Imperial College London

Railway and Transport Strategy Centre

The identification and management of bus priority schemes

A study of international experiences and best practices

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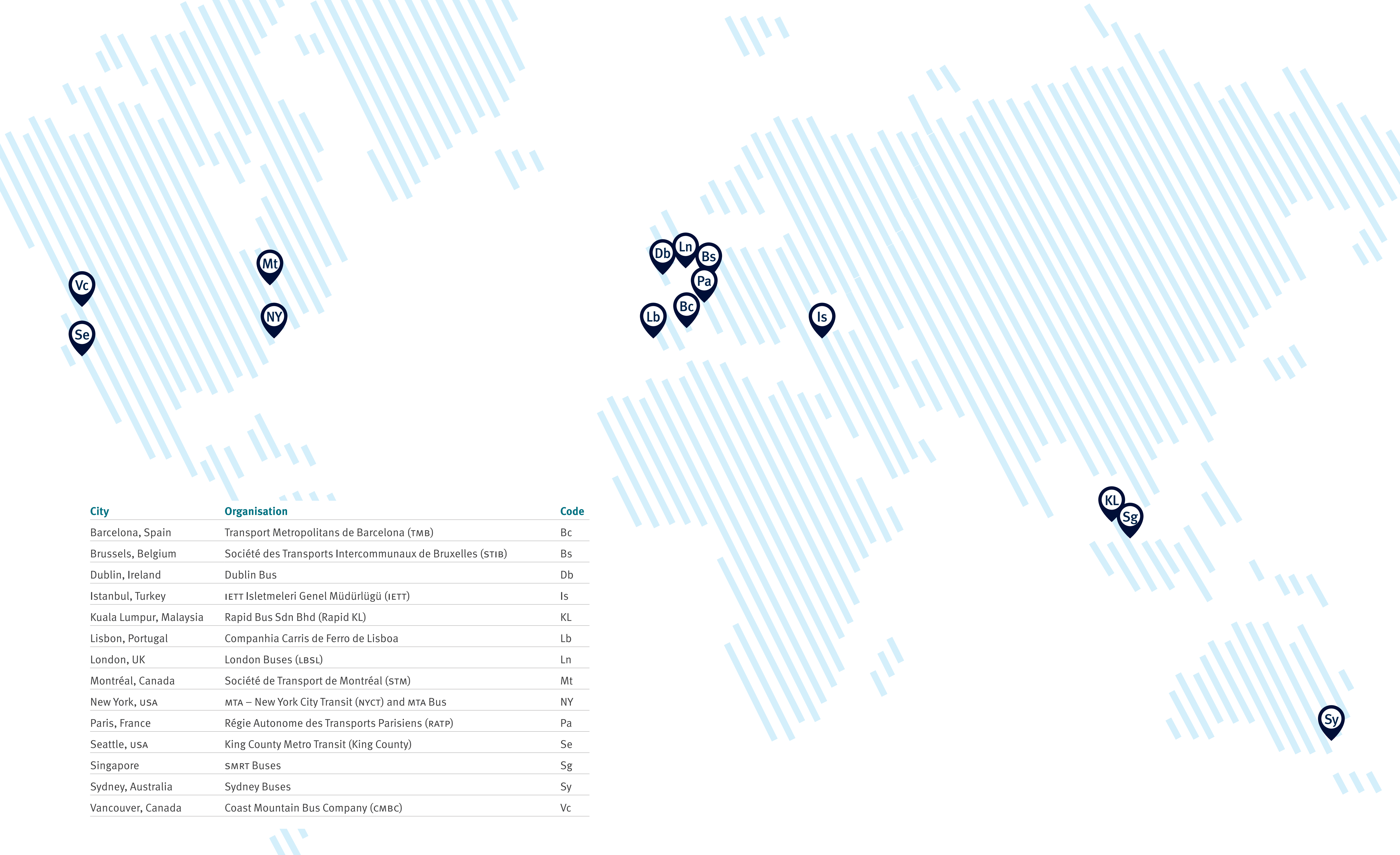
Abbreviations and glossary

AVL	Automatic vehicle location system
ANPR	Automatic number plate recognition
SCOOT	Split cycle offset optimisation technique
TSP	Traffic signal priority
QBC	Quality bus corridor (Dublin)
SBS	Select bus service (New York)
BRT	Bus rapid transit
HOV	High occupancy vehicle
MAE	Multiple account evaluation
EPA	Environment protection agency (US)
EWT	Excess waiting time
ETA	Estimated time of arrival
US$ PPP 2014	All financial values are normalised using the world bank's purchasing power parity (PPP) data to equate to 2014 us dollars.
Bus priority km	The sum of a network's bus lane km and bus-exclusive road km.
Opposite turn/ Bus only turn	Right turn for left-hand traffic. Left turn for right-hand traffic.

Study participants – cities and organisations



City	Organisation	Code
Barcelona, Spain	Transport Metropolitans de Barcelona (TMB)	Bc
Brussels, Belgium	Société des Transports Intercommunaux de Bruxelles (STIB)	Bs
Dublin, Ireland	Dublin Bus	Db
Istanbul, Turkey	IETT Isletmeleri Genel Müdürlügü (IETT)	Is
Kuala Lumpur, Malaysia	Rapid Bus Sdn Bhd (Rapid KL)	KL
Lisbon, Portugal	Companhia Carris de Ferro de Lisboa	Lb
London, UK	London Buses (LBSL)	Ln
Montréal, Canada	Société de Transport de Montréal (STM)	Mt
New York, USA	MTA – New York City Transit (NYCT) and MTA Bus	NY
Paris, France	Régie Autonome des Transports Parisiens (RATP)	Pa
Seattle, USA	King County Metro Transit (King County)	Se
Singapore	SMRT Buses	Sg
Sydney, Australia	Sydney Buses	Sy
Vancouver, Canada	Coast Mountain Bus Company (CMBC)	Vc

Introduction

Priority measures for bus services can deliver significant benefits both for passengers and the operator. For example, green light priority or the conversion of road space to dedicated bus lanes can deliver journey time benefits thereby improving both quality of service and operational efficiency.

This study investigates how bus priority schemes are identified and managed in 14 different cities across Asia, Australia, Europe and North America. The information within this study is sourced from 15 participating bus organisations, all of which are members of the International Bus Benchmarking Group (IBBG), a consortium of 15 medium and large bus organisations involved in a comprehensive programme of benchmarking urban bus operations facilitated by Imperial College. Data for the study was collected through questionnaire surveys completed by the participants and follow-up telephone interviews with select organisations.

The participating organisations are listed on page six.

Decisions on whether (and how) to implement bus priority schemes are often made by external parties (e.g. local governments or road authorities) with a varying degree of input from bus organisations into the process. The study reviews the decision making processes, and associated input from bus operators, involved in identifying necessary bus schemes. The different methods of bus priority enforcement adopted within the cities of the participating bus organisations (either by themselves or the relevant enforcing agency) is explored to establish interesting and successful ways to ensure effective enforcement of bus priority measures.

This report may be useful to different stakeholders experiencing difficulties with bus priority: city/borough governments, road authorities, bus operators, passenger groups, police, and other organisations. This study can be used to inform stakeholders on the following:

- Understand how bus priority opportunities are identified and selected;
- Gain ideas and good practices for quantifying benefits and making the case to stakeholders and overcoming competing interests;
- Learn from bus priority success stories and understand the success factors behind projects and their implementation;
- Understand the challenges and risks of bus priority projects;
- Share interesting and successful best practices to enforce schemes.

For the purposes of this study, bus priority is defined as "the use of technology or physical infrastructure to influence the external environment within which buses operate to improve commercial speed for buses and mitigate the impact of other road traffic."

The study considers two broad categories of bus priority schemes and their enforcement:

Technology schemes
Using traffic signal systems with bus priority or pre-emption capabilities, and other technologies that improve the travel speed of buses, thereby reducing journey time variability and improving punctuality and reliability of buses.

Physical infrastructure schemes
Bus lanes, queue jump lanes, bus bulbs, and other physical changes to the road network that improve the travel speed of buses, thereby reducing journey time variability and improving punctuality and reliability of buses.

In many cases, a combination of the above may be used in a larger bus priority scheme and the different types of bus priority are defined in Tables 1 and 2.

This report provides an overview of the current level of bus priority measures in place on the bus networks of the organisations participating in the study and summarises examples of their most successful bus priority projects.

The different bus priority identification and selection processes adopted are presented in the third section, whilst section four summarises the benefits delivered by bus priority measures in the cities, and which were quantified. Thereafter, the study explores the challenges and risks that operators have experienced with the implementation, operation and enforcement of bus priority solutions.

The sixth section focuses on Traffic Signal Priority (TSP), looking at the technology in terms of its advantages and disadvantages, the equipment required, approaches adopted to manage obsolescence, and the different settings used on the bus networks reviewed within this research.

The different stakeholders, implementation and planning bodies involved in bus priority are presented in section seven. This section also looks at the extent of communication that takes place throughout the bus priority planning and implementation process.

The final section concludes the report by summarising the key findings and good practices identified within the analysis.

ACTIVE TRAFFIC SIGNAL PRIORITY (TSP)

Active TSP systems enable buses to get a green light earlier than they would without priority. Systems may use one or more of the following methods to achieve this:

- **Early green phase (red phase cut short) –** signal turns green earlier than normal when a bus approaches the signal (and the signal is red).
- **Green phase extension –** the green phase is extended when a bus approaches.
- **Phase insertion –** special signal phase added on or inserted into the normal signal phase.
- **Special public transport phase –** special signal only for buses, e.g. for a bus lane or bus-only turn signal.
- **Phase rotation –** changing the sequence of signals to benefit buses.

Table 1 Types of bus priority – technology schemes

Image sources: Vancouver Coast Mountain Bus Company, 2015; Transport Metropolitans de Barcelona, 2015

Table 2 **Types of bus priority – physical infrastructure schemes**

KERBSIDE UNSEGREGATED BUS LANE

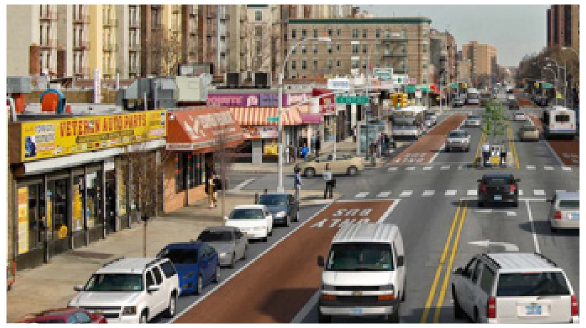
At edge of road, with or without coloured surface

Image source: Transport Metropolitans de Barcelona, 2015.

SEGREGATED BUS LANE

Fully separated from main road, completely or partly reserved for buses. Can be kerbside, middle of road, or entirely separate road.

Image source: Régie Autonome des Transports Parisiens, 2015



OFFSET UNSEGREGATED BUS LANE

Bus lane one lane away from the kerb to allow kerbside parking.

Image source: New York City Department of Transportation, 2015

MEDIAN UNSEGREGATED BUS LANE

Unsegregated bus lane in the middle of the road.

Image source: New York City Department of Transportation, 2015

HIGH OCCUPANCY VEHICLE LANE

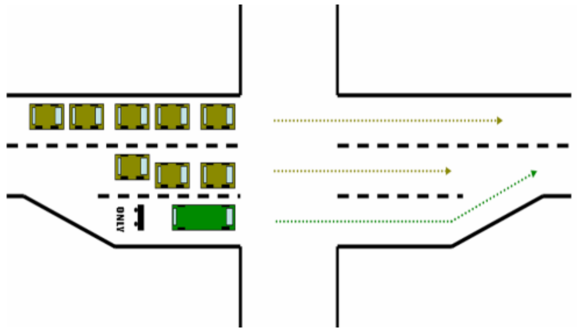
Lane reserved for high-occupancy vehicles including car pools and buses.

Image source: UK Department for Transport, 2015

BUS BULB/BUS BOARDER

Build-out from the kerb past a line of parked cars, so a bus using an offset bus lane can stop in-lane without pulling in.

Image source: King County Metro Transit, 2015



QUEUE JUMP LANE

Lane on the approach to traffic lights which enables the bus to overtake queuing traffic and/or get a green signal before other vehicles.

Image source: King County Metro Transit, 2015

EXTENT OF BUS PRIORITY ON STUDY PARTICIPANTS' NETWORKS

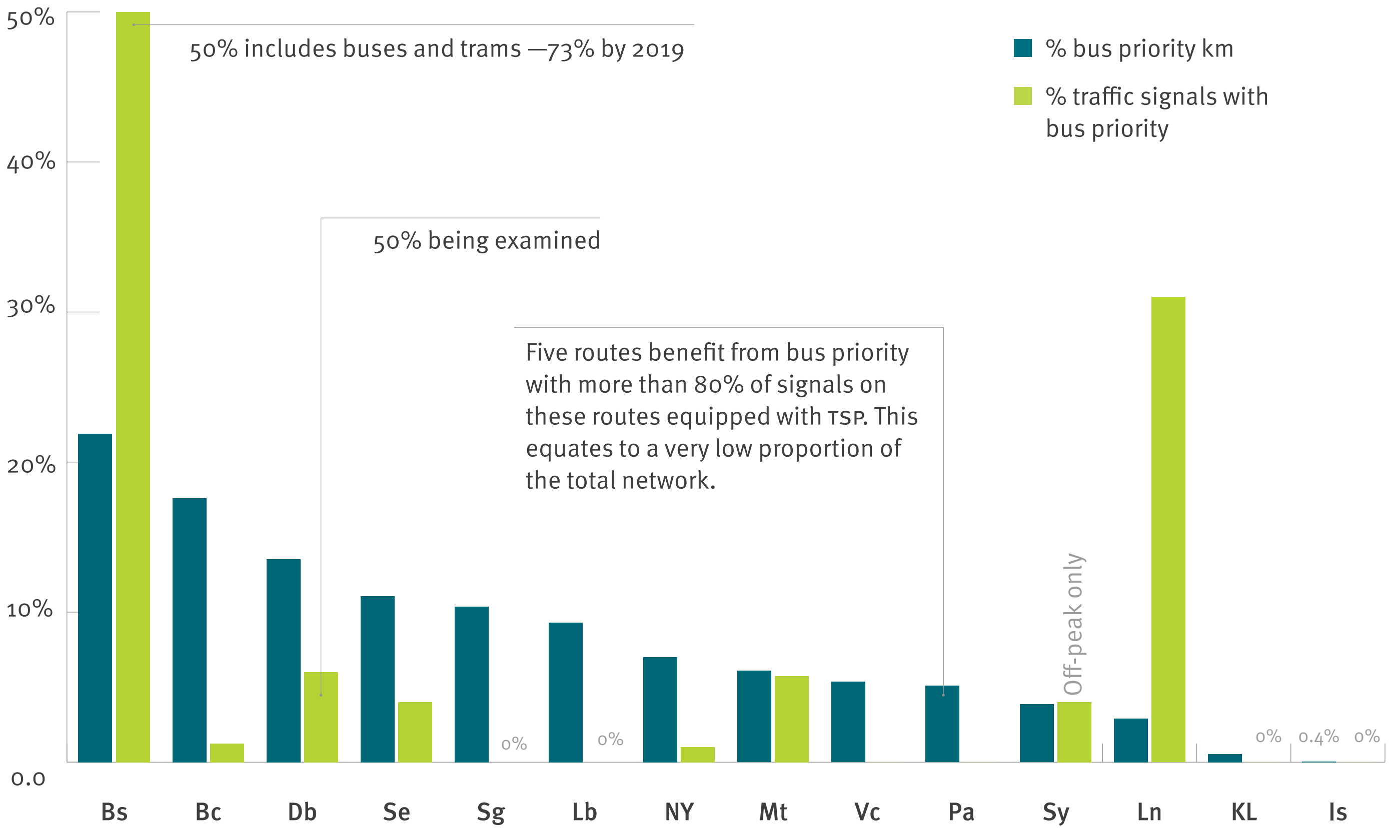
Figure 1 shows the percentage of bus priority infrastructure kilometres and traffic signals with bus priority as a percentage of each participating city's bus network.

The networks of the bus operators participating in the study are ranked from highest percentage of bus priority infrastructure kilometres to lowest percentage of bus priority kilometres, as a proportion of the operator's total route kilometres. Brussels STIB's network is shown to have the highest proportion of bus priority kilometres whilst Istanbul IETT's bus network has the lowest.

In terms of traffic signals with bus priority, Brussels also has the highest proportion with 50% of traffic signals having bus priority, however this covers signals serving both buses and trams in the city. More than 30% of traffic signals on London's network have bus priority, however less than 5% of the network has bus priority. This can be explained by the fact that London's bus network extends into the suburbs of Greater London where congestion is much lower.

In terms of queue jump lanes, the study identifies that this type of bus priority is not widely used across the bus networks reviewed in this study. A queue jump lane allows a bus to bypass general traffic whilst approaching a junction.

Figure 1 Extent of bus priority on study participants' networks (2014)



In some cases the traffic signal may also give priority to buses. As can be seen in Table 3, London has the most queue jump lanes (103) whereas many cities such as Kuala Lumpur, Paris and Singapore do not have any such measures on their networks. London's higher number of queue jump lanes is due to previous investment in the easiest locations to implement the measure. London Buses has identified an additional 30 locations for queue jump lanes but only five of these are in the process of being implemented with a further four in design. The slow progress is largely due to difficulties in coordinating with local authorities and physical issues and constraints arising during the design process.

Finally, the majority of cities within which the study participants operate also have bus lanes on expressways. In Europe (Lisbon, Paris, and London), most expressway bus lanes can be found on routes to and from an airport, whereas outside Europe (New York, Seattle, Sydney, and Vancouver), expressways with bus lanes are more common in the city. Study participants reported that a number of considerations were required to enable bus lanes on expressways, including the congestion of expressways during peak hours (Barcelona), the need for multi-agency collaboration and working (New York), and the challenges posed by regulations requiring HOV use of lanes rather than bus-only lanes (Seattle). Combined High Occupancy Vehicle (HOV)/bus lanes are in use in Barcelona, New York, and Seattle.

Table 3 **Queue jump, HOV lanes/expressways on study participants' networks (2014)**

	Ln	Se	Bc	Db	NY	Mt	Is	Lb	KL	Pa	Sg	Bs	Sy	Vc
No. of queue jump lanes	103	20	10	10	5	3	1	1	0	0	0	Not Quantified		
Expressway HOV Lanes / Bus Lanes	✓	✓	✓	×	✓	✓	×	✓	×	✓	×	×	✓	✓

Successful and unsuccessful bus priority project examples

Study participants were asked to provide details of their most successful bus priority scheme. This section summarises these most successful bus priority schemes with information on project cost, benefits and success factors provided for each example.

The following successful projects, arranged by large and small schemes, are summarised.

LARGE SCHEMES

of Infrastructure Priority >2km

- Seattle King County – *E-Line corridor prioritisation* (2013)
- New York – *Bx41 Select Bus Service (2013)*
- Dublin Buses – *Stillorgan Road Quality Bus Corridor* (1997)

SMALL SCHEMES

of Infrastructure Priority <2km

- Barcelona TMB – *Gran Via de les Corts Catalanes: Double bus lane and green wave* (2012)
- Vancouver CMBC – *Marine Drive bus lane* (2011)
- Paris RATP – *Avenue de Clichy* (2013)
- London Buses – *A100 Tower Bridge Road/ Tooley Street* (2006)
- Brussels STIB – *bus lane on bus route L29* (2012)
- Lisbon Carris – *bus priority signal (routes 701 and 728)* (2010)

Seattle King County

E-Line Corridor Prioritisation 2014

A 2006 Seattle King County voter initiative (Transit Now) called for service expansion stemming from an increase in sales tax. This initiative resulted in bus rapid transit branded as Rapid Ride. Bus priority on the E-Line corridor was implemented to improve speeds for rapid transit.

THE SCHEME

The E-Line operates between downtown Seattle and the Aurora Village Transit Center via Green Lake and North Seattle. The E-Line corridor prioritisation includes TSP at 29 intersections and 11.3 km of kerbside unsegregated bus lanes along a total route length of 16.5 km. One 9km segment of bus lane operates 24 hours, while the remainder operate during AM and PM peak hours (06:00-09:00 and 16:00-18:00). 26 out of a total of 37 bus stops (70% of bus stops) are placed after intersections. The project successfully delivered improvements to travel time for inbound buses by 5.4 minutes, far exceeding the projected benefit by 42%: it was expected that the E-Line corridor prioritisation would achieve average inbound route runtime savings of 3.8 minutes.

SUCCESS FACTORS

The cities of Seattle and Shoreline were very supportive of King County's needs of implementing TSP, retiming signals and installing bus-only lanes. Voters within the City of Seattle have historically been very supportive of King County and transit services in general and there is a continuing trend amongst communities in the Seattle area that sees promoting transit as a way to improve travel through congested areas. Therefore the mayor, city council, and directors at the Seattle Department of Transportation provided key political support for transit projects. In addition, the City of Seattle signal and traffic operations staff had experience in implementing Rapid Ride C and D Line prior to working on E Line. As such they were comfortable with the TSP system and familiar with the level of outreach needed to implement bus lanes.

COST

The project was relatively cost efficient due to much of the key infrastructure already being in place along the corridor. King County was able to repurpose an underutilised kerbside lane into a bus-only lane in the city of Seattle, whereas in the city of Shoreline, the bus lanes were previously installed as part of a larger corridor construction project that had been implemented under a different programme. Similarly, the equipment required for TSP had largely already been installed and upgraded before Rapid Ride.

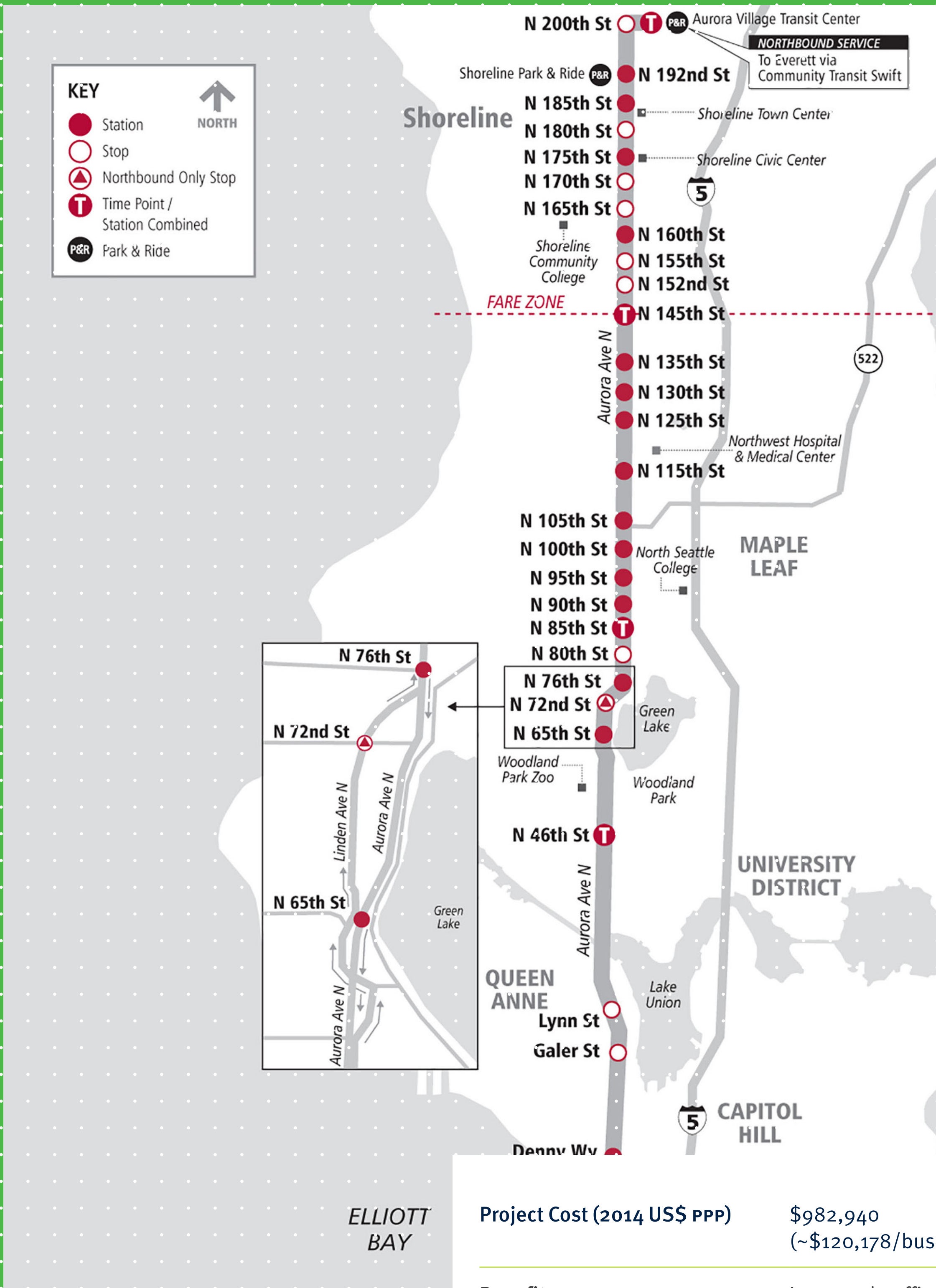


Image source: King County Metro Transit, 2015

Project Cost (2014 US$ PPP)	$982,940 (~$120,178/bus lane km)
Benefits	Improved traffic flow
	Improved service reliability
	Journey time reductions by 5.4 minutes
Success Factors	Political support
	Staff experience

New York

Bx41 Select Bus Service on Webster Avenue 2013

In 2013, the 8.5km Bx41 Limited-Stop bus route was upgraded to a Select Bus Service (SBS) route, which is a BRT type service. New York City Transit (NYCT) and the Department of Transportation launched the Bx41 Select Bus Service on Webster Avenue in the Bronx. Prior to the launch of SBS, Bx41 speeds were very slow and unreliable. This was due to traffic congestion, double parking, and a high number of passenger boardings along the route. In addition, on some sections, the existing two lanes in each direction were excessive for the traffic volumes and local residents were concerned about speeding. The objectives of the project were to improve bus speed, reliability, safety for all users, and to support community needs.

