A study of homogeneity of operating programs on operation quality considering the occupancy of infrastructure

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ABSTRACT

The homogeneity of operating programs plays a significant role in the efficient utilization of a railway network. During last decades, many researchers tried to describe and/or define the homogeneity of operating programs in railway systems. According, there are several main methods to evaluate the homogeneity of operating programs considering variations in speed and headway. But, the occupancy of infrastructure has not been discussed in the existing definitions and methods.

This article defines the homogeneity of operating programs from the perspective of the occupancy of infrastructure which can be characterized by variations in blocking time, buffer time and running direction. Based on this definition, a new occupancy based method to evaluate homogeneity of operating programs is presented in this paper. By this method, the homogeneity of operating programs can be calculated based on the blocking times, buffer times and running directions without identifying other factors such as the speed or length of a train. The occupancy based methodology is successfully used to quantify the homogeneity of railway operations, not only for track sections but for an entire network, which contributes significantly to the efficient utilization of complex infrastructure. Finally, the interrelationship between homogeneity of operating programs and operation quality is investigated.

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1. Introduction

As economies develop and thrive, railway operations worldwide are confronted with a general increase in traffic demand. The increase in regions with well-developed railway infrastructure is particularly critical driving operations to the capacity limits. The consequence is a system more sensitive to disturbances and in turn, more prompt to a decrease in operation quality (i.e. larger delays and lower average punctuality). Therefore, how to accommodate this significant amount of mixed traffic demand with adequate operation quality is a major issue for infrastructure manager as well as train operators. This issue can be addressed through the improvement of signaling systems and infrastructure, while it is inarguably not an efficient solution regarding money, time and labor. In addition, the space for an extensive construction is limited after decades

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1 Capacity Limit: A typical value that if the infrastructure occupation [% of time-window] is higher than or equal to, the analyzed line section shall then be called congested infrastructure and no more additional train paths may be added to the timetable (UIC, 2013).

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of infrastructure development, especially in bottlenecks and high-density station areas. Comparatively, the efficient utilization of existing infrastructure turns out to be a flexible solution, which plays an important part in the future development of the railway systems.

Efficient use of infrastructure requires a certain amount of train paths; on the other hand, the operation quality should meet the requirement of passengers and operators. Schittenhelm points out that capacity consumption levels compared with homogeneity level of train traffic can give a picture of efficient use of the available infrastructure (Schittenhelm, 2013). It is generally accepted that an efficient utilization of existing infrastructure can be achieved with a more homogeneous operation (Hertel, 1992; Carey, 1999; UIC, 2004b; Vromans et al., 2006; Landex, 2008; Pachl, 2013; Schittenhelm, 2013). From another perspective, inhomogeneity as the result of offering customized services for different market segments usually leads to larger capacity consumption and smaller buffer times between consecutive trains (smaller buffer times normally locate where the trains catch up each other) if no improvement has been made to signaling system and infrastructure, which may increase delay propagations in operation.

However, homogeneity is not easy to define comprehensively related to railway operation; in fact, many researchers have tried to address this problem for last decades. A definition is given by Vromans who considered railway traffic to be homogeneous if all trains have similar characteristics, especially the same average speed per track segment, resulting from the running and stopping times (Vromans et al., 2006). Another description, based on timetables, is given by Landex who explained that a timetable is homogeneous when there is no variation in speed, stop pattern, and headway times (Landex, 2008). In UIC leaflet 406 (UIC, 2004b), inhomogeneity was related to differences in running times between different train types on the same track. In general, the variations in the speed (and thereby the stop pattern) and/or headways were taken into account to describe the homogeneity in the railway system. However, so far, no literature that considers the occupancy of infrastructure to define homogeneity has been found. Therefore, an expansion of existing definition of operational homogeneity for general usage is presented in this article including the aspect of occupancy of infrastructure.

Based on the existing definitions of homogeneity, there are various approaches to evaluating homogeneity quantitatively (see Table 1). Hertel put forward that the coefficient of variation of inter-arrival time\(^3\) (headway) and service time\(^4\) (minimum headway) indicate the homogeneity in railway operation which determine the lower and upper limitations of the “recommended area of traffic flow”\(^5\) (Hertel, 1995; Chu, 2014). In 1999, Carey described several methods for the measurement of homogeneity which focused on headways between consecutive trains (Carey, 1999): the percentage of headways smaller than a certain size, the percentiles of headways distribution, the range, the standard deviation, and the variance or the mean absolute deviation of headways. These approaches don’t account the behavior of trains on the surrounding track sections since the headways are measured at one single location. Therefore, Vromans et al. (Vromans et al., 2006; Vromans, 2005) developed indicators \(\text{SSHR}\) (Sum of Shortest Headways Reciprocals) and \(\text{SSBR}\) (Sum of Shortest Buffer Reciprocals). \(\text{SSHR}\) considers the smallest headways between two consecutive trains on a particular track section instead of at one single location. \(\text{SSBR}\), besides, uses buffers instead of planned headways to calculate homogeneity. Under the assumption that the headway at arrival station is more important than that at departure station for secondary delays, indicator \(\text{SAHR}\) (Sum of Arrival Headways Reciprocals) considers only the headways at arrival station (Vromans, 2005). However, these measurements of homogeneity give different results depending on the number of trains examined. In (Landex and Jensen, 2013), homogeneity indexes independent of the number of trains examined were developed, as the sum of the ratios between the headway and the following headway and divided it by the number of headways minus 1. Measurements were further improved by taking the variation in headways and speeds into account in (Landex, 2008; Lindfeldt, 2015). The SAHR is equal to the SSHR only when trains are running at same speed. In inhomogeneous cases, the SAHR is smaller than the SSHR, and the difference between them increases with the increases in speed. The ratio of SAHR and SSHR, therefore, was calculated as an indicator to represent the variation in the speed (Landex, 2008). Nevertheless, the calculated ratio is still equal to 1 if identical trains are operated with different headway times, resulting in an inhomogeneous operation. Therefore, the ratio of the headway at a departure station to the following headway, multiplied by the ratio of headways at arrival stations, took the variation of headways into account. As a supplement to SSHR and SAHR, indicators \(\text{MDSR}\) (Mean of the Difference in Scheduled Running time) and \(\text{MDFR}\) (Mean of the Difference in Free Running time) were introduced, based on the timetable, to describe the differences in running time (Lindfeldt, 2015). MDFR was found to have higher explanatory value than MDSR due to that MDFR is independent of traffic load, while MDSR depends on the traffic load. These methods evaluate the homogeneity of operation at stations and/or on particular track sections, without considering the operational use of track sections. Also, it is hard for them to get the overview of the homogeneity of operation across an entire network. As a consequence, a new method for the evaluation of homogeneity, including the aspect of occupancy of infrastructure, is proposed in this article.

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\(^2\) Occupancy of infrastructure means the operational use of track section by a train movement in this article.

\(^3\) Inter-arrival time: The inter-arrival time is the difference between succeeding arrival times of requested trains or train paths in queueing theory, which is equivalent to the headways in railway operation (Hertel, 1992; Chu, 2014).

\(^4\) Service time: Service time is the time a customer (train) occupies a certain part of the infrastructure for service based on the queueing theory.

\(^5\) Service time: Service time is the time a customer (train) occupies a certain part of the infrastructure for service based on the queueing theory. In railway operation, the service times are often represented by the minimum headway times (not to be confused with blocking time) (Hertel, 1992; Chu, 2014).
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