SOCIAL COST BENEFIT ANALYSIS FOR PRE-PAYMENT BUS STOPS: AN APPLICATION IN TRANSANTIAGO

Guillermo Soto, Corresponding author
Departamento de Ingeniería de Transporte y Logística, Pontificia Universidad Católica de Chile
Los Navegantes 1963, Providencia, Santiago, Chile, 7520246
Tel: 56-2-23544270; Email: gbsoto@uc.cl

Sebastián Tamblay
Departamento de Ingeniería de Transporte y Logística, Pontificia Universidad Católica de Chile
Los Navegantes 1963, Providencia, Santiago, Chile, 7520246
Tel: 56-2-23544270; Email: sjtambla@uc.cl

Juan Carlos Herrera
Departamento de Ingeniería de Transporte y Logística, Pontificia Universidad Católica de Chile
Avenida Vicuña Mackena 4860, Macul, Santiago, Chile, 7820436
Tel: 56-2-23544270; Email: jch@ing.puc.cl

Ignacio Guimpert
Departamento de Ingeniería de Transporte y Logística, Pontificia Universidad Católica de Chile
Avenida Vicuña Mackena 4860, Macul, Santiago, Chile, 7820436
Tel: 56-2-23544270; Email: iaguimpert@uc.cl

May 31, 2018
ABSTRACT

In Santiago, the decision to convert a regular bus stop into a pre-payment stop has been mainly driven by its passengers’ demand and bus frequency. However, there are no studies supporting the thresholds used in this process, and thus no guarantee that they are socially desirable. In this study, a social Cost-Benefit Analysis model is introduced, which enables to determine whether or not a pre-payment stop is socially profitable. The model considers that pre-payment stops allow dwell time savings, as passengers pay the fare once they enter the station, allowing them to board using all doors. This generates savings in cycle time of services, which brings social benefits to users, from the reduction of travel time, and to bus operator companies, from fleet and bus drivers reduction. On the other hand, pre-payment stops produce social costs such as an initial infrastructure investment and operational costs every period. The model was tested with data from Transantiago, resulting in two main results. First, the study concluded that, along with frequency and passenger demand on stop, occupancy of buses is also an important variable in the social appraisal. Second, results showed that some of the current pre-payment stops from Santiago were not socially profitable, showing that there is room for improvement. Furthermore, over 550 new opportunities of socially profitable pre-payment stops were identified. Results from this study are expected to guide future infrastructure investment in order to improve authority’s decision-making.

Keywords: Social appraisal, Pre-payment stop, Cost-benefit analysis, Bus stop, Transantiago.
1 INTRODUCTION

In cities with high rates of motorization and rising levels of traffic congestion, prioritization of alternatives to the private transportation becomes attractive from a social and city planning point of view. Particularly, the provision of a high quality public transport system offers a travel alternative that is more efficient in the use of the road space and less pollutant compared to private transportation in terms of emissions per passenger.

To attract trips from private modes to public transport, it is necessary to understand how users evaluate the attributes of the transit system. According to Andreassen (1) and Hensher et al. (2) studies, which are focused on defining a quality index for the public transport, fare and speed are critical attributes for users’ satisfaction.

This work addressed speed improvements as a result of decreasing time at bus stops in surface public transport systems, by means of a fare collection system external to the vehicle called pre-payment stops. A pre-payment stop is a bus stop that has a mechanism in which passengers must pay the fare when entering the stop, before boarding the vehicle. This way, all doors remain available for a sequential boarding, similar to a subway, and passengers’ boarding and alighting times can be reduced.

Navarro et al. (3) propose a model that allows to estimate dwell and queue times, which requires to know operational variables of the bus stop, such as the passenger demand and the frequency of the services. Physical characteristics of the environment are added, such as the presence of overtaking lanes, the number of berths in the stop, the distance to a downstream traffic light and whether or not it operates as a pre-payment stop. This study demonstrates that, with the implementation of pre-payment stops, it is possible to achieve a reduction in the dwell and queue times of the vehicles, increasing the capacity of the bus stop.

