Transportation Research Part C 57 (2015) 68–84

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Standardization of capacity unit for headway-based rail capacity analysis

Yung-Cheng Lai *, Yun-Hsuan Liu, Yi-Ju Lin

Department of Civil Engineering, National Taiwan University, Taipei, Taiwan

ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form 22 May 2015
Accepted 28 May 2015
Available online 21 June 2015

Keywords:
Rail transportation
Capacity analysis
Base train equivalents

ABSTRACT

Determining the required capacity upgrades to accommodate future demand is a critical process in assisting public and private financing of capacity investments. Conventional railway systems usually operate multiple types of trains on the same track. These different types of trains can exert substantially different capacity impact, and can cause serious operational conflicts. In the past, rail line capacity is commonly defined as the maximum number of trains that can be operated on a section of track within a given time period. However, a specific unit (trains/hr or trains/day) does not reflect the heterogeneity of train types. According to the concept of base train equivalents (BTE) and base train unit (BTU), this study developed headway-based models to determine BTE for transforming different train types into a standard unit (i.e., BTU). An approximate method for lines with three and more types of trains was also proposed to compute BTEs for non-base trains. Results from the case studies demonstrate that this method enables the standardization of rail capacity unit, facilitates assessment of the impact from heterogeneous trains, and allows comparison and evaluation of the capacity measurements from different lines and systems.

1. Introduction

Determining the required capacity upgrades to accommodate future demand is a critical process in assisting public and private financing of capacity investments (Abril et al., 2008; Sogin et al., 2011, 2013; Xu et al., 2014). Conventional railway systems usually operate multiple types of trains on the same track; their differences in train characteristics lead to different capacity impacts on the system (Harrod, 2009; Murali et al., 2009; Corman et al., 2012; Yaghini et al., 2014; Dingler et al., 2014; Corman and Quaglietta, 2015). Rail line capacity is commonly defined as the maximum traffic flow (i.e., number of trains) that a rail line can accommodate within a given time period (Krueger, 1999; Kittleson and Associates et al., 2003; Kozan and Burdett, 2005, 2006; Sun et al., 2014). However, disregarding the concern of heterogeneity can lead to the failure of a particular unit (trains/hr or trains/day) to adequately represent the capacity that the unit refers to. For example, 10 trains per hour can refer to the ability to operate "10 fast intercity express trains" or "10 slow local trains" in an hour; it may even jointly refer to a mix of fast and slow trains. The impacts of their capacity can be substantially different. For a more accurate capacity calculation, the classification of different train types must be converted into a standard unit (Lai et al., 2012).

Several methods have been applied to assess passenger car equivalents (PCE) for highway capacity analysis. Different traffic conditions in different heterogeneity may result in the same V/C ratio; hence, the difference in traffic conditions with the same V/C ratio can be used to determine PCE (Linzer et al., 1979; May, 1990; Ingle, 2004). Several studies computed PCE

* Corresponding author. Tel.: +886 2 3366 4243.
E-mail addresses: yclai@ntu.edu.tw (Y.-C. Lai), vincentliu0113@gmail.com (Y.-H. Liu), b97501011@gmail.com (Y.-J. Lin).

http://dx.doi.org/10.1016/j.trc.2015.05.013
0968-090X/

based on equal speed or density method because the level of service is defined as the average running speed and density in the Highway Capacity Manual (Huber, 1982; Van Aerde and Yagar, 1984; TRB, 1985). Delay-based approaches have been developed to estimate the capacity impact from heavy vehicles compared with that from passenger cars (Benekohal and Zhao, 1999; Cunagin and Messer, 1983; Kozan and Burdett, 2005; Rodriguez-Seda and Benekohal, 2006). Headway-based methods have also been proposed to compute PCE based on headway between adjacent vehicles (Werner and Morrall, 1976; Seguin et al., 1982; Krammes and Crowley, 1986). These studies found that an appropriate method to compute PCE for each type of capacity model should be consistent with the model characteristics.

