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Review

Research and development of automatic train operation for railway transportation systems: A survey

Jiateng Yin, Tao Tang *, Lixing Yang, Jing Xun, Yeran Huang, Ziyou Gao

State Key Laboratory of Traffic Control and Safety, Beijing Jiaotong University, Beijing 100044, China

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A B S T R A C T

With the rapid development of communication, control and computer technologies in the last several decades, automatic train operation (ATO), for which the driver no longer has to cautiously operate the control handle, is emerging in many urban rail systems to replace traditional manual driving in recent years. As technology advances in railway systems, one theoretically challenging and practically significant problem is how to use the ATO system to make the current railway network more efficient with higher carrying capacity, lower cost and improved quality of service by optimized railway traffic management and train operation. In this review, we focus on this emerging technology of automatic train operation (ATO) for its theoretical development and practical implementations. Specifically, this study first presents the background of ATO technology in railways, which involves the detailed description of its development and implementation in urban metro systems, fundamental features and basic structure of a typical ATO system. Then, we present a comprehensive literature review in this area, in which the current studies are generally classified into three main aspects, i.e., train operation modeling techniques, train trajectory optimization and train speed control methods. Finally, the emerging requirements for current ATO systems and the most promising research directions in this area in the future are discussed explicitly, including (i) the practical implementation of ATO in main line and high-speed railways, (ii) the cooperative train operation methods for energy-saving issues and (iii) the integration of railway traffic control with advanced ATO technology.

Contents

* Corresponding author.
E-mail addresses: jiatyin@bjtu.edu.cn (J. Yin), ttang@bjtu.edu.cn (T. Tang).

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1. Introduction

Railway transportation, involving the main line railway, urban rail transit (*or metro, subway, underground system, etc*) and the new high-speed railway (HSR), is an efficient means of public transport mode by way of vehicles running on railway tracks. In the past decades, rail transportation systems have changed dramatically in the technology level, total length, travel speed, service qualities, etc. The current rail transport system is playing an essential role in driving sustainable economic growth, providing access for passengers into and between the major economic centres and fulfilling a vital position in the supply chain (TSAG, 2010). In particular, due to the environmental and traffic congestion problems in large cities, urban rail transport is being stressed as an ideally green and convenient transport mode in large cities, such as Beijing, New York, Tokyo, London, etc (Wang et al., 2015). According to the published data by The International Association of Public Transport (UITP), there are more than 148 cities around the world that have a metro system until late 2014, adding up to nearly 540 metro lines, 9,000 stations and 11,000 km of line infrastructure (UITP, 2014). As one of the busiest metro system in the world, Beijing Subway has operated 19 lines with a total length of 574 km, as shown in Fig. 1(a). According to the published data by Beijing Subway, it carried over 10.28 million passengers to their destinations during a single day in April 21, 2017 (see in Fig. 1(b)), which greatly releases the public transport pressures for the alleviation of urban traffic congestions.

How to control the running of trains in order to achieve safe and efficient operation for a railway system is a long-lasting issue dating back to the birth of rail transportation. For traditional railway systems, this is usually realized through (i) a timetable and rolling stock plan that are formulated by an extensive planning process (Cacchiani et al., 2014), which is often made long time ahead of the real-time operations, and (ii) real-time train operation by drivers with the help of fixed signal devices that can deliver train movement authorities, routes, etc, to the on-board drivers (Clark, 2012). Nevertheless, this manual labor based train operation framework has a lot of drawbacks with the rising concerns on increasing transport demand with limited railway infrastructures. In particular, manual driving is generally based on training and experience, which is short of rigorous computation and systematic consideration, and thus, it is difficult to guarantee safety, service quality (e.g., carrying capacity, punctuality, station stopping accuracy) and operational costs (e.g., energy consumption, infrastructure occupation). And this issue is especially severe in urban rail systems, where the passenger demand is extremely high and train departure headway is very short.

With the development of communication, control and computer technologies in the last several decades, automatic train operation (ATO) is considered as an emerging technology to replace traditional manual driving in many urban rail systems (Dong et al., 2010; Miyatake and Ko, 2010; Yasunobu and Miyamoto, 1985). Typically, ATO aims to improve the efficiency of railway traffic operations by automatically making real-time decisions of the optimized train accelerating, coasting and braking commands. With the increasingly serious environmental problems and energy issues, ATO is also widely recognized to be a very promising approach by optimized train control decisions, to reduce the energy consumption and carbon emissions while delivering an improved quality of services (TSAG, 2010). Currently, this important technology has been widely applied to many new established urban rail transit lines, for example the Paris Métro, London Underground, Beijing Subway and Tokyo metro, and has shown its great advantages in reducing the manual labor, enhancing the transport capacity of the infrastructure and improving the service quality for passengers (higher punctuality and more precise train station stopping, etc.). In Beijing Subway, all the lines (except for Line 5, Line 13 and Batong Line) are operated by ATO systems under normal circumstances. In particular, since Line 5 in Beijing Subway is still operated by drivers, the train arrival punctuality is only about 99.5% in the first quarter of 2017. Meanwhile, with ATO systems, the train departure headway of Line 1 in Beijing Subway can be as short as nearly 2 min and the punctuality is kept as high as 99.99%, which illustrates the improvement by implementing ATO systems in urban rail systems.

Meanwhile, the real-world implementations of ATO technologies are still limited to the urban rail lines. To apply ATO system in main line railway or HSRs, a lot of theoretical studies and field tests are still being conducted to verify its feasibility and effectiveness. At the same time, a large number of mathematical optimization models and ATO methods have also been