These reductions in dwell and queue times caused by the pre-payment stop produce three main benefits: (i) a reduction in users’ travel times; (ii) a fleet size reduction (fewer buses are required to offer the same frequency); and (iii) a decrease in the total number of bus drivers. To improve investment decision-making, these benefits should be contrasted with the costs of implementation of a pre-payment stop, which are given by an initial infrastructure investment and an operational cost. Due to budget restrictions, it is not always suitable to change the stop to a pre-payment stop, so bus stops must be prioritized according to their net social benefit.

The main objectives of this investigation are: (i) to identify, by means of the Cost-Benefit Analysis (CBA), the costs, benefits and Net Present Value (NPV) of implementing and operating a pre-payment stop in a bus stop; (ii) to identify which operational conditions (frequency, demand at stop and bus occupation) justify the investment of a pre-payment stop; and (iii) to contrast the results of the Cost-Benefit model with criteria based on the operational saturation rate of a stop, taking as a study case the public transport system of Santiago de Chile.

In Transantiago, the public transport system of Santiago de Chile, 156 of 11,339 bus stops are currently pre-payment stops (4). Until now, the decision of adapting a regular stop into a pre-payment stop is mainly promoted using criteria based on the boarding of the passengers to the services and the total bus frequency per operational period in the station. Nevertheless, there are no studies validating the thresholds used in this process, so this work aims to evaluate them.

In section 2, a cost-benefit model for the social appraisal of the pre-payment stops is introduced. In subsection 2.1, the infrastructure and operational costs are defined. Next, in subsection 2.2, the benefits from the reduction in users’ travel times, savings in the fleet size, and savings in the number of drivers due to the reduction of the stop times are presented. Finally, in subsection 2.3, the costs and benefits are integrated in a NPV. In section 3, two experiments are presented: (i) the indifference curve of the NPV value for different values of frequency, passenger
Soto, Tamblay, Herrera, Guimpert

demand at stop and bus occupancy; and (ii) a comparison between the results of the proposed model and a saturation criteria that considers the current pre-payment stops in Transantiago. Finally, in section 4, the main conclusions of the investigation are presented.

2 COST-BENEFIT ANALYSIS MODEL

The CBA approach is a commonly used methodology to estimate the social appraisal of projects (5), highlighting important cognitive, technical and political advantages (6). In this section, the elements composing the social cost-benefit function of operating a pre-payment stop are introduced, which are calculated using the CBA approach.

First, the modified variables between the situation with and without the project are identified, and then, based on the social evaluation, the cost and benefits for each period are calculated. Each period represents the operation of a determined hour along the day. Finally, with these costs and benefits, an income flow during the useful life of the project (i.e. NPV) is calculated, which determines the profitability of the stop. Figure 1 presents the framework with which the NPV of installing a pre-payment stop is calculated:

![Figure 1: Framework of the CBA method for evaluating pre-payment stops.](image)

It is to be noted that Figure 1 neglects some benefits, such as the pollution or fuel costs reduction due shorter stop times. Said variables were not incorporated in this investigation because their magnitude is estimated to be marginal when compared to other benefits and, additionally, they require specific information related to the engine of each service. Nevertheless, they are easily incorporable for a subsequent work.

Also, potential benefits due to the reduction of fare evasion are not considered, which can be achieved by the provision of inspectors in the stops in order to check the payment of the fare. In Santiago, fare evasion has had an increasing trend in recent years, currently reaching more than 30% of the total number of travels and implying a significant financial problem (4). The analysis of this phenomenon is excluded from this paper, since from the fare payment is considered an exchange between agents of the economy from the social evaluation perspective. Therefore, fare evasion reductions should not imply any social benefit. However, it is acknowledged that the
contribution of pre-payment stops, as a mechanism of evasion control, is also important for the authority, so future research in this line is suggested.

2.1 Costs
The costs of turning a normal stop into a pre-payment stop are divided in two components: (i) an infrastructure cost, which contemplates the installation of barriers that limit the access to the stop, and (ii) an operation cost, including inspectors, monitors and supervisors at the pre-payment stop.