THE SCHEME

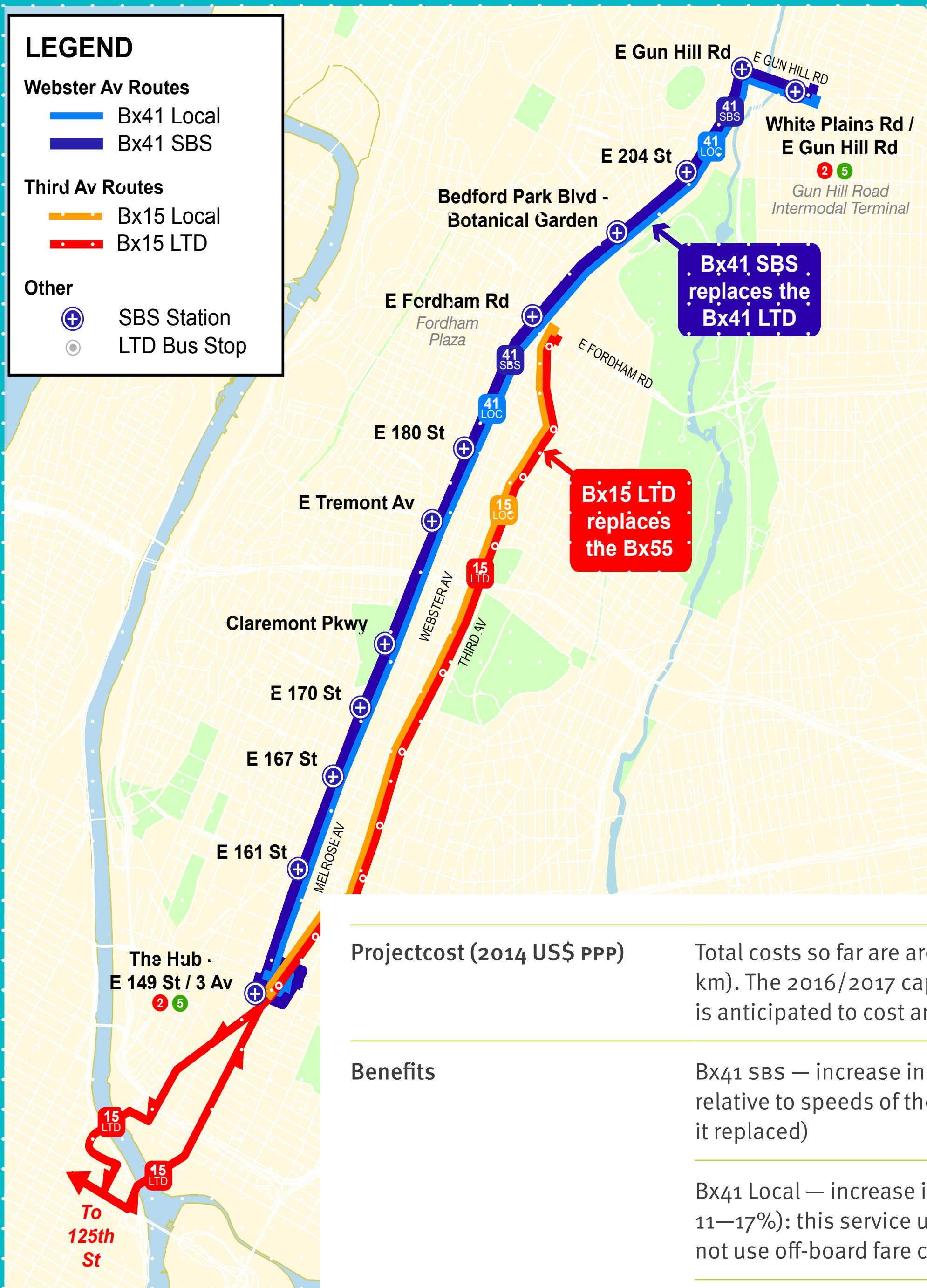
As an SBS scheme, the service stops in fewer locations and uses off-board fare collection at almost all stops. The project has 12.8km of primarily offset bus lanes, along with intersection and pedestrian improvements. Less than 0.8km (6% of the total bus lane length) of the corridor is kerbside bus lane. This was necessary for highway geometry reasons and traffic volumes. The offset bus lanes are operational 24/7. Kerbside lanes are operational from 07:00-19:00 Monday to Friday.

The scheme also includes loading zones, parking restrictions, and some opposite-turn bans (US left turn). The bus lanes are distinguished through red coloured road surface and there are also large overhead signs. TSP was introduced in 2015 and 2016. 2016/17 is also seeing bus bulbs built at most stops.

SUCCESS FACTORS

A key reason for the success of the project was the highway geometry and road width. This allowed for bus lanes to be designed without significantly impacting general traffic. Furthermore, there was significant scope to improve the bus route due to the very slow speeds and widely-varying travel times.

The second key success factor was the very high political and community support for the project, resulting in planning and implementation of the project in less than two years at a relatively low cost.



Projectcost (2014 US$ PPP)	Total costs so far are around \$9M (~\$710,000/bus lane km). The 2016/2017 capital project (TSP and bus bulbs) is anticipated to cost another ~\$20M
Benefits	Bx41 SBS — increase in commercial speed (up 19—23% relative to speeds of the Bx41 Limited-Stop service that it replaced)
	Bx41 Local — increase in commercial speed (up 11—17%): this service uses the bus lanes but does not use off-board fare collection
	Bx41 SBS — increase in ridership
	97% of Bx41 SBS customers are "satisfied" or "very satisfied" with the service
	General traffic largely unaffected
Success factors	Political and community support
	Road geometry and conditions
	Previous slow travel speeds and variable travel times
	Project planned and implemented in less than two years — inexpensive

Dublin

Dublin Bus, Stillorgan Road Quality Bus Corridor 1997

A Dublin Bus initiative called the 'Dublin Quality Bus Corridor (QBC)' was a major factor in kick-starting the implementation of good bus priority projects in the city. The initiative was supported by the implementation bodies, government funding was made available and local councils put in the resources for the work. Dublin Bus had to put in additional buses to support the increase in demand.

THE SCHEME

The Stillorgan Road scheme (circled in the plan) was implemented to improve the corridor, which suffered from slow bus speeds and low modal share of buses. The Stillorgan Road QBC is operational from 07:00—19:00 Monday to Saturday. Whilst TSP is not currently used along the route, it is expected that 15 of the 30 traffic signal junctions on the corridor will have the technology in 2017. An objective of the scheme is for buses to only stop at bus stops (i.e. free-flowing bus travel between stops) and TSP is expected to help achieve this.

The project successfully delivered its objective of making travelling by bus faster than by car with a 42.56% reduction in car use between November 1997 and 2007. Benefits included reduced bus run time, reduced journey time variability, and increased ridership by 176.16% between November 1997 and 2007. These impacts are shown in the monitoring table.

Since 2010, there have been further enhancements in performance due to both economic improvements and the straightening of the previously circuitous route. This was possible due to political support. It has led to longer walks for some customers by two to three minutes, but Dublin Bus compensated in part by making changes to other local routes.

SUCCESS FACTORS

Success factors of this project included political support, the finance for the works being available, and framing the scheme as a QBC project given the widespread support for the QBC initiative. However, despite the support the scheme encountered some opposition from major agencies including local politicians, traders and car lobby groups.

Dublin's QBC scheme increased ridership significantly in the first couple of weeks and Dublin Bus was only able to handle the additional demand because extra buses were available due to fleet replacement that was ongoing at the time.

Project Cost (2014 US$ PPP)	$8.8M (~$876,000/bus lane km)
Benefits	Peak hour bus speeds ~30% faster than car speeds
	Increase in regularity
	Increase in ridership by 176%
	Decrease in run time variability
Success Factors	Political support
	Finance for works & buses
	Framing the scheme as a 'QBC Project'

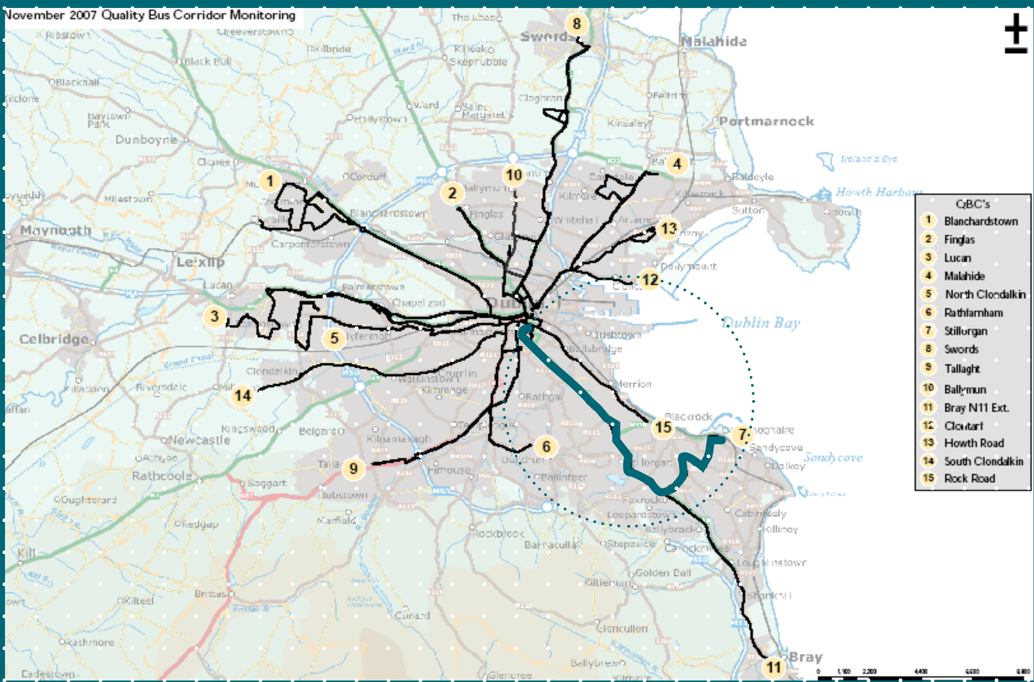


Image source: Dublin Bus, 2007

QBC Monitoring November 1997 — November 2007

Corridor	Mode	11.1997	11.2007	% change
Stillorgan	**Cars**	5794	3328	-42.56
	Buses	40	120	200.00
	Bus passengers	1787	4935	176.16

Barcelona

Gran Via de les Corts Catalanes: Double bus lane with green wave 2012

A permanent double bus lane (kerbside and offset lanes) with green wave was implemented to accommodate a high number of bus routes (local and express bus routes) and frequency in the northern direction on Gran Via de les Corts Catalanes. In the southern direction buses continue to share lanes with general traffic.

Prior to the implementation of the bus lane, the high number of buses obstructed one another. Therefore it was key for the solution to allow a bus to easily overtake other buses.

THE SCHEME

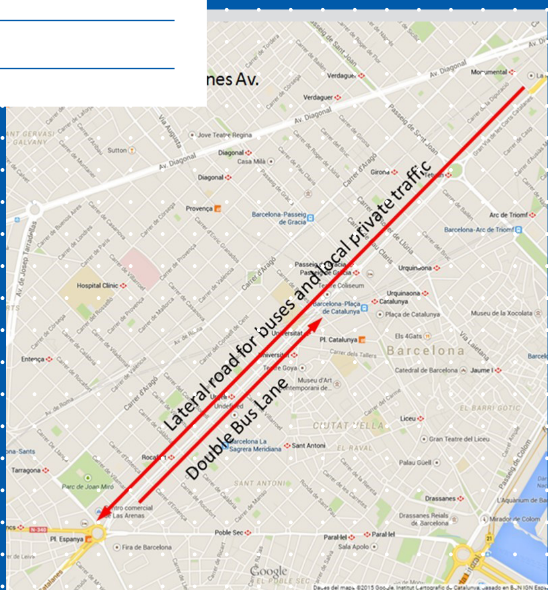
The double bus lanes (kerbside lane = bus only; offset lane = bus and taxi) of the scheme are complemented with double bus stops to accommodate the high number of buses using the corridor.

The project successfully delivered its objective of achieving an improvement in commercial speed by 10–15% along with a runtime reduction on routes H12, 50 and Aerobus routes A-1 and A-2.

SUCCESS FACTORS

Success factors included the scheme design (traffic capacity was maintained) and political support for the scheme.

Project cost (2014 US$ PPP)	$449,700 (~$224,850/bus lane km)
Benefits	Increase in commercial speed in northern direction by 10—15% on this section
Success factors	Scheme design
	Political support



Background mapping source: Google Maps, 2015 Image source: Transport Metropolitans de Barcelona, 2015

Vancouver

Vancouver CMBC, Marine Drive Bus Lane 2011

The Marine Drive Bus Lane is 1.8km in length spanning various intersections leading towards the Lion's Gate Bridge. Marine Drive suffers from severe delay and congestion due to heavy traffic flow across the Lions Gate Bridge connecting Downtown Vancouver and North Vancouver. The bus lane was implemented to reduce congestion and delay for buses and is operational during the weekday peak hours from 06:00—09:30 and 15:00—18:30.

THE SCHEME

The project successfully delivered its objective of mitigating delay and improving bus speeds. However Vancouver CMBC has not undertaken a post-implementation study to quantify the benefits delivered by the scheme. These are based on bus operator observations and fewer customer complaints of delay and congestion.

CHALLENGES

The project was relatively expensive to deliver at approximately 1.3M US$ PPP per bus lane km. The high cost is largely related to two factors: a) land purchase was required to provide the necessary space for the bus lane; and b) construction costs were increased as a result of the tough geometry of the road on the approach to the bridge.

Project cost (2014 US$ PPP)	$2.5M (~$1.3M/bus lane km)
Benefits	Decrease in delay
	Decrease in travel time
	Increase in service reliability
Success factors	Good match between problem and solution
	Effective marketing and communication of benefits
Challenges	Land acquisition
	Road geometry

Paris

Paris RATP, Avenue de Clichy 2013

The Avenue de Clichy accommodates very high daily vehicle, cyclist and pedestrian flows, resulting in chaotic peak hour travel conditions with buses caught up in heavy congestion and parked vehicles obstructing the lanes. The new arrangements of the street layout include a segregated bus lane and dedicated delivery areas. These works were promoted and financed by the city of Paris. After 14 months of construction, the works completed in August 2013.

THE SCHEME

The key objective of the project was to improve circulation for all road users, including bus services 54, 74 and 81 using this corridor. Other objectives included reducing the number of accidents, calming traffic flow, de-cluttering footways and improving the appeal of the corridor as a whole.

With these objectives in mind, the key elements of the project included:

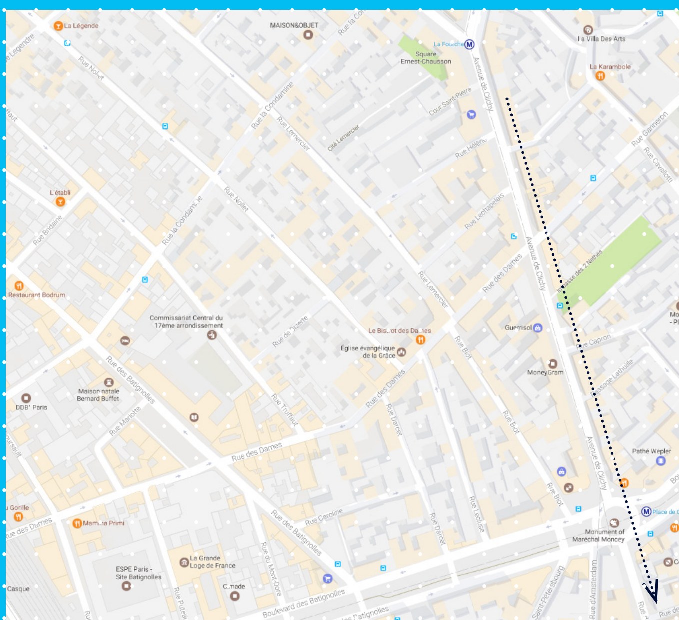
- 30km/h speed restrictions;
- a segregated bus lane travelling south between La Fourche and Place de Clichy (cyclists also permitted);
- more frequent and wider pedestrian crossings; and
- dedicated delivery areas.

There is a lane in each direction for general traffic with northbound bus services also using the regular traffic lane.

Before

After

Project Cost (2014 US$ PPP)	$4.8M for entire street rearrangement and redesign including works relating to the utility networks. (~10M/bus lane km)
Benefits	Improved traffic flow
	Increase in service reliability



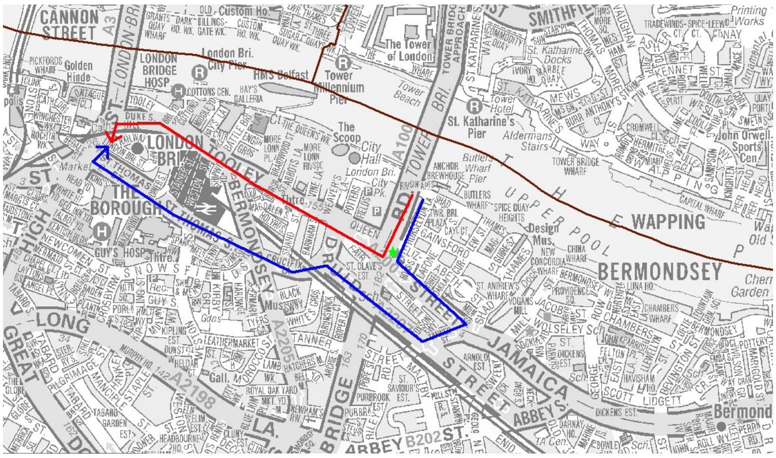
Background mapping source: Google Maps, 2015; Image source: Mairie de Paris, 2013

London

London Buses, A100 Tower Bridge Road/ Tooley Street 2006

Prior to a right turn lane being introduced, buses on route RV1 were required to turn left and take a circuitous route to reach London Bridge Station. The introduction of the right turn lane reduces the distance from 1,742m to 1,114m; a drop in route distance of 628m.

The works also consisted of retiming the traffic signals, which was implemented in conjunction with a left turn facility for another route (route 343).



THE SCHEME

The right turn is bus-only and is operational 24 hours a day, seven days a week. The junction also has TSP and the bus lane is coloured red (as shown in the photograph).

The project successfully delivered its objective of improving bus journey times and the reliability of buses along the section of the bus route. The scheme resulted in average savings of 636 seconds (~10 minutes) in the AM peak, 391 seconds (~6.5 minutes) in the inter-peak, and 591 seconds (~10 minutes) in the PM peak.

SUCCESS FACTORS

The bus routing was much more efficient as the bus-only turn allows buses to turn right without having to take a 600m detour. This combined with the implementation of bus priority measures delivered a successful scheme.

Project Cost (2014 US$ PPP)	$176,000 (~$158,670/bus lane km)
Benefits	Decrease in journey time
	Decrease in route distance
	Decrease in average bus journey times of approximately 10 minutes
	1st year rate of return of 277% (net savings in journey time of $490,057)
Success Factors	Providing more efficient routing with bus priority measures
	New bus standing provision enables much shorter dead-running when route is shortened

Background mapping source: Transport for London, 2008 Photographs: Transport for London, 2008

Brussels

Brussels STIB, Avenue des Cerisiers 359m permanent bus lane 2012

Prior to the implementation of a bus lane between 'Levie' and 'Diamant' in October 2012, the Avenue des Cerisiers was a road with two sections in the same direction to the complex 'Diamant' junction where it was joined by several other streets. During peak hours buses were constantly delayed by dense traffic from the bus stop 'Levie' towards the 'Diamant' junction. The traffic volumes at this busy signalised junction (no TSP) resulted in severe congestion during peak hours.

THE SCHEME

A lane is now reserved for buses (including taxis and bicycles) on a permanent basis allowing buses to travel to the 'Diamant' junction without getting caught up in traffic congestion. The bus lane is an unsegregated kerbside lane with signage indicating its use to other road users.

The objective of the scheme was to increase commercial speed and reduce bus delay. Interestingly an objective by the Brussels Region requires commercial speed to always exceed 18km/h and that no vehicle speeds (i.e. cars and buses) are below 12 km/h. However as shown in the table overleaf, these thresholds have not been met despite the bus lane, yet the measure has been very successful in increasing commercial speed across all peak hours except for the evening period (21:00 – 24:00).

Figure 2 shows the 'before' and 'after' bus lane implementation situation of bus journey time variability along this section. These clearly show the impact that the bus lane has had on improving bus speeds, regularity and journey times.

Time is represented by the x axis; journey time is represented by the y axis; and AM and PM peak periods are highlighted.

As shown in Figure 2, prior to the implementation of the bus lane, in particular during the morning and afternoon/evening hours, journey times varied much more significantly between five to nine minutes. Journey time variability, measured after implementation of the bus lane, displays a much flatter profile with much more consistent journey times across all times of the day.

Similarly, Figure 3 shows the variability in bus delay pre- and post-implementation. Weeks (form September to December 2012) are represented by the x axis; bus delay (minutes) is represented by the y axis; and the implementation of the bus lane in mid-October 2012 is also shown. The graph shows the delay experienced by buses between stops Mai and Diamant during different periods across the day (before 07:00, 07:00—09:00, 09:00—16:00, 16:00—18:00, 18:00—20:00, with each time period represented by a line.).

As observed with journey time variability, this graph clearly shows that the bus lane has significantly reduced bus delay. Prior to the implementation of the bus lane, buses experienced up to seven minutes delay between the Mai and Diamant bus stops across all periods of the day, with the exception of the morning period before 07:00. Since the implementation of the bus lane, the delay along this section generally does not exceed one minute.

The section between stops Levie and Diamant has followed a similar trend since the installation of the bus lane. Average bus delays of more than three minutes were typically experienced between 08:00—09:00 and 16:00—18:00 prior to implementation of the bus lane. With the bus lane in place, average bus delay does not exceed 0.6 minutes across all hours of the day.

