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Framework for Bus Rapid Transit Development and Deployment Planning

Authors

Miller, Mark A.
Yin, Yafeng
Balvanyos, Tunde
et al.

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Mark A. Miller, Yafeng Yin,
Tunde Balvanyos, Avishai Ceder

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Mark A. Miller
Yafeng Yin
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ABSTRACT

This report presents the results of its investigation into deployment planning for bus rapid transit systems. In this study, we conducted a macro-scale examination of bus rapid transit systems from technical, operational, institutional, and planning perspectives. We then developed the theoretical foundation for a deployment planning framework for bus rapid transit systems that specifically takes into account the unique features of bus rapid transit that differ from other transit alternatives.

The planning process of a BRT system can generally be divided into three inter-related stages initially consisting of a feasibility study or major investment study in which bus rapid transit is investigated compared with other transit alternatives to find out the most cost-effective investment over a corridor; second, deployment planning that determines what BRT elements will be included in the BRT system and their deployment sequence; and finally, operations planning including designing routes and stations, setting timetables, scheduling vehicles, and assigning crew. While the first and third stages are essentially planning-specific for any transit service, the second stage deals with the special features associated with a bus rapid transit system due to its flexibility in incremental deployment of elements. The report focused on this second stage in the planning process for bus rapid transit systems in the development of the deployment planning framework, in which a systems optimization approach was used.

We then demonstrated how the framework may be used in the context of a site-specific case study by focusing on the Metro Rapid Wilshire corridor in Los Angeles.

Key Words: bus rapid transit systems, deployment planning

EXECUTIVE SUMMARY

This report constitutes the final deliverable for PATH Project RTA 18365 under contract 64A0027 — "A Framework for Bus Rapid Transit Development and Deployment". This project was one of five elements of a suite of research efforts conducted by PATH approximately three years ago to advance the development and deployment of bus rapid transit systems in the United States with special focus on California. These projects included the development and implementation of

- An Adaptive Bus Priority System
- A Bus Precision Docking System
- Advanced Bus Stops
- Evaluation Tools
- Framework For Deployment Planning

This report is for the fifth project in the list above, which has investigated the deployment of bus rapid transit systems relative to an array of factors ranging from macro-scale and generic to microscopic and site-specific cases. From this investigation, we have designed a methodological framework or "route map" that transit agencies can use as a tool to assist them in planning the deployment for bus rapid transit systems in their jurisdictions through the decision-making process of selecting which bus rapid transit attributes work best in their environment.

Such factors include technical aspects, design attributes, operational policies, institutional issues, and planning perspectives. From the more specific case study perspective, we have performed a site-specific case study using Los Angeles Metropolitan Transportation Authority's Metro Rapid Bus along the Wilshire Boulevard corridor. In this case study, we demonstrate the use of the bus rapid transit deployment framework.

There are several technological systems that may be involved in the implementation of bus rapid transit systems. They include collision warning systems, transit signal priority systems, precision docking and automatic steering control systems, and automatic speed and spacing control systems.

Design attributes of bus rapid transit systems deal with the physical attributes of the system, namely, the vehicle and the infrastructure, that is, the bus and both the running way and bus stops and stations, respectively. Running ways for BRT may be on- or off-street in nature. Generally on-street BRT running ways provide downtown and residential distribution, and serve corridors where market factors, costs, or right-of-way availability preclude providing busways (or reserved freeway lanes).

In terms of operational and service planning, bus rapid transit system service should be clearly marked to customers, direct, frequent and rapid. Fare collection should permit rapid boarding of buses. Service patterns and frequencies should reflect the types of running way, city structure, potential markets, and available resources. Buses may run totally or partially on dedicated rights-of-way when such running ways are available. Service should be simple, easy to understand, direct, and operationally efficient. The busway route structure should include a combination of basic all-stop service that is complemented by express, feeder and connector service. The all-stop service can run all-day, seven days a week, and the express service should operate weekdays throughout the day, or just during morning and afternoon peak periods. The basic BRT all-stops service should operate at small headways during morning and afternoon peak periods and slightly longer headways during off-peak times.

BRT running ways may be used by all transit operators in a region where vehicles meet established safety requirements. They can share running ways with high-occupancy vehicles in reserved freeway lanes, where the joint use does not reduce travel times, service reliability, and BRT identity. Running times and average operating speeds should be maximized by providing wide station spacing and by reducing dwell times at stops. Fares should be integrated with the rest of the bus system, but they may not necessarily be the same. Fare collection systems should facilitate multiple door boarding, at least at major stops during busy periods. Off-board collection (preferred) or on-board multi-point payment should be encouraged. Marketing should emphasize the unique features of BRT such as speed, reliability, service frequency and span, and comfort. It should create a unified system image and identity that clearly "brands" BRT. Distinctive logos, color combinations and graphics should be applied to vehicles, at stations and on printed materials.

