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Bus Public Transport Planning and Operations

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Abstract

Public transport authorities (or transit agencies) face a considerable challenges in operating a service that is not only efficient and reliable but also appealing to users. To meet these goals they use several types of operational and physical transit service improvement strategies (or preferential treatments). This chapter starts with presenting the key concepts and terminology used in transit service planning and operations. This is followed by a description of bus transit users' perception of service quality. Afterward, a critical representation of several bus transit service improvement strategies while highlighting their benefits and the faced challenges in implementing them. These strategies include transit signal priority (TSP), limited-stop service, articulated buses, all-door boarding, and service coordination. Finally, the chapter wraps up with a reiteration of the main conclusions.

Keywords

1. Public transport
2. Bus service
3. Transit operations
4. Transit agencies perspective
5. Transit Users perceptive
6. Improvement strategies
7. Preferential treatments
8. Reserved bus lanes
9. Transit signal priority (TSP)
10. Limited-stop service
11. Articulated buses
12. All-door boarding
13. Service coordination

Introduction

Over the past decades, public transport has been introduced as a solution to solve many environmental and social goals in our cities. Bus transit service (or fixed-route bus transit systems) is the dominant form of public transport in most cities around the world and is the backbone of any public transport system. It comprises more than half of ridership compared to all other modes (e.g. commuter rail, light rail, paratransit, vanpool, etc.) in North America, where other modes are present.

Whilst, bus public transport system is a central element in the mobility in our cities, it is one of the most challenging systems to operate in an efficient and reliable manner due to the variety of internal and external factors that impacts its performance. For example, external factors such as weather conditions, traffic congestions, and demand fluctuations, while internal factors includes operators (or drivers) absences, scheduling and transferring problems, and equipment failures. These factors present a persistent challenge for public transport agencies, hindering their ability to achieve the required level-of-service needed to enhance users' experience. Therefore, public transport agencies are in continuous search for new ways to enhance service quality, to retain existing riders and attract new ones.

Public transport users consider a system to be reliable only when they have easy access to the service (at both origin and destination) and with low and consistent waiting and travel times. To achieve these goals, over the past few decades, many strategies have been widely introduced to improve the bus service quality and users' experience.

Bus Transit Operations Concepts and Terminologies

Good transport planning and efficient transit operations are required to balance the trade-offs among the goals, constraints, and values of transit agencies and passengers. ***Transit service operations*** refers to a wide range of activities done by a transit agency, which covers system management, scheduling, and functioning. ***Reliability*** is a key concept in the planning and operations of the public transport service. It refers to invariability of transit service attributes at certain locations. In the transportation setting, ***service planning*** involves the evaluation, assessment, and design and siting of transportation facilities. Other important operational concepts that will be used in this chapter includes *service headway and frequency*, *service capacity*, *bus stopping, running and travel times*, and *cycle time.*

The concepts of ***headway*** and ***frequency*** mean the same thing; however, they are often confused. ***Headway (h)*** usually refers to the time interval (in minutes) between two successive transit vehicles passing a fixed point (a stop) on a transit line in the same direction, while offering service for users. Headway is calculated based on departure times of successive transit vehicles. ***Frequency (f)*** refers to the number of transit vehicles that pass a point on a line (vehicles per hour). That said, it is the reverse of headway—a route with 20-minute headway has a frequency of 3 vehicles per hour. The mathematical relationship between both can be expressed as follows:

$$Frequency\ (f)_{veh/hr} = 60/\ Headway\ (h)_{minutes.} \quad \text{………………………….} \qquad 1$$

There is always an important trade-off between users and transit agencies related to service frequency. Users are interested in shorter headway service (more frequent service) to minimize their waiting time. In contrast, transit agencies are interested in reducing their operational costs by operating fewer vehicles with large capacity (e.g., articulated buses, discussed later) rather than a large number of vehicle with smaller capacity.