From a social investment point of view, the private and social costs are to be differentiated. For example, the private cost of hiring a pre-payment stop inspector corresponds only to the monthly salary of the employee, whereas the social cost is determined based on the alternative work cost of the worker. This social cost represents the marginal cost in which society incurs by employing an additional worker. This means that the social cost of hiring in an area with high unemployment is zero, because the worker does not have an alternative work use for his or her time.

2.1.1 Infrastructure Costs

In this work, infrastructure for pre-payment stops are classified in two types: (i) dynamic pre-payment stops, and (ii) fixed pre-payment stops. The infrastructure of a dynamic pre-payment stop allows an easy installation and removal of the stop for functioning hours. A fixed pre-payment stop, as its name indicates, consists in a stop with a fixed infrastructure, which is available during all periods of the day. Figure 2 presents an example of a smart card collection system from Santiago, Chile:

![Figure 2 Smart card fare collection at pre-payment stop on Santiago, Chile.](image)

Additionally, two service standards are identified: (i) regular and (ii) high standard. The regular standard keeps the physical conditions of the stop, modifying only its perimeter in order to control the access to the stop. In contrast, a high standard stop, in addition to access control, can provide some additional service level elements, such as charging modules (for systems using smart cards), toilets and information panels for users. However, it is difficult to include benefits associated to these service standards, since there are few studies that evaluate this aspect from a social evaluation perspective. Figure 3 presents an example of a fixed regular service pre-payment stop infrastructure:
FIGURE 3 Fixed and regular service pre-payment stop infrastructure in Santiago, Chile.

It is assumed that the infrastructure cost is paid in a unique investment at the start of the project, which depreciates on each period. In this case, because it is an infrastructure cost, the social cost is considered equal to the private cost. Therefore, the social cost of providing infrastructure for pre-payment stops (IC) corresponds to:

\[ IC = \theta_{IC} \quad (1) \]

In the case of fixed, regular standard pre-payment stops, it is assumed that the private cost, \( \theta_{CI} \), of providing infrastructure for the pre-payment stop depends on the linear meter of segregation of the stop. Therefore, it is function of the perimeter of the stop.

2.1.2 Operation Costs

For the purposes of this work, we will assume that the operational cost depends on two elements: (i) the payment of man-hours for its operation and (ii) the rent of payment devices. The man-hour cost must be corrected by a factor based on the qualification level of the worker (\( k_{OS} \)) in order to represent the cost of hiring him or her. The rent of payment devices has a social cost equal to the private cost.

Then, the operational cost (\( OC_t \)) in each period \( t \) is given by:

\[ OC_t = \theta_{OS}^t \cdot k_{OS} + \theta_{PD}^t \quad (2) \]

Where \( \theta_{OS}^t \) corresponds to the private cost to pay the operator’s salary of the pre-payment stop, \( k_{OS} \) is the correction factor to social cost, and \( \theta_{PD}^t \) is the private cost of renting the payment devices in the stop.
2.2 Benefits

As shown in Figure 1, total dwell time savings and bus requirement reduction produce social benefits that are translated into: (i) profits in travel time for users, (ii) fleet size reduction, and (iii) less bus drivers needed. This section introduces the methodology used to calculate these benefits, together with the parameters needed for each model.

2.2.1 Benefits of travel time

Total dwell time is considered to be composed by a queue time, in which the bus must wait to access the bus stop, and a dwell time at the bus stop, in which boarding and alighting of passengers occur. Research about models of dwell time at bus stops are abundant in literature (7, 8, 9, 10, 11), and parameters associated with time spent at bus stops and boarding and alighting time per passenger have been calibrated in these reports.

The model of Tirachini et al. (11) was used in this study because it properly meets the differences between an operation with and without pre-payment stops, but without the need to obtain difficult information such as the identification of the critical door. Dwell time in a stop without pre-payment ($td_{t}^{nps}$) is described by the following formula:

$$td_{t}^{nps} = c_{nps} + \max \left( a_{nps} \cdot m_{t}; b_{nps} \cdot \frac{A_{t}}{N-1} \right)$$

(3)

Where $c_{nps}$ represents a dead time in which the bus driver is already positioned at the bus stop but doors are still closed. Parameters $a_{nps}$ and $b_{nps}$ correspond to the marginal contribution of each boarding ($m_{t}$) and alighting ($A_{t}$) passenger to the dwell time at the bus stop. Finally, $N$ is the number of doors operating at time period $t$.