Benefits	Peak journey speeds increased by 38%, on average
	Less journey time variability and bus delay
	Improved bus service regularity
Success factors	Good match between problem and solution.
	Buses have one free road section which allows them to drive directly to the ‘Diamant’ junction.

Bus speed	Before priority	After priority	Change
AM Peak (07:00—09:00)	11.2 km/h	15.3 km/h	36.6%
Off Peak (09:00—16:00)	15.1 km/h	15.5 km/h	2.6%
PM Peak (16:00—18:00)	10.7 km/h	15.0 km/h	40.2%
Evening (21:00—24:00)	22.2 km/h	19.6 km/h	−11.7%

Image source: Société des Transports Intercommunaux de Bruxelles, 2012

Figure 2 Bus journey time variability pre- and post-implementation of bus lane
Original source: Société des Transports Intercommunaux de Bruxelles, 2012

Before variation in bus delay and journey times across most of the day

After reduced bus delay, more consistent journey times across the day

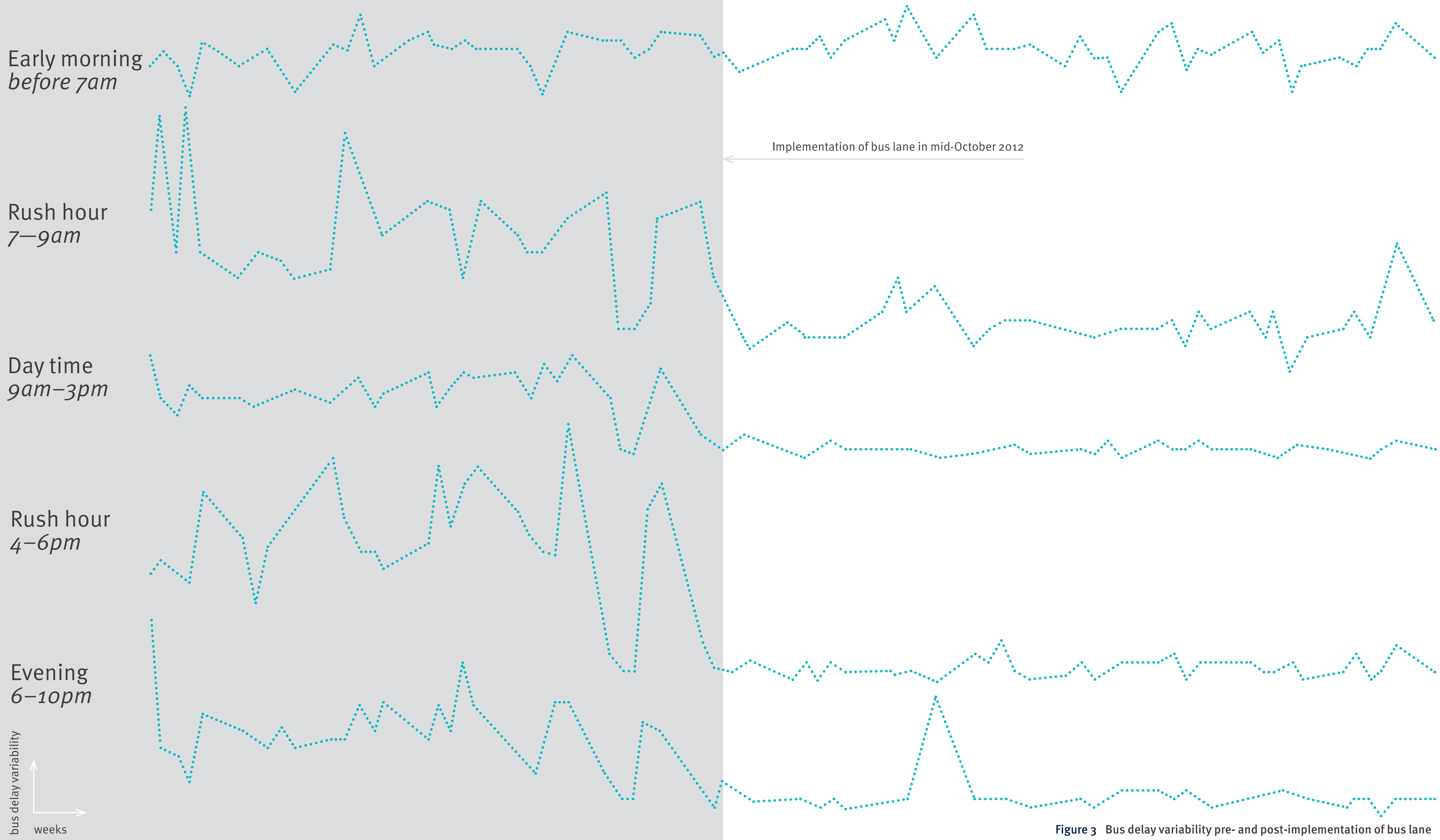


Figure 3 Bus delay variability pre- and post-implementation of bus lane

Original source: Société des Transports Intercommunaux de Bruxelles, 2012

Lisbon

Lisbon Carris, bus lane Rua António Albino Machado (2010)

Prior to the implementation of the bus lane, buses only used Azinhaga das Galhardas and Rua António Albino Machado in one direction. In the opposite direction (shown in red) buses were required to take a longer route and to share the roads with general traffic. Rua Pedro Monjardino and Av. Lusíada suffered from heavy traffic in the peak hours resulting in delays to buses.

THE SCHEME

Since the implementation of the bus lane, buses use Rua António Albino Machado and Azinhaga das Galhardas in both directions, reducing the distance for each journey by almost 700m. The bus lane is only for Carris vehicles and these are therefore not delayed by general traffic conditions. When approaching the intersection between Av. Prof. Egas Moniz and Azinhaga das Galhardas, the lights give priority to Carris buses.

Upon entering the bus lane, a coil (orange circle shown on the plan) automatically identifies the bus, through the use of a special frequency. The traffic lights at the intersection receive this information and the traffic lights (pink circles shown on the plan) change to yellow and then red. The bus traffic light (blue circle shown on the plan) turns to green before the bus reaches it, allowing it to proceed without stopping.

Project cost (2014 us$ PPP)	$145,040 (~$438,187/bus lane km
Benefits	Decrease in run time variability
	Decrease in distance by 700m
	Increase in ridership

Image source: Comphania Carris de Ferro de Lisboa, 2013

SUMMARY OF SUCCESSFUL BUS PRIORITY PROJECT EXAMPLES

Based on study participants' most successful bus priority projects described in the previous sections, key success factors of schemes include the following:

- Public and political support for bus priority projects (e.g. Barcelona, Brussels, Dublin, New York, Seattle);
- Addressing routes that suffer from very slow bus speeds and have widely varying travel times (e.g. New York, Brussels);
- Good match between problem and solution (e.g. London's rerouting of a circuitous route);
- Framing corridor upgrades as part of a programme or initiative with widespread political support (e.g. Dublin's QBC initiative);
- Implementing bus priority on roads that have sufficient road width to accommodate bus lanes (e.g. New York); and
- Clear communication and marketing strategies to gain public support (e.g. Vancouver).

Six of the successful projects on study participants' networks relate to bus lanes, four of which are in operation on a permanent basis (Barcelona, Brussels, Lisbon, London) and two bus lane schemes (New York, Seattle) have permanent hours of operation on at least some sections of the corridor.

Some operators believe that the most effective bus lanes are those that run over several kilometres and junctions, and are in operation 24 hours a day, seven days a week rather than during peak hours or weekdays only. Hours of operation of bus lanes are however often influenced by a number of factors such as bus demand, traffic volumes and peak flow, and safety issues. Therefore, hours of operation often vary by location.

In terms of TSP, only four of the successful case studies highlighted (Barcelona, London, New York, and Seattle) had TSP equipped signals on either all or part of the corridor. TSP is discussed in full in a later section of the study. However, participants' experiences with TSP indicate that the technology does not necessarily work well in slow-moving traffic.

In addition, study participants mentioned that unsegregated kerbside bus lanes can benefit less mobile passengers (Sydney), whilst unsegregated offset bus lanes keep areas commercially vibrant (Dublin) and are preferred by local communities (New York). Double bus lanes on the other hand, appear to often be self-enforcing with fewer incidents of violations (Dublin).

UNSUCCESSFUL BUS PRIORITY PROJECT EXAMPLES

This section summarises the following unsuccessful bus priority schemes that study participants have experienced:

- 3rd Generation Bus Priority Programme (3GBP), London;
- M4 bus lane between Heathrow Airport and Central London;
- Bus lane on Swords Road, Dublin;
- Bus lane on Avinguda Diagonal, Barcelona; and
- Bus lane on Millet Avenue, Istanbul

The unsuccessful examples of bus priority measures failed for a number of reasons and include issues related to politics, public opinion, traffic volumes, impact on other modes, and a lack of enforcement.

Politics

Political support for bus priority measures is often important for the success of bus priority schemes. An example of a failed scheme due to political factors is London's 3rd Generation Bus Priority programme (3GBP).

London's 3rd generation bus priority (3GBP) programme

London Buses had a negative experience with a particular bus priority initiative, the 3GBP.

The issues experienced with this programme included a lack of political support for future traffic predictions during consultations, which meant that evidence and justifications for the programme were not clear to stakeholders. For example, proposals for a 24-hour southbound contra-flow bus lane and new bus stand on an existing one-way northbound road in South West London was opposed by local politicians for reasons related to noise, safety, parking, road width, cost and location of the new bus stand. Whilst Transport for London argued that the contra-flow bus lane would reduce journey times by around three minutes each, strong opposition from residents and politicians meant that Transport for London did not proceed with the plans.

A further challenge was that 3GBP was planned under a previous mayoral administration prior to 2008. After 2008, political, management, and funding changes were focused into other programmes which reduced progress with the 3GBP programme.

Further to the above, the 3GBP programme was selected based on ridership. However, most of the obvious and easier measures to implement had already been covered in other programmes (London Bus Priority Network, London Buses Initiative or Red Route Local Plan) prior to 3GBP. Consequently these corridors had already been reviewed and a number of viable schemes had been implemented.

Overall impact

An example of a bus lane removal is the former M4 bus lane between Heathrow Airport and Central London. The monitoring process identified greater overall benefits following a trial suspension of the lane.

WHY?

The objective of the 3GBP programme was to minimise the effect of increasing traffic congestion on London's buses.

HOW?

The programme set out to achieve this by delivering efficient and reliable bus corridors in form of whole-route bus priority measures on a number of London's most popular and most congested bus routes.

WHAT WENT WRONG?

Key problems included a lack of political support in the mayoral administration and some local authorities. Some schemes were also too ambitious and not feasible for the proposed locations.

M4 bus lane between Heathrow Airport and central London

An interesting unsuccessful example of a bus lane on an expressway is the former M4 bus lane (approximately 5.6 km) which operated between Heathrow Airport and Central London from 1999 to 2010. Only buses, licensed taxis and motorcycles were allowed to use the lane. The bus lane was suspended in 2010 for 18 months as a trial. Highways England (previously the Highways Agency) monitored the impact of the bus lane suspension to inform the Government's decision as to whether the bus lane should be removed on a permanent basis. The monitoring process included the review of before and after traffic data (journey times, speeds and flows) as well as noise, air quality and accident data.

The findings showed that despite increased traffic, journey times were quicker overall following the suspension of the bus lane. Journey times for buses and taxis increased, but the report suggested that the overall gains outweighed these increases.

In addition, findings showed a reduction in the number of accidents after the suspension. It should be noted that there is still a bus lane on the last section of expressway approaching Heathrow Airport.

Traffic

The implementation of bus lanes in locations where there may be conflicting traffic movements or higher volumes of traffic can be problematic. An example of such a situation is described below.

Swords Road, Dublin

Dublin's bus lane project on Swords Road includes a straight-through bus movement from one bus lane to another across a big junction and major car movements turning left across the bus lane at the junction.

Consequently, the blocking up of general traffic lanes infringes into the bus lane. Many bus lanes at junctions perform poorly due to cars often trying to pass through the junction as the signal turns red. As a result, vehicles end up blocking the junction until traffic starts moving again.

Possible solutions to resolve this include implementing a 'bus gate' island costing around $2,380 US$ PPP in Dublin (per scheme) or using flexible delineators or bollards costing around $11,900 US$ PPP in Dublin (per scheme).

Public opinion

The public may have a negative reaction to the installation of a bus priority scheme. An example from Barcelona is summarised below, which highlights the importance of ensuring that bus service frequency in the bus lane is sufficiently high.

Avinguda Diagonal, Barcelona

A frequency of less than 15 buses per hour on a bus lane on Avinguda Diagonal resulted in complaints from private vehicles stuck in traffic as general traffic had to queue in the regular lanes in the morning peak whilst the bus lane was empty with only one bus every four minutes.

This example highlights the impacts a bus lane may have on corridors suffering from high traffic volumes, and the negative reaction it can cause when bus frequencies are low. In this particular case, the routes of other bus services were consequently changed to take advantage of the bus lane and increase its usage.

Traffic / lack of enforcement

In the absence of bus lane enforcement and a high level of unauthorised use of lanes, buses may be delayed which is counterproductive to the purpose of a bus priority scheme. This is demonstrated in an example from Istanbul below.

Millet Avenue, Istanbul

A bus lane was introduced on Millet Avenue which had traffic speeds of less than 10km/h. A kerbside unsegregated bus lane was implemented (operational during the morning and evening peak hours) and the scheme also includes one queue jump lane.

Due to the unseparated nature of bus lanes in Istanbul and a lack of dedicated enforcement to monitor bus lane use, the Millet Avenue bus lane is frequently used by other vehicles not authorised to travel on the bus lane. These vehicles obstruct and thereby delay bus services on this route.

Bus priority identification and selection process

This section focuses on how opportunities for bus priority are identified and selected for implementation. It firstly examines how locations are identified as places which would benefit from bus priority measures and whether there are any specific criteria and thresholds that guide bus priority project implementation, as well as the removal or cancellation of a scheme that is already in place.

The study continues to explore how identified projects are then prioritised and selected, and whether different approaches are used to identify large and small projects. The final subsection describes the processes in place to confirm the appropriate bus priority solutions for implementation (e.g. analysis and testing).

THE IDENTIFICATION PROCESS

This study found five approaches used to identify locations for bus priority measures:

- Identify problem areas (Brussels, Dublin, Istanbul, London, Paris, Seattle, Singapore, Sydney, and Vancouver)
- Urban growth (London, Seattle), ridership growth/high ridership routes or areas (Vancouver, New York, and Seattle)
- Opportunism (London and Brussels)
- Identify high importance routes/strategic connections (Lisbon)
- Implementation feasibility (Barcelona)

Among these approaches, the most common one is to identify problem areas where bus priority can solve a problem.

In London, New York, and Seattle high patronage numbers are used to identify routes.

For example, in New York the approach is to upgrade existing limited-stop routes with high ridership and slow speeds to SBS routes. Additionally, small projects are implemented to improve key bottlenecks.

In Brussels and London however, opportunism is an approach often used to implement bus priority (Brussels, London). In Brussels, where the political nature of planning means that it is difficult for bus operators to have a say in implementing infrastructure projects, STIB's proactive approach is to seize every possible opportunity when there are plans to rearrange a street layout and to include bus priority in the new design of streets. London Buses also takes an opportunistic approach to implementing bus priority. In the UK the planning system requires major new developments to make financial contributions to transport improvements and this means that planning applications present an opportunity for implementing bus priority.

In Lisbon important routes or those with a strategic connection are identified. Note that around 20 years ago, the authority in Lisbon built a significant amount of bus lanes to increase the city's bus lane mileage. At the time it was easy to introduce bus lanes as roads were wide and less congested, thereby providing an opportunity for bus priority but the schemes were not necessarily implemented where they would have been most useful.

In Barcelona, all bus routes are assessed in terms of their feasibility for bus priority. The aim is to implement bus lanes where possible to ensure high commercial speeds and regular services.

The methods used to identify potential problem areas can be divided into two categories: 1) the analysis of bus runtime data and traffic data (journey time variability, stopped time, speeds); and 2) the review of staff reports and customer complaints.

In Dublin, the process has historically been to review driver and controller opinions, and to examine complaint trends. However, with AVL it is now possible to know where, when and for how long every bus stops. Using AVL for this purpose has so far been very successful.

In Seattle there are three different approaches: 1) projects are frequently identified by operators and supervisors who see problems on a daily basis; 2) priority routes or networks are identified based on ridership, connection to urban growth zones and service to under-served populations; 3) improvements along a specific route are identified by delay assessment (informed by AVL data). Once high bus delay is identified for a route or location, the initial assumption will be to include a future priority for the service. Traffic analysis and modelling will then inform the project teams if the treatment is beneficial for transit or too detrimental to other road users.

In Lisbon, projects are prioritised by analysing the number of customer complaints, observations by inspectors and drivers, and service operating indicators supported by data collected from the AVL system. For example, journey times and schedule irregularity are analysed for different weekdays and hours.

Istanbul and Singapore identify routes with heavy traffic and lower than average bus speeds as problem areas. Singapore SMRT then highlights these areas to the Authority.

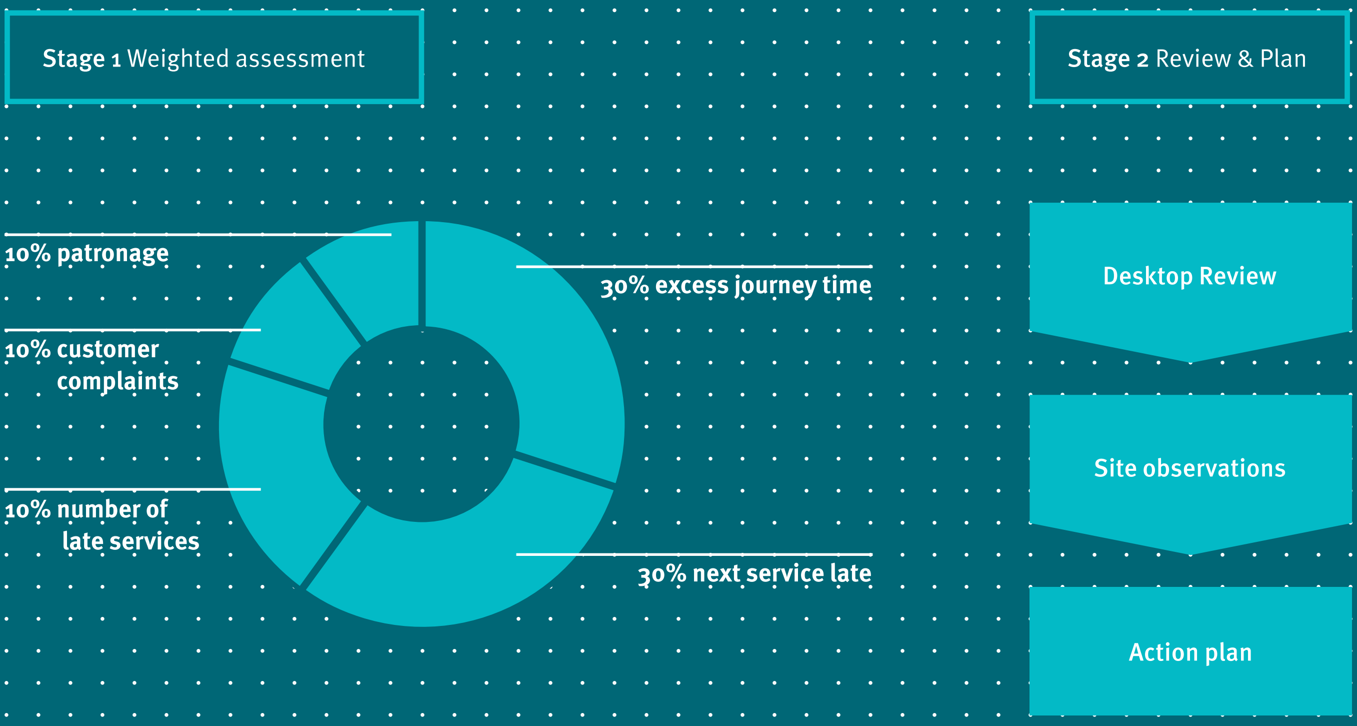
A further method used is collaborative working: NYCT and MTA Bus work with the Department of Transportation to identify areas where buses are slow, using AVL data and other observational data.

In London, there are three different methods that are used to identify problem areas that may benefit from bus priority measures:

'Growth' schemes
Identifying locations where redevelopment will deliver increased patronage;

'Reliability' schemes
Identifying existing challenging sites on the network; and

Figure 4 Sydney Buses' two-stage approach



'Road Modernisation Plan' schemes
Supporting the Roads Modernisation Plan (a major road investment programme focusing on safer roads and better spaces to walk and cycle) by mitigating the adverse predicted bus route impacts of this programme in inner and central London as far as possible through bus priority schemes and interventions.

London's three methods are informed by strategic modelling to identify potential future areas where bus priority will be required, and existing locations of delay commonly identified using AVL data (iBus) to isolate specific areas of priority.

In Brussels, there is a three-stage approach to the bus priority identification process. The approach is to select locations by average commercial speed (from lowest to highest commercial speed) and by journey time variability "standard deviation" (from highest to lowest). The next step is to analyse if adjustments are physically possible. This information and the findings then determine the solutions to be proposed.

Sydney Buses has recently worked with Transport for New South Wales in identifying routes/corridors that require bus priority. A two-stage approach as illustrated in Figure 4.

The first selection stage is a weighted assessment. Different weightings (%) are applied to the factors excess journey time (30%), next service late (30%), number of late services (20%), customer complaints (10%), and patronage (10%).

The projects with the highest scores are then moved to the project identification stage which includes a desktop review and on-site route or corridor observations. The findings of these reviews and observations are then incorporated into an action plan.

It is noteworthy that a few organisations differentiate their approaches for identifying major versus minor projects or investment, see Figure 5.

In New York, there is some differentiation to an extent. SBS projects (major projects) are driven by ridership, slow speeds, where the biggest opportunities lie for improvement, and whether there is political and community support for the project (to a lesser extent). Minor projects can be driven by all sorts of possible reasons, including safety concerns and potential opportunities.

Similarly, in Seattle major projects are driven by ridership and applicability to grant funding. Smaller projects are driven by issues identified by drivers and supervisors.

In Dublin, length of delay and frequency will influence and decide the level of investment.

Figure 5 **Identification of major versus minor bus priority projects**

Major projects

NEW YORK SBS projects, driven by ridership, slow speeds, biggest opportunities for improvement, political and community support

SEATTLE Driven by ridership and applicability to grant funding

DUBLIN Locations with major delays for large volumes of buses – a solid case can be made for a large investment

Minor projects

NEW YORK Driven by a variety of possible reasons (including safety concerns and opportunities)

SEATTLE Driven by issues identified by drivers and supervisors

No significant difference between major and minor projects in Barcelona, Istanbul, Lisbon, London, Paris, Sydney and Vancouver

Where there are major delays for large volumes of buses, Dublin Bus can make a strong case for large investment. However, the challenge is often road space constraints for implementing bus priority measures.

In London, the approach to bus priority project identification remains the same and the difference between major and minor projects is determined by the opportunity at each specific site.

THE SELECTION PROCESS

Once the locations for bus priority have been identified, there are further processes in place to select final projects for implementation. The approaches used by organisations to score and prioritise projects and any eligibility criteria or guidelines available are discussed in turn in the following subsections.

Scoring and prioritisation approaches

Scored assessment

The most common approach is to undertake a scored assessment. This approach is adopted in Brussels, London, New York, Vancouver, Seattle and Sydney.

In London, a cost-benefit analysis and a scoring matrix are used to identify pilot schemes. Transport for London (TfL) has developed an Assessment Tool that TfL employees or local authority officers complete for areas that may benefit from bus priority measures. The tool considers both bus operational and passenger benefits alongside other factors (e.g. road safety, cycling, traffic, urban realm, commercial/environmental benefits). TfL has a process in place for the prioritisation of future bus priority schemes, see Table 4. London boroughs are required to submit brief details of proposed schemes including information on location, a description of the issue, the proposed solution, and the affected bus routes.

