model to establish the optimal schedule with the goal of energy minimization for trains in view of their uncertain delays and the behavioral responses of drivers. Li et al. [22] propose a multiobjective fuzzy scheduling model to minimize the energy consumption, carbon emission, and passenger time of multitrains.

Despite the valuable research findings of the previous studies, the question on how to decide the target speed, FS, and RTC of a train from a comprehensive perspective for its traction energy saving under the premise of meeting the passenger transport demand in each time period of the daily operation of a URT line has not been answered in an adequately convictive manner. Based on computer-aided simulations, this study analyzes the changes of the energy cost and time usage of each transport of two representative types of metro trains in China with the improvements of their target speeds by taking into account the impacts of their FSs, RTCs, and so forth to provide a key to this question from the quantificational viewpoint of train traction calculation.

The latter parts of this paper are organized as follows. Specifications of the studied trains and their rail lines are presented in Section 2. Next, the computer-aided simulation approach utilized to compute the traction energy cost (TEC) (i.e., the energy consumed by each operating condition, namely, halt, motoring, coasting, and braking) of a train for its passenger transport and the technical operation time (TOT) (i.e., the travel time spent from the startup of the train in the original station to its final stop in the terminal station) of the whole trip are explained in Section 3. Thereafter, Sections 4 and 5, respectively, analyze the changes of the TECs per 10,000 passenger-km (p-km) and TOTs per 10,000 p-km of different types of trains with improving their target speeds in the effect of various FSs and RTCs. Finally, Section 6 draws conclusions to answer the aforeexplained question and indicates some future research issues.

2. Trains and Rail Lines

The TECs and TOTs of the passenger transports of the metro trains called the MT-Type-A and the MT-Type-B on, respectively, the Line-No. 1 of City-A and Line-CP of City-B in China are comparatively studied in this work for different FSs, RTCs, and target speeds of these two types of trains. Line-No. 1 and Line-CP have their respective lengths of 17.97 km and 21.24 km, and the numbers of their stations are 16 and 7 correspondingly. As a result, the average stop spacing of Line-CP is nearly three times of the Line-No. 1′s. The target speeds of the MT-Type-A and the MT-Type-B are both changed from 40.00 km per hour (km/h) to 100.00 km/h in the simulation analyses of this research in view of the usually adopted target speeds of most metro trains in China for different transport conditions. According to the most commonly applied FSs of the metro trains in China, each of these two types of metro trains consists of 4 cars, 6 cars, or 8 cars in this study and the number of their motoring cars changes from 1 to 4, 6, or 8 for corresponding FSs to have them obtain different RTCs. If a metro train is made of X motoring cars and Y trailers, the abbreviation of XMYT is used to account for the composition of this train. Some technical specifications of the cars of the TM-Type-A and the TM-Type-B are presented in Table 1. The standard passenger capacities of these cars are designed for the case that there are on average 6 passengers per square meter inside train. It is also assumed that the average mass of one passenger here is 60.00 kg in comparison to the 80.00 kg which is the average mass of one passenger with his/her hand baggage in an intercity train [23].

3. Simulation Approach

With referring to the studies of Chandra and Aqarwal [24] and Andrews [25], the computer-aided simulation approach shown in Figure 1 is applied in this work to calculate the TEC and TOT of the passenger transport a train. The transport process of the train from one stop to another is simulated for each of the successive calculation intervals which are set to be equal to 0.10 second(s) in this study. As explained by (1), the traction power and traction force of the train are assumed to be unchanged in one calculation interval. The train at a station is started up with its full traction power towards a target speed. Once initially achieving the target speed by consecutive accelerations as interpreted by (2), the train adjusts its traction power in view of its basic resistance force for the target speed according to (1) and (3) to make its speed stabilized as much as possible at the target speed. If the additional resistance force, for example, from a slope of the rail line as illuminated by (4), makes the deviation of the speed of the train from the target speed reach certain values, the train adopts the operating condition of more powerful motoring, coasting, or braking correspondingly. In order to ensure the train's safe passing through somewhere requiring a speed limit or safe stop in the next station, the train begins

Table 1: Technical specifications of the metro cars.