If it is assumed that all users board the first passing vehicle, the relationship between demand of passengers at the bus stop ($\lambda_{t}$) and bus frequency of time period $t$ ($f_{t}$) determines the mean number of users per bus ($m_{t}$):

$$m_{t} = \frac{\lambda_{t}}{f_{t}}$$

(4)

Under an operation of this type, the boarding and alighting process of passengers is simultaneous. It is assumed that while passengers alight the bus they do it using the rear doors, at the same time the front door allows access of boarding passengers. Then, the boarding and alighting time is determined by the maximum between both.

Regarding the dwell time at a bus stop with pre-payment system ($td_{t}^{ps}$), it is assumed that it has the following formula:

$$td_{t}^{ps} = c_{ps} + \frac{a_{ps} \cdot m_{t} + b_{ps} \cdot A_{t}}{N}$$

(5)

Unlike equation (3), it is assumed that this operation is sequential, similar to what occurs in the subway. When the bus arrives, all doors remain available for alighting of passengers. After alighting is finished, it is assumed that passengers start to board using all doors, since they already paid the bus fare, and therefore this time corresponds to the sum of boarding and alighting.

The model is formulated under the assumption that, with pre-payment stop, passenger alighting is uniformly distributed in each door, as well as boarding. In this way, the difference between dwell time ($\Delta td_{t}$) in the time period $t$ is defined as:
\[ \Delta t_{d_t} = t_{d_t}^{nps} - t_{d_t}^{ps} \]  

(6)

On the other hand, the queue time corresponds to the time spent by the bus waiting to access the bus stop. In this study, the model of Navarro et al. (3) is used, wherein queue time has an exponential form, which is presented in equation (7):

\[ t_{q_t} = m \cdot e^{p \cdot f_t} \]  

(7)

Where \( m \) and \( p \) depend on the number of overtaking lanes (0 or 1), a dummy of the proximity, in meters, to a downstream traffic light intersection (10, 20, 40 or more), frequency of bus services, and the number of berths (1 or 2) at the bus stop. Additionally, from equation (7) it is possible to solve frequency as a function of queue time, \( m \) and \( p \), representing the capacity of the bus stop in buses per hour:

\[ C_t = \frac{\ln t_{q_t} - \ln m}{p} \]  

(8)

The variation of queue time \( \Delta t_{q_t} \) produced when installing a pre-payment system at the bus stop is relevant to this study. This difference is defined as:

\[ \Delta t_{q_t} = t_{q_t}^{nzp} - t_{q_t}^{zp} \]  

(9)

Once both time variations have been calculated (dwell time and queue time), it is possible to quantify total time variation \( \Delta D_t \) that will be produced at the bus stop. This time depends on passenger demand at the bus stop \( \lambda_t \), alighting in the period \( A_t \), frequency \( f_t \) and a vector of attributes particular to each stop:

\[ \Delta D_t(\lambda_t, f_t, A_t) = \Delta t_{q_t}(\lambda_t, f_t, A_t) + \Delta t_{d_t}(\lambda_t, f_t, A_t) \]  

(10)

This way, benefits per travel time are divided in two groups: (i) passengers on the bus which do not alight at the bus stop being studied; and (ii) passengers alighting from the bus. The first group experiments a reduction in travel time equal to a \( \Delta D_t \), while the second group only benefits from reduction of queue time, \( \Delta t_{q_t} \). Then, social travel time benefits \( TTB_t \) produced by a decrease in travel time of period \( t \) are calculated as followed:

\[ TTB_t = \theta_{TT} \cdot (\Delta D_t \cdot (\delta_t - A_t) \cdot f_t + A_t \cdot \Delta t_{q_t} \cdot f_t) \]  

(11)

Where \( \theta_{TT} \) represents the social value of travel time, and \( \delta_t \) the mean occupation of buses on period \( t \). It is also assumed that services in a same period experiment the same dwell time, queue time and mean bus occupation.

