Ex-Ante Evaluation of Exclusive Bus Lanes Implementation

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Abstract

This article presents a comprehensive approach for the ex-ante evaluation and the identification of relevant impacts related to the implementation of Exclusive Bus Lanes (EBL). It proposes indicators to measure the impacts related to key stakeholders: public transport operators, taxis, private vehicle drivers and passengers, as well as society regarding energy and the environment. Impact values are estimated from the application of relevant transportation planning models. The ex-ante evaluation method is based on cost-benefit analysis (CBA) and is designed to assist any decision regarding implementation of EBL by determining whether it is beneficial. To demonstrate the capability of the approach, a numerical application is provided for an area in Athens where EBLs were introduced to accommodate traffic for the Athens 2004 Olympic Games.

Introduction

As part of transportation management planning, most cities have introduced exclusive lanes, initially for all high occupancy vehicles (HOVs) and later for buses, to facilitate traveling with public transport and to maximize the person-carrying capacity of the roadway by changing the usage of a specific traffic lane. Thus, exclusive lanes provide priority treatment for buses, resulting in reduced travel time and improved time reliability.

Several studies specifically examined bus priority measures, including the introduction of exclusive bus lanes (EBL), since the 1960s (Hounsel et al. 1988; King 1983; Tee 1994; Denco 1995; Pitsiava-Latinopoulou et al. 1988; Frantzeskakis et al. 1997; Tsamboulas et al. 1999; Astrop et al. 1995). However, in most cases, a comprehensive method for the ex-ante evaluation of EBL implementation is not applied. Even when an evaluation is done, it is not applied separately, but in conjunction with other measures for mass public transport, usually as part of transportation management schemes (Horowitz et al. 1994; Mandl 1980; DETR 1997; Jacques et al. 1997; Environmental Protection Agency 2005).

This article presents a comprehensive approach that incorporates the analysis of impacts and the socioeconomic ex-ante evaluation regarding EBL implementation. The approach is based on the outputs of transportation model applications; for example, estimation of passenger and vehicle volumes on traffic assignment and mode choice models, costs elements related to EBL implementation and technical design studies; and benefits to tripmakers on travel times and operating costs. The implementation costs, in most cases, are negligible compared with the impacts related to vehicles and passengers/drivers. The ex-ante evaluation is based on the widely applied and well-documented cost benefit analysis (CBA; Tsamboulas et al. 1999).

Methodology

Basic Principles

The methodology comprises two stages: (1) identification of the impacts and their measurements and (2) the evaluation methodology based on the difference of total resource (economic) costs between the current conditions and the situation when EBL is implemented. If such difference is positive, then benefits are generated. Additional benefits are associated with operational elements (e.g., travel time, environment). The evaluation uses the well-established CBA method. Traffic-related inputs derived from the application of transport models are employed.

The innovative element of the methodology lies in the identification and measurement of impacts associated with the main stakeholders: (1) for public transport operators, the impacts relate to vehicle operating costs and driver working hours; (2) for drivers of taxis and other public-purpose vehicles (trucks, vans etc.), the impacts focus on whether acceptable working conditions are maintained; (3) for transport companies operating taxis, vans, trucks, etc., the impacts concern possible decreases in vehicle fleet costs; (4) for tripmakers (drivers or passengers), the impacts are about trip costs and travel time, and (5) for the general public, the impacts relate to energy consumption and the environment.

At the first stage, the measurement of impact values is based on the outputs of transportation simulation models (either generic or commercially available models, such as NETSIM, TRANSYT, CUBE, VISUM, EMME II). These models produce outputs that could be used for impact measurement if the appropriate variables are introduced in the models' configurations. The next critical step is to define the area where the models have to be applied. Itinerary routes and vehicles currently using the roadway segment where the EBL will be implemented are included in this step. This area could be extended to include any alternative route followed by private vehicles and transport modes when EBL is introduced. In brief, it is the area that comprises all possible alternative routes for all passenger O-D pairs currently using the roadway segment under consideration.