Parameters	TM-Type-A		TM-Type-B	
	Motoring car	Trailer	Motoring car	Trailer
Mass	36.00 tons (t)	33.00 t	35.00 t	30.00 t
Length	22.10 meters (m)	23.69 m	19.00 m	19.50 m
Standard passenger capacity	306	318	240	250
Designed top speed	100.00 km/h		110.00 km/h	

to check whether brakes are necessary or not in a calculation interval when there is a certain distance away from there. This is determined according to the speed (v_1) of the train at present and the currently permitted maximum speed (v_2) which is computable based on the braking performance of the train and the transport distance from its current location to that rail site or the next stop. If $v_1 \geq v_2$, the train brakes to decrease its speed as soon as possible to a small value which is able to absolutely ensure the safety; if $v_1 < v_2$, the train coasts. Such a decision is made for each latter calculation interval till the train passes through the rail site in safety or stops in security in the next station. After the stop with the engine working, that is, keeping the operating condition of halt, for some time at this station, the train commences to repeat the aforeexplained process by starting up again with its target speed and full traction power till its final arrival at the terminal station.

Each type of trains has a certain unchanged traction force for its startup (which is a special operating condition of motoring) and also has its own set of operating handle positions which make its traction power change from 0 W (e.g., for the operating condition of coasting or braking) to its full traction power. The traction force of a train for its mobility after its startup is determined by both the speed and the traction power of this train. If a train adopts the operating condition of halt, its traction force is 0 N. The change of the traction force of a train from its startup at a station to its completion of the halt at the next station is interpreted by:

$$f_k^{\mathrm{ch}} = \begin{cases} F_0, & \text{if } (k = 0), \\ \dfrac{P_k^{\mathrm{ch}}}{v_{k-1}^{\mathrm{ph}}}, & \text{if } (k = 1, 2, \ldots, m), \\ 0, & \text{if } (k = m + 1, m + 2, \ldots, n), \end{cases} \tag{1}$$

where f_k^{ch} is the traction force of the train positioning its operating handle at ch in the kth calculation interval, unit: N, F_0 is the traction force of the train for its startup, unit: N, P_k^{ch} is the traction power of the train positioning its operating handle at ch in the kth calculation interval, unit: W, and v_{k-1}^{ph} is the speed of the train at the end of the $(k-1)$th calculation interval in which the operating handle of the train is at the position of ph, unit: m/s.

The speed of the train at the end of a calculation interval is determined by its speed at the end of the previous calculation interval, the traction force of the train in this calculation interval, the resistance force (including the basic resistance force and the additional resistance force) of the train in this calculation interval, and the mass of the train, which is explained by:

$$v_k^{\mathrm{ch}} = v_{k-1}^{\mathrm{ph}} + \frac{f_k^{\mathrm{ch}} - f_k^{b} - f_k^{a}}{M} \times \Delta t, \tag{2}$$

where v_k^{ch} is the speed of the train at the end of the kth calculation interval in which the operating handle of the train is at the position of ch, unit: m/s, f_k^b is the basic resistance force in the kth calculation interval, unit: N, f_k^a is the additional resistance force in the kth calculation interval, unit: N, M is the mass of the train together with all of its passengers, unit: kg, and Δt is the equivalent length of the calculation intervals, that is, 0.10 s, in this study.