The implementation of bus rapid transit systems traverses numerous stages of system design, development, testing, evaluation, and deployment culminating in a completed and fully operational system. Moreover, all these activities take place in a context with organizational stakeholders participating at various levels. As each stage of bus rapid transit implementation proceeds through its more technological, design, and operational aspects, questions may arise concerning the impacts of actions to be taken or decisions to be made. These impacts — the institutional issues — that usually arise from the more technical and operational questions and issues, need to be considered and addressed as well to successfully implement a bus rapid transit system.

All field-deployed bus rapid transit systems will not necessarily experience the same set of institutional issues because each BRT deployment will be affected by local and regional factors. Moreover, even when the same issues arise in different settings, there will likely be local and regional site-specific differences. The importance of identifying and working out such issues should not be underestimated as they contribute to the overall success of implementing bus rapid transit systems in terms of how transit operations and quality of service for passengers are enhanced.

When planning for the deployment of bus rapid transit systems, there are at least two distinct types of stakeholders playing primary roles. One is the local and/or regional transit agency whose interest lies foremost in reducing its own costs while also enhancing the quality of transportation services that it delivers to its passengers. The other primary stakeholder is local and/or regional highway and traffic department along the route the transit agency's bus runs and this latter stakeholder could include multiple operators depending on whether the bus runs through multiple political jurisdictions. Other stakeholders include the regional metropolitan planning organization, the state department of transportation, federal transportation agencies, various local public officials and/or decision makers, and the general public. The significance of these stakeholders' roles and influence depends on local and regional conditions encompassing the bus route/traffic corridor where the bus rapid transit system is to be implemented.

Bus rapid transit systems differ from more traditional transit services by its features that combine elements associated with other forms of mass transit such as light and heavy rail transit with highly flexible service and advanced technologies to improve customer convenience and system reliability. Bus rapid transit systems can thus be seen as a bus-based "rapid" transit system that combines vehicles stations, running way, and intelligent transportation systems technologies into a fully integrated system with a unique identity. The planning process of a BRT system can generally be divided into three inter-related stages:

- Feasibility study or major investment study in which bus rapid transit is investigated compared with other transit alternatives to find out the most cost-effective investment over a corridor
- Deployment planning that determines what BRT elements will be included in the BRT system and their deployment sequence
- Operations planning including designing routes and stations, setting timetables, scheduling vehicles, and assigning crew.

While the first and third stages are essentially planning-specific for any transit service, the second stage deals with the special features associated with a bus rapid transit system due to its flexibility in incremental deployment of elements.

There are numerous BRT elements available for transit agencies from which to choose to equip their BRT systems and currently deployed BRT systems in the U.S. and internationally exhibit various configurations, designed by transit planners based on their professional considerations and judgments. For example, Los Angeles County Metropolitan Transit Authority Wilshire-Whittier BRT corridor includes a simple route layout, frequent service, less frequent stops, level boarding and alighting, color-coded buses and stations, bus signal priority, next bus displays and is headway based.

Different system combinations of BRT elements exhibit different service levels and reflect different budgetary constraints. Upon deciding to invest in BRT, a transit agency must select that combination of elements that maximize the cost-effectiveness of deployment. Cost-efficiency and effectiveness are affected by local and site-specific factors, such as land use, transit demand, passenger behavior, transit feeder service, traffic volume and road geometry, which contribute to a deployment's degree of success. Subject to budgetary, institutional and other constraints associated with the corridor, transit agencies have to cost-effectively configure their BRT systems, which must be tailored to site-specific characteristics. To achieve this goal, a systems optimization approach should be adopted with adequate and realistic objectives and constraints. A planning framework, reflecting this approach, is proposed to assist transit agencies with this task. The proposed deployment-planning framework, described in a series of steps, is depicted in Figure ES-1. Using this approach to develop the theoretical foundation for a deployment-planning framework, gaps have been filled in the overall planning process for bus rapid transit systems.

This framework and its formulation, once operationalized, can provide transit agencies a practical tool for determining the optimal deployment strategy, i.e., what BRT elements should be included in the system, given budgetary, institutional and other types of constraints associated with the proposed BRT corridor, along with steps to take to meet future needs based on available funding.

Steps in Bus Rapid Transit System Deployment Planning Framework:

1) Determine possible combinations of BRT elements, while taking into account the existing transit system, feasibility of implementation, institutional issues and other considerations;

2) Assess the capital cost associated with each combination;

3) Derive feasible combinations consistent with budget constraints;

4) Evaluate each feasible combination;

5) Conduct sensitivity analyses with respect to available budget, travel demand, cost of components, etc., and

6) Recommend optimal alternatives of combinations for implementation.