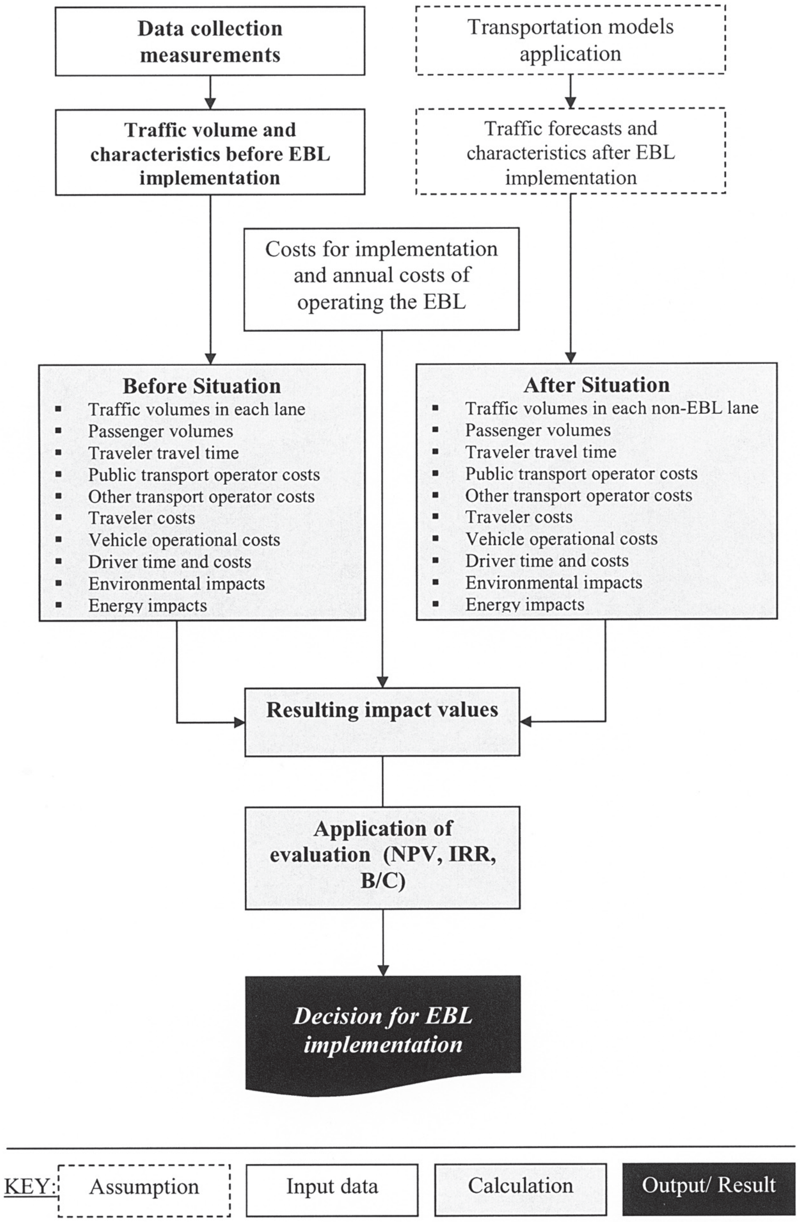
At the second stage, the ex-ante evaluation is applied. Decisions on two issues are required before the application: (1) choice of the criterion for CBA (i.e., selection of the Net Present Value [NPV] or B/C ratio or the Internal Rate of Return [IRR]); and (2) the time period for evaluation (usually three to five years since EBL is a low-cost transportation management measure, and as such changes could occur within this time horizon). The developed ex-ante evaluation compares the alternative (implementation of EBL) with the current situation (do nothing). Transportation simulation models are applied for both cases, and the corresponding values for the impacts are produced. The overall structure and components of the approach are presented in Figure 1.

Tripmakers' Related Impacts

Two broad categories of tripmakers are identified: (1) those who after implementation of EBL continue to use the same transport modes as before and (2) those who decide to change transport modes (usually taking buses that move along the EBL).