It is clearly illuminated by (3) that the basic resistance force of a train mainly because of the air and rail frictions is much concerned with its speed. When the speed of the train is 0 m/s, the basic resistance force for its startup is determined with its mass and its own resistance force intensity, but in contrast, the basic resistance force of the train after its startup is increased with its speed, which is able to be described by a quadratic equation:

$$f_k^b = \begin{cases} q \times M, & \text{if } (k = 0), \\ \alpha_0 + \alpha_1 \times \left(v_{k-1}^{\mathrm{ph}}\right) + \alpha_2 \times \left(v_{k-1}^{\mathrm{ph}}\right)^2, & \text{if } (k = 1, 2, \ldots, n), \end{cases} \tag{3}$$

where q is the resistance force intensity for the startup of the train, unit: N/kg, and α_0, α_1, and α_2 are the resistance coefficients for the mobility of the train (and their values are directly affected by the FSs of the train).

The additional resistance forces of a train are caused by many factors such as the ramps and curves of the rail line, the strong wind, and the very high or very low temperature. Due to the inadequate data support, only the additional resistance forces from the ramps and curves of the rail line are considered on the assumption that the mass of the train with all of its passengers is equably distributed as a thread in this research, as explained by:

$$f_k^{a,R} = m_k^R \times g \times \sin\theta, \tag{4}$$

$$f_k^{a,C} = \frac{0.60 \times g \times m_k^C}{\mathrm{Ra}}, \tag{5}$$

where $f_k^{a,R}$ is the additional resistance force from the rail's ramp R in the kth calculation interval, unit: N, m_k^R is the mass of the car(s) with its/their passengers on the rail's ramp R in

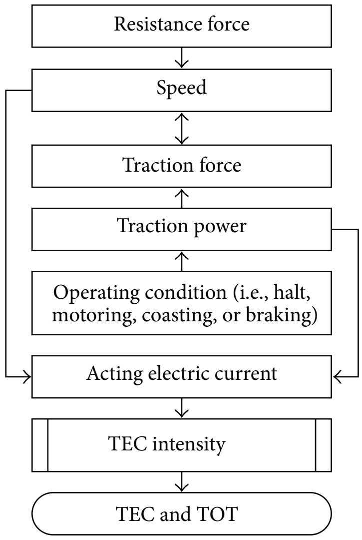

Figure 1: Simulation approach for calculations of TEC and TOT.

the kth calculation interval, unit: kg, g is the gravitational acceleration, unit: N/kg, θ is the angle between the level and the slope of the ramp R, unit: degree, $f_k^{a,C}$ is the additional resistance force from the rail's curve C in the kth calculation interval, unit: N, m_k^C is the mass of the car(s) with its/their passengers on the rail's curve C in the kth calculation interval, unit: kg, and Ra is the numerical value of the radius of the curve C, unit: m.

On the basis of both traction power and average speed of a train for a calculation interval, the average value of the acting electric current of the train is obtained in the consideration of the truly utilized electric current for train traction and the wasted electric current in this calculation interval. Therefore, the TEC intensity of a train for each calculation interval is determined by:

$$\mathrm{TEC}_k^I = \overline{U}_k \times \overline{I}_k, \tag{6}$$

where TEC_k^I is the TEC intensity of the train for the kth calculation interval, unit: W, $\overline{U}_k$ is the average voltage provided for the transport of the train in the kth calculation interval, unit: V, and $\overline{I}_k$ is the average value of the acting electric current of the train in the kth calculation interval, unit: A.

As a result, the TECs of all of the calculation intervals from the startup of a train at its original station to its stop at the terminal station are computed by utilizing the TEC intensity of the train for each of the calculation intervals and summed into the TEC of the trip, as clarified by (7), and the TOT of the train between these two stops is computable by summation of all calculation intervals of the transport, as explained by (8):

$$\mathrm{TEC}_{ij}^v = \frac{\sum_{k=0}^{N}\left(\mathrm{TEC}_k^I \times \Delta t\right)}{1000 \times 3600}, \tag{7}$$

$$\mathrm{TOT}_{ij}^v = \frac{\sum_{k=0}^{N}\Delta t}{3600} = \frac{(N+1)\times\Delta t}{3600}, \tag{8}$$

where TEC_{ij}^v is the TEC of the train with the target speed of v from station i to station j, unit: kilowatt hours (kWh), and TOT_{ij}^v is the TOT of the train with the target speed of v from station i to station j, unit: hours (h).