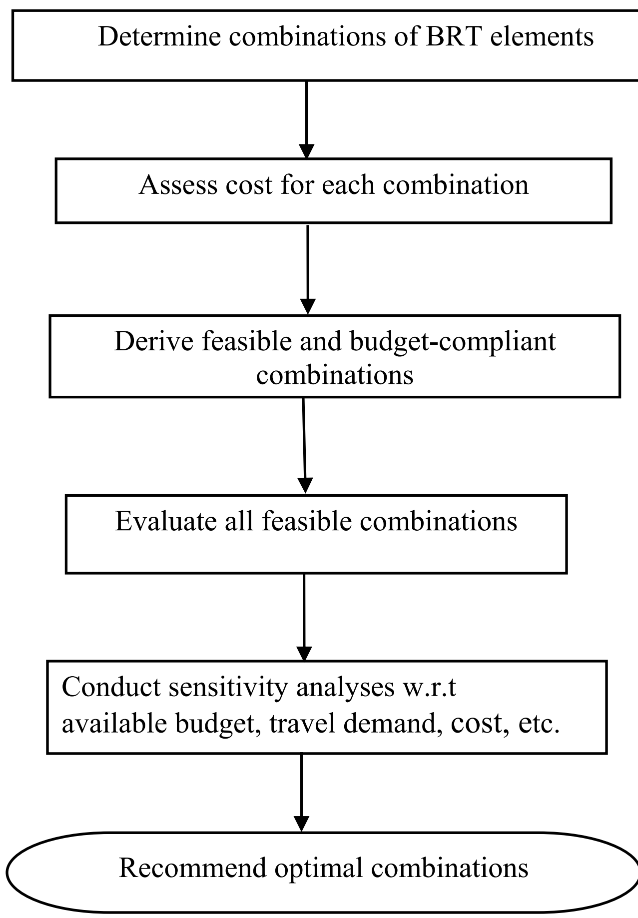

FIGURE ES-1 A Framework for BRT Deployment Planning

We demonstrated the use of the proposed deployment planning framework by exercising it on a site-specific case: LACMTA's Wilshire BRT corridor. On this corridor, LACMTA has deployed simple and single route layout without any route variations, frequent and headway-based service, less frequent stops, level boarding and alighting, color-coded buses and stations, bus signal priority and Next Bus displays. LACMTA also has plans to expand their BRT system for part of this corridor along a 13-mile segment of the entire 27-mile long corridor between the Los Angeles CBD and the Pacific Ocean. MTA is considering for the system expansion:

a. Bus signal priority (extended over existing deployment)
b. Exclusive lanes
c. Articulated buses
d. Multiple door boarding and alighting
e. Stop enhancements
f. Electronic fare payment
g. Precision docking

Given these seven BRT elements the deployment-planning framework can be used to determine cost-efficient combinations of elements for the system's expansion.

We initially developed a set of combinations of BRT elements. There are certainly other possible combinations of elements. However, most of them are likely to be dominated in terms of efficiency by the above combinations. Next, we performed a cost assessment for each combination of elements starting with unit costs. The next step involved determination of feasible combinations taking into account constraints. Next, we performed an evaluation of feasible combinations of BRT elements that was done at a high-level macroscopic level that served the purpose of demonstrating the use of the proposed framework. As part of this evaluation, we considered the effectiveness of each bus rapid transit system element listed above, including bus signal priority, exclusive lanes, articulated buses, multiple door boarding and alighting, electronic Fare Payment, and precision docking. The evaluation was performed, consistent with the systems optimization approach, by minimizing the values of two objective functions constructed in terms of specific measures of performance across different combinations of BRT elements. The final step was to recommend an optimal combination(s).

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ABBREVIATIONS AND ACRONYMS

ACS	**Advanced Communication Systems**
ATSAC	**Automated Traffic Surveillance and Control**
AVL	**Automated Vehicle Location**
BOCC	**Bus Operations Control Center**
BRT	**Bus Rapid Transit**
Caltrans	**California Department of Transportation**
CBD	**Central Business District**
CNG	**Compressed Natural Gas**
DGPS	**Differential Global Positioning System**
EIS	**Environmental Impact Statement**
FTA	**Federal Transit Administration**
GPS	**Global Positioning System**
ITE	**Institute of Traffic Engineers**
ITS	**Intelligent Transportation Systems**
LACMTA	**Los Angeles County Metropolitan Transportation Authority**
LADOT	**Los Angeles Department of Transportation**
LPA	**Locally Preferred Alternative**
LRT	**Light Rail Transit**
LOS	**Level of Service**
MIS	**Major Investment Study**
MTA	**Metropolitan Transportation Authority**
NABI	**North American Bus Industries**
O-D	**Origin-Destination**
ROW	**Right-Of-Way**
TCRP	**Transit Cooperative Research Program**
TOD	**Transit Oriented Development**
TOS	**Transit Operations Supervisors**
TPM	**Transit Priority Manager**
TSP	**Transit Signal Priority**

VISSIM	**A microscopic traffic simulation tool**

1.0 PROJECT OVERVIEW

This report constitutes the final deliverable for PATH Project RTA 18365 — "Bus Rapid Transit Development and Deployment Framework". This project was one of five elements of a suite of research endeavors that PATH undertook approximately three years ago to advance the development and deployment of bus rapid transit systems in the United States with special focus on California. These projects included the development and implementation of

1. An adaptive bus priority system
2. A bus precision docking system
3. Advanced bus stops
4. Evaluation tools
5. Framework for deployment planning

This project, number five in the list above, has investigated the deployment of bus rapid transit systems relative to an array of factors ranging from macro-scale and generic to microscopic and site-specific cases. From this investigation, we have designed a methodological framework or "route map" that transit agencies can use as a tool to assist them in planning the deployment for bus rapid transit systems in their jurisdictions through the decision-making process of selecting which bus rapid transit attributes work best in their environment.