All tripmakers' related impacts are calculated with the application of the relevant transport models for existing conditions (before application of EBL) and after application of EBL. The latter necessitates changes in the transport network employed by the models since the EBL should be considered as a change in one or more links of the transport network.

Figure 1. Methodology's Structure and Components



Implementation and Operation Costs

Costs related to implementation and operation of the EBL are identified below.

Construction (C^k). EBL construction costs are associated with design studies, works for implementation (i.e., roadway signaling, vertical signs, traffic lights at intersections, pavements), other necessary interventions (i.e., road widening, pavement reconfigurations, bus stops changes); and possible modifications of infrastructure (i.e., catenaries for trolley buses).

Police Surveillance (C^a). Police surveillance is related to observation for incident detection or violations by private vehicle or taxi drivers of EBL use. A minimum number of fines are imposed by the police to cover surveillance costs. Once the costs are covered, additional revenue could be used by the municipality or the public transport operator to finance EBL maintenance and improvements in public transport services.

Maintenance (C^μ). Maintenance includes any expenses related to the upkeep and efficient operation of EBL.

Tripmakers' Travel Time Cost Impacts

Travel Time Changes. Travel time changes concern tripmakers regardless of transport mode (passengers for buses and taxis, drivers or passengers for private vehicles) who currently use the roadway section where EBL will be implemented. Changes are based on travel time differences "before" and "after" conditions that exist for vehicles moving along the section of the road on which EBL is implemented.

Consequently, the change in travel time costs (€/hr) is

$$DC = \sum_{\mu} \sum_{i} \sum_{j} [(T_{ij}' * E_{\mu}' * a_{\mu})/60) - (T_{ij} * E_{\mu} * a_{\mu})/60)] \qquad (1)$$

See Table 1 for an explanation of symbols.

Changes in Passenger Waiting Time at Stops. The movement of buses along the EBL will trigger changes in passenger travel times, other than in-vehicle travel time. Thus, increases in frequency of bus service will result in changes in waiting times at bus stops, producing changes in time-related costs (€/hr).