The Bus Priority Delivery Portfolio (BPDP) allows London boroughs to propose schemes with the objective of improving bus priority and reliability in their boroughs. The BPDP supports the ambitions of the "Mayor's Transport Strategy" for London for "a bus network that is developed to provide an even better value for money service, building on its success and expansion over the last decade." The objectives are to:

- Reduce the impact from increasing traffic volumes and congestion on bus journey times and reliability through tackling congestion at key junctions;
- Potential reliability schemes may include measures such as yellow box junctions, new/extended bus lanes, amended bus lane hours of operation, bus gates, revisions to bus turning movements, improved road alignment, inset parking/loading bays, changes to parking/loading restrictions; and
- Unlock opportunity areas and supporting growth and increasing bus modal share at these locations to encourage 'car-lite' developments and reduce congestion that would otherwise affect bus journey times and reliability.

While there may be secondary benefits to other modes, proposed schemes must show benefits to buses and the focus of the schemes must be on buses.

In Brussels, a cost-benefit analysis was done for bus route L71. This involved trip estimation (i.e. driving time and layover time using STIB driving time data) and a budgetary estimation of options (including external costs estimated using European Commission calculation methodologies).

In Sydney, the Roads and Maritime Services generally provide the cost-benefit analysis. The schemes are rated and those showing the greatest benefits are implemented.

In Vancouver, the Multiple Account Evaluation (MAE) approach puts together separate evaluations of a range of factors to identify the benefits and impacts.

'Top 10' / Shortlist approach

Dublin and Lisbon have a 'Top 10'/shortlist approach. In Dublin, there isn't a formal scoring process, but the organisation has a live 'worst 10 pinch point' list for when funding for bus priority becomes available. This is a judgemental call balancing the following:

- How bad is the delay?
- How possible is it to solve physically?
- Are the funds available?

However, it is often the case that the worst congestion points are almost physically impossible to improve due to space constraints.

Comprehensive process of analysis

Barcelona has an ongoing process of analysis covering each of the corridors on the new bus network. As part of the analysis, costs are taken into account and a number of diverse indicators are assessed. These are:

- Average daily traffic;
- Remaining number of lanes;
- Number of buses per hour;
- Parking places to be removed;
- Feasibility of hourly/non-permanent bus lanes; and
- Benefits for buses in terms of time savings.

If the benefits for buses are significant and general traffic can be accommodated by the remaining number of traffic lanes, TMB gets approval to install a bus lane. In most cases TMB does not get approval for a bus lane with permanent hours of operation.

Bus priority selection criteria

The impact of bus priority on other road users
This subsection discusses any guidelines that organisations have in relation to the acceptable level of impact of bus priority schemes on other road users, and any specific or non-specific criteria that projects are reviewed against prior to final selection for implementation.

Figure 6, Guidelines on the acceptable impact of bus priority on other road users ,summarises which organisations have guidelines in relation to the acceptable level of impact that bus priority measures can have on other road users.

The majority of organisations do not have specific guidance on the acceptable level of impact that bus priority measures can have on other road users. Where guidance is available for this purpose, this can be classified into guidance suggesting minimising the impact on cars (for example, in Barcelona where bus priority should not result in a reduction to car speed by more than 5%) and guidance encouraging improvements to the walking and cycling environment. In these cases, car impacts are often considered acceptable.

Minimise car impact
In London, national legislation (The Traffic Management Act 2004) imposes a 'Network Management Duty', which means that Transport for London, as a traffic authority, is required to manage and secure the efficient movement of traffic on their road network and to facilitate traffic movement on other traffic authorities' road network (i.e. the London boroughs).

New York's Department of Transportation typically follows local environmental review guidance, which states that delay for general traffic should not exceed 45 seconds at intersections. However, this is guidance only and therefore not always followed at locations with particularly high bus ridership or particularly congested existing conditions.

Pro-pedestrian/public transport
In Dublin, there is a policy that bus priority should not negatively impact pedestrians and cyclists as there is a shift in local authority policy resulting in the impact on cars becoming of less concern and encouraging other modes is seen as more important. The current hierarchy in Dublin is: 1) pedestrians, 2) cyclists, 3) public transport, and 4) cars.

Table 4 London's bus priority delivery portfolio selection process

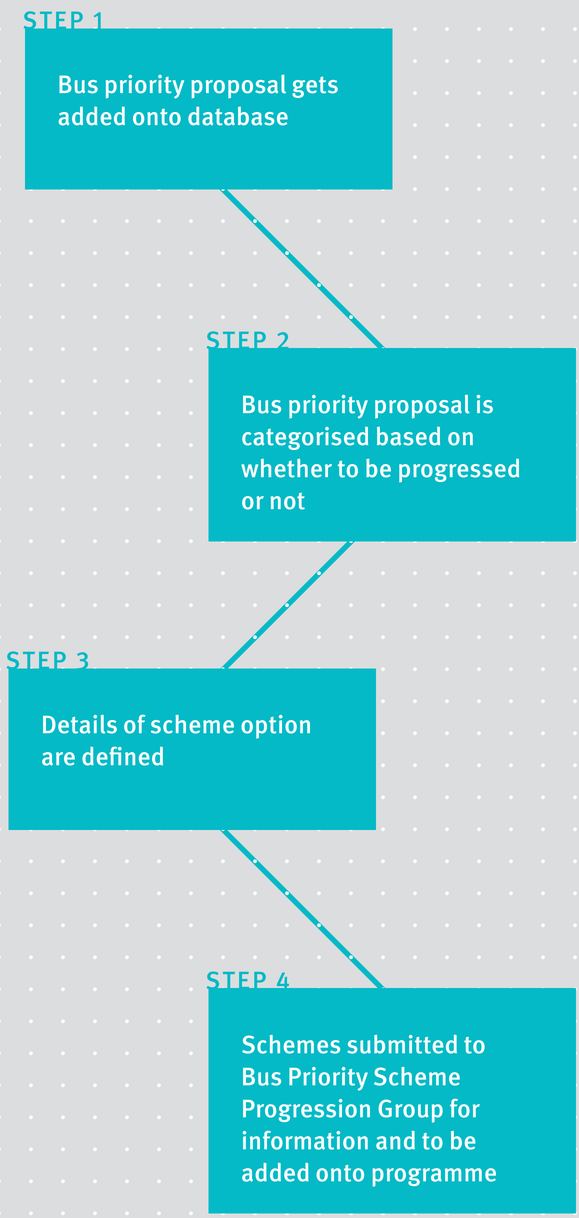


Figure 6 Guidelines on the acceptable impact of bus priority on other road users

Minimise car impact

SPECIFIC GUIDELINES

BARCELONA No reduction to car speed by › 5%

NEW YORK General traffic delay ‹ 45s at any intersection

NON-SPECIFIC GUIDELINES

LONDON Manage and secure movement of traffic

Pro-pedestrian / public transport

CAR IMPACT ACCEPTABLE

BRUSSELS 20% reduction in car traffic by 2018 = strategic objective

SYDNEY Access strategy

MINIMISE WALKING AND CYCLING IMPACTS

DUBLIN Minimise impact on pedestrians and cyclists

BARCELONA Minimise impact on pedestrians at traffic signals

BRUSSELS Improve cycling and walking conditions

LONDON Manage and secure movement of traffic

No guidelines

BARCELONA, DUBLIN, ISTANBUL, KUALA LUMPUR, NEW YORK, PARIS, SINGAPORE, SYDNEY

Brussels has a strategic objective to reduce car traffic by 20% by 2018 (IRIS – strategic transport plan).

Importantly, since 28th June 2015 the city centre of Brussels has a new circulation plan, which is significantly impacting the city's bus network:

- Extension of the central pedestrian zone to 50 hectares (central boulevards are car-free);
- Transit traffic is discouraged but the use of bicycles is encouraged;
- New termini for several bus routes serving the city centre with some of the most important routes from the south and east of Brussels continuing to serve the city centre (routes 29, 66, 71);
- The number of bus termini in the city centre will be limited to three instead of five.

Based on the above changes resulting from the new circulation plan, it is expected that Brussels will lose some of its bus lanes in the city centre as bus routes are given new termini.

In Sydney, many of the recent projects (particularly in the Sydney Central Business District) relate directly to the Sydney City Centre Access Strategy which promotes public transport use at the disbenefit of other vehicles. Project examples include the bus lanes on Elizabeth Street which reduce available road space for private cars by around 60%.

Minimum criteria for bus priority

In addition to the two groups of guidelines discussed above, there may also be minimum criteria that need to be met for implementing bus priority, see Table 5. It is also clarified whether these criteria relate to bus lanes (+), TSP (T) or both (+T). Where there are no minimum criteria or thresholds to bus priority measures, this is marked by a cross. It is interesting to note that there appear to be wide variations across study participants in terms of minimum criteria for bus priority measures, as highlighted in the above table. In particular, bus frequency criteria in Dublin is six buses per hour whereas in Lisbon 20 buses per hour is considered to be the threshold before a location is eligible for bus priority measures. The number of bus routes on a corridor in Istanbul should be no less than 30 to be eligible for a bus lane, whereas in Lisbon two to three routes are enough for a corridor to qualify.

As shown in the figure, Seattle's specific criteria are associated with minimum bus frequency and ridership. Non-specific criteria relate to the number of routes, general traffic and impacts on others. Whilst there are no specific criteria for these categories, they are considered in the assessment. For example, if service is expected to decrease in future, then a corridor will be eliminated from consideration for priority measures. And finally, some additional criteria relating to schedule variability (buses that vary considerably in total travel time can benefit from bus priority), social equity factors (whether a route serves low-income and minority neighbourhoods adds points to the prioritisation evaluation), and geographic value (the number of activity centres served by a route) are considered.

Sydney has no minimum criteria apart from road size e.g. a minimum of two lanes of traffic is required. Sydney Buses noted that the impacts on other road users are also considered (e.g. typically separate cycle paths are installed or cyclists/taxis can share bus lanes). Subject to individual circumstances and conditions, it may also be the case that a bus lane is reverted back to general parking when not in use but this is decided on a case by case basis.

Whilst New York NYCT and MTA Bus do not have any minimum criteria, bus frequency is considered in the sense that the balance between bus passengers and general traffic is taken into account (e.g. a bus with 50 people is given more weight than a car with one person). Similarly, Paris does not have a formal methodology in terms of minimum criteria for bus priority, however they do consider all these different elements in their assessment.

Brussels does not have any minimum criteria for bus priority. It is mainly political support and opportunity that influences bus priority selection.

Table 5 Minimum criteria for considering bus priority measures

	Bc	Db	Is	Lb	Pa	Se	Sy
Bus frequency	✓+	✓ *6 buses/hour*	×	✓+ *20 buses/hour*	✓	✓*	×
Number of routes	✓+T	×	✓+ *30 routes*	✓+ *2–3 routes*	✓	×	×
Ridership	✓+T	×	×	✓+ *1,600 pax/hour*	✓	✓*	×
Commercial speed	✓+T	×	✓+ *10 km/hour*	✓+ *12km/hour*	✓	×	×
Road size	✓+T	×	×	✓	✓	×	✓ *2 lanes*
Non-bus traffic flow	✓+	×	×	✓+ *1,600 veh/hour*	✓	×	×
Impacts on others	✓+	×	×	✓+	✓	×	✓
Other	✓T	✓	×	×	✓	✓*	×

*** See Figure 7: Seattle's Bus Priority Selection Criteria**

Figure 7 Seattle's bus priority selection criteria

	Bus priority criteria	Seattle criteria
Specific criteria	Bus frequency	Peak frequency must be ‹15 minutes
	Ridership	Weekday ridership provides a basis for scoring a corridor
Non-specific criteria	Number of routes	No threshold: however, if service is expected to decrease in future then a corridor will not be considered for priority treatments
	Non-bus traffic flow	No threshold: however, roads with increased levels of congestion are a prime location for bus priority due to potential delay/travel time savings
	Impacts on others	No threshold, but impacts on other road users considered
Other criteria	Other	• Journey time variability (total route travel time) • Social equity factors • Geographic value

To further explain bus priority selection criteria, Seattle's specific and non-specific criteria are explained in the following paragraphs.

Bus lane removal/cancellation criteria

The study also sought to establish if there are any cases of bus lane removal or cancellation and if there are any criteria for the removal or cancellation of a bus lane. There are typically no specific criteria for such purposes and issues are generally dealt with and reviewed on a case-by-case basis.

A low frequency bus route on Leopardstown Road, Dublin, with very high general traffic flows was cancelled as it lead to a major worsening of conditions for both general traffic and buses: the higher bus speed as a result of the bus lane was more than negated by the drop in bus speed before accessing the bus lane.

In Barcelona bus lane cancellations are very infrequent, but a bus lane was cancelled due to a non-bus traffic flow of more than 2,000 vehicles per hour per lane.

London bus lanes have in the past been removed after a review of bus lane operations and road network priorities (particularly as London had a substantial amount of bus lanes built in the past, some of which were used extensively and others hardly at all).

In Lisbon, a bus lane has recently been removed to implement a cycle path, resulting in the reduction of commercial speed. There is some concern that other bus lanes may be repurposed in this way in the future. However, the removal of this bus lane did not have much of an impact on bus services due to the fact that the street did not have high traffic flows and the bus lane had been installed on a large street mainly because it was easy to implement. This happened at a time when the council wanted to increase the city's bus lane mileage and this location represented an easy opportunity to do so.

On the bus lane on 1st Ave South, Seattle, buses were travelling too close to the kerb and some were hitting utility poles, resulting in the removal of the bus lanes.

In Montréal, bus lanes are typically not removed. One case involved a complete overhaul of the road infrastructure which led to changes in bus routes in the area. As a result, a 100m reserved bus lane on St-Catherine Street was no longer required.

In Paris, a change in the traffic plan in the 'rue de Rennes' municipality was required to allow highway infrastructure maintenance. Consequently, a bus lane needed to be removed.

Bus lanes in Sydney have not been cancelled but have had operating hours reduced following an application for reduced hours by the local Chamber of Commerce as bus lane operation restricted customer parking outside shops. Bus lane operating hours were reduced from 15:00—19:00 to 16:00—19:00 (a one hour reduction) to help sustain the local shopping precinct.

However, some cities apply non-specific criteria. In Istanbul, a bus lane that does not deliver benefits to users may get cancelled. In Paris, cancellation criteria depend on the policy of the municipality. In Seattle, bus lanes are removed if there is a lack of transit service.

BUS PRIORITY IDENTIFICATION AND SELECTION EXAMPLE – NEW YORK

New York NYCT used ridership, potential benefit and other transit options to shortlist the best corridors for BRT (Bus Rapid Transit – or SBS) by the process illustrated in Figure 8: NYCT's Bus Priority Selection Process.

The 'opportunity corridors' in the initial candidate phase are those with no current end-to-end route, or ones with low ridership but expectation of growth. There are seven scoring aspects, one of which is the speed ratio, i.e. h is the ratio of travel speed in the peak time to that at night (free-flow conditions). This was used to highlight corridors with the greatest potential for BRT to reduce the overall travel time. Manhattan cross-town routes were eliminated because they have a short length, and the bus would have to stop at every intersection, which would limit the benefits of the BRT.

The criteria are defined to emphasise transit deficiencies both in terms of location and in terms of trips that take too long. The key example is transit to LaGuardia airport, where SBS service was planned to deal with the problem of long journey times. This was implemented even though routes to the airport did not ideally meet all criteria, but the M60 SBS to LaGuardia Airport was launched in 2014.

Following the above selection process, the 36 shortlisted corridors were then assessed in more detail to consider their compatibility with BRT and their benefits of BRT.

The assessment of BRT benefits included:

- Potential to support BRT ridership, based on predicted levels of passengers that switch from limited-stop/local to BRT;
- Potential to support all-day frequent service based on existing off-peak headways (aggregated between all services serving that corridor);
- Assessment of time saved by those passengers due to increased speed;
- Additional assessment of time saved due to traffic signal priority;

- Potential for ridership growth, based on ridership growth history and adopted urban development plans.

The assessment of BRT compatibility considered:

- Impact on traffic operations (e.g. dedicating a lane on a corridor with existing significant bus flows is less disruptive than on a lightly-used bus corridor);
- Need for major parking changes to support a BRT scheme, including an assessment of whether illegal parking already affects bus operations;
- How likely enforcement is needed for the BRT concept to work (self-enforcing schemes such as those with a physical barrier were favoured);
- Physical limitations that would make BRT implementation excessively difficult (e.g. narrow streets).

Figure 10 illustrates this assessment. It shows schemes as a scatter plot with benefits on the y axis and compatibility with BRT on the x axis. The

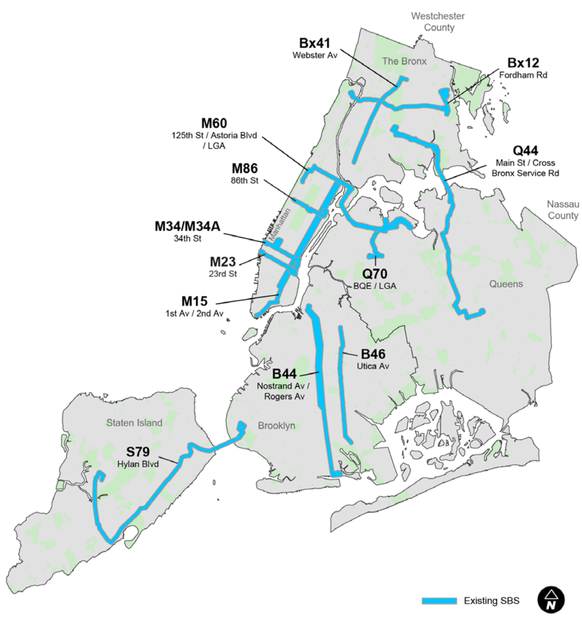


Figure 9 New York City Bus Rapid Transit (2016)

Image source: New York City Department of Transportation, 2016

Figure 8 NYCT's bus priority selection process

Define 80 initial candidate corridors
- Corridors with >15,000 passengers daily
- 'Opportunity corridors' with expectation of growth

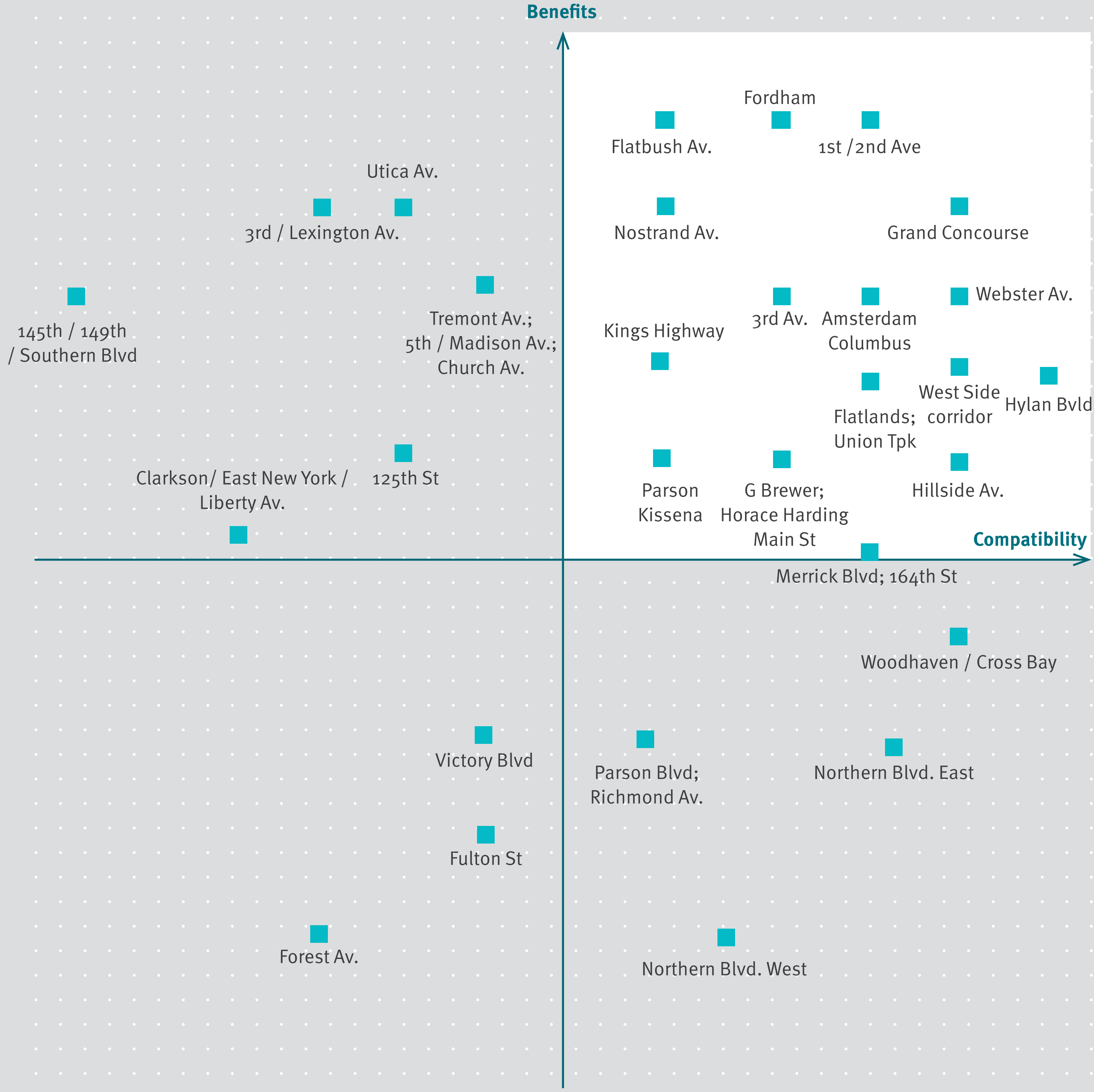
Scoring corridors on seven aspects
- Ridership, existing limited-stop, peak headway, base headway, speed ratio, CBD served, ridership history

Total scores calculated
- Scores less than 2 out of 7 eliminated
- Circuitous routes eliminated
- Manhattan cross-town routes eliminated

Re-examination of eliminated corridors
- Ensure no good opportunity missed

36 corridors taken forward for detailed analysis

Figure 10 Benefits of and compatibility with BRT – New York NYCT and MTA Bus



Original source: McNamara, et al. Bus Rapid Transit in New York City – Corridor Evaluation and Screening. Transportation Research Board of the National Academies. Washington, 2006.

top right quadrant contains schemes with above average benefits and compatibility. The selected corridors are illustrated in Figure 9, New York City bus rapid transit (2016).

BUS PRIORITY – DECISION-MAKING AND FINAL SCHEME SELECTION

The study identifies two key overarching ways of deciding on the final schemes to be taken forward for implementation: a) analysis and problem identification; and b) political decision.

Analysis and problem identification

The approach of identifying the most appropriate solution through analysis and testing is adopted by Barcelona, Dublin and Vancouver. Dublin's bus priority solutions are informed by a combination of site visits and discussions with local managers, drivers and controllers, and the use of AVL will usually answer to what degree the priority is needed. In Vancouver, cost-benefit analysis and road size/space constraints determine the bus priority measure suitable for implementation. Similarly in London, "measures are contextually driven by the opportunities that the identified site presents. Furthermore, sites are often identified by scope for potential bus priority opportunity."

Seattle King County also identify solutions through a process of analysis and modelling of bus priority options: "priority treatments are first brought up through brainstorming, using past ideas as well as new ideas found to have worked in other areas. Thereafter engineering judgement is used to screen for the most viable and appropriate options. Analysis and extensive modelling assures the proposed improvement is appropriate."

New York NYCT and MTA Bus engage in collaborative working with the Department of Transportation "to determine which measures are most appropriate, going block by block to analyse the primary causes for slow bus speeds and deciding which tools are most suited to improve the situation. Most SBS projects include bus lanes, signal priority, and bus bulbs, but not necessarily on every block or at every stop."

