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# Balise arrangement optimization for train station parking via expert knowledge and genetic algorithm

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A B S T R A C T

With the rapid development of urban rail transit, train parking accuracy has received much attention, especially for subway lines with platform screen doors. In actual operation, several balises are mounted on the track to enhance the parking accuracy by providing exact positioning data for the train. Currently, the number and positions of the balises are determined by experience and iterative experiments that may greatly increase the costs. Combining expert knowledge and train dynamics, this paper formulates a balise arrangement optimization (BAO) model to study the relationship between the number & locations of balises and parking errors. The resistances, nonlinearity and time delay in train braking system and variable initial speeds that a train enters the parking area are considered in the formulation of BAO model. Moreover, we propose a genetic algorithm (GA) to solve the BAO model and present numerical experiments based on field data collected from Beijing Subway Yizhuang Line. The results indicate that the BAO model can enhance the parking accuracy to about 0.10 m via changing the positions of the balises. Furthermore, we found that: (1) more balises lead to better performance of train parking accuracy; (2) four or five balises are appropriate for balancing the device cost and parking errors.



## 1. Introduction

Railway plays an important role in economic and social development throughout the world since it is regarded as an environmentally friendly transportation with high carrying capacity [1]. In recent years, railways, especially urban rail transit and high-speed railway have received increasing attention in many cities. For example, London, Paris, Madrid, New York, Beijing, etc. own the largest and fastest growing metro networks and the length of the Beijing Subway will extend from 456 km in 2013 to 6606 km until 2016. To ensure the safety of passengers on the jam-packed platforms and enhance the service quality of subway system, nearly all new established subway stations have installed platform screen doors (PSD), which help to prevent passengers from falling down the platforms [2,3]. Accordingly, drivers are required to stop a train more precisely at stations than before.

Meanwhile, balise has been a key positioning equipment for both European train control system Level-3 (ETCS-3) and Chinese train control system(CTCS) [4]. Various data, such as the position and speed of the train, can be transmitted to train onboard when a train passes a balise. In Beijing Subway, several balises are mounted at a station to stop the train

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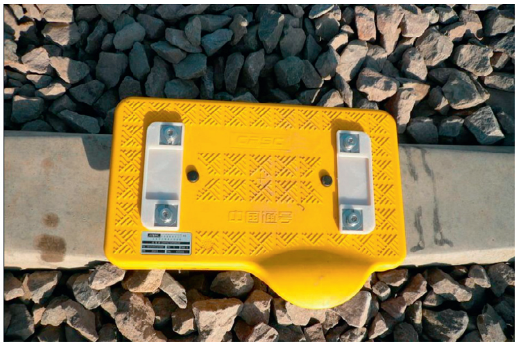
(a) Balises of Xi Zhi Men station in Beijing subway



(b) A balise on the railway track

**Fig. 1.** Balise and its application in train station parking.

more precisely (Fig. 1(a)). When a train passes a balise (Fig. 1(b)), it transfers the stored precise location data to the train instantly. The driver receives the positioning data and makes dynamic adjustments of braking ratio until the train stops at the parking point.

However, how many balises are needed to guarantee the train parking precision and how to place these balises at the best locations still rely on the managers' experience and repeated tests, which is cumbersome and expensive. We called this a balise-arrangement (BA) problem. On one hand, if the number of balises are fixed, the parking errors are affected by the positions of these balises. For example, in actual operation, we place two adjacent balises neither too close nor too far. On the other hand, the number of balises have a great influence on parking errors. We take it for granted that, the more balises that can provide more positioning data, the higher parking precision we can achieve. But more balises will cost more in device and maintenance. In addition, there are some uncertain factors that affect the parking error, *i.e.*, the initial speed when a train enters the parking area in a station, train braking performance and various resistance forces.

One feasible way is to construct a train braking simulation platform with actual operation data. Thus, the arrangement of balises can be tested and verified through this platform. However, there are usually 6 to 7 balises in a subway station, and each balise needs to be placed precisely at the right position so that the train can stop accurately. It is impractical to carry out such amounts of tests to get these positions of the balises. In addition, this trial and error process is time-consuming and the local optimal solution is often obtained in limited field experiments. Therefore, in order to enhance the parking accuracy and reduce the system costs, this paper proposes a mathematical model based on expert knowledge to address the BA problem. First, we formulate an integrated balise arrangement optimization (BAO) model with the consideration of a train's initial speeds, braking performance and the complex resistances. Then, the optimal solution is calculated by a genetic algorithm. The results are verified and compared with field parking data in Beijing Subway Yizhuang Line on a Train Stop Control Platform (TSCP). We study the relationship among the number, positions of balises and the train parking errors. Finally, some practical conclusions are summarized.

The rest of this paper is organized as follows. In Section 2, we review some recent literature on train control system, especially on train station parking or stopping. In Section 3, we analyze the detailed process of train station parking, train braking model and resistances, and then formulate a nonlinear BAO model to minimize the train parking error. In Section 4, we design a genetic algorithm to solve this nonlinear problem. Numerical examples with actual data from Beijing Subway Yizhuang line (BSYL) are presented in Section 5. We conclude this paper in Section 6.

## 2. Literature review

Researches on train control methods contain three levels, *i.e.* energy-efficient train operation, automatic train control and train station parking algorithm. These researches focus on the energy-consumption of rail system and service quality, *e.g.*, punctuality, parking error and comfort of passengers.

On one hand, to save energy-consumption and reduce the cost, researches have paid attention to energy-efficient train operation strategy [5,6]. Howlett [7] and Howlett and Pudney [8] bu ilt a discrete control model and confirmed the fundamental optimality of the accelerate-coast-brake strategy for energy-efficient train operation. Liu and Golovitcher [9] estimated a continuous traction force model with constant efficiency to find the optimal control change points on a multilayer state-variable plain. Wang et al. [10] estimated a comprehensive train operation model with consideration of variable gradient, complex speed limits and comfort of passengers, and proposed two approaches that were pseudospectral methods and a mixed-integer linear programming method. Yin et al. [11] summarized experienced drivers' operation strategies and put forward intelligent train operation algorithms based on expert system and reinforcement learning. In addition, aiming to realize energy-efficiency for multi-trains, cooperative optimization models and algorithms have been studied by Li and Lo [12], Li et al. [13], Yin et al. [14] and Su et al. [15].

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