2.2.2 Benefits of fleet size reduction

In this section, the potential fleet size reduction of buses \( \Delta B_t \) produced by the implementation of a pre-payment stop is analyzed. This reduction is produced because the decrease of dwell time and queue time not only positively impacts users, but also diminishes the cycle time \( \Delta D_t \) in the
same extent. Also, since fleet size required for a service is directly proportional to its frequency 
\(f_t\) and cycle time, savings in \(\Delta D_t\) produce a reduction in the bus fleet requirement equivalent to:
\[
\Delta B_t = f_t \cdot \Delta D_t \quad (12)
\]

Unlike the benefits in travel time, the reduction in the bus fleet is counted only at the beginning of the project. This is due to the assumption of maintaining a fixed frequency which generates a unique adjustment in the service operation. Then, the fleet reduction benefit (FRB) is calculated as follows:
\[
FRB = \theta_{NB} \cdot \sum_{t=0}^{T} \Delta B_t \cdot \frac{(B_{ul}-B_{a})}{B_{ul}} \quad (13)
\]

Where \(\theta_{NB}\) corresponds to the social value of a new bus, and \(B_{ul}\) and \(B_{a}\) represent the useful life of a new bus and average age of buses being operative, respectively. These parameters allow to perform a correction of the social cost of a new bus to reflect the depreciation of buses that operate at the bus stop to be intervened.

2.2.3 Benefits of reducing the number of bus drivers
Fleet size reduction also brings social benefits on the reduction of bus drivers, since they become available to perform other activities, which releases a resource for society. Because of this reason, this benefit is perceived in all periods of analysis. Drivers reduction benefits (DRB\(_t\)) of period \(t\) are calculated according to the following formula:
\[
DRB_t = \theta_{DS} \cdot \Delta B_t \cdot d_B \cdot k_{DS} \quad (14)
\]

Where \(\theta_{DS}\) corresponds to the private cost of a bus driver salary, and \(d_B\) is the number of drivers assigned to operate a bus \((B)\) of the service under study. The factor \(k_{DS}\) adjusts private costs to reflect the marginal social benefit of releasing man-hours of a bus driver. For example, if the job market of drivers is reduced, i.e., there is few supply of drivers, the factor will be very close to 1, reflecting a social cost very similar to the private cost. Otherwise, if there exists and abundance of drivers this factor will tend to 0.

2.3 Net Present Value
The Net Present Value (NPV) groups in a single expression the elements defined in sections 2.1 and 2.2, and brings it to present value. To do this, an evaluation horizon of the project equal to useful life of the pre-payment stop infrastructure is defined, in order to reach all its depreciation. Equation (20) shows the formula with which NPV is calculated:
\[
NPV = -IC + FRB + \sum_{y=0}^{Y} Q \cdot \sum_{t=0}^{T} \frac{(TTB_t+DRB_t-OC_t)}{(1+r)^y} \quad (15)
\]

Where \(Y\) correspond to the evaluation horizon of the project measured in years, \(Q\) is the number of periods \(T\) in one year, and \(r\) is the annual social discount rate. By means of this rate of return the authority guarantees a minimum profitability level in their projects, which additionally provides a tool to compare and generate a prioritization.

If NPV is positive, then the project is cost-effective, since benefits overcome costs, producing a social profitability greater than \(r\). On the contrary, i.e., if it is negative, it means that,
from a social point of view, investing in that pre-payment stop under those operation conditions is not socially convenient.

3 APPLICATION

The CBA model was applied in the context of the public transport system of Santiago, Transantiago, which possess more than 11,000 bus stops. Parameters of the dwell time model are based on values reported by Tirachini et al. (11), while those for queue time model were obtained from Navarro et al. (3). Parameters of social appraisal are obtained from an annual report from Ministry of Social Development, which is used to define investment priorities of Chilean State, by means of the social appraisal of projects from Chilean State (12). On the other hand, costs related to the operation of pre-payment stops are referential based on information from the agency in charge of Transantiago. These parameters, along with those considered for CBA model of equation (20), are presented in Table 1:

