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# Commercial bus speed diagnosis based on GPS-monitored data

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ABSTRACT

Commercial bus speed is a key factor in the operation of public transport systems because it represents a direct measure of the quality of service provided to users and also considerably affects system costs. By commercial speed, we are referring to the average speed of buses over stretches, including all operational stops. Evaluating system performance by monitoring the commercial speed provided by bus services is highly desirable; however, in dense networks, it becomes a difficult task because of the amount of information required to implement such a monitoring procedure. The introduction of GPS technology in buses can overcome this difficulty in terms of information availability, although it presents the challenge of processing huge amounts of data in a systematic way. Here, we present a method based on GPS-generated data to systematically monitor average commercial bus speeds. The framework can be applied to each bus route as a whole, as well as over segments of arbitrary length, and can be divided into time intervals of arbitrary duration. The results are presented as matrices and graphs that can be read and interpreted easily. We discuss the potential of this methodology to provide useful insights for bus system planners and operators. The method and its applications are illustrated with data coming from the Santiago–Chile public transport system (Transantiago), where GPS observations of more than 6000 buses operating on over 700 different routes are available every 30 s.



## 1. Introduction

In operational terms, commercial bus speed is a key variable in the operation of public transport systems because it is related to both the level of service provided to users and the system cost. By commercial speed, we are referring to the average speed of buses over stretches, including all operational stops (bus stops, terminals, and traffic lights). This definition of commercial speed is different from what is defined as running speed, which only considers moving buses. Monitoring the status of commercial speed (hereinafter referred to as speed) is important, although it becomes very difficult in cases of dense route networks, mainly because of the amount of information required for such a process. Currently, vehicles are equipped with GPS technology, which allows us to overcome this difficulty by means of proper interpretation and handling of the data provided by GPS devices.

In this study, we present a method based on GPS-generated data to systematically monitor average bus speeds. The framework can be applied to each bus route as a whole, as well as over segments of arbitrary length, and can be divided into time intervals of arbitrary duration. The proposed methodology is able to capture and process valuable information, such as system performance based on bus movement data using GPS devices. In addition, the described methods facilitate the use of

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tools to depict speed indicators in a useful way for diagnostic purposes, even for intricate bus networks. These results are presented as matrices and graphs that can be read and interpreted easily. We discuss the potential of this methodology to provide useful insights for bus system planners and operators.

Some typical difficulties faced in the daily operation of a bus system can be caused by unexpected traffic conditions in cases where buses are mixed with other vehicles in most routes, which increases travel time uncertainty and delays at bus stops. In cases of severe congestion, it may be advisable to propose the construction of exclusive bus-ways and specialized infrastructure for fare collection outside of buses or traffic light optimization to improve bus circulation. The development of a tool that is able to provide a diagnosis of bus speed is useful for planners and operators to make decisions regarding the implementation of major projects and management measures. The analysis can be performed at different disaggregation levels, starting from a global picture of the situation and moving to a detailed description of a specific bus route over a specific segment of interest.

Broadly speaking, the literature concerning the applications of GPS information for improving bus system operations can be classified into three major areas. First, there is an area of study that utilizes real-time GPS pulses for the design and development of online control algorithms, management measures and real-time information systems for users and operators. Second, several studies have proposed to estimate travel time of general traffic by using offline GPS data of buses as probes. Finally, some studies have used offline GPS data for speed monitoring to evaluate system conditions or improve transit service by managing schedules or creating timetables.

With regard to the first area of study (online GPS data for operational control strategies), the most popular real-time control strategy for buses is holding, where vehicles are held at certain bus stops to homogenize headways. Eberlein (1995) showed that holding strategies could reduce the variance of passenger waiting times as well as the expected values of both waiting and travel times. Several authors have explored holding models that rely on real-time vehicle location information (Eberlein et al., 2001; Hickman, 2001; Sun and Hickman, 2004; Zolfaghari et al., 2004). Another attractive real-time strategy is known as stop-skipping. Stop-skipping involves speeding up buses by skipping (one or more) bus stops so that vehicles may recover their planned schedules after disruptions or unexpected delays. Khoat and Bernard (2006) showed that this strategy would effectively reduce in-vehicle travel time for passengers; however, the decision maker must be aware of the increase in waiting times experienced by passengers whose stops were skipped. This strategy has been studied by Lin et al. (1995), Eberlein (1995), Eberlein et al. (1999), Fu and Liu (2003), and Sun and Hickman (2004), among others. Recently, Cortés et al. (2010) and Sáez et al. (2010) designed and evaluated a predictive control strategy that integrated the two strategies (holding and stop-skipping) to solve a real-time predictive control problem with uncertain passenger demand.

In a second area of research, some studies used buses as probes to characterize and evaluate arterial performance. Tantiyanugulchai and Bertini (2003) used information of one corridor from both AVL and GPS data and found that the maximum instantaneous bus speed achieved between stops was the most reliable output to represent general traffic movement (i.e., non-bus traffic). Pu and Lin (2008a) reviewed five cases of using buses as probes and highlighted the limitations of the methodology in the following situations: the understanding of the bus-car interaction in urban traffic streams, the uncertainty of bus operations, the lack of traffic data and the difficulty of handling and processing massive AVL data. Pu and Lin (2008b) studied a short segment of a bus route to compare the use of archived driven space, AVL (fixed position at certain points along bus routes) and online time-driven data (data provided by a GPS). They concluded that both types of data have a similar capacity to estimate travel time, although time-driven information is able to better describe the bus operation phenomena. Berkow et al. (2007) also discussed the possibility of using buses as probes to evaluate arterial performance.

Finally, the third line of research, which has grown recently, deals with the use of GPS data of varying coverage levels that provide a reliable source of information with great potential for speed monitoring. For example, Storey and Holtom (2003) presented a United Kingdom application that uses historical data from different types of vehicles and concluded that GPS speed measurements are more accurate than moving car observer measurements. Jiang (2001) studied the effect of road work areas (on the Indiana freeway) on speed using a test vehicle equipped with a GPS. They estimated acceleration and deceleration rates based on one-second time intervals. They affirmed that GPS data are more accurate than data obtained using traffic counters. Greaves and Figliozzi (2008) used a GPS survey of commercial vehicles in Melbourne, Australia to obtain profiles of truck speeds. Furthermore, Gurushinghe et al. (2002) reported the result of an empirical study made on a probing field, which concluded that the accuracy of the data obtained using GPS technology was superior to that of the same data obtained using conventional measurements.

With regard to potential applications for vehicle dispatch and schedules, Berkow et al. (2007) studied the potential uses of information available from Tri Met transit operators in Portland, Oregon. They developed aggregate measurements that focused on determining schedule adherence. They analyzed the speed/time-of-day relation for buses on one particular route. Moreover, in a web page application, Strathman et al. (1999) proposed a new bus dispatch scheme based on a system that captured vehicle position and passenger boarding data. Four service reliability indices were optimized (headway ratio, run time ratio and a coefficient of variation associated with both). They showed the benefits of such a system compared to the current automatic dispatch implementation. Dueker et al. (2003) used the same information system to determine the dwell time and alighting time of passengers; they performed a sensitivity analysis with respect to conditions such as the type of route and the height of the bus floor. Finally, Kimpel (2007) developed a methodology for visualizing passenger boarding data at bus stops as scaled circles on a whole-city map. Finally, Quiroga and Bullock (1998) proposed a method to estimate the speed over a segment of a bus route using GPS data points emitted by buses when they are close to either the entrance or exit of the defined segment.