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Regularity-driven bus operation: Principles, implementation and business models

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ABSTRACT

Service reliability is a key determinant of public transport performance. In the context of high-frequency urban lines, irregular service results with long waiting times, bunched vehicles, long delays, uneven passenger loads, poor capacity utilization and higher operational costs. Field experiments were conducted in Stockholm, Sweden, in order to test the feasibility and implications of a regularity-driven operation scheme designed to mitigate bus bunching and facilitated by a real-time control strategy. This paper investigates alternative service indicators and business models that could best support the long-term implementation of operation geared towards better regularity performance. A paradigm shift towards regularity-based service evidently requires the consideration of a series of measures along the service chain as it involves a paradigm shift in production planning, operations, control center and performance monitoring.

1. Introduction

Service reliability is one of the most important level-of-service determinants for both public transport users as well as for attracting car users (Redman et al., 2013). Moreover, public transport reliability also influences operation efficiency. In the context of high-frequency urban lines, an unreliable service results in long waiting times, bunched vehicles, long delays, uneven passenger loads and poor capacity utilization. In addition, more reliable public transport performance can also imply lower operating costs and more efficient crew management. Public transport operating environment is very uncertain. Sources of uncertainty include dispatching from the origin terminal, travel time between stops, and dwell times.

Service reliability could be considered either in terms of punctuality or regularity. In the context of high-frequency services, passengers typically arrive randomly at stops without consulting the timetable. Hence, service regularity is the main determinant of passenger waiting time and reliability needs to be interpreted in terms of regularity rather than punctuality. Waiting time unreliability is therefore manifested in terms of excessive waiting time which could be approximated based on the statistics of the waiting time distribution (e.g. Pulley et al., 2006).

Transport planning authorities and bus operators have deployed throughout the years a large range of measures of counteract sources of service uncertainty and improve service reliability. These measures include dedicated right of ways such as bus lanes and bus signal priority which aim to reduce running time variability. Other measures such as pre-ticketing or on-board validation, allowing passengers to board from all doors and allowing buses to overtake each other at stops are designed to decrease dwell time variability. Previous studies analyzed the impacts of such strategies and quantified their implications on service reliability (Tetreault and El-Geneidy, 2010; Diab and El-Geneidy, 2010). While these measures may reduce the underlying sources of service uncertainty, service reliability also depends on operation practices such as dispatching regime, driving patterns and control strategies along the line.

Public transport control strategies are designed to improve service performance by applying various operational methods (Van Oort and Van Nes, 2009; Cats et al., 2011). Holding strategies are among the most widely used aiming at improved service regularity by regulating departure time from stops according to pre-defined criteria. The design of holding strategies includes the stops where control is exercised, the conditions under which holding is used, and the amount of holding time. The common practice among bus operators is to hold buses based on their punctuality with a certain time window allowance. Therefore buses hold at certain stops if they are early with respect to the timetable. The commonly used on-time performance incentive exercises numerous drawbacks as it neither captures the extent of service reliability nor reflects passenger perception of service reliability.

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Moreover measuring the performance only at a small subset of stops along the line contributes to abrupt performance patterns.

Measures to reduce waiting times for high-frequency service must therefore focus on keeping even headways between buses rather than adhering to the schedule. Nevertheless, the common practice is to operate all services with punctuality as the main measure of performance (TCRP, 2003). On-time performance is thus often an important clause in procurement contracts between public transport agencies and operators (Camen, 2010).

This paper analyses a new regularity-driven operation scheme that was tested in two field experiments in Stockholm, Sweden. The proposed scheme demonstrated its capability to mitigate bus bunching. The aim of this paper is to present this new real-time control strategy and to investigate based on theory and empirical results how it could be embedded into business models in order to improve bus service regularity by supporting its full-scale implementation. The development of a service focused on regularity involves a paradigm shift in production planning, operations, control centre and performance monitoring.

2. Indicators of service regularity

In order to improve service reliability it is essential to monitor and predict the level of service reliability. A large range of measures aimed to assess service regularity were proposed by previous studies. Ideally, all buses would be equally spaced along the line resulting with even intervals between successive bus arrivals. However in reality there are many factors that hinder buses from running regularly. These factors include variations in travel conditions, driver behavior and passenger demand. Moreover, buses do not even depart from the first stop regularly. These factors are of course interrelated through the relation between the headway between consecutive buses, the number of waiting passengers and dwell times as well as the propagation of delays through trip chaining. This results with a vicious cycle since a bus with a long headway will have to pick up more passengers causing it to be further late while the succeeding vehicle increasingly catches up. As service becomes more irregular, the average waiting time and average crowding level increase and yield an inefficient capacity utilization. This process leads to the well-known bunching phenomenon.