4. Energy Cost Efficiency Evaluation

The TEC per 10,000 p-km of a train with the target speed of v between different stops, as explained by (9), is utilized to comparatively evaluate the energy utilization efficiencies of this train with different target speeds, FSs, and RTCs to, respectively, complete the same transport mission:

$$e_{ij}^v = \frac{\mathrm{TEC}_{ij}^v}{\sum_{s=0}^{j-i-1} P_{ij}^v \times R_{(i+s)(i+s+1)}^v \times D_{(i+s)(i+s+1)}^v}, \tag{9}$$

where e_{ij}^v is the TEC per 10,000 p-km of the train with the target speed of v from station i to station j, unit: kWh/10,000 p-km, P_{ij}^v is the standard passenger capacity of the train with the target speed of v from station i to station j, $R_{(i+s)(i+s+1)}^v$ is the utilization ratio of the standard passenger capacity of the train with the target speed of v from station $(i+s)$ to station $(i+s+1)$, and $D_{(i+s)(i+s+1)}^v$ is the transport distance of the train with the target speed of v from station $(i+s)$ to station $(i+s+1)$, unit: 10,000 km.

The travel demand of the passengers for each station along a URT line usually has little change in a certain daily time. In other words, the p-km completed by one trip of a train in one service time of the URT line is relatively fixed. In view of the extremely high travel demands of the passengers of Line-No. 1 and Line-CP in their busy times, the utilization ratio of the standard passenger capacities of the metro trains here is supposed to be unchanged as 100.00% for each stop spacing in peak hours. As for one transport of an MT-Type-A from the 1st station to the 16th station of Line-No. 1, the changes of its TECs per 10,000 p-km with the increase of the target speed for different FSs and RTCs are revealed in Figure 2. Such TEC changes of the MT-Type-B are displayed in Figure 3 for the transport from the 1st station to the 7th station of Line-CP. The time of the operating condition of halt of a train in each of the stations between the original and terminal stations of a metro line is set to be 0.10 s in the simulation studies to simplify the TEC and TOT calculations.

It is clearly shown in Figures 2 and 3 that the increase of the TEC per 10,000 p-km of a metro train with raising its target speed is accelerated with the improvement of its RTC for a certain utilization ratio of the standard passenger capacity of the train. When the RTC is smaller than 0.50, such accelerations are obvious. However, if the RTC exceeds 0.50, this accelerative effect becomes apparently small in comparison. Moreover, as for the same RTC, different FSs of a metro train have little impact on the change of its TEC per 10,000 p-km with increasing its target speed for the same utilization ratio of its standard passenger capacity. Now it is able to be confirmed that decreasing the RTC of a metro train below approximately 0.50 is able to evidently increase the efficiency of its traction energy utilization especially for a relatively high target speed. In addition, it is also proved that a

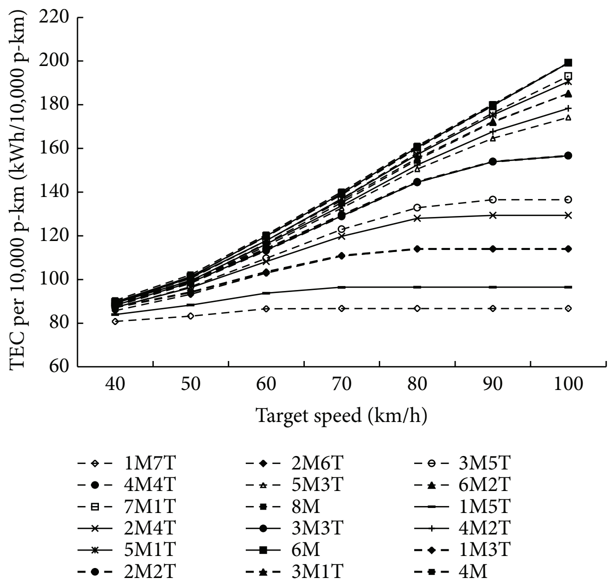

Figure 2: TECs of the transports of the MT-Type-A.