Political decision

In some cities, the final decisions regarding bus priority projects are ultimately driven by political decisions and choices. This is the case for study participants in Brussels, Sydney and Singapore.

In Brussels, the political nature of the environment heavily influences bus priority scheme selection and choices are ultimately decided on a political level. Similarly in Singapore, the introduction of bus priority measures is at the discretion of the transport authority.

In Sydney, each government agency (Roads, Transport and Sydney Buses) have their own ideas, bias and preferences and whilst it is a collaborative approach to determine the best solution for a problem, the final decision regarding which measure(s) will be used to address a specific problem ultimately rests with Transport for New South Wales and/or the Roads and Maritime Services.

Identifying benefits of bus priority schemes

Getting public and political backing for schemes is a particularly difficult part of getting bus priority projects approved and implemented. Having proven evidence of quantified benefits delivered by a particular measure can therefore be a very powerful tool in getting the necessary public and political support for future bus priority plans. With bus operators increasingly using AVL technology and related data, it is becoming easier to collect data on speed and journey times, before and after implementation of any bus priority measures.

This section looks first at how study participants calculate benefits of bus priority measures. It then goes on to summarise the benefits that have been measured or observed for specific types of bus priority.

MEASURING BUS PRIORITY BENEFITS

AVL is the most common technology used to collect data on bus journey times and reliability, alongside a number of other methods such as undertaking surveys (often prior to the installation or availability of AVL) or bespoke studies, analysing customer feedback, assessing any reduction in conflicts or through reviewing fuel consumption models.

As an example, Seattle King County measures benefits using both AVL for travel time, punctuality, speed and ridership; and Synchro modelling/government estimates from the EPA (Environment Protection Agency) for assessing fuel and CO_2 savings.

For this study participants were asked to provide information on quantifiable benefits that have been measured as a result of bus priority measures. A summary of these quantified benefits are detailed in the following paragraphs.

Focusing on bus lanes only, Table 6 summarises the benefits (shaded in blue) that study participants have measured as a result of this particular type of bus priority.

Faster commercial speed/ journey time
Barcelona, Brussels, New York and Sydney have experienced up to a five minute reduction in journey time per bus trip as a result of bus lanes.

More consistent commercial speed / journey time reliability
More consistent commercial speeds have led to a reduction in journey time variability standard deviation by up to 1.3 minutes on some participants' networks. Improvements have been measured in Brussels, Dublin, New York and Seattle. The improvements experienced in Seattle were measured on the Rapid Ride E-line.

Ridership
Higher passenger numbers have been measured for many routes with bus lanes. Dublin Bus reported an average increase of 61% in the peak and 25% off peak for the city's best four Quality Bus Corridors.

Fewer buses or increased frequency
In Barcelona, the bus lane on route V7 resulted in the reduction of one bus required to operate the service.

Customer satisfaction
Bus lanes delivered improved customer satisfaction in Seattle (Rapid Ride C-line and D-line) and Barcelona, with Barcelona reporting a score for its new bus network that is 20% higher than the score for the overall bus network.

Table 6 Quantified benefits of bus lanes

Benefit	Bc	Bs	Db	Ln	NY	Se	Sg	Sy
Faster commercial speed /journey time per trip	4–5 min	0–4 min			19–23%			3–5 min
More consistent commercial speed/journey time reliability		4.1–4.3 km/h	7 km/h		SD: 0.8–0.9 min	SD : 1.3 min		
Ridership increase	25%		61%	4%	7%			
Fewer buses or increased frequency	1 bus						Marginal Decrease	
Customer satisfaction increase	20%					13.5–16.7%		
Punctuality/regularity increase		20%						
Emissions reductions	175,000kg CO_2 450kg NOx 8kg PM					14,804 kg CO_2		
Fuel use savings	1%							

SD = standard deviation

Table 7 Quantified benefits of technology schemes

Benefit	Bc	Lb	Ln	Se	Sy
TSP					
Faster Commercial Speed/Journey Time		5 min			3–5 min
Intersection Delay			2s	1.5 min	
Green Wave					
Punctuality/Regularity	10%				
New Signals/ Signal Retiming					
Punctuality/Regularity				8%	
Fuel Use Savings				670,567 litres	

Punctuality/ regularity

Bus lanes in Brussels increased punctuality and regularity of services by 20%.

Emissions and fuel use

Barcelona reports yearly emission reductions in CO_2, nitrogen oxides (NO_x) and particulate matter (PM). Barcelona's additional 25km of bus lanes between 2012 and 2014 resulted in a 1% fuel consumption reduction.

Seattle reports CO_2 reductions on one of its routes (route 150) with bus priority measures.

Table 7 summarises the benefits that study participants have measured as a result of technology schemes (TSP, green wave, new or retimed signals).

Further details on some of the benefits of technology schemes shown in Table 7 are explained in the following paragraphs.

TSP

TSP delivered a reduction in total intersection delay of up to 1.5 minutes for a corridor with bus priority measures (Seattle's Rapid Ride E-Line). Studies in London have shown that on average each bus travelling through a TSP equipped junction saves at least two seconds.

Green Wave

The implementation of a green wave for 5km on General Mitre Av. has improved regularity in Barcelona by 10%.

New signals/ signal retiming

Improvement to signals in Seattle has resulted in the 12-month rolling average on-time performance to go up by 8% on route 44 and by 2% on route 20. In addition, route 150's fuel use went down by a significant amount.

Wider benefits (safety, regeneration and development, social inclusion)

Bus priority measures have also delivered wider benefits relating to safety, regeneration and development, and social inclusion.

New York has seen a reduction in crashes of approximately 20%, particularly for projects where at least one lane of general traffic has been converted into a bus lane. The first SBS corridor on Fordham Avenue increased retail activity (increase in sales tax revenue) relative to other comparable areas in the neighbourhood. SBS increased sales tax revenue despite initial business concerns about parking. Studies by New York City have shown that most people are walking or using public transport as the streetscape changes associated with SBS create a friendlier pedestrian environment and encourage footfall.

In Barcelona, improved journey times between L'Hospitalet and the city centre brought the neighbourhood within 30 minutes travel time of the central area of Barcelona.

In Dublin, the benefits of bus priority (QBCs) meant that local authorities could plan higher density developments with reduced parking.

Pollution reductions

In Barcelona, bus lanes have contributed to a reduction in emissions.

Seattle reports CO_2 reductions on one of its routes (route 150) with bus priority measures. Emissions savings from bus priority projects in Seattle largely come from increased ridership, reduced vehicle trips and mileage.

Mitigating risks of bus priority schemes

This section looks at actions taken by organisations to mitigate the risks associated with bus priority measures. It is important to consider potential risks prior to implementation to avoid unwanted outcomes once the measure is in place. This section is first dedicated to analysing bus lane use, understanding the different users permitted in bus lanes, and the actions taken to mitigate the impact of other modes on bus services. This will set the context as to how conflicts may occur.

Next, this section focuses on challenges that participants have experienced with bus lane enforcement and the level of success achieved with different methods of enforcement. The study asked participants to provide the number of bus lane violations over the past year and to indicate the extent to which violations are detected and penalised on their networks (along with information on associated penalty charges).

The study then explores potential challenges of bus priority further, and details any difficulties that participants have experienced with bus lanes that were already in place or in the process of being implemented. The final part of this section is a review of the methods adopted to mitigate against the risk of bus priority. A number of methods have been successfully used to test the impact of projects, details of which are provided and summarised.

BUS LANE RULES AND REGULATIONS

Figure 11 shows the types of vehicles that are permitted to use bus lanes across participants' networks, ranging from vehicle types permitted to use all bus lanes at all locations (indicated by the fully filled circles) to vehicle types never permitted to use bus lanes (indicated by the empty circles).

From left to right, cities are ranked from those with least to most restricted bus lanes. For example, seven different vehicle types are permitted to use bus lanes in Vancouver to just two different vehicle types that are permitted on bus lanes in Istanbul. Similarly from bottom to top, the vehicle types are ranked based on the types of vehicles that are least authorised to most authorised to use bus lanes. Commercial vehicles are only permitted to use bus lanes to load/unload in three of the 14 cities whereas long-distance coaches are permitted on bus lanes in 12 cities.

In London, long-distance coaches are permitted on all bus lanes, except where there is a 'local bus' designation (10% of bus lanes in London). Only five out of 1,100 bus priority lanes or bus gates permit access to HGVs and where there is a loading and unloading facility in operation in a bus lane, a vehicle can legally move into the bus lane to access or egress the facility even if a bus lane is in operation. However, most loading facilities in bus lanes are not in operation during peak hours.

Cyclists and taxis are authorised on all bus lanes except at locations where there are road safety issues (e.g. speeds greater than 40mph, lanes leading into bus stations, offside bus lanes).

Lisbon only permits long-distance coaches on their bus lanes and do not allow private buses to use the lanes.

Cyclists are not permitted in bus lanes, even though Portuguese law authorises cyclist access to bus lanes in other parts of the country. Given the narrow width of Lisbon's bus lanes it is considered unsafe for buses to share these with cyclists and the slow speed of cyclists means that buses need to a) overtake cyclists which increases the risk of accidents, and b) travel behind cyclists which is counterproductive to the original purpose of bus lanes (i.e. increasing bus speeds). It is interesting to note that motorcyclists are not considered to be as much of a problem as they travel at higher speeds and therefore overtaking is not an issue.

In Barcelona, there is a similar problem with narrow bus lanes which means that cyclists cannot be overtaken and therefore commercial speeds often remain slow despite the high number of bus lanes in the city.

Interestingly, in Brussels motorcycle and scooter use of bus lanes is not authorised, however is tolerated and the action does not result in a fine. Similarly, commercial vehicle loading and unloading is not authorised but at the same time is not penalised.

In Montréal, there is currently only one bus lane permitting cyclist access (Viau St.) with two new lanes planned in 2017 for use by both buses and cyclists. A local bus lane on Saint-Jean Boulevard permits carpooling vehicles (two people or more) and two new lanes also allowing car pool access were implemented on Des Sources Boulevard in 2015 and on Lacordaire Boulevard in 2016.

In Sydney, there are two types of bus lane: a) regular bus lanes, and b) bus only lanes reserved for the exclusive use of buses.

Emergency vehicles are always permitted on bus lanes in five cities (Barcelona, Dublin, London, New York, Singapore) and on some lanes in Sydney.

BUS LANE HOURS OF OPERATION

Bus lane hours of operation range from more permanent bus lanes to bus lanes with more controlled hours of operation, see Figure 12.

Permanent bus lanes

In six cities (Barcelona, Brussels, Lisbon, London, Paris, and New York) bus lanes are typically in operation on a permanent basis. In Barcelona, TMB request permanent bus lanes wherever this is possible. Those that are not are operational during the daytime only. In New York, offset bus lanes are typically in effect 24/7 and kerbside lanes typically allow parking overnight and in some cases parking or deliveries at midday. In Dublin, many of the more recent bus lane locations are operational on

Figure 11 Vehicle types permitted on bus lanes

Bus lane restrictions for other modes → Increasing restrictions

	Vc	Bs	Ln	Sy	Db	KL	Sg	Bc	Mt	Se	Lb	Pa	NY	Is
Most permitted														
Long-distance coaches	●	●	◕	◗	●	●	●	●	●	●	●	○	●	○
Private buses/coaches	●	●	◕	◗	●	●	●	●	●	●	○	○	●	○
Taxi	●	●	◕	◗	●	●	○	●	◗	○	●	●	○	●
Cyclists	●	●	◕	◗	●	○	●	○	◗	●	○	●	○	○
Minicab taxi	●	●	◗	◗	○	●	○	○		○	●	○	○	●
HOV	●	●	◗	◗	○	○	●	◗	◗	◗	○	○	◗	○
Motorcycle/scooter	●	○	◗	◗	○	○	○	○	○	○	○	○	○	○
Heavy goods vehicles	○	○	◗	◗	○	○	○	○	○	○	○	○	○	○
Commercial vehicles loading/unloading	○	○	◗	◗	○	○	○	○	○	○	○	●	○	○
Other* – emergency vehicles	○		●	◗	●		●	●		●			●	
Other* – passenger drop-off & pick-up													●	
Least permitted														

● All lanes ◕ Most lanes ◗ Some lanes ○ Never * The table reflects the information provided for the study, however it may be that other vehicle types are also permitted in bus lanes in other cities.

Figure 12 Bus lane hours of operation

More permanent

Permanent

Barcelona, Brussels, Dublin, Lisbon, London, Paris, and New York

Daytime only

eg. 7am–9pm, Mon–Fri or Mon–Sat

Barcelona, Dublin, Kuala Lumpur, New York , and Singapore

Both peak hours

eg. 7am–10am and 4pm–8pm

Dublin, Istanbul, Montréal, and Singapore

Peak direction only

Montréal and Vancouver

More restricted

Hours of operation vary by location: Dublin, Lisbon, London, Montréal, New York, Seattle a 24/7 basis, however others are in effect during the daytime only between 07:00-19:00, or during both peak hours. Dublin Bus believe that the default should be 24 hours a day, seven days a week and that the local case should be made for narrowing this.

Daytime only bus lanes

In Kuala Lumpur the authorities decided to operate bus lanes during the daytime. This decision is based on traffic conditions, with traffic particularly in the city centre being uniform between the morning and evening peaks. In Singapore, full-day bus lanes are operational between 07:30—20:00 Monday to Saturday.

Both peak hours

In Istanbul, bus lanes are in effect during the morning and evening peaks which is when traffic volumes, congestion, and bus ridership are highest. Istanbul's morning peak is between 07:00—10:00 and the evening peak is between 16:00-20:00. In Singapore, some bus lanes are only operational between 07:30—09:30 and 17:00—20:00 Monday to Friday. Montréal has some bus lanes operating during both peak hours, however this is dependent on location and demand.

Peak direction only

In Vancouver, some bus lanes are operational for the peak direction only. In Montréal, this is the case for the majority of the bus lanes in the city.

Variable hours of operation

In London, the hours of operation are based on demand, traffic volumes and the impact on bus reliability but in some locations where there is a safety issue or a bus only movement is required, permanent lanes are implemented. In Seattle, hours of operation are also dependent on traffic volumes and off-peak use of the kerbside lane. For example, if there is a high level of off-peak parking demand, bus lanes will be opened to general traffic and parking during off-peak hours. In Lisbon, most bus lanes are permanent except for two bus lanes that are operational during peak hours and in the daytime respectively. Lisbon Carris noted that it is better to have bus lanes in operation for less time if this means they are more respected by other road users. However, currently drivers respect permanent lanes more than non-permanent lanes.

Generally, high bus demand, high levels of traffic and standard practice result in longer hours of bus priority. At the other end low bus demand, low-off peak traffic volumes, low impact on speed, and high parking demand typically result in off-peak relaxation of restrictions. Dublin Bus believe that the most effective bus lanes are those that run over several kilometres and junctions, and when they are in operation 24 hours a day, seven days a week rather than during peak hours or weekdays only.

BUS LANE ENFORCEMENT

Types of bus priority enforcement

This subsection focuses on enforcement challenges that study participants have experienced on their bus lanes. It reviews experiences with different methods of enforcement, in particular whether they were successful or not.

Figure 13 'Push and pull factors' of bus lane hours of operation

High bus demand Istanbul
High traffic congestion Kuala Lumpur, Seattle
Standard local practice Brussels, Barcelona, New York

Longer hours of bus priority

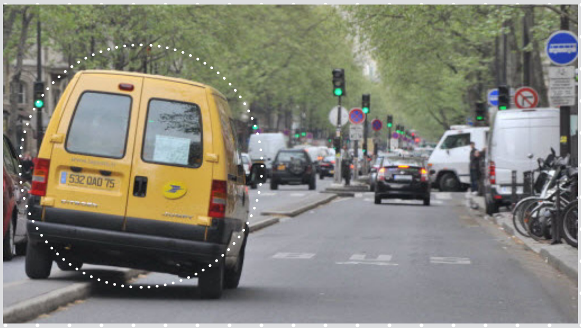
Low bus demand Lisbon
Low off-peak congestion Montréal
Low impact on speeds London
High parking demand Seattle

Off-peak relaxation of restrictions

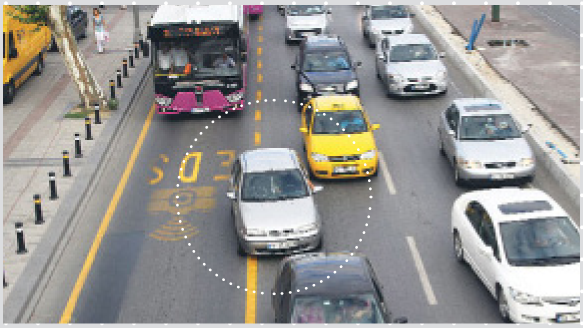
Figure 14 Bus priority enforcement challenges

Paris RATP
A delivery vehicle is parked in a segregated bus lane, resulting in a bus being unable to enter the bus lane and unable to stop at a bus stop to pick up and drop off passengers. Consequently, the bus is required to stop in a lane of regular traffic, requiring passengers to walk across the segregated bus lane to board the bus. This not only represents a safety concern for passengers having to cross part of the carriageway, but the stopping bus also negatively impacts regular traffic flow by having to stop in the lane of traffic. This scenario highlights a risk specific to physically segregated bus lanes.

Paris RATP
Parked vehicles alongside a segregated bus lane reduce the effective width of the bus lane and the space available for the passage of buses is constrained.



Paris RATP
A vehicle is partially parked on a segregated bus lane and is obstructing the movement of buses.



Istanbul IETT
A vehicle does not abide by bus lane rules and is partially obstructing buses down the lane.

Examples of challenges experienced by Paris RATP and Istanbul IETT are shown in Figure 14.

Measures to minimise violations on bus lanes can be divided into three categories: design solutions (e.g. off-set bus lanes), passive enforcement (e.g. signage, road markings), and finally active enforcement (issuing penalties for offences). In some locations, such measures have been successful in minimising the risk of activity on bus lanes.

Design solutions

Design measures have seen some success in reducing illegal activity on bus lanes. Successful measures include inset parking and loading bays in the footway area in London, and offset bus lanes in New York. These both remove the motivation for drivers to stop and load in bus lanes.

The offset bus lanes in New York are implemented where possible and loading zones are created allowing deliveries at specific times of the day. These were reported to have been mostly successful where applied.

Passive enforcement

Passive bus priority enforcement techniques, an example of which is differentiating the colours of the road surface between bus lanes and regular lanes, have had varying levels of success across cities.

In the past, bus lanes in London were demarcated by white lines on the road surface only. Since the introduction of red bus lanes however, motorist compliance has increased to the extent that the number of penalty charge notices issued per week has significantly reduced from 10,000 down to 250 – this equates to a 97.5% reduction in penalty charge notices. In addition, road users do not use the lanes even outside of the bus lane hours of operation.

Positive results from passive enforcement strategies have also been achieved in Seattle and Vancouver. Red bus-only lanes in Seattle have resulted in a significant decrease in violations as coloured bus lanes and highlighting these as such to road users have been particularly effective for deterring non-authorised users.

There are however unsuccessful examples of passive enforcement. In Kuala Lumpur, clearly demarcated yellow lines or broken yellow lines indicating use for "Bus and Taxi Only" as well as signage showing bus lane operating hours were not effective. In New York, NYCT has noticed that whilst motorists stayed out of red bus lanes when they were first implemented, they are now unfortunately starting to use them again unless active enforcement is also used.

Active enforcement

The study identifies that manual spot checks are the most common enforcement method, followed by using fixed cameras (e.g. roadside cameras in fixed locations) and mobile cameras (e.g. cameras mounted on vehicles) to capture violations.

Successful measures reported include a "mobile system of inspection and collaboration with the police" in Lisbon and fixed cameras in London and Dublin. In Paris, fixed cameras are used during peak hours only. RATP noted that the system is not always effective particularly in congested conditions when vehicles are too close to a junction and it is not possible to see the registration number. In London, observations suggest that there are fewer bus lane violations at locations with a high number of fixed cameras. In Dublin, the use of fixed cameras is being investigated but has not yet been implemented. Singapore SMRT has proposed to the Authority that enforcement should be done with enforcement officers or CCTV.

Interestingly in New York, the MTA piloted on-bus video cameras, but this program was not continued. It was difficult to ascertain other vehicles' intentions since both the vehicle and the bus could be moving. Fixed cameras in rotating locations were found to be much more effective. Note that the reason for the

Table 8 Responsibility for enforcement

	Bc	Bs	Db	Is	KL	Lb	Ln	Mt	NY	Pa	Se	Sg	Sy	Vc
Police			✓	✓	✓	✓		✓	✓	✓	✓		✓	✓
Local Government	✓	✓			✓	✓+			✓				✓*	✓
Transport Authority					✓		✓					✓		
Operator	✓	✓				✓								

✓ the funding body = the enforcement agency + the funding body only

* The Roads & Maritime Services, a New South Wales State Government Agency.

difficulty in identifying vehicle intentions is because New York City permits a vehicle to drive in the bus lane if it makes the next right turn.

No buses or supervisor cars on networks reviewed within this study are currently equipped with enforcement cameras. This raises the question as to whether there is an opportunity to use on-board outward facing cameras for enforcement purposes. Sydney Buses, for example, commented that all buses are fitted with CCTV cameras, including front facing cameras. Whilst the use of these cameras for enforcement purposes has not been explored, the technology could potentially be used to enforce bus lanes. Sydney chose not to use the cameras for enforcement, as there is no automatic way to search video footage to identify a violation. Montréal STM's new buses will include forward-facing cameras but they will be used for accident evaluation rather than bus lane enforcement. This is due to the staff resource that would be necessary for processing such footage.

Responsibility for enforcement

In many cities bus lanes are typically enforced by the police, which is funded by local government. In most cases, the bus operator or transport authority are not responsible for activities relating to bus lane enforcement and funding.

The agency (or agencies) responsible for the enforcement of bus lanes (often the police) and for funding enforcement (in few cases the same organisation) are summarised in Table 8.

Income from penalty charges are used to part-fund enforcement in few locations.

In London, enforcement is carried out and funded by the transport authority alongside other traffic enforcement activity. Costs are covered indirectly from income received from penalty charge notices. In Paris, public transport infrastructure is funded in several ways: by the municipalities and by the transport authority, which receives part of the income from the penalty charges. In Sydney, the State Government funds enforcement agencies and associated activities. Some penalty revenue is allocated to road safety but there is no direct re-allocation of penalty revenue back to enforcement agencies.

Many participating cities, including Kuala Lumpur, Istanbul and Sydney, mentioned that the enforcement of bus lanes isn't a top priority for the police. In Istanbul for example, this has proven to be an issue and means that bus lanes are often used by general traffic since there is a lack of enforcement. This raises a question about how an operator can get the police to enforce when they are not responsible for enforcement and have no control over this activity. Perhaps, having the transit police as the enforcement agency would deliver improved results as they may be more committed and more focused on detecting bus lane offences, amongst other priorities. In Vancouver for example, the local municipal police is responsible for the enforcement of bus lanes but if violations are spotted by transit police, then they also have the authority to enforce. Lisbon Carris noted that the transit police in the Portuguese capital city have a large area to cover and few resources to enforce. As a result, Carris pay the municipal police to ride in their enforcement vehicles with a driver. The cost for this equates to around $42,550 US$ PPP per year for a police person, plus another 42,550 US$ PPP for the Carris driver and car. Carris also noted that the transit police are not motivated to enforce bus lanes because they know that the municipal police are tasked to do it.

In Sydney, the strategy to address illegally parked vehicles is supervisors and bus drivers reporting these vehicles to the control centre. The control centre then requests that the offending vehicle is issued with an infringement notice. Note that Sydney Buses can only issue infringements for illegal parking in bus zones and not bus lanes. A bus zone in Sydney relates to a specific zone where vehicles other than buses are not permitted to stop. This is indicated on signs and for some zones hours of operation may apply.

In the case of multi-agency enforcement, this typically follows one of the following three structures, see Figure 15.