Such factors include technical aspects, operational policies, institutional issues, and planning perspectives. From the more specific case study perspective, we have performed an evaluation of bus rapid transit system impacts in the context of a case study using Los Angeles Metropolitan Transportation Authority's Metro Rapid Bus along the Wilshire Boulevard corridor.

1.1 Motivation

Bus Rapid Transit systems (BRT) are a relatively new form of transit systems that apply integrated land use and planning, advanced design concepts and intelligent transportation systems (ITS) and bus technologies to provide significantly faster operating speeds, greater service reliability, and increased convenience, which strive to match the quality and level of service of rail transit when implemented in appropriate settings. The transit industry nationwide has developed significant interest in BRT as currently there are in excess of 200 transit agencies in the United States that at least considering BRT alternatives and a few dozen properties are conducting planning exercises, utilizing planning methods such as Major Investment Studies (MIS), Alternatives Analyses, Preliminary and Final Engineering Studies, and Environmental Impact Studies (EIS) to evaluate the viability of BRT for their agency and the community within which that agency operates.

Recent deployment of BRT systems have demonstrated that such systems can deliver similar levels of service as rail transit and offers significant advantages over the transitional rail system. For example, BRT has the flexibility that can be integrated with current urban settings and can be deployed progressively. Recent studies have shown that a BRT system that can achieve comparable rail service level cost less than one-half of the rail system (1). BRT has become a cost effective alternative to rail systems, has potential to attract non-traditional riders, and therefore contribute to the reduction of traffic congestion.

As BRT may involve new operations, design approaches and technologies, integrated planning and deployment strategies are needed for this new mode of transportation system. However, based on input from members of the U.S. BRT consortium members, we have found that most of the current BRT deployment enterprises in the United States often lack an integrated approach to planning and implementation. As a result, the BRT systems that are currently in planning or are being deployed may not be most cost effective for realizing their full potential in terms of benefits to the bus transit passengers and the transit property.

BRT is different from traditional transit service by incorporating many rail transit features. It also differs from traditional rail with its flexibility and the possibility for incremental deployment. In deployment planning for BRT, one of the major elements is to determine how the deployment of a BRT system will be phased in. To our best knowledge there is no rigorous way to do it. For instance, the Los Angeles County Metropolitan Transportation Authority (LACMTA) has deployed BRT services on the Wilshire corridor in two stages: Phase I and II based primarily on prior experience and expert judgment. Under a contract with the Federal Transit Administration in concert with the U.S. BRT Consortium, a consultant created a brochure depicting four phases for BRT system deployment that seems to follow a rather artificial "one-size-fits-all" approach to BRT deployment (2). Instead, the phases or stages of BRT deployment should be decided after a careful systematic analysis. When and which BRT element should be implemented is a tradeoff between the costs associated with it, its ease of implementation (physical constraints and institutional issues) and resultant benefits.

We have begun this process in this project by developing a planning framework to determine a set of optimal combinations of BRT attributes given the budgetary, institutional and other types of constraints.

1.2 Objectives

The primary objective of this work was to develop a methodological framework for the deployment of bus rapid transit systems that can be used as a decision-support tool by transit agencies, transportation planning organizations, as well as other transit practitioners, who have an interest in planning for and carrying out the deployment of bus rapid transit systems. Another objective was to illustrate the use of this tool in the context of a site-specific bus rapid transit case study.

1.3 Methodological Approach

To fulfill the project's objectives, we initially conducted a review of the literature in the area of bus rapid transit systems to identify and subsequently classify their major aspects, and determine their linkages and tradeoffs. Next, we developed from a theoretical point of view the basis of the BRT deployment planning framework, followed by collecting the necessary data to exercise the framework in the context of a site-specific case study.

This is the first of five sections. Section 2 provides general background material on bus rapid transit systems from the more macroscopic perspective. Development of the deployment planning framework is presented in Section 3, followed by the case study application of the framework tool in the Los Angeles area in Section 4. Conclusions and a brief description of future work are provided in Section 5.