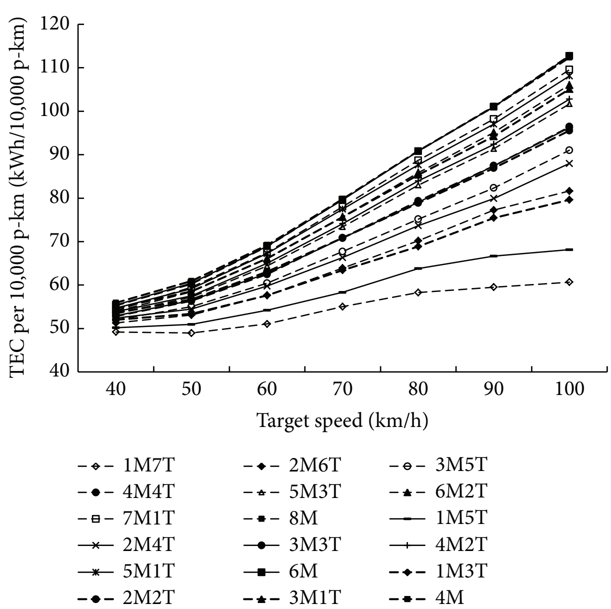

Figure 3: TECs of the transports of the MT-Type-B.

short stop spacing may make the actually reached maximum speed of a metro train extremely lower than a fairly high target speed [26] in particular for a comparatively small RTC, as reflected in Figure 2.

5. Passenger Transport Efficiency Analysis

The TOT per 10,000 p-km of a train with a target speed of v between different stops is defined by (10) and used to estimate the passenger transport efficiencies of this train with various target speeds, FSs, and RTCs to accomplish the same transport task in a respective manner:

$$t_{ij}^{v} = \frac{\mathrm{TOT}_{ij}^{v}}{\sum_{s=0}^{j-i-1} P_{ij}^{v} \times R_{(i+s)(i+s+1)}^{v} \times D_{(i+s)(i+s+1)}^{v}}, \qquad (10)$$

where t_{ij}^{v} is the TOT per 10,000 p-km of the train with the target speed of v from station i to station j, unit: h/10,000 p-km.

The decreases of the TOTs per 10,000 p-km of the afore-explained transports by the MT-Type-A and the MT-Type-B on, respectively, Line-No. 1 and Line-CP with the increases of the target speeds of these two types of metro trains are presented in Figures 4 and 5 in a corresponding way. It is indicated in each of these two figures that decreasing the RTC of a metro train below 0.50 costs obviously additional TOT per 10,000 p-km for the unchanged total number of its cars with a fixed average utilization ratio of their standard passenger capacities, which becomes more manifesting for a comparatively high target speed. That is to say the aforeillustrated distinct improvement of the traction energy utilization efficiency of a metro train by decreasing its RTC below 0.50 is at the conspicuous expense of the decrease of its passenger transport efficiency especially for a relatively high target speed. In contrast, the decrease of the RTC over 0.50 does not increase much of the TOT per 10,000 p-km of the train. Furthermore, it is also demonstrated in both Figures 4 and 5 that a long formation of a metro train with a certain RTC has an obviously lower TOT per 10,000 p-km than the one of a short formation of this train for the same utilization ratio of the standard passenger capacities of different formations, even if the long formation of the train has a much lower target speed than its short formation's. This is because of the little difference of the transport time and the big difference of the completed p-km of different FSs of the train for the same trip. Now it is clarified that, in comparison to the efficiencies of traction energy utilization and passenger transport of a metro train with a short formation and meanwhile a very high target speed, a long formation of this train with the same RTC and a relatively much lower target speed for the same transport action is able to easily have less TOT and TEC per unit transport for the same utilization ratios of the passenger capacities of different FSs.