Table 1. Variables Used in EBL Evaluation

Variable	*Description*
μ:	Tripmakers/passengers who will continue to use buses (μ=1), change transport mode and use buses (μ=2), or continue to use other modes (μ=3)
i=m,1	Public transport modes that move on EBL(i=m,1), that move on remaining road lanes or routes (e.g., metro, rapid light rail) (i=m,2), and that move on the remaining road lanes or routes (e.g., metro, rapid light rail) (i=m,3)
i=2,3,..n	Other vehicles not moving on the EBL (e.g., private vehicles, taxis, two-wheeled vehicles)
j	Trip itinerary following the route of EBL (j= 1) or alternative routes (j= 2)
T_{ij}, T_{ij}'	Average travel time (min) with transport mode i, for route j, "before" and "after" EBL implementation, respectively
E_{μ} , E'_{μ}	Number of tripmakers (persons/hr) according to the category considered, "before" and "after" EBL implementation, respectively
a_{μ}	Value of travel time for tripmaker category μ (€/h)
h, h'	Average headway between two successive arrivals of buses at the stop (in minutes) "before" and "after" EBL implementation, respectively
V_h, V'_h	Variability factor of frequency of service "before" and "after" EBL implementation, respectively
ρ, ρ'	Passenger arrival rate at the specific stop "before" and "after," respectively (passengers/minute)
s, s'	Number of stops along EBL
N_{1ij}	Traffic volume of vehicles of transport mode i on route j, expressed in vehicles/hr
d_{ij}	Length of route j followed by vehicles of transport mode i, expressed in kms
$C_{\lambda ij}'$, $C_{\lambda ij}$	Vehicle operating cost per transport mode i, based on the average speed along route alternatives j, "before" and "after," respectively, application in route j, expressed in €/km
N_{2ir}	Volume of vehicles of transport mode i, which deviate from route j (originally followed route) to route r, expressed in vehicles/hr
d_{ir}'	Length of route r, to which transport mode i deviates "after" EBL implementation, expressed in kms
d_{ij}	Length of route j of transport mode i "before" EBL implementation, expressed in kms
E_{2io}	Passengers who move to public transport "after" implementation of EBL and who were using the same route o, expressed as passengers/hr
E_{2ij}	Passengers who move to public transport "after" implementation of EBL and who were using transport mode i on other routes j, expressed as passengers/hr
$C'_{\lambda o}$	Passenger travel costs for route o (where EBL is implemented)
$C'_{\lambda j}$	Passenger travel costs based on route j (other than the one where EBL is implemented)
F_m	Passenger bus ticket fare for route o
F_{mj}	Passenger public transport ticket fare
d_o	Length of EBL section, in kms
$C_{\lambda m o}'$	Operating cost for bus along EBL on route o, expressed in €/km/bus
C_{Tm}	Bus driver costs, expressed in €/bus/hr for the specific itinerary
E_{2io}	Number of passengers of transport mode i using road o who shift to bus in route o "after" EBL application, expressed as passengers/hr
E_{2ij}	Number of passengers of transport mode i of route j who change route itinerary and will use bus in route o "after" EBL implementation, expressed in passengers/hr
Π	Capacity of public transport vehicle related to level of service, expressed in passengers.
$R_{mo, n}$,	Estimated by applying equation (8) for the nth year
$DC_{E, n}$	Estimated by applying equation (6) for the nth year
$DC_{\lambda r, n}$	Estimated by applying equation (5) for the nth year
$DC_{\lambda i, n}$	Estimated by applying equation (4) for the nth year
$DC_{\alpha, n}$:	Estimated by applying equation (2) for the nth year
DC_n	Estimated by applying equation (1) for the nth year
DE_n	Difference in external costs, expressed in €/hr for the nth year
n	Years for evaluation
e	Opportunity cost of capital to be used for interest rate
Hd	Daily operating hours for bus lane

$$DC_{\alpha}=[\{(h' * (1 + V'^{2}_{h})/2) * \rho' * s' * \alpha_{a}\}/60] - [\{(h * (1 + V^{2}_{h})/2) * \rho * s * \alpha_{\alpha}\}/60] \quad (2)$$

Vehicle Operating Costs

Vehicle operating costs include all relevant costs such as fuels, lubricants, tires, maintenance/service, and parking expenses. In public transport modes, driver costs, as well as corresponding administration costs, have to be added. The following model could be used to estimate vehicle operating costs in urban areas (Mandl 1980):

$$C_{\lambda i..} = a_{i} + b_{i}/V_{i} + f_{i} * V_{i}^{2} + C_{Tm} \quad (3)$$

where:

$C_{\lambda i.}$	equals operating cost for a typical vehicle of transport mode i, expressed in €/km
Vi	represents average operating speed of a typical transport mode i vehicle on the road section examined, expressed in km/hr
C_{Tm}	is *0* for nonpublic transport modes; *hourly wages of drivers* for public transport modes
a_i, b_i, f_i	are estimated (after model calibration) and are differentiated with transport vehicle type (i) and fuel

The above-presented model in equation (3) is an example of existing models calculating vehicle operating costs.

Consequently, changes in vehicle operating costs are for two cases identified: (1) tripmakers who continue to travel the same way and (2) tripmakers who change route after implementation of EBL.

Tripmakers Who Continue to Travel the Same Way (Transport Modes, Route Itineraries). Two cases are identified: (1) tripmakers who use the road where EBL is implemented (denoted by j=0) and who are using transport modes other than bus; and (2) tripmakers who continue to move as before implementation of EBL along route itineraries that do not include the EBL route (j=1) utilizing the same transport mode as before.