Service line capacity (C) refers to the maximum number of users that can be transported past a fixed point in one direction during one hour (or in a given time period). Therefore, the capacity of bus transit line is a function of its frequency and the used vehicle crush capacity ***(C_v).*** **Crash capacity** (or crash load) refers to the maximum number of passengers per bus targeted by the transit agency. Capacity is an important concept used by transit agencies to compare different vehicle types.

$$Capacity\ (C)_{passengers/hr} = Vehicle\ capacity\ (C_v)_{Max.\ passengers\ per\ bus} * Frequency\ (f)_{veh/h} \ldots 2$$

Running time (r_t) refers to the time that a bus takes to start travel from one station until it arrives at the next station in one direction along a route. It equals to the bus arrival time at the next stop minus bus departure time from the previous stop. ***Stop time (s_t)*** refers to the passage of time a bus spends at stops serving passenger movements. It equals to vehicle departure time minus vehicle arrival time at the same stop. The largest component of stop time is *dwell time* (or *passenger service time*). Dwell time is influenced by many factors including passenger demand (more passengers cause longer dwells), fare payment type (time required for fare validation), vehicle configuration (platform level, number of doors, number of door channels), passenger load (number of people on the bus, more standing passengers lead to longer dwells), door usage policy (alighting passengers exiting through the front door delay the start of the boarding process), and other issues related to lift usage (lifts are used to help seniors and people on wheel chairs).

Travel time **(T_r)** is the time between departure from one terminal and arrival at the other terminal. It equals to the sum of running times and dwell times between departure from one terminal and arrival at the other terminal. ***Terminal time (t_t)*** is the time spent by a bus at a line terminal (Figure 1). Terminal time (also called *Layover time*) is an important part of the bus operations practice. It used to provide a time to turnaround the vehicle, change driver, driver break for rest and/or meal, as a cushion to absorb and recover from delays. Terminal time is also used for while building bus schedules for schedule adjustment. ***Cycle time, C_t*** is the round trip time for a vehicle from the moment it leaves one terminal until the moment it leaves the same terminal after completing one cycle. ***Deadhead time*** refers to the travel time during which the bus is not in revenue service (e.g. travel from depot to start of line or travel between lines).