6. Conclusions

It is found that the increase of the traction energy cost intensity of a metro train with improving its target speed for a certain utilization ratio of its standard passenger capacity is obviously accelerated with raising its RTC below 0.50 in comparison to the increasing acceleration of its energy cost intensity when the RTC exceeds 0.50. At the same time, different FSs of the train have little influence upon its TEC per unit transport for the same RTC. However, such an apparently accelerated increase of the energy cost intensity of the train for the same number of its cars evidently promotes the improvement of its passenger transport efficiency with the increase of its target speed. Moreover, as for the same

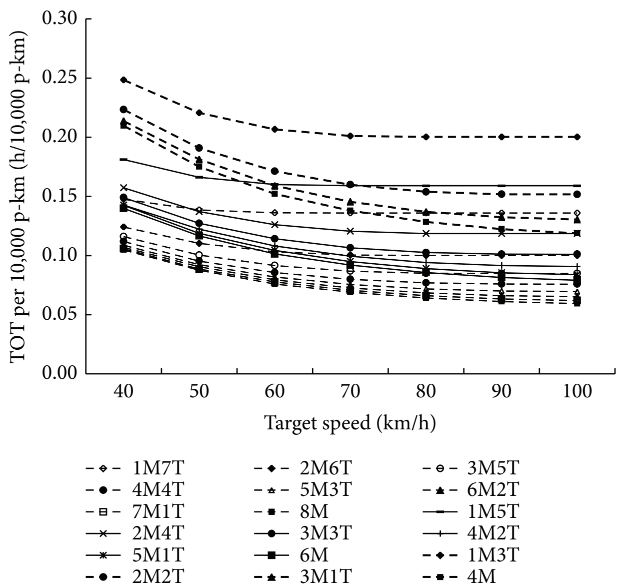

Figure 4: TOTs of the transports of the MT-Type-A.

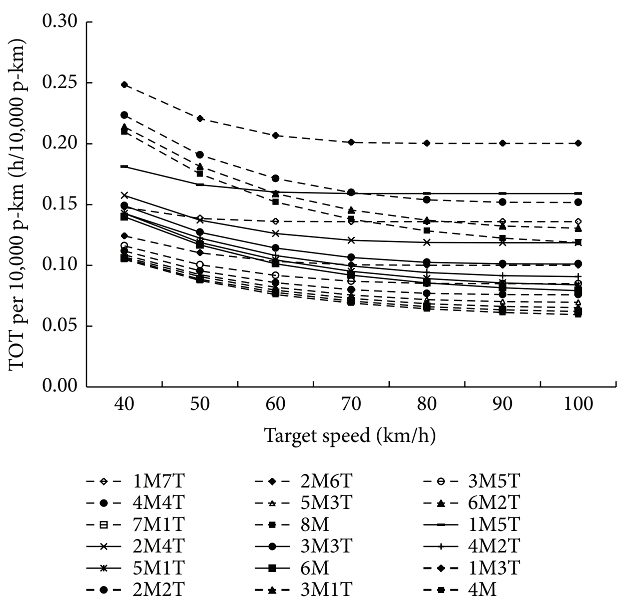

Figure 5: TOTs of the transports of the MT-Type-B.

RTC, a long formation of the train is able to easily transport passengers efficiently owing to its fairly utilized big passenger capacity even for a comparatively very low target speed which also results in less TEC per unit transport.

Therefore, on the condition of a rational general cost including labor cost and rail car purchase cost, if a metro line has its car depot(s) capable of changing the FSs and RTCs of its trains efficiently in technique and/or providing sufficient space for enough trains with various FSs and RTCs, trains with different FSs and RTCs should be applied flexibly according to the changeable travel demands of this line for different time periods in its daily operation. For instance, trains running on the metro line in rush hours ought to have long formations and their RTCs may be bigger than 0.50 for a relatively high target speed to meet the usually urgent and ordinarily big travel demands in such time with the minimum energy cost as much as possible. In nonpeak hours, most of the trains should take short formations for the improvements of the utilization ratios of their passenger capacities. Meanwhile, relatively low target speeds and the RTCs smaller than 0.50 ought to be adopted to increase their traction energy cost efficiencies to the greatest extent at the premise of ensuring necessary efficiencies of their transport services.