Most regularity indicators are based on headway distribution and its relation to the planned headway. This category includes the coefficient of variation of headway (e.g. Cats et al., 2011), headway adherence (TCRP, 2003), an index based on the Gini ratio (Henderson et al., 1991) and an irregularity index that particularly penalizes long headways (Golshani, 1983). Strathman et al. (1999) used the ratio between observed and scheduled headway as an instantaneous measure for identifying bus bunching. Trompet et al. (2011) proposed a measure that allows accounting for variations in the planned headway by calculating the standard deviation of the difference between the planned and the actual headways. Other measures refer to the share of headways that are within a certain time interval, similarly to their on-time performance counterparts. This includes the share of headways that deviate by no more than a certain time interval from the scheduled headway where the interval could be specified in either absolute terms or relatively to the scheduled headway (Trompet et al., 2011). Similarly, the average deviation from the planned headway could be expressed as a percentage of this headway.

An additional category of regularity indicators is based on passenger waiting time distribution. Osuna and Newwell (1972) established the relationship between headway variation and average passenger waiting time measure based on the assumption that passengers arrive uniformly at stops. Average passenger waiting time was shown to be the sum of half the average headway and the ratio of headway variance to be twice the average headway. London Buses use a variation of this indicator which computes the difference between the actual and scheduled waiting times at the disaggregate level based on individual headways. The scheduled waiting time is calculated as half the planned headway. This measure indicates how much longer than intended passengers are waiting on average—for example a value of 1.5 indicates that passengers wait 50% longer than planned (Transport for London, 2012).

The distribution of headways is the fundamental input necessary for computing regularity indicators. A bus fleet that is fully equipped with automatic vehicle location (AVL) system will enable the calculation of robust regularity measures. Each headway observation, $h_{k,s}$, corresponds to the actual headway between trip $k \in K$ and the successive trip at stop $s \in S$, where K is the set of vehicle trips traversing a specific line under a certain period, S is the set of stops on the respective line and h_p is the corresponding planned headway.

The selected key performance indicators should be both comprehensive and concise in order to facilitate a consistent and understandable comparison among various lines and operators. Three regularity indicators are used as the primary measures of performance in this study:

- *Headway coefficient of variation*, CV(h)—the ratio between the standard deviation and the mean actual headway is

  $$\mathrm{CV}(h) = \frac{\sigma_{h_{k,s}}}{\sum_{k \in K} \sum_{s \in S} h_{k,s} / (|K| \times |S|)} \tag{1}$$

  where $\sigma_{h_{k,s}}$ is the standard deviation of the observed headways. It is a normalized measure of headway variability which takes the value of zero in the ideal case that all headways are equal. The more irregular the service is the higher the CV(h). This is a robust statistical measure that provides a direct indication of service variability. However, it is not intuitive and may not be fully representative of users' experience.
- *Headway adherence*, HA—the share of buses that arrives with a headway that does not deviate from the planned headway by more than a certain percentage:

  $$HA = \frac{\sum_{k \in K} \sum_{s \in S} \delta_{k,s}}{|K| \times |S|} \tag{2}$$

  where $\delta_{k,s} = 1$ if $\left|(h_{k,s} - h_p/h_p/h_p)\right| > \alpha$ and α is a pre-defined threshold. Depending on the service and the level-of-service standards, α may vary between 0.1 and 0.75, although for most urban services this range can be truncated to $0.2 \le \alpha \le 0.5$. This measure is easy to communicate as it is percentage-wise and comparable across lines and systems. However, it penalizes evenly all headways that satisfy the threshold requirement regardless of the extent of deviation. This measure also captures the impact of missed trips.
- *Average excess waiting time*, EWT—the additional waiting time that passengers experience due to irregular bus arrival.

  $$EWT = \sum_{k \in K} \sum_{s \in S} b_{k,s} \frac{h_{k,s}}{2} - \frac{h_p}{2} \tag{3}$$

where $b_{k,s}$ is the number of passengers boarding trip k at stop s. The first expression is the average waiting time assuming that passengers arrive randomly during the headway, from which one subtracts the theoretical waiting time that would have occurred if buses followed the planned headway. In case passenger counts are not available for each trip, the number of boarding passengers could be estimates as linearly proportional to the corresponding headway based on the average of historical or sample passenger counts.

The aggregation of excess waiting time results with subtracting the waiting time of a perfectly reliable service from the actual waiting time induced by the service delivered. A perfectly regular