Only four participants (Barcelona TMB, Brussels STIB, Lisbon Carris, and Sydney Buses) are themselves jointly responsible for enforcement, with local government or the police. In Lisbon, the driver and police inspector in enforcement vehicles take photographs of any violations. The offender then needs to go to court and a penalty is subsequently issued.

For four participants (Kuala Lumpur RapidBus, New York NYCT and MTA Bus, Sydney Buses, Vancouver CMBC), enforcement is a multi-agency operation between the police, government and/or transport authority.

In New York, the New York Police Department is responsible for in-person enforcement, and the Department of Transportation is authorised by state legislature to enforce via video camera. The City is authorised to install bus lane cameras on up to 16 routes, with enforcement allowed seven days a week between 07:00 and 19:00. In Sydney, the Roads and Maritime Services, a New South Wales Government Agency, is partly responsible for enforcement.

Generally, bus drivers within organisations featuring in this study do not have a specific role in enforcing bus lanes but many are able to notify or alert the relevant agencies of offences that they witness. Where drivers can report back to the control centre or police, this isn't always specifically incentivised, as is the case for drivers at Dublin Bus and Vancouver CMBC. In Lisbon, drivers can feed back their opinions and problems and annual prizes are given for the best ideas, however this is not only related to enforcement and is more of a general scheme.

Whilst many organisations do not incentivise drivers to report bus lane violations, others do have more of an operational teamwork incentive that is encouraged. For example in London, drivers are incentivised by meeting their agreed headways. Bus drivers are not directly rewarded for meeting their agreed headways, however each high frequency route is given an Excess Waiting Time (EWT) target and a low frequency route is given a percentage on time target. Bonuses or penalties are applied depending on performance on target.

Therefore drivers can be motivated to report violations such as cars parked in the bus lane to help colleagues in following buses stay on time. In Sydney, alerting bus lane violations gives drivers the opportunity to clear the bus lane for subsequent services, and having drivers engaged in the process can help detect any problems on bus lanes sooner rather than relying on the relevant enforcement agencies to identify offenses.

Automated enforcement vs manual enforcement

The enforcement process is manual for the majority of study participants. Manual enforcement applies to Brussels, Dublin, Istanbul, Kuala Lumpur, Seattle and Vancouver.

The enforcement process is partially automated in London, New York, Barcelona and Singapore.

Figure 15 Identification of major versus minor bus priority projects

Joint enforcement	Requires both organisations to act together Bc, Bs, Lb, Sy	BARCELONA Barcelona TMB drivers operate the surveillance and enforcement vehicles on the bus lane. The police mananges cameras and broadcast devices and issue penalties
Multiple enforcement	› one agency can enforce Enforcement is autonomous from other enforcement agencies KL only	KUALA LUMPUR All three enforcement agencies have the authority to enforce as per the Road Transport Act
Division by method	Split between agencies by type of enforcement NY and Sy	SYDNEY The police operates mobile and static cameras and the Roads and Maritime Services (Government Authority) operates fixed bus lane enforcement camersa

In London, fixed cameras are used for enforcement, however these do not have Automatic Number Plate Recognition (ANPR) technology.

In New York, video cameras are used for enforcement on up to 16 SBS corridors (the full number allowed under state law as of 2015). This provides much more substantive enforcement than would be available from the New York Police Department (NYPD).

However, enforcement videos are reviewed by Department of Transportation personnel and the process is therefore not entirely automated.

In Barcelona, the pictures are manually taken but then the processes that follow are automated.

In Singapore, CCTV cameras are used for bus priority enforcement purposes.

Sydney is the only location with a fully automated enforcement process using cameras with ANPR technology. Notices are then mailed to the registered vehicle owner after an offence is detected. The fixed nature of camera enforcement in those locations means that cameras are always operational and capture all bus lane offences which correlates with Sydney's high detection rate.

Enforcement problems and solutions

The problems organisations have experienced with enforcement and subsequent actions taken to try and solve these are summarised in Table 9.

Some organisations suspend the enforcement of bus lanes during exceptional or specific circumstances. Based on the responses from study participants there are four categories.

The first category relates to road works. In London, bus lanes are occasionally suspended during road works, whereas in Seattle, bus lanes may be open to general traffic in the event of road works. Local agencies consider the traffic impacts of lane closures during construction projects and request the use of bus lanes if necessary.

Secondly, emergency vehicles are permitted on bus lanes in some locations.

For example in New York, emergency vehicles are exempt from bus lane restrictions and vehicles entering bus lanes to allow emergency vehicles to pass are authorised to do so.

Thirdly, bus lanes may be suspended if general traffic lanes are fully obstructed or for any activity needed for road safety reasons (e.g. avoiding a crash), which is the case in New York.

Finally, a vehicle may be exempt from a bus lane rule where the vehicle has a genuine need to access the lane, e.g. to collect refuse. This is the case in London.

In Dublin, Paris, and Sydney, bus lane restrictions are rarely lifted but this can happen. These choices are made at the discretion of the police.

It is also worth noting that in Sydney, legislation allows any vehicle to use a bus lane for up to 100 metres to enter or leave a side street or property, but this is enforced with limited bus lane cameras and limited on-site monitoring/policing.

Methods used to identify exceptions to enforcement typically involve reviewing enforcement videos and camera footage. In New York, all enforcement videos are reviewed by the Department of Transportation to identify any mitigating circumstances. In London, camera footage may be reviewed if a compliance

Table 9 Enforcement problems and actions taken

	Problems	Actions Taken
Barcelona	Lack of compliance on Sundays and bank holidays. The police tolerate motorcycle use of bus lanes on weekdays.	Barcelona TMB asked the police to increase the penalty amount to tackle the problem of vehicles parking very close to bus stops on non-permanent bus lanes.
Dublin	Up to recently, the penalty and risk of being caught were low.	Driving in bus lanes can now result in the application of penalty points on driving licences and this has helped enforcement.
London	Camera location/ enforceability issues.	On-street cameras and a team of compliance officers to identify and capture non-compliance.
New York	NYPD often has other important priorities.	Use of automated enforcement where allowed, payments to NYPD for additional overtime enforcement.
	Public perception of parking tickets.	Community education.

officer isn't certain whether a vehicle using a bus lane required access to the lane. This is reviewed alongside supporting documents (e.g. a log of refuse collections, road maintenance, emergencies). Transport for London reviews and considers all supporting information during any appeal of a contravention.

BUS LANE VIOLATIONS

Very few study participants were able to provide information on the actual number and type of bus lane violations on their networks over the past year. Only four participants (New York, Barcelona, Brussels, and Lisbon) were able to provide total violations with only Brussels and Lisbon providing the split between driving and parking violations. Two participants (Dublin and London) were able to provide information on driving violations only.

Given how few operators have evidence of bus lane violations, this raises a question as to how bus operators can make the case for enforcement without supporting evidence of the amount of offences that occur on their networks.

When normalised by bus lane km, out of those participants who were able to provide total violations for 2014, New York appears to have a very high rate of offences (1,128 offences per bus lane km), whilst Lisbon has a very low rate of offences (1 offence per bus lane km), as shown in Table 10.

The percentage of expected violations detected and ultimately penalised varies across locations. In London, for the majority of monitored sites, detection is 100%. In New York, the level of detection is high for camera-enforced locations (more than 95% of violations detected), but for other locations the percentage is unknown.

In Sydney, motorists are aware of fixed camera locations and therefore the level of violations in these locations is low. Sydney Buses reported that violations increase in areas without fixed enforcement cameras. It should be noted that the low level of detection in this case does not necessarily mean that Sydney is unsuccessful in enforcing bus lanes, but rather that the city is successful at preventing violations from occurring in the first place given that the enforcement process is largely automated.

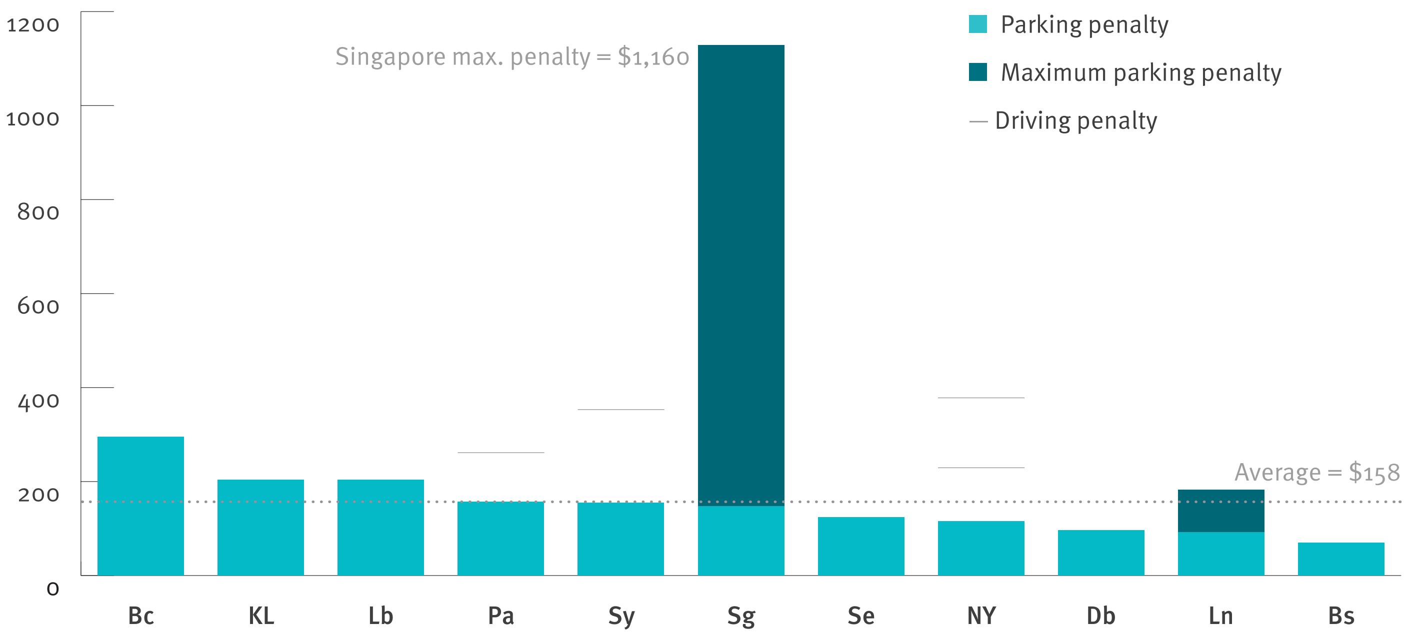
In Istanbul the percentage of violations detected is high at 90% if there is active enforcement by the police.

As enforcement is monitored and coordinated by the enforcement agencies, Rapid KL do not have information on the amount of violations detected

Table 10 Total violations per bus lane km (2014)

	Total violations (driving & parking) per bus lane km, 2014
New York	1,128
Brussels	224
Barcelona	223
Lisbon	1

Figure 16 Bus lane violation penalty (2014 US$ PPP)



but suspect that the percentage is very low. It is likely that this is also the case for the organisations that could not provide data on detections (Lisbon, Paris, Seattle, Singapore, Vancouver).

Study participants were asked to what extent observed violations are penalised. Five participants responded that when a violation is detected, the offender receives a fine (Istanbul, New York, Seattle, Sydney and Vancouver). Where violations are not always penalised (Barcelona, Brussels, Dublin, Lisbon, Paris), reasons include a lack of resources (Brussels) or the fact that only the authorised enforcement agency is permitted to issue a fine (Paris). Barcelona TMB issue penalties for violations depending on the quality of the pictures taken by the police.

The penalty for bus lane offences is highest in Barcelona at just under $300 (US$ PPP 2014). Brussels has the lowest fine at around $70 (US$ PPP 2014). In general, bus lane violation penalties are relatively consistent between $100 and $200 (US$ PPP 2014) and the average penalty is $158 (US$ PPP 2014) across cities. Only three organisations have different penalty fees for either parking or driving violations: New York and Sydney charge a higher fee for driving offenses, whilst Paris' fine is higher for a parking offense. Penalties are displayed in Figure 16.

Note that in some cities (Dublin and Sydney) a penalty point is recorded on a person's driving licence after committing a motoring offence. Penalty points stay on a person's driving licence for a certain number of years. If, during this time period, a points threshold is reached (e.g. 12 points in three years), the motorist may be banned from driving for a specified time.

Additional city-specific notes regarding bus lane violation penalties are listed below:

- **Sydney** Fine plus 1 penalty point issued.
- **New York** $115 (US$ PPP2014) if the violation is caught on camera, $150 (US$ PPP 2014) if the violation is caught by a police officer.
- **Dublin** Fine plus 3 penalty points issued for illegal parking. Fine plus 1 penalty point issued for illegal driving.
- **London** The fine is $92 (US$ PPP 2014) if paid in 14 days, rising to $184 (US$ PPP 2014) if unpaid beyond this 14 day period.
- **Singapore** Whilst the typical penalty is $150 (US$ PPP 2014), the law allows for a penalty of up to $1,160 (US$ PPP 2014) or even three months imprisonment.

CHALLENGES

The challenges experienced (during or after implementation of bus priority measures) by study participants fall into two (and sometimes overlapping) key themes, operational issues and public perceptions and behaviour, as shown in Figure 17. For example, the unseparated nature of bus lanes (and lack of enforcement) in Istanbul results in a high number of unauthorised vehicles using bus lanes.

Bus priority challenges – Dublin

Bus priority measures have had the following negative consequences in Dublin: cyclist safety issues; good schemes have resulted in unofficial park and ride sites in residential areas; and negative reactions from traders if a scheme bypasses small villages.

Bus priority challenges – Barcelona

Barcelona TMB's bus network includes a significant amount of bus lanes, however one of the issues with the lanes is that many are too narrow. As a result any cyclists travelling in a bus lane cannot be overtaken and this has an impact on commercial speed. In some locations there are many incidents of buses hitting wing mirrors and bus shelters.

Barcelona TMB also reported that lane spacers providing a physical separation between the bus lane and regular traffic lanes resulted in increased motorcycle safety risks. The lane spacers were consequently removed.

Bus priority challenges — Brussels

An example from Brussels demonstrates that it is important to consider traffic light settings and the changes required to signal timings when planning a bus lane. In this particular example, traffic light settings were not considered during the planning stage of the project. It was only when the bus lane was already in place and the traffic signals needed to be reprogrammed that the issue was discovered: the implementation of a bus lane may require additional phases at traffic signals which means that cycle times are increased and more time is spent at signals.

Brussels STIB noted that since projects are driven by political decisions, the impacts of bus priority projects are therefore rarely assessed in Brussels.

Bus priority challenges – London and Seattle

London and Seattle have experienced similar challenging situations where bus lanes create a traffic bottleneck before the bus lane begins, meaning that buses cannot access the lane. The bus lane is therefore counterproductive as all traffic is forced to queue in the adjacent lane. In the case of London, the bus lane is either removed or shortened in these situations. In Seattle, no action has been taken to mitigate the negative impacts of the bus-only lane in this example. King County's Transit Systems and Traffic Engineering team has identified the issue as one needing further review. This review, however will be conducted in conjunction with future capital improvement projects along the corridor before progressing with any changes.

Bus priority challenges — New York

Two examples from New York showcase further schemes with unintended consequences.

Often, journey time savings as result of bus priority are not estimated accurately. This means that the first schedule after implementation of the bus lane can be inaccurate and needs to be adjusted retrospectively.

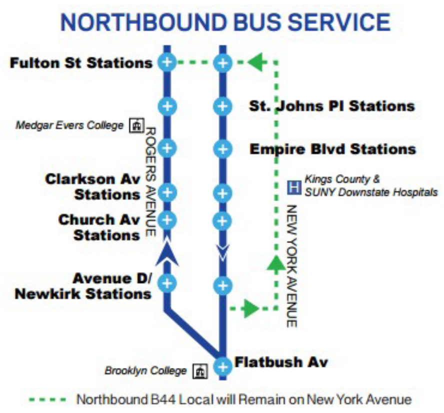


Figure 18 Northbound B44 SBS and B44 Local

Image source: New York City Department of Transportation, 2015

Figure 17 Bus priority challenges — key themes

Operational issues

Public perceptions and behaviours

BARCELONA, DUBLIN Cyclist / Motorcyle safety

ISTANBUL Lack of enforcement and poor compliance

BRUSSELS Poor junctions designs / traffic lights need reprogramming

SYDNEY, BARCELONA Adverse publicity

LONDON, SEATTLE Queues preventing / delaying bus access onto bus lane

NEW YORK Unexpected customer behaviour / not adapting to change

NEW YORK Estimated travel time savings

DUBLIN Negative reactions from traders

DUBLIN Unofficial park and ride sites

In the second example bus priority delivered unintended consequences in terms of how it affected customers' choice of travel route. The B44 SBS (Rogers Avenue) is a parallel route to New York Avenue where the route it replaced (Limited Stop route) previously ran and the B44 local still runs, see Figure 18. Rogers Avenue was chosen because of its width and was considered suitable for the SBS service as it would be able to accommodate the necessary infrastructure (bus lanes and bus bulbs). However, once implemented, customers did not adapt to this change either because of the extra walking distance (only 480m) or they considered that the travel time savings did not outweigh the additional walking time. This meant that the remaining services on New York Avenue were overcrowded and more service needed to be added.

MITIGATION

All participating operators in this study apart from Istanbul IETT, Rapid KL, Lisbon Carris and Singapore SMRT, adopt a number of different methods to mitigate against any undesired impacts of bus

Figure 19 Bus lane mitigation – New York example

Image source: New York City Department of Transportation, 2015

priority, including using modelling software to predict impacts of bus priority and implementing pilot studies to test the impacts of projects on bus operations. Pilot studies and traffic modelling software are discussed in the subsections of this chapter.

Different actions have been taken by organisations to minimise the impact of vehicles entering bus lanes to turn at junctions. Solutions include junction design, physical restrictions, signage and enforcement. Junction design solutions are however most commonly used to address this issue.

In London, bus lane set backs (i.e. the distance a bus lane is set back from a junction stop line) are calculated based on the traffic light cycle time, so that buses leaving the bus lane waits a maximum of one traffic cycle before progressing through a signal. A further example from London, is the implementation of a 'left turn only except buses' at a traffic light junction stop line, which means that vehicles travelling straight ahead do not need to merge after the traffic light if a bus lane restarts.

Similarly, Vancouver implements lane changes, such as left turn bays, to mitigate against potential impacts of bus priority schemes.

In Sydney, legislation allows any vehicle to use a bus lane for up to 100 metres to enter or leave a side street or property.

Lisbon Carris noted that the most common violations occur towards the end of bus lanes, for example drivers accessing the bus lane 1km before the turn. In Lisbon, some bus lanes have a continuous line whilst others have a dotted line along the whole length to indicate that taxis can enter.

Dublin Bus reported that the standard mitigation approach is to maintain junction capacity, i.e. to not give buses first priority through the junction. However, this often has the effect of reducing the bus lane benefits.

In Seattle, impacts to minor street traffic as a result of TSP implementation is mitigated through the use of frequency lock-outs for recovery cycles. This means that the signal is allowed a period of time to adequately serve all traffic movements after a bus has been given priority until the entire recovery has been completed.

In New York, there has been a move from kerbside lanes to offset lanes where feasible, as the public's reaction to removing parking was stronger than removing a lane of traffic. The hours of operation of kerbside bus lanes have also been changed to mitigate impacts on local business, parking and residents. Kerbside lanes typically allow parking overnight and sometimes parking and loading at midday.

The images from New York shown below demonstrate a successful way of mitigating the impacts of bus lanes on other road users.

Traffic modelling, simulation and assignment software

The majority of organisations (or their authorities) use traffic modelling to predict the impacts of projects on bus operations and other road users (Barcelona, Brussels, Dublin, London, Montréal, New York, Paris, Seattle, Sydney, Vancouver).

In London, LinSig and TRANSYT modelling software are used for simple schemes. Montréal and Vancouver use Synchro software to test the impact of projects on traffic, whilst in New York, the Department of Transportation uses a range of modelling software depending on the level of analysis required (including Synchro and HCS).

In London, VISSIM is used for larger schemes. Montréal uses SimTraffic software to test the impact of projects on traffic whilst VISSIM is used to specifically test the impact on buses and bus operations. New York's Department of Transportation uses Aimsun and VISSIM simulation software.

In Brussels, VISSIM simulations have been used to estimate the impacts of a traffic signal priority project on road users. It is possible to run simulations for all projects, however once again project choices are more dictated by political decisions rather than modelling outcomes.

A VISSIM model was created to test the impacts of bus lanes along Rapid Ride corridors in Seattle, both on general traffic and bus travel times. Model outcomes were used as a baseline to negotiate bus priority strategy with local government.

Only London mentioned using traffic assignment software (VISUM). Again this software is relevant for larger schemes.

Bus priority pilot studies

Implementing pilot projects can help minimise risks associated with bus priority measures. The study identifies that most participants do not use pilot studies for this purpose. However, where pilot projects have been implemented (Barcelona, Brussels, London, Seattle, Sydney and Vancouver) they have helped validate expectations, reduce concerns and optimise designs.

In Seattle, a traffic signal priority strategy at an intersection was piloted which included a before and after study to evaluate the impact on pedestrian and general traffic. The outcomes of the pilot helped reduce concerns that the Seattle Department of Transportation had about the scheme (negative impacts on general traffic and increased jaywalking). The pilot study found that impacts to traffic were minimal and the increase in jaywalking was only marginal. In addition, the study also found that the benefits to journey times outweighed these minor impacts. These findings meant that Seattle King County was able to implement phase-skipping at the intersection.

London implements pilot projects at the beginning of a wider programme to ensure that the approach and delivery capabilities are correct. An example of a pilot is the A406 Brentfield Road where two existing bus routes are able to follow the same route in both directions across a major arterial road, reducing each round trip mileage by 1km.

In Vancouver, queue jump kerbside lanes were piloted on King George Highway at 96th Avenue. The pilot delivered better bus travel times and improved customer service.

Traffic signal Priority (TSP)

The focus of this section is on Traffic Signal Priority (TSP), currently used in eight participating cities (Barcelona, Dublin, London, Montréal, New York, Paris, Seattle, and Sydney). In particular, the study reviews the success factors of the technology, the software and system settings and includes a brief review of when buses are granted priority on operators' networks.

The different types of equipment used, the hardware required to implement the system and its relationship with AVL, and the benefits and disbenefits of TSP as experienced by study participants are discussed towards the end of the section.

TSP TECHNOLOGY AND SETTINGS

TSP technology can be divided into two categories: Passive TSP and Active TSP.

Passive TSP: There is no interaction between the bus and the traffic signal. Traffic signal timings are optimised or coordinated to give successive green signals to traffic along a road/corridor (e.g. green waves). Traffic is improved for all vehicles along the route. Generally no specialised on-bus hardware is required.

Active TSP: Bus detection technology allows for dynamic signal timing adjustments to be made when a bus is approaching an intersection. An example of this is the SCOOT technology. Active TSP requires specialised on-bus hardware.

Active traffic signal priority (TSP) systems enable buses to get a green light earlier than they would without priority. Systems may use one or more of the following methods to achieve this:

- **Early green phase (red phase cut short)** Signal turns green earlier than normal when a bus approaches the signal (and the signal is red)
- **Green phase extension** The green phase is extended when a bus approaches
- **Phase insertion** A special signal phase added on or inserted into the normal signal phase
- **Special public transport phase** A special signal only for buses, e.g. for a bus lane or bus-only turn signal
- **Phase rotation** Changing the sequence of signals to benefit buses

The different types of TSP systems on participants' networks are sumarised in Figure 20.