In this research, only the transports of two representative types of the metro trains, respectively, on two metro lines in China have been analyzed. More transport operations of other kinds of trains on various URT lines are necessary to be studied to further validate the conclusions of this work. In addition, the impacts of more factors such as aerodynamic resistance, regenerative braking, and interaction between multitrains in their tracking operations, on the efficiencies of energy utilization and passenger transport also need to be systematically explored in future research, in view of the instability of a system when its behavior changes seriously during the system operation [27].

Acknowledgments

This research is supported by the National Natural Science Foundation of China (71201006, 71131001), the National Basic Research Program of China (2012CB725406), and the Fundamental Research Funds for the Central Universities (2011JBM248).

References

[1] W. Wang, W. Zhang, H. Guo, H. Bubb, and K. Ikeuchi, "A safety-based approaching behavioural model with various driving characteristics," *Transportation Research C*, vol. 19, no. 6, pp. 1202–1214, 2011.

[2] Research Group of the Annual Report of China Urban Mass Transit, *2011 Annual Report of China Urban Mass Transit*, Beijing Jiaotong University Press, Beijing, China, 2012.

[3] R. Liu and I. M. Golovitcher, "Energy-efficient operation of rail vehicles," *Transportation Research A*, vol. 37, no. 10, pp. 917–932, 2003.

[4] K. K. Wong and T. K. Ho, "Coast control for mass rapid transit railways with searching methods," *IEE Proceedings-Electric Power Applications*, vol. 151, no. 3, pp. 365–375, 2004.

[5] K. Kim and S. I.-J. Chien, "Simulation-based analysis of train controls under various track alignments," *Journal of Transportation Engineering*, vol. 136, no. 11, pp. 937–948, 2010.

[6] G.-F. Ignacio and G.-A. Alberto, "Can high-speed trains run faster and reduce energy consumption?" *Procedia*, vol. 48, pp. 827–837, 2012.

[7] P. Lukaszewicz, *Energy consumption and running time for trains: modelling of running resistance and driver behavior based on full scale testing [Ph.D. dissertation]*, Royal Institute of Technology, Stockholm, Sweden, 2001.

[8] Institut für Energieund Umweltforschung Heidelberg GmbH, "Energy savings by light-weighting," Final Report, International Aluminium Institute, Heidelberg, Germany, 2003.

[9] E. Lindgreen and S. C. Sorenson, *Simulation of Energy Consumption and Emissions from Rail Traffic Evaluation*, Technical University of Denmark, Lyngby, Denmark, 2005.

[10] X. Feng, "Optimization of target speeds of high-speed railway trains for traction energy saving and transport efficiency improvement," *Energy Policy*, vol. 39, no. 12, pp. 7658–7665, 2011.

[11] Y. V. Bocharnikov, A. M. Tobias, C. Roberts, S. Hillmansen, and C. J. Goodman, "Optimal driving strategy for traction energy saving on DC suburban railways," *IET Electric Power Applications*, vol. 1, no. 5, pp. 675–682, 2007.

[12] M. Chou and X. Xia, "Optimal cruise control of heavy-haul trains equipped with electronically controlled pneumatic brake systems," *Control Engineering Practice*, vol. 15, no. 5, pp. 511–519, 2007.

[13] S. Lu, S. Hillmansen, and C. Roberts, "A power-management strategy for multiple-unit railroad vehicles," *IEEE Transactions on Vehicular Technology*, vol. 60, no. 2, pp. 406–420, 2011.

