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An integrated framework for assessing service efficiency and stability of rail transit systems

Yung-Cheng Lai *, Chi-Sang Ip

Railway Technology Research Center, Department of Civil Engineering, National Taiwan University, Taipei, Taiwan

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ABSTRACT

A well-designed service plan efficiently utilizes its infrastructure and ensures an acceptable level of service stability with consideration of potential incidents that disturb or disrupt the rail transit services. To perform service evaluation, an integrated process combining capacity, resource usage, and system reliability is required to quantify service efficiency and stability in a consistent way. This study adopts capacity-based indices, "capacity utilization" and "expected recovery time", as the attributes for service efficiency and stability, and develops a comprehensive evaluation framework with three corresponding modules to incorporate capacity, service plan, and system reliability and maintainability simultaneously. The capacity analysis module computes the rail transit capacities under normal and degraded operations. The reliability module classifies and fits the proper reliability and maintainability distributions to the historical interruption data. The service efficiency and stability module analyzes the results of the previous two modules and evaluates the service efficiency and stability of rail transit service plans. Empirical results show that the established evaluation framework can not only evaluate the service efficiency and stability but also identify critical sections and time slots. This tool can help rail transit operators rapidly assess their operational changes and investment strategies related to efficiency and stability so as to provide efficient and stable services to their customers.

1. Introduction

1.1. Background

A rail transit service plan describes the routes and service frequency the system provides to passengers. A well-designed service plan should efficiently utilize its infrastructure as well as ensure an acceptable level of service stability with consideration of potential incidents that disturb or disrupt the rail transit services. Disturbances usually refer to incidents with short service interruptions while disruptions refer to incidents incurring long interruptions to the system (Zilko et al., 2016). For rail transit systems in Taiwan, all types of disturbances and disruptions, both regarded as "interruptions", should be recorded to reflect the reliability of the system. In consideration of potential system interruptions, operators should incorporate an appropriate level of slack in the service plan to allow for the efficient recovery of the system to the normal state (Nilsson, 1999; Gallo et al., 2011; Lai et al., 2015).

* Corresponding author.
E-mail address: yclai@ntu.edu.tw (Y.-C. Lai).

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A successful rail transit operation presents a balance mix of service efficiency and stability. Infrastructure capacity, service plan, and system reliability and maintainability of a rail transit system should be considered simultaneously to evaluate service efficiency and stability (Fig. 1). Capacity is defined as the maximum transportation capability of a rail transit system. A service plan dictates how much capacity is used in actual operations. Reliability and maintainability reflect the potential interruptions and their effects on the system. Evaluating the service efficiency and stability of a rail transit service is comparable to assessing the efficiency and stability of the usage of a water cup. The size of the cup defines its capacity. The amount of water inside the cup represents the actual use of these resources. The higher the usage the higher the efficiency. However, a certain slack is usually left in the cup to absorb possible interruptions when lifting the cup. A stable usage of the cup can keep the water inside the cup even with the interruptions whereas an unstable usage of the cup may end up with spilled water all over the ground. Therefore, it is important to capture the level of the interruptions through experiences or historical data. Consequently, an integrated framework combining capacity, resource usage, and system reliability is needed for efficiency and stability evaluation.

This study aims to develop an integrated framework and corresponding modules to evaluate rail transit service efficiency and stability based on infrastructure capacity, service plan, and system reliability and maintainability. This process can help planners to quickly assess the impact on service efficiency and stability from possible changes in the service plan or potential improvements in the system reliability. Operational changes and/or investment strategies can be evaluated before actual implementation so as to ensure the service efficiency and stability.

1.2. Literature review

Measurement and monitoring capacity enables more efficient utilization of the rail transit systems (Kittelson and Associates et al., 2003; Abril et al., 2008). Rail transit capacity models use the characteristics of the traffic and infrastructure to compute the amount of traffic (e.g., trains) that can move over a specific segment in a given time period (Parkinson and Fisher, 1996; Thurston, 2004; UIC, 2008). The timetable-compressing method recommended by UIC 406 Leaflet (UIC, 2004) is a popular method for computing capacity consumption (in percentage). However, the UIC 406 method can only be used in the condition with a known timetable. As a result, it can evaluate the capacity consumption for normal condition (with a given timetable) but cannot estimate capacity in the degraded mode (without a different timetable). Furthermore, several studies in the past indicated that the UIC 406 method is not suitable for computing section capacity, and showed that using this method may lead to inaccurate capacity consumption if the rail line is not correctly chosen (Landex, 2009; Tobias, 2011). Several other capacity models have been developed specifically for rail transit systems (Parkinson and Fisher, 1996; Kittelson and Associates et al., 2003; Chen et al., 2009; Jong et al., 2010, 2011; Legara et al., 2014; Xu et al., 2014; Canca et al., 2016). The Transit Capacity and Quality of Service Manual (TCQSM), which is the most popular capacity evaluation tool for North American rail transit systems, provides a detailed introduction on the fundamental concepts and factors in rail transit capacity analysis (Kittelson and Associates et al., 2003). Jong et al. (2011) adapted the concepts in TCQSM, established a set of comprehensive rail transit capacity models by considering modern signaling systems, including systems with speed codes, distance-to-go, and moving blocks, identified possible movements for critical track layouts. The aforementioned studies focus on the determination of the maximum capacity without considering the reliability of the system and subsystems. Furthermore, existing rail transit capacity models can evaluate rail transit capacity during the normal operations but cannot be applied to estimate capacity in the degraded mode. When the rail transit operation is disturbed or disrupted by interruptions, such as track outage, breakdown of trains, or failure of the signaling or power supply system, some of the tracks may be out of service, and the capacity is significantly reduced. In order to understand the capability of the system during the degraded mode, a rail transit capacity model to estimate capacity during degraded operations (i.e., degraded capacity model) is needed.

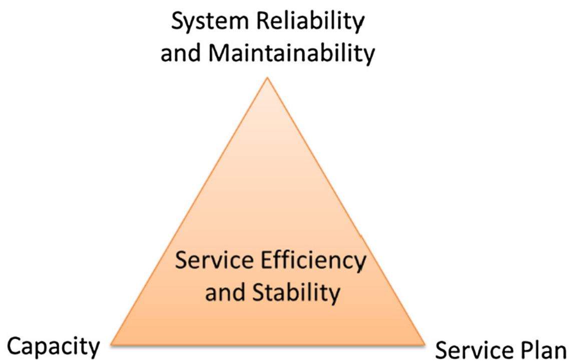

Fig. 1. Key factors in the evaluation of rail transit service efficiency and stability.