### TABLE 1 Parameters of CBA model for pre-payment stops

<table>
<thead>
<tr>
<th>Definition</th>
<th>Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social appraisal of time</td>
<td>$\theta_{\text{TT}}$</td>
<td>2.58</td>
<td>USD/h</td>
</tr>
<tr>
<td>Costs of new bus</td>
<td>$\theta_{\text{NB}}$</td>
<td>200,000</td>
<td>USD/bus</td>
</tr>
<tr>
<td>Useful life of new bus</td>
<td>$B_{ul}$</td>
<td>12</td>
<td>Years</td>
</tr>
<tr>
<td>Average age of buses</td>
<td>$B_a$</td>
<td>6.6</td>
<td>Years</td>
</tr>
<tr>
<td>Bus driver salary</td>
<td>$\theta_{\text{DS}}$</td>
<td>752</td>
<td>USD/driver-month</td>
</tr>
<tr>
<td>Drivers per bus</td>
<td>$d_B$</td>
<td>3</td>
<td>Drivers/bus</td>
</tr>
<tr>
<td>Driver salary factor</td>
<td>$k_{\text{DS}}$</td>
<td>0.98</td>
<td>-</td>
</tr>
<tr>
<td>Operator salary factor</td>
<td>$k_{\text{OS}}$</td>
<td>0.98</td>
<td>-</td>
</tr>
<tr>
<td>Private cost of infrastructure</td>
<td>$\theta_{\text{IC}}$</td>
<td>2,598</td>
<td>USD/pre-payment stop</td>
</tr>
<tr>
<td>Salary of pre-payment stop operators</td>
<td>$\theta_{\text{DS}}^l$</td>
<td>27.41</td>
<td>USD/h</td>
</tr>
<tr>
<td>Payment device rental cost</td>
<td>$\theta_{\text{PD}}$</td>
<td>0.71</td>
<td>USD/h</td>
</tr>
<tr>
<td>Social discount rate</td>
<td>$r$</td>
<td>6%</td>
<td>-</td>
</tr>
<tr>
<td>Project assessment horizon</td>
<td>$Y$</td>
<td>3</td>
<td>Years</td>
</tr>
<tr>
<td>Working days per year</td>
<td>$Q$</td>
<td>240</td>
<td>-</td>
</tr>
<tr>
<td>Periods per day</td>
<td>$T$</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>

The model considers the following assumptions: (i) Project assessment horizon ($Y$) is three years, considering that this is the useful life of pre-payment stop infrastructure; (ii) each year is composed of 240 working days ($Q$), and (iii) each day has two peak periods ($T$), morning peak time and afternoon peak time with a duration of two hours each.

This section presents two experiments: (i) analysis of the profitability curve based on the occupancy level of buses, frequency and users demand at bus stops; and (ii) analysis of the social profitability of current pre-payment stops, comparing it to those that would be installed under the criteria of saturation ratio presented in Navarro et al. (3) and the proposals under the CBA model.

3.1 Profitability Curve

Profitability curve is defined as the curve separating the positive NPV zone (i.e. socially profitable project), from the negative area (i.e. socially unprofitable project). This curve changes depending
on variables with which it is calculated, so its behavior was observed for variations of the average
occupancy level of services (δΔt), frequency (ft) and users demand at bus stops (λt). Then, any
point belonging to the profitability curve must fulfill the following equation:

\[ NPV(λt, ft, δt) = 0 \]  \hspace{1cm} (16)

Five profitability curves were calculated for services occupancy levels of 0, 25, 50 and 75
passengers per bus. All scenarios assume that there were no alighting passengers, in order to better
study the interaction of these three variables and model parameters in the initial section of the bus
route. Additionally, for the dwell time model of Navarro et al. (3) it was assumed that services had
three doors. The queue time calculation assumes stops without traffic lights in less than 40 meters,
with one berth and without overtaking lanes. Results of the experiment are shown in Figure 4.

![Figure 4: Profitability curves according to frequency (buses/h), demand at stop (pax/h) and occupancy level (pax/bus).](image)

It is noteworthy that, for the five occupancy levels, any bus stop found over the profitability
curve is socially profitable and therefore candidate to become a pre-payment stop. On the contrary,
if the bus stop is located under this curve, investment is not socially recommended. Taking into
account the results shown in Figure 2, the occupancy curve of the empty bus (i) is always above
the others, indicating that a higher frequency and demand at stops are required to reach social
profitability. This suggests that the occupancy level is an important variable when assessing
profitability of a pre-payment stop due to the reduction in travel time for users. Moreover, it is
highlighted that neither the frequency, bus demand nor occupancy are self-enough to reach
profitability of a pre-payment stop, being necessary a combination of requirements over these three
variables.