Thus, the cost difference, $DC_{\lambda j}$, is estimated by

$$DC_{\lambda j} = \Sigma_i \Sigma_j N_{1ij} * d_{ij} * (c_{\lambda ij}' - c_{\lambda ij}) \qquad (4)$$

The impact on other public transport modes using fixed track (e.g., light rapid rail, metro, suburban rail) is negligible, and thus is not included in the calculations.

Tripmakers Who Change Routes After Implementation of EBL. In the case of tripmakers changing route itineraries after EBL implementation, the impact on vehicle operating costs is attributed to possible increases in speed and vehicle-km traveled since alternative routes could be longer.

Change in total operating costs is estimated by

$$DC_{\lambda r} = \Sigma_i \Sigma r N_{2ir} * [(C_{\lambda ir}' * d_{ir}') - (C_{\lambda i j} * d_{ij})] \qquad (5)$$

Travel Cost Impacts of Tripmakers Changing Transport Mode

The most probable case is that of tripmakers using transport mode i (usually private car or taxi) who become users of public transport m, after implementation of EBL. Other cases (e.g., change of bus mode for metro) are rather negligible, and thus they are not included. It is evident that these tripmakers will no longer use their private cars or take a taxi, and thus there will be a decrease in traffic volumes.

Hence, changes in traveling costs are estimated as follows:

$$DC_E = \Sigma_i E_{2io} *(C'_{\lambda o} - F_m) + \Sigma_i \Sigma_j E_{2ij} *(C'_{\lambda j} - F_{mj}) \qquad (6)$$

Travel time costs are estimated by equation (1), and passenger and traffic volumes are estimated from the application of the well-known transport four-step process and the corresponding models.

Additional Revenue to Public Transport Operators

The modal shift from private vehicles to public transport generates the need for more frequent service to cover the increased passenger demand. The additional volume of public transport vehicles that will sufficiently cover the generated demand is estimated according to the available capacity of the buses.

These new bus services will result in additional operating costs for the transport operations, estimated by

$$DC_{\lambda mo} = [(\Sigma_i E_{2io} + \Sigma_i \Sigma_j E_{2ij}) / \Pi] * (d_o * C_{\lambda mo}' + C_{Tm}) \qquad (7)$$

On the other hand, generated revenues from additional passengers on buses along route o are

$$R_{mo} = (\Sigma_i E_{2io} + \Sigma_i \Sigma_j E_{2ij}) * F_m - DC_{\lambda mo} \qquad (8)$$

External (Noneconomic) Costs

External costs mainly concern environmental impact (air quality, noise, and vibration) and energy-related costs. Potential impacts attributed to construction will not be considered since they are temporary impacts and will be mitigated through the use of best management practices. Conversion of physical units to monetary units is not an easy application. Thus, ways of converting physical units to monetary values have to be included.

Energy Consumption. Fuel consumption and emission rates per passenger-km depend on load factors. A bus with 50 passengers consumes about one tenth the energy per passenger-km as an average automobile, but energy consumption per passenger-km could be little higher for transit systems than private vehicles if low load factors are observed. A National Research Council study (Committee on the Science of Climate Change of the NRC 2001) estimates these externalities at about 30 cents per gallon on average.

Since the cost of energy consumption is already included in the operating costs, it will not be estimated separately to avoid double counting.

Noise Impacts. Motor vehicle traffic imposes noise pollution. Noise-related costs tend to be much higher on local urban roads where traffic tends to be closer to houses. Levels of traffic noise are quantified depending on the traffic volume and composition, speed, type of road (gradient, surface quality, and type) as well as the elements of the urban model that represent the geometry of the particular region.

For all road sections, the level of noise at the reception point (facade of a building next to EBL) could be estimated by applying the equivalent 24-hour noise level based on traffic volumes.

On the other hand, the methodology introduces a threshold, the transgression of which produces the costs. This threshold corresponds to 50dB (A) for public transport vehicles at urban areas where EBL is implemented (Federal Transit Administration 1995; Environmental Protection Agency 1974). If construction and operation of the EBL results in changing the level of noise related to the 50dB(A) threshold, then the values produced in the Delucchi and Shi-Ling Hsu study (Delucchi and Hsu 1998) can be used with proper modifications in currency and distance units.