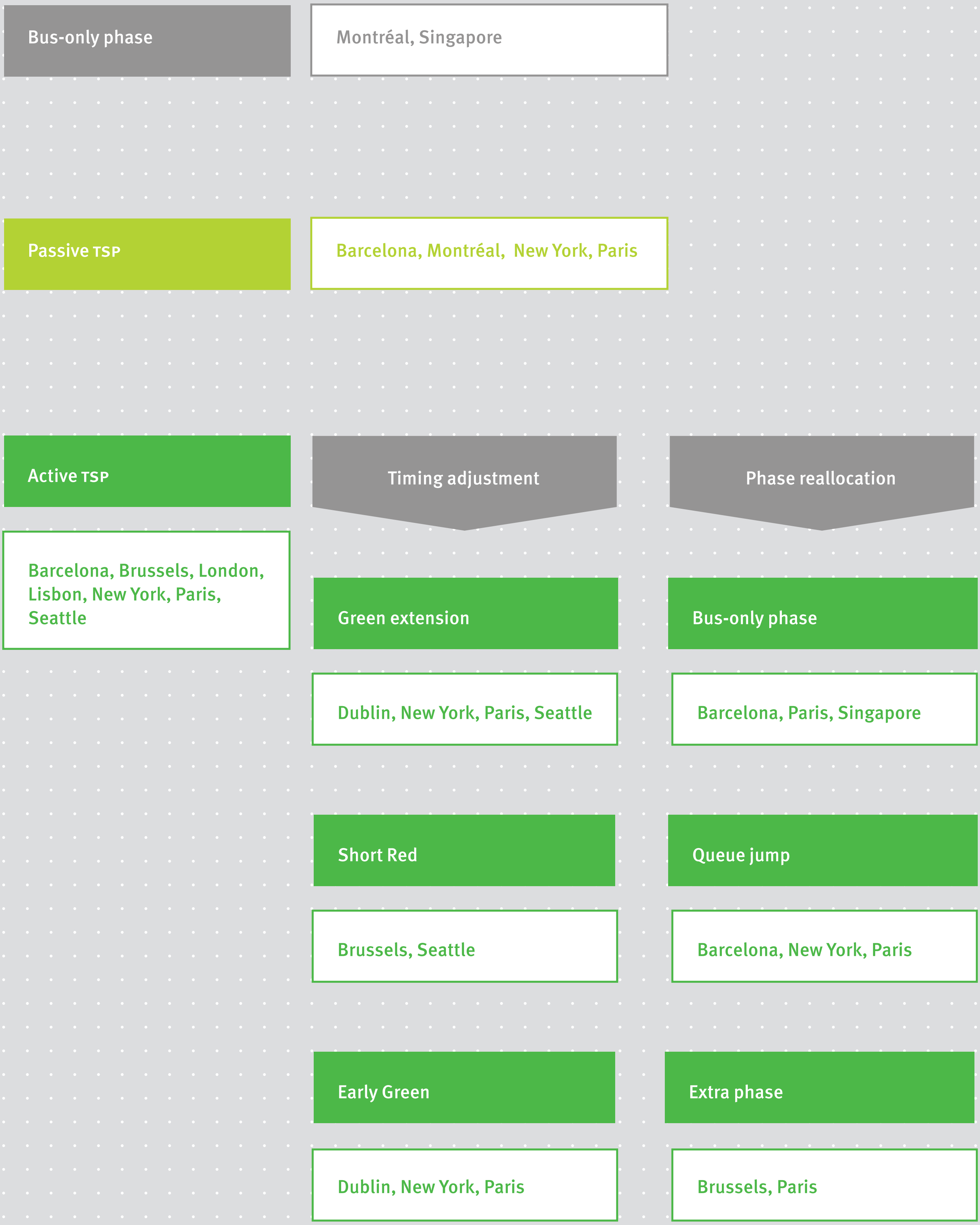
Passive TSP

Singapore uses a passive TSP system (i.e. no detection of buses) whereby the bus signal priority gives a special green 'B' signal at specific junctions. This allows buses to proceed without interference from other traffic.

In Barcelona, traffic signals (20 locations) are pre-programmed for green waves and are activated when traffic conditions are appropriate.

New York uses passive TSP (splits, offsets, lane striping, and 'green wave'). Dublin Bus believes that

Figure 20 The different types of TSP



implementing a 'green wave' is the ultimate goal for signal priority.

Montréal currently only uses passive TSP technology on its bus network, however active TSP is planned for implementation in 2017/2018.

Active TSP

Dynamic timing adjustment

All types of TSP are used across different locations in Dublin, sometimes in operation collectively at the same junction depending on the bus arrival at the junction relative to the phase. Queue detection is reported to be the most popular type which can either provide an early green phase or green extension (depending on where the bus is picked up in the queue detector).

London uses several TSP technologies: SCOOT (Split Cycle Offset Optimisation Technique) control by coordinating junctions dynamically, SCOOT bus priority, and SCOOT PROMPT bus priority. Lisbon has a dynamic system that manages all traffic. Only some signals have bus priority.

In Paris and Seattle, buses must arrive at a pre-defined check-in point during defined times of the cycle in order to receive timely prioritisation. Two types of priority are provided: a) green extension if a bus is approaching an intersection towards the end of a green phase; and b) short red when a bus is approaching an intersection at a red signal, and the green phase for other movements is shortened to bring in a green phase for the bus sooner.

Dynamic phase reallocation

In Barcelona, bus only phases/queue jump lanes are activated when a bus has been detected.

In Paris, it is possible to insert an extra phase at certain junctions.

New York's system has the ability to give active priority queue jumps (used in the past with different technologies), but currently none of the five queue jumps have active TSP (all five work on a fixed-timing basis). The system is also capable of inserting phases but this has not been used to date on the network. New York does use actuated phases at queue jumps at other locations around the city that do not have active TSP.

Detection of early/late running of buses

Four organisations' TSP systems can currently detect the early or late running of buses (Brussels, Dublin, London and New York). Out of the participants with TSP systems that are able to detect early or late running buses, only Dublin reported that this information is used to decide on priority (e.g. to avoid bus bunching). Dublin Bus uses two different detection systems: the first system detects general traffic speeds (bus and car) and does not differentiate between early or late buses; the second system only detects a single bus approaching a single traffic light. This system differentiates between early and late buses. Ultimately, it is hoped that both systems will be able to make this detection. It should be noted that not all buses will get priority. For example, Dublin Bus takes account of other factors such as bus bunching to not give all buses priority.

In London, the SCOOT PROMPT system has the capability to optimise more strongly for late buses and the GPS iBus (AVL) has the capability to send how late a bus is to the signal controller. In New York, Phases 1 and 2 of the MTA TSP program did not include schedule adherence. Phase 3 might include this, depending on the results of current analysis being done on the TSP system in place so far.

TSP system calibration

The majority of TSP systems are calibrated differently subject to local factors. Barcelona TMB and Paris RATP apply the same settings across the network, whilst others apply different TSP settings according to junction. The latter are discussed in further detail below.

Brussels STIB prioritises bus services on routes with the highest demand (major routes). Larger and newer buses are put on these major routes at high frequencies. The objective is that these routes are not slowed down at an intersection with a minor route and therefore have greater priority at a junction.

Several participants calibrate junctions such that different settings are applied according to time of day. In the case of Dublin, the peak direction during the peak hour will receive higher priority. London's SCOOT PROMPT bus priority is calibrated for each junction by a traffic control engineer: following good practice guidance, settings are fine-tuned by time of day. The parameters are reviewed every three years under the Signal Timing Review Programme undertaken by Transport for London.

In New York, TSP settings are tailored to individual geometry and traffic flows.

TSP check-in distances

This subsection reviews the typical check-in distances for TSP (i.e. the distance from the traffic signal at which the bus is detected and the TSP request is made).

In Brussels, each junction has a reaction time that takes into account the physical infrastructure (length of crossing, number of phases). By converting the vehicle speed, this allows to determine the distance at which the priority demand has to be activated. STIB use two types of check-in distance for TSP: the announcement (between 700m and 250m) and the confirmation (between 150m and 100m).

In Paris, the check-in distance is between 100m and 300m depending on the position of the junction and the bus stops. Seattle King County noted that the ideal distance for TSP detection is around 200m but like Paris it varies based on road and bus stop conditions. Intersections with a near-side bus stop could be set as close as 6m before the intersection, so the bus only checks in once it has left the stop. In Dublin, the check-in distance is never more than 200 meters, but the placement of bus stops may reduce this down further. The polling cycle (currently 20 seconds) is also a factor of the distance.

In London, different types of priority are given depending on whether detection is far enough from the junction or within a couple of meters of the junction. For example, if detection is close to a junction, then there may be a re-call to bring the traffic stage back around as quickly as possible. If detection is further away then there may be a green extension: this extends the stage if a bus is approaching to allow it to go through on green without having to stop.

Similarly, the check-in distance varies by junction in New York. Since TSP is a time-based system, the Estimated Time of Arrival (ETA) and distance thresholds are set using the average speed for a given time period. If the bus travels faster than the average speed, ETA still gives enough time to make the request. If the vehicle travels slower than the average speed, the distance threshold is used.

Granting bus priority at junctions

Conditions under which buses are granted priority through a junction vary across cities.

In some locations the impacts of bus priority at a junction is considered and thresholds to the impact on pedestrian movement (Barcelona) and general traffic (London, Seattle) are applied to regulate the number of bus priority requests that are granted.

In Barcelona, priority requests are granted when traffic flow conditions are good (not when congested). The City Council wants to avoid congested intersections at all times, particularly in the peak time. This appears to be a common situation across cities. Based on this, it can be said that TSP (and associated practices) often further improves road conditions when traffic is flowing, but does not necessarily improve traffic conditions when a road is congested.

Buses in London are granted priority when the impact on general traffic does not exceed the threshold set by the traffic control engineer. These tolerances are calibrated for each junction and dependent on road type and location.

Seattle King County's buses must meet several logic requirements: a) frequency lockouts of 120 seconds (on average) prevent buses arriving within 120 seconds after a previous bus from receiving priority to minimise the impact on other traffic movements; b) maximum green extensions and red truncations are controlled by pedestrian phase minimums and can be as long as 30 seconds.

A second category relates to more of a general rule, for example in Dublin a rule of thumb is that priority should be sought for all buses that aren't running early. Green time is normally held for up to 20 seconds, but can vary per junction. Note that in the absence of passenger counters on buses, there are no passenger-related thresholds in Dublin.

In some locations (Dublin, London, New York) circumstances vary according to junction. For example, Dublin Bus noted that the percentage of TSP requests granted depends on the junction but there is no schedule adherence restriction. In reality, 70—80% of request are granted.

Brussels STIB always grants priority to buses during both peak and off-peak hours.

BENEFITS AND DISBENEFITS OF TSP

Benefits of TSP

This subsection discusses the benefits and disbenefits of TSP as experienced by study participants. The benefits that participants have experienced using TSP are shown in a flow diagram in Figure 21.

Many operators consider TSP to be a positive element of their bus network, delivering a range of benefits. Brussels noted that TSP delivers benefits in the range of a 10% increase in commercial speed and regularity. In Seattle, TSP reduced journey time by up to five minutes as well as a reduction in total intersection delay of up to 1.5 minutes for a corridor with bus priority measures. In Barcelona, the implementation of a green wave has improved punctuality by up to 10%.

London Buses noted that studies undertaken on behalf of their organisation into the benefits of London's bus priority system have identified that on average each bus travelling through a TSP equipped junction saves at least 2 seconds, thereby providing significant time savings over the entire bus route. In addition, there are monetary benefits associated with not needing extra buses to fill gaps within the service.

Disbenefits of TSP

A number of downsides to TSP technology have been reported by participants. One of the key disbenefits reported by several participants is that TSP impacts on general traffic (London), including lower speeds for general traffic (Istanbul, London, Singapore, Vancouver), impacts on non-priority approaches and possibly neighbouring intersections (Lisbon). In London however, the effects of this are limited by the use of SCOOT traffic control which ensures that general traffic is normalised before allowing another priority to be given to buses.

An interesting comment from Brussels STIB stated that "the officials charged with programming the traffic lights don't have any clear instructions on the acceptable reduction of road capacity. In case of complaints, they 'adjust' the traffic light programming in favour of car traffic (and at the expense of public transport)."

The second key disbenefit of TSP mentioned by participants is that the technology does not work well in slow-moving traffic or congestion where there is no dedicated bus lane (Barcelona, New York, Sydney). In these situations priority requests are not always granted and therefore benefits not delivered. Sydney Buses has experienced similar issues and reported that TSP cannot be used during peak hours when there are too many requests for priority for too many intersections. The system cannot manage which request gets priority over the other.

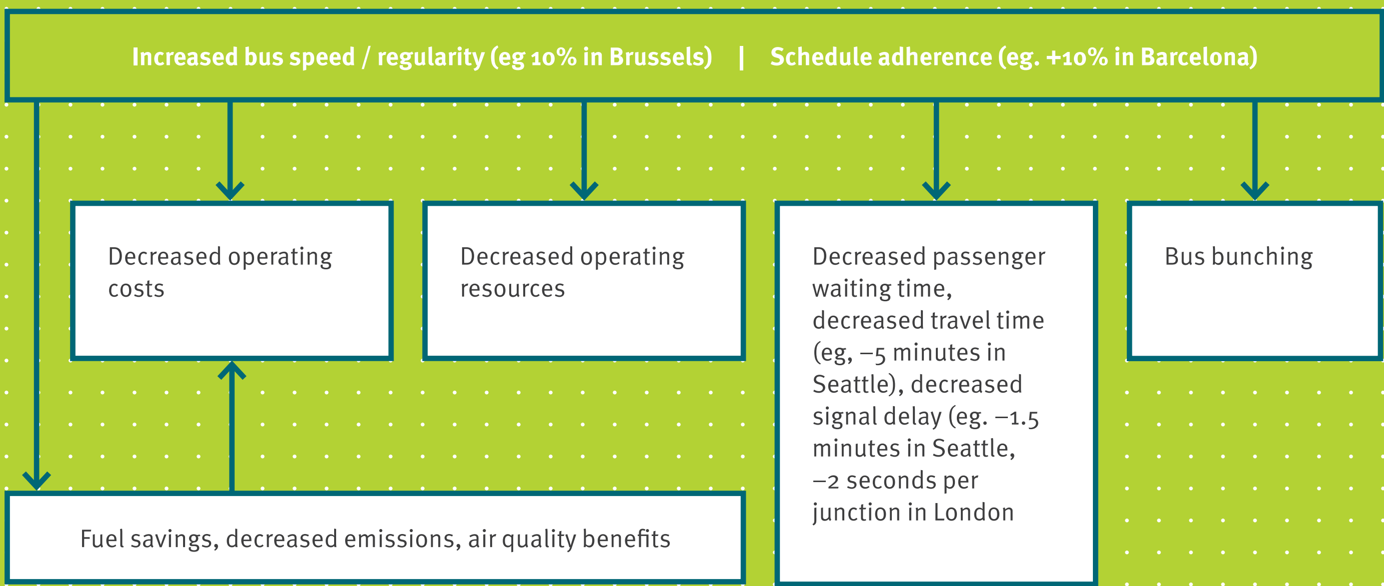
In Vancouver, TSP has not been a success. A key issue was that signal priority locations in the city were decided by political factors and not by scheduling needs (i.e. not based on operational priorities and not planned alongside bus lanes and other priority measures). For signal priority to be a success CMBC consider that it needs to be part of a suite of improvements and the bus operator needs to be included in the decision making.

A study was undertaken in 2013 by TransLink (the transport authority) into Vancouver's experience with TSP to identify lessons learned and best practices for future successful TSP implementation. The key findings from the study report include having a clear dissemination of roles and responsibilities between agencies and that these need to be set out from the beginning of the TSP project. The report also advises that successful evaluation of the scheme requires monitoring and fine tuning the TSP system after initial implementation and that data from the TSP system and the traffic signal control system must be readily available.

Transit signal priority work program report
TransLink, June 2013

- *"Prior to implementation, the system owner should be clear on goals and objectives, and how the system's performance will be measured and evaluated.*
- *TSP is not a 'silver bullet' that will work in all situations: careful and diligent planning is thus required to ensure success.*
- *TSP technology is continually changing with the result that any system that is installed needs to be upgradeable and expandable as new technology becomes available or new TSP routes are added.*

Figure 21 TSP benefits



- *Relevant organisations must be actively involved in the planning, design, specification, procurement, deployment, operating and maintenance phases of the TSP project."*

A further challenge raised by Paris RATP about TSP is that the systems are difficult to maintain over time and that they interact with other highway systems managed by other services.

Finally, some participants mentioned that TSP requires significant financial resources (capital costs mentioned by Lisbon Carris and Vancouver CMBC). Similarly, Dublin do not consider TSP to have any major disbenefits, however many junctions need to be set up individually which is a time consuming activity.

TSP EQUIPMENT

This subsection reviews the different types of TSP equipment used as well as the hardware that is generally required for TSP technology. The on-bus hardware requirements for TSP vary across participants. Barcelona TMB's on-bus hardware (detection card device) is installed specifically for TSP whilst other operators' hardware can be used for other purposes such as real-time information and AVL (London, New York, Seattle).

In Brussels, STIB's buses need to be equipped with a radio transmitting antenna as there are no receiving sets or activation systems of radio beacons on buses. The broadcasting of radio waves (signals giving priority to a bus) is fixed in advance at defined locations. The AVL system then ensures that buses passing these locations are detected.

London Buses use a GPS based location system which communicates wirelessly via transponders to the traffic signal controller. This system (iBus) is used for TSP as well as other purposes such as the provision of live bus arrival information at bus stops and through mobile applications. Similarly, in Seattle, King County buses' hardware forms part of a larger system requirement for AVL.

In New York, the MTA TSP implementation incorporates the use of shared GPS and communication devices supplemented through MTA Bus Time (AVL) hardware, with the exception of a single on-board computer.

Dublin Bus bought their system primarily for AVL, however the supplier (Init) feature TSP as a potential benefit and Dublin Bus made the purchase of the AVL system with this benefit in mind.

Managing TSP hardware and software obsolescence

Bus organisations are taking a number of approaches to manage the risk of hardware and software obsolescence. The study identifies five practices that participants adopt to manage TSP hardware or software obsolescence (i.e. software or hardware being discontinued or no longer supported by manufacturers or vendors): spare equipment, system upgrades, using commercial off-the-shelf hardware, safehousing the source code, and collaborating with TSP manufacturers.

Barcelona TMB keep spare detection cards for replacement purposes. Similarly London Buses' maintenance department keep a supply of spare equipment. Several participants upgrade and update systems as required. Dublin Bus' system is relatively new and will be upgraded in time. This also applies to Brussels STIB but there is no systematic follow-up of hardware or software obsolescence. New York noted that by using commercial off-the-shelf hardware, components are easily interchanged as they become outdated or need replacing. In terms of software, the MTA requires the vendor to safehouse the source code for the TSP application in a third party account. In the event that the vendor discontinues or no longer supports the application, this can then be extracted. The mobile computer operating system (Windows) is commercially available through various sources and does not require any third party software.

A final practice is close collaboration with TSP manufacturers. Seattle King County works closely with their TSP manufacturer (McCain) to ensure that the TSP software is current and functioning. The collaboration between the two organisations also allows for King County to make recommendations to McCain.

An interesting example from London is that the technology used is specific to London Buses. The equipment installed in the signal controllers is compatible with on-bus equipment and the maintenance department keep spares for the existing equipment.

Only two participants (Barcelona TMB and New York NYCT/MTA Bus) use open source hardware or software for the purpose of their TSP system. New York noted that the use of open source hardware (e.g. commercial mobile computers, enhanced GPS, cellular communications) allows other on-board applications to leverage existing hardware. Benefits include reduced overall cost, maintenance and footprint on the vehicle. The TSP and real time information systems (MTA Bus Time) share the same GPS and communications devices.

Stakeholders, planning and implementation

The final section of this study investigates the distribution of responsibilities between bus operators and stakeholders in the planning and implementation process of bus priority projects. This section also addresses how operators (or their authorities) make the case to stakeholders for bus priority, including how they market and communicate schemes to funders, local authorities, other stakeholders and the public. In particular, the study explores how benefits of bus priority, using a road once a scheme is in place, and enforcement of a scheme are communicated. The study also summarises successful methods used by participants to get public support for bus priority projects.

STAKEHOLDERS AND DISTRIBUTION OF RESPONSIBILITIES

The stakeholders typically involved in the various stages of bus priority projects are summarised in Figure 22.

Montréal STM is the only participant entirely responsible for designing schemes, with some input from external consultants. Conversely, in Istanbul, the local government is fully responsible for bus priority schemes, and IETT is only the user of the bus priority measures. Similarly, in Kuala Lumpur, it is the local government and transport authority that hold these responsibilities.

Bus priority stakeholders in London

The stakeholders involved in the various stages of bus priority projects in London are presented in Figure 23.

- Transport for London (authority and operator) is involved in identifying potential bus priority schemes with input from the local government.
- The highway authority (both Transport for London and local government) is involved in selecting suitable projects.
- Transport for London (authority and operator) funds bus priority projects either through the organisation's own programme or through funding allocation to local government.
- The highway authority (both Transport for London and local government) is involved in designing and obtaining permission for bus priority measures.
- Transport for London and local government share responsibilities of marketing and public communication, financial management and overall management of bus priority schemes.

Figure 22 Bus priority stakeholders and responsibilities

Project inception

Identifying projects is typically a shared responsibility (local government & operator / transport authority).

Local government (sometimes jointly with the transport authority / operator) generally makes the final decision regarding project selection.

Obtaining permission for a project is the responsibility of local government in most cases.

The design of bus priority projects is typically a joint effort between local government / transport authority and operator.

The government is the key funding source for projects in many cities.

In only four cases (out of 15) the operator provides some financial input (Mt, NY, Se, and Vc).

Marketing responsibilities vary by location. Project communication to the public may be done (jointly) by the government, authority or operator.

Overall project management of construction is generally led by the highway authority responsible for the relevant streets.

Project completion

Figure 23 Bus priority stakeholders in London

TRANSPORT AUTHORITY
Project identification

TRANSPORT AUTHORITY
Project funding

HIGHWAY AUTHORITY
Project selection

HIGHWAY AUTHORITY
Design

HIGHWAY AUTHORITY
Obtaining permission

HIGHWAY AUTHORITY
Marketing & Communications

HIGHWAY AUTHORITY
Financial management

HIGHWAY AUTHORITY
Overall project management

Figure 24 Bus priority stakeholders in Seattle

OPERATOR + LOCAL GOVERNMENT
Project identification

OPERATOR + LOCAL GOVERNMENT
Project funding

OPERATOR + LOCAL GOVERNMENT
Project selection

LOCAL GOVENMENT
Design

OPERATOR
Obtaining permission

OPERATOR
Marketing & Communications

OPERATOR
Financial management

OPERATOR
Overall project management

In London, the Highway Authority comprises the transport authority and local government

Bus priority stakeholders in Seattle

The stakeholders involved in the various stages of bus priority projects in Seattle are presented in Figure 24.

- Seattle King County (Transit Speed and Reliability programme) together with local governments are responsible for identifying potential bus priority projects.
- Seattle King County and local governments are both involved in selecting the bus priority schemes for implementation.
- Seattle King County and local governments use grants and local match funding to fund projects.
- Seattle King County and local governments design projects with input from external engineering consultants.
- Seattle King County obtains permission for projects within the respective jurisdictions. For example, Transit Signal Priority improvements in Seattle, Renton, Burien, Bellevue and Tukwila were all reviewed and approved by city engineers in the respective jurisdictions. If King County or a contractor conducts the work, permits will be obtained according to local standards.
- Seattle King County or local jurisdictions are then responsible for marketing, public communications, financial management and project management of bus priority projects.

Brussels STIB example – management contract with stakeholder

Brussels STIB and their authority use AVL data to determine funding supplements/reductions based on changes in operating costs resulting from changes in commercial speed, see Figure 25.

Brussels STIB's management contract with the authority specifies service and performance to be provided, and the correlated funding and incentives. Within this contract, there is a scheme to reflect change in operating costs as a result of changing commercial speed. This was originally designed by the authority because the authority were planning to make congestion improvements and wanted STIB to pay them back for operational savings due to improved traffic flow. This agreement is bi-directional so if commercial speed reduces, STIB receive additional funding. The compensation formula covers 80% of the change in operating costs based on the speed (the other 20% should come from efficiencies). For example, if commercial speed gets slower by 1km/hour, operating costs increase by about €3m, so STIB would get paid an additional €2.4m.