It is also interesting to compare these results with the operational criteria of the agency in
charge of Transantiago. This criterion fixes two thresholds that must be jointly fulfilled to
determine the implementation of a pre-payment stop:
1. Demand of passengers at bus stop is greater or equal than 500 passengers per hour.
2. Accumulated frequency of buses is greater or equal than 50 buses per hour.

However, it is important to mention that the installation of pre-payment stops also responds to other objectives aside from the system’s efficiency, such as reducing fare evasion rates in conflictive stops with high demand. This implies that the criterion mentioned before is not the only criterion used, so there are pre-payment stops that do not comply with the thresholds defined previously.

Compared to the curves of Figure 4, the operational criteria of Transantiago is highly demanding. Although there are scenarios in which the second criterion of minimum frequency does not ensure social profitability, the criterion of passenger demand at bus stop is very strict, since it demands a value much above the curve of profitability of services with null occupancy. This suggests that there are bus stops that are socially profitable as pre-payment stops, but do not fulfill the requirement of this operational criteria, which translates to a loss of potential social welfare.

3.2 Study Case: Pre-payment stops in Transantiago

In this section, an analysis of profitability of the pre-payment stops in Santiago is performed. Additionally, two criteria for the implementation of pre-payment stops are contrasted and analyzed based on the criteria of profitability of the CBA model. In order to achieve this, the NPV for each bus stop in the system is calculated, and then it is determined whether or not the stop should be a pre-payment stop according to each criterion. Data from the morning peak hour, from 06:30 to 08:30, and from the afternoon peak hour, from 18:00 to 20:00, are analyzed.

The first criteria is based on the model of Navarro et al. (3), in which a saturation ratio (SR) is calculated from the ratio between the planned frequency and the practical capacity of the bus stop \((f_t/C_t)\) under certain queue time standard (10 seconds for this experiment). When this ratio is greater than 100% under an operation without pre-payment stop, its installation is recommended. The second criteria is based on the CBA model and determines which bus stops have a positive NPV and, therefore, are recommended for pre-payment stops.

The data from the boarding and alighting of each bus stop are at a half hour level and are based on estimations of the program ADATRAP, according to information from a week of May, 2015 (13). Additionally, for the application of the model of Navarro et al. (3), each stop counts with information of distance to the traffic light crossing. Furthermore, it is assumed that all the stops are of one site, without overtaking lane, and that the services have buses with three doors.

The results for the morning and afternoon peak hour are shown in Table 2:

**TABLE 2 Number of pre-payment stops for morning and afternoon peak period**

<table>
<thead>
<tr>
<th>Period</th>
<th>Time Interval</th>
<th>Transantiago’s Criterion</th>
<th>Saturation Ratio Criterion</th>
<th>Cost-Benefit Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morning peak</td>
<td>06:30 - 08:30</td>
<td>79</td>
<td>651</td>
<td>633</td>
</tr>
<tr>
<td>Afternoon peak</td>
<td>18:00 - 20:00</td>
<td>107</td>
<td>496</td>
<td>425</td>
</tr>
</tbody>
</table>

As shown in Table 2, both the SR and CBA identify a much greater number of pre-payment stops than the current criteria on each operation period. Particularly, when the current number of pre-payment stops is compared to the number proposed by the CBA and SR criterion, it is
identified that there are many bus stops in which it would be socially beneficial to install new pre-payment stops.

In addition to the number of pre-payment stops, the match level between the current criteria and the social profitability of the bus stops is studied. In Figure 5, six maps are presented with the pre-payment bus stops according to each criterion, separating the non-profitable (red) from the profitable (green) ones with the CBA criterion. Results are shown for the morning peak defined in Table 2. The size of the stops indicates its value of NPV:

**FIGURE 5** Map of unprofitable (red): (a), (b) and (c), and profitable (green): (d), (e) and (f), pre-payment stops according to each criterion for the morning peak period.