2.0 BUS RAPID TRANSIT SYSTEMS: THE FUNDAMENTALS AND MACROSCALE ISSUES

For purposes of this project, we use the following definition of bus rapid transit taken from the recently completed Transit Cooperative Research Project A-23 (3 and 4):

"A flexible, rubber-tired form of rapid transit that combines stations, vehicles, services, running ways, and intelligent transportation systems into a fully integrated system with a strong image and identity. BRT applications are designed to be appropriate to the market they serve and their physical surroundings, and they can be incrementally implemented in a variety of environments (from rights-of-way totally dedicated to transit to streets and highways where transit is mixed with traffic."

Running ways for BRT include mixed traffic lanes, curbside bus lanes, and median busways on city streets; reserved lanes on freeways; and bus-only roadways, tunnels, and bridges. Most stations are located curbside or on the outside of bus-only roadways and arterial median busways. Similarly, BRT stations have low platforms since many are already or will eventually be served by low-floor buses. Conventional standard and articulated diesel buses are in wide use for BRT operations, though, there is a trend toward innovations in vehicle design, including environmentally clean or green vehicles, such as diesel-electric vehicles and compressed natural gas-fueled vehicles, dual mode operations in particular environments such as tunnels, low-floor buses, additional as well as wider doors, and use of distinctive and dedicated bus rapid transit vehicles. Service innovations include fare collection procedures, station design and location, and more attractive vehicle designs. Intelligent transportation systems range from existing and more customary automatic vehicle locations systems, transit signal priority systems, and passenger information systems to more advanced systems including collision warning systems (frontal, side, and rear), and automation technologies including lane assist systems — precision docking and automatic steering systems — and automatic speed and spacing control systems.

The *earliest* deployments of automation technologies in road vehicles will likely be on heavy vehicles — *buses* (and trucks) — operating on their own special rights-of-way because:

- It is easier to develop and acquire rights-of-way for public purposes like transit service
- In some cases, buses already operate on separate facilities, which could, if demand warranted, be switched over to automation
- Costs of the technologies are a smaller percentage of total bus costs and buses are used much more intensively so these costs are amortized faster
- Benefits in travel-time reduction, trip reliability and safety can be translated more directly into cost savings and revenue increases than for private passenger cars
- Customized, small-lot production of vehicles makes it possible to introduce automation technologies into the bus production process faster than for automotive mass production
- Packaging of new technological elements is easier on buses than on passenger cars
- Buses already have more onboard electronic infrastructure (such as data buses and electronic engine controls) to use as a foundation for more advanced capabilities than passenger cars
- Maturing technologies can be used more safely by professionally trained bus drivers on professionally maintained buses than by the general public on passenger cars that may not be well maintained.

For the remainder of this section, we describe the four primary components and tradeoffs among them that are essential in the deployment of bus rapid transit systems:

- <u>Technological aspects</u>: What technologies will the system be comprised of?
- <u>Design attributes</u>: What will the system look like
  - On its vehicles (interior, exterior)
  - At its stops and stations, and
  - On the roadway?
- <u>Operational and service plans</u>: How will the system operate and what services will it deliver to passengers?

- Institutional and policy issues: What, if any, are the conflicts among stakeholders arising from decision-making and actions taken relative to planning for and implementing a bus rapid transit system?

2.1 Technological Aspects

There are several technological systems that may be involved in the implementation of bus rapid transit systems. They include collision warning systems, transit signal priority systems, precision docking and automatic steering control systems, and automatic speed and spacing control systems.

2.1.1 Advanced Public Transportation Systems

These systems may be split among those that are operations oriented such as fleet management, e.g., automatic vehicle location (AVL) systems and automatic passenger counters, and electronic fare payment systems and customer/passenger oriented, namely passenger information systems. AVL systems automatically determine and track the real-time geospatial location of a bus. Several different technologies may be used to perform AVL, such as GPS, ground-based radio, signpost and odometer, dead-reckoning, and combinations of these. Automatic passenger counters are devices that count passengers automatically as they board and alight transit vehicles, typically buses. Most common technologies include treadle mats or infrared beams. Electronic fare payment systems provide an electronic means of collecting and processing fares. Customers can use a magnetic stripe card, smart card, or credit card instead of tokens or cash to pay for transit trips. Smart cards have the ability to store monetary value and other information on an embedded integrated circuit or micro-chip.

2.1.2 Collision Warning Systems

Collision warning systems could augment the driver's normal driving and could provide alerts to hazards of which he may be unaware, and could also help out in conditions in which the driver is distracted or less than fully alert, e.g., due to fatigue. Such systems may take the form of forward, rear, and side hazard warnings and can be delivered to the driver by either auditory, haptic[1], or visual cues. The driver retains responsibility for corrective actions based on the warnings provided. Technologies that may be used in these systems include radar, ultrasound or laser sensors and threat assessment software and the driver interface. Benefit opportunities include a reduced risk of property damage, injuries, and fatalities; reduced liability and vehicle repair expenses; improved vehicle utilization, and improved rider/passenger perception of bus performance. The primary incremental cost generator is for the installation of warning systems on vehicles.