An agreed formula is used to sum up the yearly average actual commercial speed as measured by the AVL system. This incorporates seven billion datapoints. The use of AVL to measure commercial speed is key to this arrangement because the data are transparent and can be checked by the authority.

Although the original intention was that commercial speed would increase and hence STIB would receive less funding, in fact every month since this agreement was made, commercial speed has decreased. Therefore the authority has been compensating STIB. STIB see this agreement as insurance for them against external factors they cannot control. In addition, they see it as an incentive for the authority to improve traffic flow and implement better anti-congestion policy (e.g. parking charges, congestion charging), as well as bus priority.

MARKETING AND PUBLIC/STAKEHOLDER COMMUNICATIONS

The focus of this subsection is the communication of bus priority projects and how schemes are marketed to the public and stakeholders. In particular, this section addresses how benefits of bus priority, using a road after the implementation of a scheme, and enforcement are communicated. Participants were also asked to share any successful methods used to get public support and these examples are summarised.

Figure 25 Linking changes in commercial speed to funding changes

Bus priority marketing and communication strategies

The study found that bus priority benefits are communicated in a number of ways (depending on the scale of the project i.e. larger projects generally receive more attention):

- **Leaflets, flyers, posters** Barcelona, Dublin, New York, Paris, and Sydney
- **Website** London, New York, Sydney, and Vancouver
- **Press release** Dublin, Istanbul, New York, and Paris
- **Meetings and community consultation** New York, Paris, and Sydney
- **House drops** Dublin and Sydney **and door knocks** Sydney
- **Media blitz at shelters for big schemes** Dublin
- **Documents for public release** Seattle

Brussels STIB is the only participant to report that there is no communication of the benefits of bus priority. In Singapore and Sydney, the responsibility for marketing and communicating bus priority to the public lies with external agencies. In Singapore, the responsible agency is the Transport Authority, whereas in Sydney Transport for New South Wales and the Roads and Maritime Services (government agencies) are the lead agencies for these activities. Sydney Buses noted that State Transit (a bus operating agency of Transport for New South Wales) have been involved in bus priority programs as a key stakeholder.

A number of communication methods are used to communicate how to use a road once a bus priority project is implemented (depending on the scale of the project). This information is communicated through distributing leaflets providing information on new street directions (Barcelona and Sydney), press releases (Istanbul and Vancouver), and on relevant websites (London, New York, Sydney). *London example, A406/Brentfield Road/ Drury Way Junction, consultations.tfl.gov.uk/roads/ a406-brentfield-road*

However, not all organisations (or their authorities) communicate this information to the public (e.g. Brussels). In Paris, the local authority is responsible for this activity and RATP only has to inform customers if the project affects the itinerary of any bus services.

Amongst the study participants reviewed there appears to be limited communication about the enforcement of bus priority projects. Participants that do communicate enforcement do so online (London, New York, and Sydney) and through distributing leaflets (Sydney). An example of marketing and public communication from Sydney is detailed in the following paragraphs and relates to the Inner West Bus Programme (aimed at improving bus travel times and service reliability).

The information communicated to the public in TfNSW's consultation exercise focused on how the works would improve journey times, such as through reducing the number of locations at which buses need to stop; making it easier for buses to move in and out of bus stops; reducing delays for buses at traffic signals; and improving the traffic management response to incidents affecting bus journeys.

The community consultation included newspaper advertisements, posters and displays on bus services in the affected area, distribution of community update brochures (letterbox drops and door knocks), as well as meetings and door knocks of businesses and residences.

The community update brochure produced by Transport for New South Wales also included detailed information on how the proposals would affect bus stops and stopping/parking/loading zones. The proposals and planned changes were clearly shown on maps and plans within the brochure, including changes to no stopping and no parking zones, changes to loading zones, and bus stop relocations and closures. Information on next steps along with a timeline and indicative timescales for implementation of the changes were also provided.

Successful communication methods

Study participants were asked to state their most successful communication methods to gain public backing for bus priority projects. The responses indicate that interagency collaboration, public outreach, representative support, and putting projects to popular vote can successfully impact public support, see Figure 26).

Interagency collaboration is identified by Barcelona TMB and New York NYCT and MTA Bus as a successful method in getting public support for bus priority projects. Barcelona TMB works together with the City Council to design marketing materials for public dissemination and to launch press kits. New York NYCT and MTA Bus noted that cooperation between the bus operator and the roads authority is essential as a first step to ensure that both agencies are working towards the same objectives.

Secondly, thorough public consultation should follow to ensure that the public is informed and their voice can be heard. Subject to consultation outcomes, compromises can be reached if necessary. In New York this consultation exercise engages with elected officials (federal, state, city); community boards (appointed, non-elected neighbourhood representatives); the public (with a special emphasis on reaching customers and advocates); business improvement districts; and other stakeholders (e.g. senior centres, hospitals, schools).

Interestingly, Dublin Bus commented that general 'public' support is less key than public representative support at planning stage and that public support becomes more critical for further schemes as the benefits become apparent. Dublin Bus CEO/senior management meet with local elected representatives or present to elected members of the authority. Paris RATP also noted that the emphasis is on getting local authority backing.

Vancouver CMBC reported that a successful method is to provide funding to the local authorities for the installation of bus priority works.

Different approaches are taken by London Buses and Seattle King County. London Buses focuses on communicating the investment in London's growth (articles issued on TfL's website), whereas Seattle King County's approach can be demonstrated through the example of the 'Transit Now' initiative which was voted in by the public and resulted in funding sources for bus priority. The initiative ultimately led to the implementation of Rapid Ride.

Figure 26 **Sucessful communication methods for public support**

Interagency co-operation	BARCELONA Close working with the City Council's Press & Communications departments
	NEW YORK Collaboration between bus operator and roads authority
Public outreach	NEW YORK Public outreach "We have found that it is crucial to make sure everyone feels that their voice is being heard." "If need be, we have compromised on minor parts of project design in order to get to implementation, but we have tried to hold firm on the most crucial elements."
Public representative support	DUBLIN Public representative support more important than general 'public' support at planning stage "Our CEO or senior management would often meet the local elected representatives and seek individual support."
Popular vote	SEATTLE Voter supported measures expand funding sources and can assist the implementation of bus priority schemes

Summary and conclusions

Innovative priority measures for bus services can deliver significant benefits both for passengers and the operator. The range of potential benefits from bus priority schemes are often far-reaching and can positively affect both customer and operator.

This section brings together the study by summarising key findings, drawing conclusions, identifying opportunities and good practice examples relating to all aspects of bus priority from the initial stages of identifying and selecting bus priority projects through to measuring the impact of implemented schemes and quantifying the benefits delivered by projects.

This study investigates how bus priority schemes are identified and managed in 14 different cities across Asia, Australia, Europe and North America. The information within this study is sourced from 15 participating bus organisations, all of which are members of the International Bus Benchmarking Group (IBBG), a consortium of medium and large bus organisations involved in a comprehensive programme of benchmarking urban bus operations facilitated by Imperial College. These organisations are: Transport Metropolitans de Barcelona (TMB), Société des Transports Intercommunaux de Bruxelles (STIB), Dublin Bus, Istanbul IETT Isletmeleri Genel Müdürlügü, Rapid Bus Sdn Bhd (Rapid KL), Companhia Carris de Ferro de Lisboa, London Buses (LBSL), Société de Transport de Montréal (STM), MTA New York City Transit (NYCT) and MTA Bus Company New York, Régie Autonome des Transports Parisiens (RATP), Seattle King County Metro Transit (King County), Singapore SMRT Buses, Sydney Buses, and Vancouver Coast Mountain Bus Company (CMBC).

The report explores how the organisations pursue the identification and selection of bus priority measures (including the challenges and risks of different types of bus priority solutions), and identifies successful examples of bus priority enforcement and communication.

Decisions on whether (and how) to implement bus priority schemes are often not made by bus operators themselves but by external parties, such as local governments or road authorities, with a varying degree of input from bus operators into the process. The study therefore explores operators' experiences with decision making processes such as how they have identified necessary bus schemes and then made the case for these schemes to key stakeholders. The responsibility for the enforcement of bus priority schemes also varies on an international level and reviewing the different methods of enforcement adopted by the bus organisations participating in this study is useful to establish interesting and successful ways to ensure the effective enforcement of bus priority measures.

Data for the study was collected through questionnaire surveys completed by the participants and follow-up telephone interviews with select organisations.

SUMMARY OF STUDY FINDINGS

Current bus priority schemes

A review of the current extent of bus priority on the networks (in route km terms) of all bus operators participating in the study reveals that there are significant differences between cities. For example, Brussels STIB's network has the highest proportion of bus priority kilometres (>30%) of the road network, whilst Istanbul IETT's network has the lowest (0.04%). In terms of traffic signals with bus priority, more than 30% of traffic signals on London Buses' network have bus signal priority (representing the highest proportion of all networks studied), but their proportion of bus priority km is less than 5% of the road network.

In terms of queue jump lanes (i.e. a lane allowing a bus to bypass general traffic on the approach to a junction) the study identifies that this type of measure is generally not widely used on organisations' networks. London leads with the most queue jump lanes (103) however cities such as Kuala Lumpur, Paris and Singapore do not have any measures of this type on their networks.

Successful experiences with bus priority

The report describes some of the most successful bus priority schemes as experienced by the bus organisations included in this study. For each scheme details are provided on project cost, benefits, success factors, and any challenges and lessons learned throughout all stages of the bus priority process.

Based on participants' most successful bus priority projects one of the key success factors relates to securing public and political support for schemes. A success factor of Dublin's Quality Bus Corridor (QBC) initiative for example, was the programme's widespread political support despite opposition from local politicians and car lobby groups. Clear communication and marketing strategies of schemes are also crucial to gain public support.

In addition, framing whole-corridor upgrades as part of a branded programme enables later projects to benefit from previous project success (e.g. Seattle's Rapid Ride, Dublin's QBC, and New York's Select Bus Service). Other key elements reported to have contributed to the success of bus priority schemes include a scheme design that does not significantly impact general traffic (e.g. Barcelona's Gran Via de les Corts Catalanes), and targeting routes with very slow bus speeds and widely varying travel times as there is significant scope for improvement (e.g. New York's Bx41 SBS).

A selection of unsuccessful experiences with bus priority are also detailed in this study. Based on the sample of member examples, the study identifies that bus priority schemes may fail due to issues relating to junction design and layout, a lack of bus lane enforcement, as well as matters relating to politics (e.g. a lack of political support) and public opinion.

Bus priority identification and selection

The most common approach to identify potential locations for bus priority is to identify problem areas where bus priority may be useful to solve the issues. Other approaches adopted to a lesser extent include focusing on ridership growth/high ridership routes (e.g. New York, Seattle, Vancouver) or areas experiencing urban growth (London), identifying routes providing strategic connections (e.g. Lisbon), reviewing bus priority feasibility on all routes (e.g. Barcelona), and opportunism (e.g. Brussels and London).

An interesting example is Sydney Buses' approach to identifying and selecting bus priority. A two-stage approach is adopted, where the first stage weights a number of different factors (including patronage, the number of late services and excess journey time) followed by the second stage which includes a desktop review and on-site observations. The findings of the review are then formulated into an action plan.

Similarly, Brussels has a three-staged approach to the bus priority identification process. The approach is to select locations by average commercial speed (from lowest to highest commercial speed) and by journey time variability "standard deviation" (from highest to lowest). The next step is to analyse if adjustments are physically possible. This information and the findings then determine the solutions to be proposed.

An interesting finding from the study is that there appear to be wide variations across organisations in terms of minimum criteria to qualify for bus priority measures. Criteria on bus frequency in Dublin for example is six buses per hour, whereas in Lisbon 20 buses per hour is considered to be the threshold before a location is eligible for bus priority measures. Similarly, the number of bus routes on a corridor in Istanbul should be no less than 30 to be eligible for a bus lane, whereas in Lisbon two to three routes are enough for a corridor to qualify.

Finally, implementing pilot projects to test the impacts of bus priority projects on bus operations and other road users can not only minimise risks associated with bus priority but also help with identifying suitable projects for long-term implementation. Pilot projects have in some locations helped to validate expectations (London), reduce concerns (Seattle), and optimise designs (Brussels).

Stakeholders, planning, and implementation

Decisions on bus priority schemes (i.e. identifying the most appropriate solution) are typically identified either through a process of analysis and problem identification or are simply a political decision. Where political choices define final decisions, this means that operators often have limited influence on bus priority schemes.

Nonetheless, organisations in London and Brussels have identified opportunities to influence the decision making process. In London, financial contributions from major developments towards public transport are sought through the planning process and this can represent an opportunity for implementing bus priority at the same time.

In Brussels, STIB adopts a proactive approach and uses the opportunity to include bus priority when there are plans to rearrange a street. Through pursuing the inclusion of bus priority in new street design and also linking commercial speed to the level of funding supplements or reductions they receive through their management contract with the authority, STIB is able to influence the implementation of bus priority and incentivise authorities to implement bus priority measures.

Measuring the impact of bus priority schemes

The study identifies that measuring the impact of bus priority projects is not common practice and currently very little is being done in terms of assessing and reviewing the impacts of bus priority. In the absence of monitoring and review processes for bus priority projects, there is a lack of documentation of any quantified benefits or disbenefits of bus priority measures. Given the limited activity in this area currently, much more can be done to build a benefits evidence base which can be crucial to gaining public and political backing for future schemes. A key step that can be taken is to use AVL systems to collect pre — and post-implementation data on speed and travel times to monitor the impact of bus priority measures (currently done in Brussels, Lisbon and New York). With AVL technology this information is becoming increasingly easier to collect and provides convincing information for getting public and political stakeholder support for future projects. Other options include using customer feedback to measure benefits (New York and Vancouver), adopting fuel consumption models to measure fuel and CO_2 savings (Barcelona and Seattle), monitoring changes in conflicts (Vancouver) and accident data (New York), and recording trends in regeneration and development along corridors with bus priority (Dublin and New York).

Benefits of bus priority

An interesting example of using AVL to measure the benefits delivered by bus priority is a 359m bus lane on Brussels' Avenue des Cerisiers. Brussels STIB used AVL data to identify the impacts of the bus lane and Figure 2, on page 30, shows the extent to which journey time variability along the section of road changed 'before' and 'after' implementation of the scheme. These indicate that the bus lane delivered much more consistent bus journey times, whilst prior to the implementation of the bus lane, in particular during the morning and afternoon/evening hours, journey times varied between five to nine minutes.

Furthermore, the study clearly identifies that different types of bus priority measures have delivered significant improvements to bus operations on many networks. In London for example, the implementation of a right turn lane resulted in faster bus speeds and journey time savings of more than 10 minutes on a route. Other quantified benefits of bus priority include improved journey time variability (e.g. journey time variability improved to a consistent 5 minute variability down from 5 to 60 minutes as a result of a bus gate in Dublin), and reduced journey times (e.g. 4 minute reduction in Barcelona) and improved punctuality (e.g. 10% improvement in Seattle) delivered by queue jump lanes.

Study participants also highlighted that unsegregated kerbside bus lanes can benefit less mobile passengers (Sydney), whilst unsegregated offset bus lanes keep areas commercially vibrant (Dublin) and are preferred by local communities (New York). Double bus lanes on the other hand, appear to often be self-enforcing with fewer incidents of violations (Dublin).

TSP technology

In terms of technology schemes, TSP can achieve journey time savings and reduce delay. Estimated benefits of TSP include up to a 10% increase in speed and regularity (Brussels), a reduction in total intersection delay of up to 1.5 minutes for a corridor with bus priority measures (Seattle's Rapid Ride E-Line), and two second journey time savings per junction in London.

However, a common challenge faced by operators is that the technology does not work well in slow traffic conditions (New York, Barcelona) as priority requests are not always granted and therefore benefits not delivered.

In Vancouver, TransLinks's report acknowledges that TSP is not a "silver bullet" that works in all situations and the success of the technology is dependent both on the characteristics of the bus corridor and the settings applied to the TSP system in terms of how buses are prioritised.

The study found that it can be beneficial to have different settings across a bus network with greater priority in the peak or for major routes, and to calibrate junctions by time of day to maximise customer benefit and reduce intersection travel delay. TSP can also assist with service regulation, granting stronger priority to late buses or separating bunched buses.

Enforcement of bus priority

Bus lanes are most commonly shared with private buses and long-distance coaches, as well as other modes such as taxis, cyclists, high-occupancy vehicles (HOV's) and emergency vehicles. Bus lane hours of operation range from permanent bus lanes to bus lanes with more restricted or controlled hours of operation. However, hours of operation needn't be the same at each location.

Matching bus lane hours of operation to local conditions can be considered: high bus demand and high traffic flows typically result in extended hours of operation; and low bus demand and low off-peak traffic flows typically translate into off-peak relaxation of restrictions.

However, many bus organisations face challenges when trying to enforce bus lanes, both in terms of compliance with bus lane rules and securing the appropriate enforcement. Enforcement by fixed cameras seems to be effective in detecting more than 95% of violations in London and New York, or deterring violations in camera enforced locations (Sydney). Evidence from Istanbul indicates that active enforcement by police can have a high detection rate (>90%) but most organisations struggle to get the level of active police enforcement needed for a comprehensive network-wide deterrent.

Design measures can also help significantly with reducing the amount of violations and minimising the risk of unauthorised activity on bus lanes. Passive enforcement (e.g. signage, road markings), and red bus lanes in particular, have had a big impact on reducing illegal activity on bus lanes in London, New York, Seattle, Sydney and Vancouver. This can be an effective enforcement measure in locations where violations are common.

Similarly to the lack of having a benefits evidence base, the study identifies that few of the participating operators have information on the number of bus lane violations that occur on their networks, particularly for those where the enforcement of bus priority is not within their remit. This in turn makes it hard for them to argue the case for greater levels of enforcement with the necessary authorities. Therefore, requesting and recording data on bus lane violations and using evidence of such violations can be helpful for those organisations struggling to get the necessary levels of active police enforcement.

EXAMPLES OF INTERESTING PRACTICES AND FINDINGS

The final part of this section provides an overview of key practices and findings from the study. Examples of good practices and interesting findings are listed in Table 11.

Table 11 Selected interesting practices and findings

Implementing bus only turn lanes can reduce travel distances where feasible, e.g. for a circuitous route. (Barcelona and London)

Where buses impede each other on high frequency corridors, the implementation of a double bus lane and/or double bus stops has been successful. (Barcelona)

Double bus lanes are suitable on streets with multiple express bus routes or other routes that do not make every stop. (New York)

Adopting a robust shortlisting process, assessment of benefits against the feasibility to prioritise route upgrades (New York), and minimum criteria to understand where bus priority would be suitable, beneficial and feasible (Barcelona, Dublin, Istanbul, Lisbon, Paris, Seattle, and Sydney).

Keeping a 'live' shortlist of locations suitable for bus priority measures for when opportunities become available and to avoid unnecessary duplication of the identification process. (Dublin, Lisbon)

Successful stakeholder relations can help with political backing or incentivising authorities to implement bus priority measures. (e.g. Brussels' example of linking commercial speed to the level of funding in their management contract)

Bus lane hours of operation needn't be the same at each location and can be matched to local conditions. Bus lane hours of operation range from permanent bus lanes to bus lanes with more restricted or controlled hours of operation.

High bus demand, high traffic flows typically result in extended hours of operation; and low bus demand, low off-peak traffic flows, low impact on speed, high parking demand, typically translate into longer hours of priority.

Where preference is for extended bus lane hours of operation but the minimum is typically authorised, starting off with the maximum as a default and narrowing down on a case-by-case basis can help avoid prolonged negotiations with the authority to try and extend hours of operation retrospectively. (Dublin)

Implementing permanent hours of operation where there is a safety risk or a bus only movement is required, can help ensure the safety of all road users. (London)

The enforcement of bus lanes, both in terms of compliance with bus lane rules and securing the appropriate enforcement, is a challenge in many locations.

Requesting and recording data on bus lane violations and using the data as evidence can be useful to make the case for enforcement.

Enforcement by fixed cameras with automated or manual post-processing seems to be effective in detecting more than 95% of violations (London and New York) or deterring them in camera enforced locations (Sydney).

A fully automated enforcement process using cameras with ANPR technology has resulted in a high detection rate of bus lane violations. (Sydney)

Evidence from Istanbul indicates that active enforcement by police can have a high detection rate (>90%) but most organisations struggle to get the level of active police enforcement needed for a comprehensive network-wide deterrent.

Design measures can help with reducing the amount of violations on bus lanes and minimising the risk of unauthorised activity. Passive enforcement (red bus lanes in particular) has had a big impact on reducing illegal activity on bus lanes (London, Seattle, Sydney, Vancouver and to some degree in New York) and could be effective in locations where violations are common (e.g. Istanbul).

"Operational teamwork" i.e. driver reporting of problems helps with enforcement and detecting issues sooner. (London, Singapore, and Sydney)

Monitor, measure and record quantified benefits of bus priority schemes (e.g. with AVL) to monitor the impacts of bus priority measures to understand the impacts of particular measures and use as evidence of benefits. (Barcelona, Brussels, Lisbon, London, New York, Seattle, Vancouver)

Bus lanes deliver a wide range of benefits including faster and more consistent commercial speed, increased ridership, emissions reductions and fuel use savings, fewer buses required, improved customer satisfaction, and improved punctuality. (Barcelona, Brussels, Dublin, London, New York, Seattle, Singapore, Sydney)

Projects converting at least one lane of general traffic into a bus lane have reduced crashes at these locations by 20%. (New York)

Bus priority can deliver social inclusion benefits (Barcelona) and regeneration and development benefits (Dublin and

New York). In Dublin, bus priority allowed high density developments with low levels of parking, whereas in New York, bus priority increased retail activity along a bus corridor.

The study explored how the impacts from bus priority on other modes can be minimised, both in terms of design and delivery, and unintended consequences. There are two types of unintended consequences: those related to operations and design, and those arising from public behaviour and perceptions.

Evaluating bus priority measures prior to implementation can minimise unwanted effects once the measure is in place. Measures are commonly assessed using traffic simulation studies and/or pilot installations to understand any potential impacts. This can minimise risk and outcomes can be used to make the case for political support and inform decision making.

The outcomes of a pilot study in Seattle helped reduce concerns that the Seattle Department of Transportation had about a proposed bus priority scheme.

Moving from kerbside lanes to offset lanes where feasible and changing the hours of operation can help mitigate the impact on local businesses and residents. (New York)

The shared use of bus lanes with other authorised modes, particularly of low travel speeds (e.g. cyclists), is not permitted at locations where there are safety issues. (London)

Design solutions (traffic signals, priority junctions, bus only turn lanes, bus gates) can reduce the interference of other vehicles at junctions and minimise the impact of turning vehicles entering a bus lane before or after a junction. (Brussels, Dublin, London, Paris, Vancouver)

TSP systems can be set to have a recovery cycle after a bus is given priority to allow general traffic to recover. (London and Seattle)

Framing whole-corridor upgrades as part of a branded programme enables later projects to benefit from previous project success: e.g. Seattle's Rapid Ride, Dublin's QBC, and New York's SBS.

Successive corridor upgrades as part of a programme also benefits from staff experience and allows the re-use of standard designs for quicker and more effective implementation: E.g. New York's Bx41, Seattle's E-line corridor.

A collaborative interagency approach to marketing and communicating bus priority projects can be successful. (Barcelona and New York)

Having a clear and comprehensive communication and consultation strategy can help with gaining community support and successfully making the case for bus priority:

- Comprehensive communication of the benefits of bus priority using a range of media.
- Sydney Buses focuses on delivering information on the following key elements:

  What is happening?

  Why is it happening and what are the benefits?

  What to expect once the scheme is implemented and how to use the road.

  Details on the enforcement arrangements.

  Project timeline and progress.

Improving communication about how a road can be used once a project has been implemented (and how a project will be enforced) can help avoid unauthorised activity on bus lanes by raising public awareness. (New York, Singapore)

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