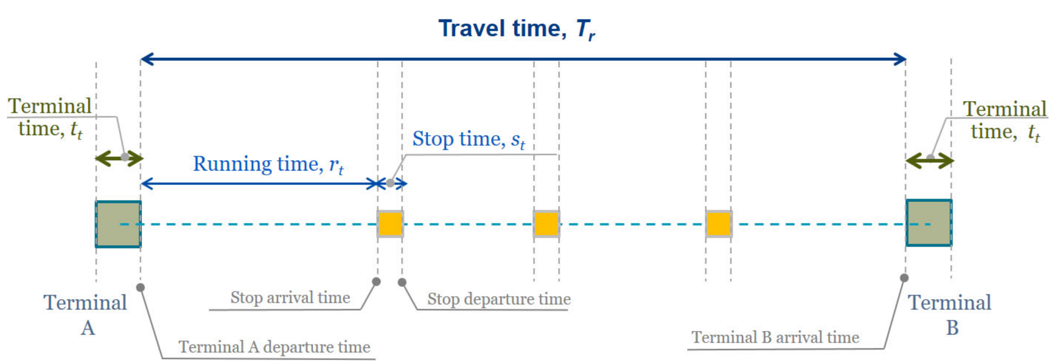

Figure 1: Bus running time, stop time and travel time

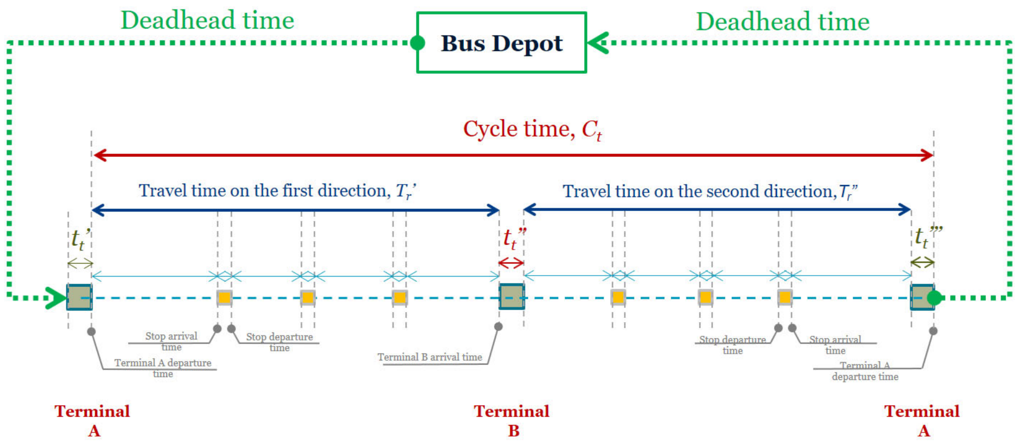

Figure 2: Bus cycle time and deadhead time

Bus Transit Users' Perception of Service Quality

A typical trip (door-to-door trip) for a passenger includes walking to transit stop (access time), waiting time at transit stop, on-board travel time in a vehicle, transferring time (to transfer between lines), on-board travel time in the vehicle, and, finally, walking to their final destinations (egress time). Passengers perceive the passage of time differently for each portion of their trip. Also the above components can include driving to a park and ride rather than walking and not all trips include transfers.

Waiting time is usually perceived differently compared to the actual time (Psarros et al., 2011). During this time portion, users are exposed to irregular weather conditions as well as the adverse surrounding traffic, noise, and pollution. They also can be stressed by not knowing if the bus is arriving as indicated on schedules or not (Hess et al., 2004). Transferring between different routes has also an exponential effect on users' perceptions, leading to a considerable overestimation of their actual spent times (Iseki and Taylor, 2009). In contrast, typically, users perceived travel times an accurate manner compared to the actual travel time spent in the vehicle.

Poor (or unreliable) service operations have undesirable consequences on both transit users and transit agencies (Evans, 2004). Transit agencies will have to provide an excessive buffer time (or layover time) between trips to absorb service delays and variation in travel times to make sure that the following trip starts on time. This means increasing the service cycle time, which will be translated into less frequent service, decreasing the quantity of the offered service to the public. Furthermore, travel time variability (or uncertainty) represents a problem for users, which they must account for during their trip planning process by employing ***buffer time***. ***Buffer time*** is the additional travel time that users add to their trips to make sure they arrive to their destinations on time, demonstrating a direct impact of unreliable service on users' time.

In addition, variations in travel time between stops can further lead to **bus bunching**, particularly for frequent service of 15 minutes or less. **Bus bunching** (or **bus platooning**) occurs when two subsequent vehicles (or more) are not able to maintain the even spaced schedule (in terms of time), and ending up travelling in close proximity to each other (as a platoon) and serving the same stops at the same time. Leading vehicles, in this case, get more delayed by picking up passengers, who are waiting for the next bus, exacerbate the delays of the leading vehicle further and further. This is converted to a gap in the service that increases users waiting time and vehicle overcrowding due to the uneven distributions of the vehicles.

For the previous reasons, passengers usually rate reliability as the second most important transit attribute after arriving safely at destinations. Transit users behavioral surveys show that passengers consider service reliability twice as important as bus frequency (number of trips per hour). Furthermore, service frequency and shorter waiting time are more important than greater accessibility, because passengers prefer to walk more than to wait longer at stops.