2.1.3 Transit Signal Priority Systems

Transit signal priority systems in its simplest form makes it possible for a bus approaching an intersection during the final seconds of the green signal cycle to request an extension of the green cycle so that the bus can pass through before the signal turns red, thereby saving the bus and its passengers the red cycle time. This tends to provide some ancillary time saving benefits to the other vehicles traveling in the same direction as the bus, while increasing the time delays to the crossing traffic. Technologies that may be utilized include vehicle detection, identification, and location systems to identify a bus and communicate to a roadside signal controller cabinet, Global Positioning Systems (GPS), Differential GPS, dead-reckoning for vehicle positioning, and wireless communication. Benefit opportunities include reduced travel time for passengers, higher utilization of the bus fleet, improved schedule adherence (assuming a schedule-based operational policy), and improved service effectiveness in terms of passengers per revenue hour or mile). Incremental cost generators include vehicle and roadside equipment such as vehicle detection systems, signal controllers, and wireless communication systems, and added delays to cross street traffic (5).

2.1.4 Precision Docking Systems

Precision docking systems involves the low-speed positioning of buses relative to the curb or loading platform at bus stops and/or stations under the direct bus driver supervision. The lateral position of the bus is precisely controlled with 1to 2 cm. tolerances. Technologies that may be utilized include roadway magnetic marker sensors

[1] Of or relating to or proceeding from the sense of touch

or visual/optical sensing systems with an electronically-controlled steering actuator. The benefit opportunities associated with precision docking include reduced bus dwell times, saving times for both passengers and fleer operators; a safer and easier boarding and alighting for handicapped/disabled passengers; less wear and tear on bus tires resulting from scuffing at curbs; reduced level of driver stress; and enhanced comfort for passengers. Incremental cost generators include electronically-controlled steering actuator, lateral-position sensing system, and reference markings at bus stops/ stations.

2.1.5 Automatic Steering Systems

Automatic steering systems enable buses to stay centered in their traveling lane. Typical technologies include roadway magnetic marker sensors, vision/optical sensing systems with an electronically-controlled steering actuator. Benefit opportunities include the ability to operate buses in narrower lanes, thereby saving rights-of-way (ROW) and construction costs, enabling operations in locations that would be too narrow for conventional buses, a smoother lateral ride quality, and reduced driver stress. Incremental cost generators include electronically-controlled steering actuator, lateral position sensing system, and reference markings along the vehicle lanes.

2.1.6 Automatic Speed and Spacing Control Systems

Automatic speed and spacing control systems have vehicle speed under automatic control rather than under manual or driver control. Vehicles can be operated very close together due to the spacing control. Typical technologies include forward ranging sensors such as radar or laser systems, electronic control of the engine and brakes, and vehicle-to-vehicle data communication systems. Benefit opportunities include an enhanced bus capacity using bus platoons (from close spacing), smooth ride quality for passengers, and a reduction in fuel consumption and level of emissions. Incremental cost generators include sensing and communication devices and electronic brake control actuators.

2.2 Design Attributes

Design attributes of bus rapid transit systems deal with the physical attributes of the system, namely, the vehicle and the infrastructure, that is, the bus and both the running way and bus stops and stations, respectively. Running ways for BRT may be on- or off-street in nature. Generally on-street BRT running ways provide downtown and residential distribution, and serve corridors where market factors, costs, or right-of-way availability preclude providing busways (or reserved freeway lanes).

2.2.1 Running Ways

On-street running ways, which are various in type may be the first stage of future off-street BRT development and establish ridership during an interim stage. BRT operations that are implemented in *mixed traffic flow* can be readily implemented at minimum cost, however, it places buses under normal conditions of everyday traffic, including its delays. Yet even in this situation, BRT operations may still have a sense of BRT identity. For example, in Los Angeles, the Metropolitan Transportation Authority has currently implemented its bus rapid transit system — *Metro Rapid* — on five corridors with very distinctive red and white buses and similarly colored bus stops along each of the corridors. Another type of running way is *concurrent flow curb bus lanes* that are easy to install with low costs and they minimize the street space devoted to BRT. They are, however, usually difficult to enforce and are the least effective in BRT travel time saved. Conflicts between right turning traffic and pedestrians may delay buses. *Contra-flow curb lanes* enable buses to operate two-way on one-way streets, may increase the number of curb faces available for passenger stops, completely separate BRT from general traffic flow, and are generally self enforcing. However they may disperse BRT onto several streets, thereby reducing passenger convenience. They require buses to run against the prevailing traffic signal progression; limit passing opportunities around stopped or disabled buses (unless multiple lanes are provided); conflict with opposing left turns; and may create safety problems for pedestrians. *Concurrent flow interior bus lanes* remove BRT from curbside frictions; allow curb parking to be retained; and far side bus "bulbs" at stops for passenger convenience. However, they generally require curb-to-curb street widths of 60 to 70 feet, and curb parking maneuvers could delay buses. *Median arterial busways* physically separate the BRT running ways from general traffic, provide a strong sense of BRT identity, eliminate conflicts between buses and right turning cars, and can enable the busways to be grade separated at major intersections. However they require prohibiting left turns from the parallel roadways, or providing special lanes and signal phases for these turns. They also require wide streets – generally more than 80 feet curb-to-curb, and their costs can be high. *Bus-only streets* remove BRT from general traffic, increase walking space for pedestrians and waiting space at stations, improve BRT identity, and improve the ambience of the surrounding areas. They need, however, nearby parallel streets for the displaced traffic, and provisions for goods delivery and service access from cross streets or off-street. They are generally limited to a few city blocks (3 and 4).