[14] X. Feng, "Energy cost of high-speed railway trains in the effect of utilization ratios of passenger seats," in *Proceedings of International Conference on Information, Services and Management Engineering (ISME '11)*, vol. 1, pp. 133–136, Beijing, China, December 2011.

[15] B.-R. Ke, C.-L. Lin, and C.-W. Lai, "Optimization of train-speed trajectory and control for mass rapid transit systems," *Control Engineering Practice*, vol. 19, no. 7, pp. 675–687, 2011.

[16] K. Kim and S. I.-J. Chien, "Optimal train operation for minimum energy consumption considering track alignment, speed limit, and schedule adherence," *Journal of Transportation Engineering*, vol. 137, no. 9, pp. 665–674, 2011.

[17] X. Feng, J. Feng, K. Wu, H. Liu, and Q. Sun, "Evaluating target speeds of passenger trains in China for energy saving in the effect of different formation scales and traction capacities," *International Journal of Electrical Power & Energy Systems*, vol. 42, no. 1, pp. 621–626, 2012.

[18] K. K. Wong and T. K. Ho, "Dwell-time and run-time control for DC mass rapid transit railways," *IET Electric Power Applications*, vol. 1, no. 6, pp. 956–966, 2007.

[19] S. Acikbas and M. T. Soylemez, "Coasting point optimisation for mass rail transit lines using artificial neural networks and genetic algorithms," *IET Electric Power Applications*, vol. 2, no. 3, pp. 172–182, 2008.

[20] L. Yang, K. Li, Z. Gao, and X. Li, "Optimizing trains movement on a railway network," *Omega*, vol. 40, no. 5, pp. 619–633, 2012.

[21] A. P. Cucala, A. Fernández, C. Sicre, and M. Domínguez, "Fuzzy optimal schedule of high speed train operation to minimize energy consumption with uncertain delays and driver's behavioral response," *Engineering Applications of Artificial Intelligence*, vol. 25, no. 8, pp. 1548–1557, 2012.

[22] X. Li, D. Wang, K. Li, and Z. Gao, "A green train scheduling model and fuzzy multi-objective optimization algorithm," *Applied Mathematical Modelling*, vol. 37, no. 4, pp. 2063–2073, 2013.

[23] International Union of Railways, *UIC Code 556 OR: Loadings of Coach Bodies and Their Components*, International Union of Railways, Paris, France, 3rd edition, 1990.

[24] C. Chandra and M. M. Aqarwal, *Railway Engineering*, Oxford Higher Education, New York, NY, USA, 2008.

[25] H. I. Andrews, *Railway Traction: The Principles of Mechanical and Electrical Railway Traction*, vol. 5 of *Studies in Mechanical Engineering*, Elsevier Scientific, New York, NY, USA, 1986.

[26] X. Feng, B. Mao, X. Feng, and J. Feng, "Study on the maximum operation speeds of metro trains for energy saving as well as transport efficiency improvement," *Energy*, vol. 36, no. 11, pp. 6577–6582, 2011.

[27] W. Wang, X. Jiang, S. Xia, and Q. Cao, "Incident tree model and incident tree analysis method for quantified risk assessment: an in-depth accident study in traffic operation," *Safety Science*, vol. 48, no. 10, pp. 1248–1262, 2010.

Advances in Operations Research

Advances in Decision Sciences

Journal of Applied Mathematics

Algebra

Journal of Probability and Statistics

The Scientific World Journal

Hindawi

Submit your manuscripts at
http://www.hindawi.com

International Journal of Differential Equations

International Journal of Combinatorics

Advances in Mathematical Physics

Journal of Complex Analysis

Journal of Mathematics

Mathematical Problems in Engineering

Abstract and Applied Analysis

Discrete Dynamics in Nature and Society

International Journal of Mathematics and Mathematical Sciences

Journal of Discrete Mathematics

Journal of Function Spaces

International Journal of Stochastic Analysis

Journal of Optimization