Atmospheric Pollution Impacts. Atmospheric pollution impacts are mainly determined by three factors: (1) carbon monoxide (CO), (2) nitrogen oxides (NOx), and (3) particulates (PM). Other possible pollutants, however, are to be taken into consideration (e.g., sulphur) if believed to be significant. For evaluation purposes, the number of persons affected by such emissions has to be considered. Determination of atmospheric pollution and the resulting benefits or costs could be based on the work by DETR (DETR 1999). Thus, atmospheric pollution impacts can be applied in the urban areas where the EBL is implemented for estimating pollution at each specific road segment. This will avoid the use of an average for the whole roadway system in an area. In addition, a threshold is determined, the transgression of which produces the respective costs. The introduced threshold corresponds to the following values (for the three pollutants) for public transport operations at urban areas where the EBL is implemented (European Environmental Agency 2003): (1) CO: 10 ppm per 8 h; (2) NO_x: 150 ppb per hour; (3) PM: 50 mg/m^3 per day.

Ex-Ante Evaluation

The above impacts constitute parameters for the ex-ante evaluation of EBL implementation. The remaining items to be considered are the evaluation period and the conversion of resulted values in present values. The evaluation criterion proposed is basically the NPV, and—if requested—the B/C ratio and/or IRR, which is based on NPV results. The evaluation period is usually three to five years, depending on the EBL implementation investment scale. As for conversion of hourly values to annual ones, daily hours as well as days per year are determined by the hours per day and days per year of the specific EBL operation (i.e., time periods when only buses are allowed to move along the specific EBL).

Thus:

$$NPV= \sum_n \{[365^* H_{d,n}{}^* (R_{mo,n} + DC_{E,n} + DC_{\lambda r,n} + DC_{\lambda i,n} + DC_{\alpha,n} + DC_n + DE_n)]/(1+e)^n\} \quad (9)$$

where the values of the parameters are based on outputs of previous relations (see Table 1).

Application

Overview

The proposed methodology was applied to an EBL to be implemented in Athens on a principal arterial road. It was introduced primarily as a measure to accommodate the increased volumes of public transport expected during the Athens 2004 Olympic Games and as part of the traffic management measures introduced in the city. Therefore, the analysis and its results will be presented separately for the Olympic Games period (which lasts only 20 days) and for the post-Olympic Games period, to be considered as four years.

Olympic Games Period

Traffic data regarding situations "before" and "after" as well as input costs (implementation and operation) and other necessary data are derived from studies and research (Frantzeskakis et al. 1997; Polydoropoulou et al. 1998) and presented in Table 2. The criterion employed is that of the NPV. By applying equation (9) with only the relevant parameters, as specified in Table 2 and without the external costs, the resulting NPV is 12.305,71€. Since the NPV is positive, the specific EBL is viable. The resulting value is low though and is attributed to the considered 20 days of Olympic Games—a very short period of operation.

A separate analysis was conducted for environmental impacts. The air quality analysis was conducted at intersections with potential high traffic volume and vehicle delays. Only two noise-sensitive receivers could be impacted as a result of the introduction of additional buses associated with the EBL implementation.

Table 2. Input Data (Traffic Characteristics, Technical and Economic Data)

1. Traffic Characteristics

Route	*Mode*	*Before*				*After*			
		Load	*Occupancy*	*Speed (km/h)*	*Time (sec.)*	*Load*	*Occupancy*	*Speed (km/hr)*	*Time (sec.)*
o	m	40	65	17	3176	42	70	28	2761
	i	1800	1,2	23	2348	1764	1,2	26	2077
j	m	-	-	-	-	-	-	-	-
	i	1800	1,2	23	2661	1818	1,2	18	3400