Numerous approaches and tools have been developed to determine rail line capacity. Each approach, which has been generally designed for a specific type of purpose, has strengths and weaknesses. Railway capacity tools can be categorized into (i) analytical, (ii) parametric, and (iii) simulation (Abril et al., 2008; Gorman, 2009; Lai and Barkan, 2009). In the analytical approach, mathematical formulas or algebraic expressions of headway and/or blocking time are generally developed according to railway infrastructure to determine railway capacity (Linzer et al., 1979; Pachl, 2002; Kittleson and Associates et al., 2003; Kozan and Burdett, 2005, 2006; Abril et al., 2008). Parametric models are formulated based on field data or simulated data; with a developed parametric model, delay and line capacity can be efficiently determined (Prokopy and Rubin, 1975; Krueger, 1999; Dingler et al., 2009; Sogin et al., 2013; Lai et al., 2014). Simulation models estimate train delay based on given infrastructure configurations and decision rules of train dispatchers (Abril et al., 2008; Bronzini and Clarke, 1985; Fransoo and Bertranda, 2000; Vromans et al., 2006). Simulation is usually more time consuming and data intensive compared with the analytical or parametric models.

Previous studies on heterogeneity in railway operations have focused on identifying the impact of heterogeneity on capacity; however, no standard mechanism can evaluate the impact of heterogeneity and subsequently convert different types of trains into a standard unit (Dingler et al., 2009, 2013; Lai et al., 2010a,b; Yaghini et al., 2014). A few studies attempt to adjust the capacity output by using a "deduction coefficient" to represent the impact of heterogeneous trains (Yang et al., 1995; Yan, 1997; Sun et al., 2001; Zhao, 2001; Tian et al., 2002). Studies by Yan (1997), Sun et al. (2001) and Tian et al. (2002) compute the deduction coefficient based on the difference in running time from freight and passenger trains. Yang et al. (1995) and Zhao (2001) consider the differences in stopping patterns to estimate the deduction coefficient for high speed trains. Although using deduction coefficient can take into account heterogeneity to certain degree, these methods are rather simple and limited to only two types of trains by using differences in running time or stopping patterns, and assuming fixed deduction coefficient regardless of the traffic mix. Capacity bottlenecks usually occur when adjacent trains enter or depart a station due to meets and passes; hence, departure and/or arrival headways govern system capacity and have to be considered (Parkinson and Fisher, 1996; Jong et al., 2009). Furthermore, users cannot freely choose the base train and determine the "standard capacity unit" as needed.

Lai et al. (2012) proposed the concept of base train equivalents (BTE) to convert multiple types of trains into a standard unit (i.e., base train unit (BTU)). They also proposed a delay-based approach to determine BTE based on the results obtained from parametric capacity analysis and simulation. Although the concept of BTE can be adopted, delay-based BTE models cannot be applied to headway-based analytical capacity analysis (Lai et al., 2012). Therefore, the present research focuses on the development of BTE models for headway-based analytical capacity analysis. Using this method enables the standardization of rail capacity unit, facilitates assessment of the impact from heterogeneous trains, and allows comparison and evaluation of the capacity measurements from different lines and systems.

2. Methodology

The concept of BTE is to reflect the difference in capacity impact between non-base and base trains, which can be defined as the ratio of the capacity impact of a non-base train to a base train. As mentioned previously, appropriate BTE methods should be established in consistent with the characteristics of the selected rail line capacity model. Every railway system has its own train types and preferences with regard to the "base train". Therefore, the developed BTE models should be general enough to permit the selection of any base train. By contrast, if different operators from different systems can form a consensus on the "base train", the capacity measurements from different lines or systems can be compared and evaluated.

In the following sections, we first summarize the basic formulation for headway-based analytical capacity models in Section 2.1 followed by the development of headway-based BTE models. Section 2.2 presents the exact formulation of headway-based models to determine BTE for transforming different train types into a standard unit. However, this exact BTE model cannot be directly applied to scenarios with three or more types of trains. Therefore, an approximate method was also proposed to compute BTEs in Section 2.3. In Section 2.4, we developed a process to evaluate the reasonableness of the BTE values computed based on the exact and approximate methods.

2.1. Headway-based capacity analysis

Headway-based capacity analysis is widely used to evaluate railway capacity (Linzer et al., 1979; Pachl, 2002; Kittleson and Associates et al., 2003; Pachl and White, 2004; UIC, 2004; Kozan and Burdett, 2005, 2006; Abril et al., 2008; Lai et al., 2010a,b). This type of analytical method can efficiently compute capacity and identify system bottlenecks. Although the detailed computational process may be different, the general concept of various headway-based models is the same: through