Bus Transit Service Improvement Strategies

In the face of the previously discussed challenges and issues, transit agencies use several public transport preferential treatments and improvement strategies. **Improvement strategies** refer to any tactic used to improve the service operations and the perceived quality of the service. While, **preferential treatments** refer to a sub-category of measures that gives public transport vehicles advantage over other mode vehicles (i.e., private cars) at intersections or along the streets. Transit agencies employ a wide range of operational and physical improvement strategies that differ according to the required (or desired) level of improvement, capital and operational costs, and political acceptance.

The most commonly used strategies include transit signal priority (TSP), new buses (articulated buses and low-floor buses), reserved bus lanes, limited-stop services (express services), and service coordination and intelligent transportation system (ITS)(Diab et al., 2015). These strategies are typically combined to improve the conventional bus system's capacity, productivity, and reliability in addition to users' experience, and called **BRT/BRT-like** systems. BRT systems also come with special promotion campaigns and advertisings to separate them from local bus services. They are considered as one of the most economically effective tools to increase transit ridership that influences users' behavior.

Reserved Bus Lanes

Overview: Reserved bus lane (or dedicated bus lane) is one of the most effective strategies used by transit agencies along urban corridors. It refers to dedicating a traffic lane for bus service operations, while prohibiting the general traffic from using this lane. There are different types of reserved bus lanes according to the infrastructure and traffic flow. Reserved bus lanes can be semi-exclusive, without any physical separation, allowing the general traffic to use the lanes at certain locations and segments (e.g. for turning movement at intersections).

Reserved bus lane can be operated only during peak periods or all day. They can be also fully exclusive, reserved of transit use at all the times, with a physical separation. Typically, these lanes are used for BRT systems, with some interference only at intersection from the perpendicular traffic. Therefore, they are combined with TSP systems at intersections (discussed later). Reserved lanes can be located adjacent to the curbside, offset to the lane adjacent to the curbside, or adjacent to the median.

Excepted impacts: Reserved bus lanes have considerable benefits for public transport service operations. They also have been associated with positive perceptions of quality of service by the users. More specifically, compared to bus operations in a mixed-traffic lanes, reserved bus lanes improves transit service travel times, while decreasing service variations in the most of the cases. This means a faster service observed by users as well as more predictable waiting and travel times. Transit users tend to overestimate their travel time savings associated with the implementation of such a measure.

For transit agencies, reserved bus lanes help in providing more accurate and efficient schedules due to the increases in service reliability. Nevertheless, these benefits can differ according to the level of delays experienced in mixed-traffic situation before the implementation of such a measure and according to the type of reserved lanes (semi-exclusive vs. exclusive). In some cases, semi-exclusive lanes slightly improve bus service travel times, with minimal or even negative impacts on bus service variations, due to turning movements at intersections and no-turn on red policy (i.e., right turns are not allowed on red) that used in some cities such as Montréal (Surprenant-Legault and El-Geneidy, 2011).

Ease of implementation: As reserved bus lanes have a physical impact on the built environment and transportation networks, the planning process for introducing reserved bus lanes needs to involve many stakeholder while assessing the potential impacts on other road users, adjacent properties, and the needs for law enforcement. Therefore, the first step in the planning process is to identify different stakeholders, which may include different department within the city (e.g., city's planning, public work and law enforcement departments) and government agencies, in addition to local community members, private industries, businesses owners and elected officials.

Due to the removal of traffic lane from car users, sometimes obtaining the appropriate political acceptance for the implementation of such measure can be challenging. Additionally, financial constraints in terms of providing the required capital cost for constructing such lanes can represent a barrier for their implementation.

Transit Signal Priority (TSP)

Overview: TSP is an operational strategy that gives priority to public transport vehicles at traffic-signalized intersections, facilitating their movement in a reliable manner. Transit vehicles typically experience substantial delays at traffic signals in busy urban areas. Therefore, one of the most popular strategies that commonly used is TSP. TSP systems can be "passive" or "active." Passive systems rely on fixing the signal timing plans based on the expected transit vehicles running and dwell times. They do not require any special technology for transit vehicle detection. However, passive TSPs provide minor benefits to no benefits, particularly if transit operations is unreliable and unpredictable. In contrast, active TSPs work on modifying signal timing in real-time to provide priority treatment to a specific vehicle at a specific location (i.e., intersection) following its detection and succeeding priority request. Therefore, active TSP systems include hardware and software technologies: detection system, priority request generator and server, and communication system.