2. Other Technical Data and Characteristics of EBL

No of Lanes	*EBL Length (km)*	*Signaling Time (sec.)*	*Turns on Nodes*	*Deceleration/Acceleration Time for Bus (sec.)*	*Passengers Waiting at Stops (passengers/hr)*	*No. of Stops Along EBL*	*Length of Routes j (km)*
2	5	120	9	15	100	5	17

3. Economic/Cost Data

Value of Time	*Construction Costs*	*Maintenance Costs*
1,61€	2.934,7€	1.173,9€

4. Other Data

Mode	*Parameters a, b and c (Equation 23- Calculation of Operational Cost)*		
	a	*b*	*c*
m	18,28	306,6	0
i	0,54	2,77	0

Post-Olympic Games Period

The traffic data regarding the situations "before" and "after" and the relationships used are the same as previously presented. In this case, using the criterion of NPV for evaluation with

n: 4 (*Years of Construction*: 1, *Years of Operation*: 3), i: 5% ,

the resulting NPV is 9.121.618,30€.

The post Olympic Games evaluation resulted in higher NPV, and if the years of evaluation were more than four, then a higher NPV would be achieved. To examine the possible changes of NPV, a sensitivity analysis was performed related to the traffic volumes. It found that even if the change in private vehicles volumes is marginal (e.g., 0,5 – 1%), the methodology application demonstrates that EBL is beneficial. By changing the second crucial parameter, the same conclusion is reached.

Conclusions

In most cities the available space for movements (road, rapid transit) is fixed, and any increases in capacity are time consuming, overly expensive, and most likely to trigger opposition for possible environmental impacts. Hence, transportation planners mainly try to implement transportation management schemes, aiming at increasing the capacity of the transportation system, measured in persons moved (not vehicle flows). Consequently, transportation planners look at generated impacts from the implementation of a specific strategy. It is within these transportation management measures that EBL implementation falls.

Any transportation management plan needs to be evaluated before its implementation to identify and measure its impacts. Thus, the resulted benefits, disbenefits, and costs will be assessed. Whether a specific EBL is evaluated as effective and beneficial depends on the criteria and assumptions used in its evaluation (Wellander et al. 2001).

In the present study, the required comprehensive methodology developed identifies all impacts related to the specific EBL implementation, and performs the ex-ante evaluation. By identifying all relevant impacts (e.g., travel time, transport operating costs, traffic diversion, bus ridership and service, environmental and energy), decision-makers can understand the positive and/or negative effects for each category of traffic and thus react accordingly.

In addition, the methodology can be used as a tool to address community concerns. Thus, if the evaluation produces a positive NPV, EBL implementation produces positive results for society and as such it must be implemented. On the other hand, if a negative NPV is produced, EBL must be avoided and thus unnecessary spending is prevented.

The presented evaluation methodology is helpful to assess the contribution of EBL as a policy measure on its own and as part of a wider transport strategy. The proposed methodology should also consider different alternatives of EBL design and whether a specific bus route segment could be an EBL or a mixed-flow one. The latter is useful in view of the opposite opinions regarding EBL implementation at least for the cases that the currently observed traffic flows are low. As proven by the application of the methodology, the advantages of EBL over mixed-traffic lanes include increases in vehicle occupancies, reductions in delays, and low vehicle emissions.

EBL implementation promotes equity among travelers. Such measures generally provide the most benefit to commuters whose travel occurs during weekday peak periods. The distribution of costs and benefits depends on an area's situation. If existing capacity is redistributed, those who rely on mass transit and are able to join will receive time-savings benefits and potential financial benefits (e.g., employers may provide EBL parking subsidies). EBL facilities may benefit low-income travelers while imposing costs on high-income travelers. For example, mass transit riders tend to be from lower income groups and value time savings less than high-income individuals.

Finally, one of the most critical components of implementing a successful EBL program is enforcement, which is addressed by the methodology. Surveys show that early and substantial enforcement of EBL rules on a new facility is the best determinant for long-term public compliance.

The proposed methodology, as it is the case for most generic ones, has to be adapted to existing conditions before its implementation. When used with real data, it can be a useful and powerful tool to any transportation planner.

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