Off street BRT running ways for "line-haul" BRT operations can permit high speeds and minimize traffic interferences. A desirable goal is to provide as much of the BRT route mileage in reserved freeway lanes or special busways as possible. The following considerations should underlie BRT development in special bus-only roads and in freeway corridors.

2.2.2 Stops and Stations

Most stations are located curbside or on the outside of bus-only roadways and arterial median busways. Similarly, BRT stations have low platforms since many are already or will eventually be served by low-floor buses.

Bus stops, stations and terminals, and associated facilities such as park-and-ride lots, form the interface between passengers and the BRT system. They should be permanent, weather-protected facilities that are convenient, comfortable, safe, and accessible to disabled passengers. These facilities should support a strong and consistent identity for BRT in the community, while respecting and enhancing the surrounding urban context.

BRT facilities should be viewed as urban-design assets. Integration of a BRT guideway into an urban setting presents an opportunity to improve and enrich streetscapes by incorporating new amenities such as landscaping and recreational trails. Because guideway construction may displace lighting, sidewalks and street furniture, these elements can and should be reconstructed or replaced so as to reinforce new, unified design themes.

Station development calls for high quality designs and passenger amenities, establishing consistent themes of form, material and color for stations and other BRT elements, having context-sensitive design and relating BRT stations to adjacent land uses. Other key BRT station concepts and guidelines include: Providing a full range of amenities at stations including shelters, passenger information, telephones, lighting and security provisions, designing for station access by disabled customers, providing a consistent pattern of station location, configuration and design to the maximum extent practical, separating BRT, local buses, automobiles and pedestrian movements in station design, coordinating station platform design with vehicles and fare collection policies, having station configurations support the service plan and operating philosophy of the BRT route, providing bypass capabilities where express and local BRT services are provided on the same running way, sizing station berths, platforms, and access facilities to serve expected riders without overcrowding or spillback, to provide capacity for future growth, and to achieve reasonable levels of service, increasing berth capacity by fostering fare prepayment and or multi-door boarding, developing station locations and designs cooperatively with the surrounding community, providing far-side stops where running ways cross streets at grade, providing convenient transfers between BRT and intersecting transit routes. Placing BRT and local bus stops in separate areas where both services use a common route, but allow for convenient transfers among them, and allowing independent bus arrival and departures at major transit centers and bus terminals for routes that terminate at the station (3 and 4).

2.2.3 Buses

Conventional standard and articulated diesel buses are in wide use for BRT operations, though, there is a trend toward innovations in vehicle design, including environmentally clean or green vehicles, such as diesel-electric vehicles and compressed natural gas-fueled vehicles, dual mode operations in particular environments such as tunnels, low-floor buses, additional as well as wider doors, and use of distinctive and dedicated bus rapid transit vehicles. Service innovations include fare collection procedures, station design and location, and more attractive vehicle designs.

BRT vehicles should be carefully selected and designed because of their impacts on travel times, service reliability and operating/maintenance costs; their impacts on the environment, and their identity and appeal to passengers. They should be customized for the markets that they will serve. They should use body styles and propulsion systems that have been proven in revenue service. Among the desire features of BRT vehicles include the following: Buses should provide sufficient passenger capacity for expected ridership levels. They may be standard 40-foot or articulated 60-foot buses for mainline service, or smaller buses for collector/distributor service.

