Transportation Research Part B 68 (2014) 123–140

Contents lists available at ScienceDirect

Transportation Research Part B

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

On the impacts of bus stops near signalized intersections: Models of car and bus delays

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ARTICLE INFO

Article history:
Received 15 February 2014
Received in revised form 5 June 2014
Accepted 6 June 2014

Keywords:
Near-side and far-side bus stops
Kinematic wave theory
Car delays
Bus delays
Bus holding

ABSTRACT

Models are formulated to predict the added vehicle and person delays that can occur when a bus stop is located a short distance upstream or downstream of a signalized intersection. Included in the set of models are those that predict the expected delays that cars collectively incur when a bus blocks one of multiple lanes while loading and unloading passengers at the stop. Others in this set predict the expected added delays incurred by the bus due to car queues. Each model is consistent with the kinematic wave theory of highway traffic, as is confirmed through a battery of tests. And each accounts for the randomness in both, bus arrival times at a stop, and the durations that buses dwell there to serve passengers. Though the models are analytical in form, solutions come through iteration. Hence model applications are performed with the aid of a computer.

The applications presented herein show that bus delays can often be shortened by placing the bus stop downstream of its neighboring signalized intersection, rather than upstream of it. In contrast, car delays are often shortened by placing the stop some distance upstream of the intersection, rather than downstream. We further show how exerting a measure of control on bus arrivals can further enhance these benefits to cars without further delaying the buses. The models are also used to assess the net person delays collectively incurred by car- and bus-travelers.

1. Introduction

Curbside bus stops are commonly located short distances from signalized intersections, in part to facilitate passenger transfers between perpendicular bus lines (Fitzpatrick et al., 1996). The bus stop may reside upstream of its neighboring intersection (a so-called near-side stop) or downstream of it (a far-side stop); see Fig. 1. In either case, buses may occupy a travel lane while dwelling at the stop to load and unload passengers. A dwelling bus can therefore become a bottleneck that constrains car flows near the intersection. This can cause car queues to expand, which can further delay the buses as well as the cars.

The above concerns have long engendered debates on where best to locate a bus stop relative to its nearby intersection. Some studies have found in favor of far-side stops (e.g. Terry and Thomas, 1971). Others have reached the opposite conclusion (e.g. Fitzpatrick et al., 1997). The matter has yet to be settled, in part because observational studies, like those cited

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http://dx.doi.org/10.1016/j.trb.2014.06.001
0191-2615/

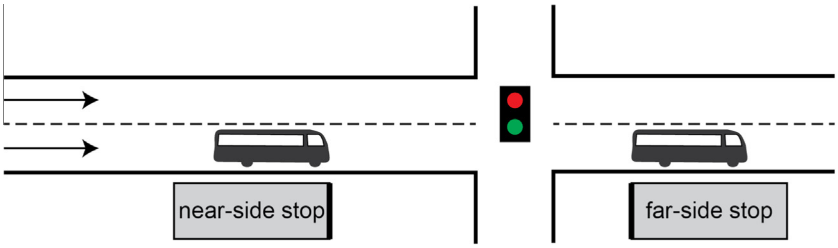

Fig. 1. Illustration of near-side and far-side bus stops.

above, and studies based on simulation or meta-heuristic search algorithms (Gibson, 1996; Joyce and Yagar, 1990; Wong et al., 1998; Zhao et al., 2007, 2008; Moura et al., 2012), have by necessity focused on relatively small numbers of select cases.

The literature also includes a few bus-stop models that are analytical in form. These would presumably allow for evaluation over a broader range of cases, except that these models have limitations. For example, some of the best known of these analytical models are in the *Highway Capacity Manual* (TRB, 2000),[1] and these have been found to be deficient in various ways (Gibson, 1996; Holt, 2004; Gu et al., 2011). Yet another of the existing analytical models is limited in that it treats bus stops as if they were isolated from car traffic (Ghoneim and Wirasinghe, 1980).

The literature also includes a more realistic analytical model that predicts the delays that cars can impart to buses (Furth and SanClemente, 2006). However, that model is formulated for cases in which stops are placed in so-called bus bays, so that dwelling buses are removed from travel lanes and do not impede cars. Hence that model says nothing about the car delays that can occur in the absence of bus bays.

In response to these limitations, some of the present authors have more recently explored one particular impact that buses can have on cars, that being: the residual queues of cars that can form at an intersection approach when its near-side stop is occupied by a bus (Gu et al., 2013). That work assumed that the approach has a fixed car demand that is lower than the capacity of the restriction created by the dwelling bus. Still, the discharge flow of queued cars may be constrained by that bus when the traffic signal turns green. The analytical models formulated for those circumstances can be used to determine where to place a near-side stop, either to limit the number of signal cycles that a residual car queue will persist, or to prevent the formation of these queues entirely.

In that same earlier work, the authors also developed and theoretically tested a strategy that postpones the arrivals of some buses at a near-side stop. This "bus holding" was done in such ways as to reduce further the occurrence of residual car queues, without delaying buses over the longer run.

The above-cited models of Gu et al. (2013) were derived as per the logic of the simplified theory of kinematic waves (Newell, 1993), and are therefore consistent with the physics of real highway traffic.[2] However, that earlier work made no attempt to predict how the selection of a stop's location might affect the delays on the approach, whether incurred by the cars or by the buses, or by the occupants of either vehicle class. Moreover, that work said nothing about far-side stops.

The present paper fills those holes. Rather than predicting the incidence of residual car queues, our new models predict the expected additional delays incurred: collectively by car traffic as a result of each dwelling bus; and by each bus, as a result of the car queues. Our focus on delay makes sense since it is a common metric for assessing quality of service (e.g. Kittleson and Associates et al., 2013; Gu et al., 2014a). Moreover, we now furnish models for far-side stops as well as for near-side ones. A model of expected car delay is also developed for cases in which bus holding is deployed at near-side stops. We shall use these models to unveil circumstances under which near-side stops are preferable to far-side ones, and vice versa.

Like those of Gu et al. (2013), the present models are formulated in accord with the simplified kinematic wave theory of Newell (1993). This makes sense given that we will compare stop types by assuming a steady-state demand for cars, as is commonly done in transport-planning applications. And like those of Gu et al. the present models are formulated for under-saturated intersection approaches, where a dwelling bus can constrain cars only as they discharge from queues during green times.

Though the present models are analytical in form, iterative solutions are required. Moreover, the models compute expectations that account for the randomness in both: the bus arrival times at a stop; and the durations that buses dwell there to serve passengers. Solutions therefore require the aid of a computer, and more will be said on this matter in due course.

Before proceeding further, we define our notation and assumptions. Some of these are borrowed from Gu et al. (2013).

[1] Some of these same models are now furnished in the Transit Capacity and Quality of Service Manual (Kittleson and Associates et al., 2013), which supplants discussion of transit systems in later editions of the Highway Capacity Manual.

[2] Notwithstanding the word "simplified," the theory has been shown to faithfully replicate highway traffic in real settings (Cassidy and Mauch, 2001; Cassidy, 1998).