Typically, modifying the signal timing is done by activating "green extension" or "early green." Green extension strategy works upon the detection of a transit vehicle upstream of an intersection (within a specific window of time) while a green phase is active—this strategy extends the green phase. The extension maximum value of time (vary between 16 to 30 seconds according to the type of intersection, using Toronto as a case study). This value of time can determine the effectiveness of the strategy and minimize the number of failed extensions. Early green (or red truncation) works upon detection of a transit vehicle upstream of an intersection (within a specific window of time) while a red phase is active—this strategy shortens the red phase and returns of the next green phase. Generally, both approaches green extension and early green can be available together along a corridor; however, they cannot be applied at the same time.

Excepted impacts: TSP systems can significantly improve the transit vehicles travel times by reducing their delay by an entire red interval (or around 90 seconds, using downtown Toronto as an example). However, in most of the cases, only fewer buses that arrive at the TSP equipped intersection within a short window of time benefit from this large saving. This means that these systems while they typically have considerable impacts on service operating times; they may have a mixed impact on transit service variations.

Users experience travel and waiting times savings due to the implementation of TSPs, However, they tend not to overestimate these time saving. In other words, TSP systems have a limited impact on users' perceptions of changes in the quality of service in contrast to reserved bus lanes and other strategies that have a physical component that can be observed by users. Furthermore, potential negative impacts of TSPs consist primarily of delays to non-priority traffic and road users and possible delays at neighboring intersections.

Ease of implementation: TSP is one of the most common and preferred strategies that have been used by transit agencies around the world. Since TSP is an operational strategy that has no physical impact on the built environment and road space, it is normally implement with a higher degree of ease compared to other strategies (i.e., reserved bus lanes).

Regarding the cost of TSP implementation, in addition to a relatively high capital cost of system hardware and software components, a considerable operating and maintenance costs are required to keep the system functioning in a reliable manner. However, typically, monetary benefits of TSP systems implementation, in regard with improved travel times and reduced delays, outweigh costs.

Limited-stop Service (Express)

Overview: Limited-stop service is an effective strategy used by transit agencies along urban corridors. In contrast to local bus services, which serves all stops along the route, limited-stop service refers to offering that transport service only at major stops (in terms of ridership volumes) and transfer locations along a bus corridor. Limited-stop bus services could be offered in combination with local bus services. A good example is Montréal Route 467, which serve only 40% of the stops of its local route, Route 67 (Diab and El-Geneidy, 2013).

BRT routes are typically limited-stop routes. It should be noted that the concept of limited-stop service is often mixed with the concept of "express service". Express services is a limited stop service in essence; however, it is used for long distance trips and for providing a direct connection between suburban areas and central locations (e.g., central business districts (CBDs)).

Excepted impacts: Limited-stop service provides a faster service compared to serving only fewer stops and usually are associated with superior performance in terms of providing more predictable and reliable service. They have also an overall positive impact on users experience and perceptions due to the addition of more buses that are fast and reliable.

For transit agencies, limited-stop services offer lower operating costs as vehicles can complete a cycle trip faster than the local services, leading to fewer buses and the possibility of adding more service (by increasing the frequency of service). The only trade-off, from the passengers' perspective, is related to the need to walk further to access destinations than otherwise needed with local services (Murray and Wu, 2003).