Based on the results of Figure 5, the current number of pre-payment stops are an underestimation of its necessity according to SR and CBA criteria, which predict a much greater number of profitable bus stops. Additionally, as it is appreciated on Figure 5-a, 11 current pre-payment stops are not profitable, and therefore it could be convenient to relocate them in order to better use public resources.

Although Table 2 shows that the SR and CBA criteria are similar in the number of proposed pre-payment stops, Figure 5-b and Figure 5-e show that the stops suggested are not the same. There
are 120 bus stops that show a negative NPV for the saturation criteria, from a total number of 651 bus stops. On the other hand, in Figure 5-c there is no negative pre-payment bus stop because, by definition, only the positive ones are selected, whereas in Figure 5-f all 633 profitable bus stops of the system are shown. This difference is explained due to this criterion does not take into account elements like the costs and the benefits for users and the bus operator companies. Finally, it is worth to highlight that this analysis was replicated for the afternoon peak hour, producing similar results.

4 CONCLUSIONS

A model of social cost-benefit analysis (CBA) was proposed in this work for calculation of social profitability of pre-payment stops. The CBA model gathers existing operational methodologies for calculation of the reduction in dwell time and queue time of vehicles by means of the comparison of scenarios with or without a pre-payment stop. These are translated into social benefits for users (less travel time) and bus operator companies (reduction of fleet size and bus drivers). Additionally, operational costs and infrastructure associated with operation and installation of the pre-payment stop are identified. Costs and benefits are projected in a time horizon to calculate the Net Present Value (NPV) with which profitability of implementing the pre-payment stop is assessed.

After the implementation of the proposed methodology to the Transantiago transport system, it was noted that the occupancy level of buses when arriving to the bus stop has an important impact on the social profitability of a pre-payment stops. Similarly, bus frequency and demand at the bus stop are significant. This gives an insight to adjust the operational criterion that is currently used by the Chilean transport authority to implement pre-payment stops, which is very strict about frequency and demand of passengers, but has no consideration for passenger’s occupancy.

When analyzing the social profitability of existing pre-payment stops, it was noted that some of them were not socially profitable, because they were implemented with different non-operation criteria such as fare evasion control, which does not produce social benefits under this methodology. With the proposed CBA methodology, more than 550 new opportunities of socially profitable pre-payment stops were identified for the morning peak; and therefore it is suggested to increase investment from authority in this matter. On the other hand, the CBA method was contrasted with saturation criterion of Navarro et al. (3), obtaining a similar total number of profitable pre-payment stops. However, differences between both criteria were also found, since saturation criterion suggests 120 pre-payment stops with negative social profitability under the CBA criterion analysis.

This first implementation of the model provides a powerful tool for the identification of potential pre-payment stops of the public transport system. However, the model may be improved, since: (i) it does not have a complete database of all the variables of interest, disaggregated at a geographical level, (ii) it was assumed that all bus stops operated in a one berth bus stop and without an overtaking lane, and (iii) a reduction in emissions, fuel requirements, wear of tires or other operational savings were not considered. Additionally, it is identified that the time dimension of the problem was analyzed with fixed peak hour periods, hiding opportunities of pre-payment stop operating in different time schedules (more extended or delimited).

It is intended to take these limitations in consideration in future studies, thus achieving a more precise model adjusted to the reality of the analyzed city. In this way, the CBA model can be reinforced as a planning tool and guide for investment in bus stops infrastructure of the transport
system, which contributes to improve system operation and travel experience of the users, making the use of public transport more attractive as the main mode of transportation of the city.

**ACKNOWLEDGEMENTS**

This research was supported by the BRT+ Centre of Excellence funded by the Volvo Research and Educational Foundations (VREF) and by the Centro de Desarrollo Urbano Sustentable (CEDEUS) (FONDAP 15110020 from CONICYT). The authors wish to thank the Directorio de Transporte Público Metropolitano (DTPM) of Santiago, Chile for their support. This study was commissioned by DTPM through a formal agreement. All the data used in this study was provided by DTPM.

**REFERENCES**