Ease of implementation: Limited-stop service is considerably simple and cheap to implement because they usually use the existing infrastructure (e.g., bus stops and routes) compared to the previous two strategies. However, due to the previously discussed trade-offs, a delicate planning process that considers "local passengers" need to access local destinations at stops and "through passengers" prospect of a faster service should be done.
From transit agencies perspective, operating a local and an express service along the same streets can represent an operational and scheduling challenge. Transit agencies should make sure that local services are not delaying the express service or the other way.

Articulated Buses

Overview: Different types of vehicles can be used to deliver public transport services in urban areas. These vehicles include minibuses, regular buses (12-meter length) and articulated buses (18-meter length). Regular buses are the most commonly used bus type in North America. However, recently more transit agencies are incorporating articulated buses into the service. Articulated buses are mostly low-floor buses and normally used along the busy corridors with high ridership volumes. They provide between 30-60% more seats and standing capacity compared to regular buses.

Expected impacts: Articulated buses offer more capacity than regular buses, helping agencies in providing more capacity without changing the number of trips along corridors by replacing regular buses with articulated buses. Transit agencies also use articulated buses to reduce the number of buses (and operational costs) along corridors, while maintaining the same offered capacity. This reduction in frequency while may have a negative impact on user perceptions due to increases in waiting times, it helps agencies to maintain better service operations by reducing bus bunching.

Research has shown that articulated buses are slightly slower than regular buses, however, they are more predictable in terms of less service variations. Therefore, implementing these buses will improve transit agencies scheduling and reliability in comparison with regular buses. Along busy corridors, articulated buses have shown positive impacts on users waiting time and travel time perceptions due to the increased offered capacity. This increased capacity raises the probability of finding a seat for users and decreases their anxiety for the need to wait for the following buses at transit stops, which occurs along busy corridors during peak periods.

Ease of implementation: Articulated buses are an operational strategy, which can be planned and implemented by transit agencies, with a minimum need for involving different stakeholders. However, if the agency is planning to reduce the frequency to introduce those buses, this will require consulting local passengers about the required changes. Reducing service frequency while maintaining the same capacity, for transit agencies, will decrease transit agencies operating costs significantly (i.e., fewer buses equal fewer operators and less operational and maintenance costs). Nevertheless, for transit agencies, replacing regular buses with articulated buses while maintaining the existing frequency is associated with higher capital costs and potential higher operational costs that are associated with modifying maintenance facilities to accommodate the new vehicles and the need for more fuel (articulated buses are typically less fuel-efficient).

All-door boarding

Overview: Traditional fare collection method that requires fare inspection and validation upon boarding a vehicle add a considerable amount of time to public transport service operations. Using data from Vancouver and Montréal in Canada, several studies showed that using exact change can take up to 4-5 seconds per passenger. In addition, while it takes around 3-4 and 2-3 seconds for using smart cards and for the visual inspection of flash passes, it takes only 1-2 seconds for entering the vehicle without presenting any fare. This shows a considerable difference per passenger associated with the type of the presented fare vs no fare. Therefore, one of the most effective strategies to decrease dwell time at stops is to use all-door boarding

All-door boarding (or pre-paid fare, proof-of-payment) refers to moving fare collection off the vehicles and allowing passengers to use all the bus doors to board at stops. This strategy can be used only at a few locations along the system (major activity nodes and transfer location) or it can be used system wide.

Expected impacts: While there are many factors affecting bus dwell time such as the number of doors, number channels per door, alighting policy, non-level boarding, and bus crowding, all-door boarding strategies have proven to have a considerable benefits on bus operations and user perceptions. All-door boarding reduces service activity time per passenger, resulting in dwell time saving that can reach up to 40-50% compared to the base case of using exact cash. According to bus route location and structure, dwell times can encompass between 10-40 % of the total trip travel time.

This previous dwell time and travel time savings are typically combined with significant decreases in dwell time and travel time variations, making the service more predictable, for transit agencies. From the users' perspective, all-door boarding has a positive impact on their perception of the quality of service, making their transfer seamless between vehicles at location with common all-door boarding areas.

Ease of implementation: All-door boarding strategies have an important physical component, which is related to the need of providing an extra space at stops for fare inspection and validation. This space is not always easy to acquire and requires changes in streets design and sidewalk configuration. Thereby, a wide range of stakeholders should be involved in the planning and the implementation of such a strategy.

As a physical strategy, a considerable capital cost will be associated with the construction of the new stops and providing fare validation machines and areas. To cut capital costs, some transit agencies use "honor system" which allows transit users to get on and off the vehicles without presenting fares, while trusting that users have proof of payment. However, this system is still associated with a substantial lose in revenue due to fare fraud and the cost of hiring a large number of inspectors.

Service Coordination

Overview: Intra-modal and inter-modal transfers are routinely done by more than 40% of passengers in North America during their trips. Nevertheless, for low frequent services, transferring between lines can represent a serious problem for users due to excessive transferring time. Therefore, transit agencies tend to tackle this problem by coordinating schedules at transferring locations, which is combined by employing intelligent transportation systems (ITSs). Automatic vehicle location (AVL) and computer aided dispatching (CAD) systems are used to protect transfers by holding vehicles to ensure adequate transferring times for users.

Timed Transfer System (TTS), known as Pulse System, is also a common approach used when different routes are connected at a single terminal. In a typical TTS, vehicles from all routes arrive shortly before a specific departure time and then depart together, leaving a small window of time for transferring between routes.

Expected impacts: service coordination has a considerable impact on users' perceptions. Users usually weight transferring time 5-to-10 times higher than in-vehicle travel time and 2-to-5 times more than waiting time. In the transportation literature, this weighting is based on the difference between the actual time and perceived time during different activities, which represents the actual value of time for users. Therefore, improving and securing transfer times will have a strong positive effect on users' perceptions of the quality of service and their future travel behavior. The main disadvantage of service coordination is related to the need for holding and delaying some vehicles (to protect transfers) which may result in extra operational costs.

Ease of implementation: Service coordination is an operational strategy, which can be implemented by transit agencies, with almost no need for involving different stakeholders. The main capital costs are related to obtaining and operating AVL/CAD systems and purchasing software that helps transit agencies in protecting their transfer. Nevertheless, most of the world modern transit agencies already have AVL/CAD systems to monitor and adjust bus operations. Therefore, the implementation of such operational strategy can be relatively inexpensive; however, it includes extensive scheduling and planning exercises to make sure that buses can arrive locations around the same time.

Concluding Remarks

Planning and the design for improving transit service is a not easy task that requires trade-offs between different objectives and values. Bus transit service improvement strategies are typically introduced to improve both the transit operations and users' perceptions. This chapter discussed the benefits and potential impacts of several operational and physical improvement strategies that are commonly used by transit agencies across the world. These strategies included Transit signal priority (TSP), limited-stop service, articulated buses, all-door boarding and service coordination.

Dwell and travel times and service reliability are the key determines of service quality, speed and capacity. In other words, strategies that decrease travel time and improve transit service reliability (i.e., all-door boarding, reserved bus lanes, TSP) reduce operating time, recovery time and, thereby, service cycle time. The can be translated to reduced fleet size and headways (offering higher capacity). This will also mean shorter travel time and budgeted travel times for existing and new passengers, with improvement in waiting time and comfort, which will be observed with the increase in service frequency and reliability.

Some improvement strategies can improve only one aspect of operations that is related to travel time (TSP), service variation (articulated buses) or transferring time (service coordination), enhancing user perceptions of the service. As a role, operational strategies are usually easier to implement and acquire the required political acceptance compared to physical strategies. However, both type of strategies are required to be reviewed, while assessing the local context. Trade-off between capital and operating costs is essential to be considered too, while estimating each strategy cost and benefits. Overall, these strategies will help cities in achieving their broader sustainability and equity goals

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