Vehicles should be easy for boarding and alighting achievable by using low-floor buses with floor heights 12 to 15 inches above street level and wide, multi-use doors. Buses using high-platforms at stations can also speed boarding, but they may require the use of precision docking systems. A sufficient number of doors should be provided, especially where coordinated with off-vehicle fare collection. Generally, about one-door channel should be provided for each 10-feet of vehicle length (two double-stream doors for a 40-foot bus). Providing doors on both sides of buses (as with light rail vehicles) enables both center island and side station platforms to be used. Internal vehicle design generally should maximize the number of people each bus can carry, rather than the number of seated passengers. This is less relevant for routes with long person-trips where vehicles should accommodate as many seated passengers as possible. Wide aisles should be provided to maximize internal circulation space. The minimum aisle width of 34 inches available on some specialized BRT vehicles is preferable to the 24-inch width used on most North American buses. Bus propulsion systems should be “environmentally friendly” by minimizing air pollution and noise. Conventional diesel buses can reduce emissions by using catalytic converters and ultra-low sulfur fuel. Other low-pollution options include compressed natural gas (CNG) diesel-electric hybrids, electric trolley buses, and dual-mode trolley/diesel propulsion. Vehicles should have a distinctive BRT identity and image that should be clearly marked and recognizable to convey the BRT theme. Ideally, BRT routes should only be served by dedicated BRT vehicles. Vehicles should have a high passenger appeal and give passengers a comfortable ride with desirable features including air conditioning, lighting, panoramic windows, automated station announcements, and upholstered seats. Vehicles should be reliable with a long mean distance between failures. Life service costs should be reasonable, both to acquire and operate. Conventional articulated buses cost about $400,000 to $600,000 and have a 12-15 year design service life as compared to some of the BRT "purpose built" vehicles that cost about $1,000,000 with an 18-25 year design life. Existing BRT vehicles range from conventional single unit and articulated buses to "special purpose" vehicles that resemble light rail vehicles. They include articulated low floor vehicles (conventional) and specialized BRT vehicles. BRT vehicles may also have automated, multi-axle rear-wheel steering systems that permit precision docking at stations.

2.3 Operational and Service Plans

Bus rapid transit system service should be clearly marked to customers, direct, frequent and rapid. Fare collection should permit rapid boarding of buses. Service patterns and frequencies should reflect the types of running way, city structure, potential markets, and available resources. Buses may run totally or partially on dedicated rights-of-way when such running ways are available. Service should be simple, easy to understand, direct, and operationally efficient. Providing point-to-point one-seat rides should be balanced against the need for easy-to-understand high frequency service throughout the day. It is generally better to have few high frequency BRT routes than many routes operating at long-headways. The busway route structure should include a combination of basic all-stop service that is complemented by express (or limited stop), feeder and connector service. The all-stop service can run all-day, from approximately 6 AM to midnight, seven days a week, and the express service should operate weekdays throughout the day, or just during morning and afternoon peak periods. The basic BRT all-stops service should operate at 5 to 10 minute intervals during morning and afternoon peak periods and 12 to 15 minute intervals at other times.

BRT running ways may be used by all transit operators in a region where vehicles meet established safety requirements. They can share running ways with high-occupancy vehicles in reserved freeway lanes, where the joint use does not reduce travel times, service reliability, and BRT identity. Running times and average operating speeds should be maximized by providing wide station spacing and by reducing dwell times at stops. Fares should be integrated with the rest of the bus system, but they may not necessarily be the same. Fare collection systems should facilitate multiple door boarding, at least at major stops during busy periods. Off-board collection (preferred) or on-board multi-point payment should be encouraged. Marketing should emphasize the unique features of BRT such as speed, reliability, service frequency and span, and comfort. It should create a unified system image and identity that clearly "brands" BRT. Distinctive logos, color combinations and graphics should be applied to vehicles, at stations and on printed materials.

2.4 Institutional and Policy Issues

This section has thus far has focused on the more technical, design, and operational aspects of bus rapid transit systems, ranging from system requirements, available technologies and practices, system architecture, and simulation tools for system testing and evaluation. The implementation of bus rapid transit systems traverses numerous stages of system design, development, testing (simulation and field), evaluation, and deployment culminating in a completed and fully operational system. Moreover, all these activities take place in a context with organizational stakeholders participating at various levels. As each stage of BRT implementation proceeds through its more technological, design, and operational aspects, questions may arise concerning the impacts of actions to be taken or decisions to be made. These impacts are often of a non-technical nature and are referred to as institutional issues. Such less technical or operational questions and issues resulting from them need to be considered and addressed as well to successfully implement a bus rapid transit system.

All field-deployed bus rapid transit systems will not necessarily experience the same set of institutional issues because each BRT deployment will be affected by local and regional factors. Moreover, even when the same issues arise in different settings, there will likely be local and regional site-specific differences. The importance of identifying and working out such issues should not be underestimated as they contribute to the overall success of implementing bus rapid transit systems in terms of how transit operations and quality of service for passengers are enhanced.

When planning for the deployment of bus rapid transit systems, there are, at a minimum, two distinct types of stakeholders playing primary roles. One is the local and/or regional transit agency whose interest lies foremost in reducing its own costs while also enhancing the quality of transportation services that it delivers to its passengers. The other primary stakeholder is local and/or regional highway and traffic department along the route the transit agency's bus runs and this latter stakeholder could include multiple operators depending on whether the bus runs through multiple political jurisdictions. Other stakeholders can certainly include the regional metropolitan planning organization, the state department of transportation, federal transportation agencies, e.g., Federal Transit Administration and Federal Highway Administration, various local public officials and/or decision makers, and the general public. The significance of these stakeholders' roles and influence depends on local and regional conditions encompassing the bus route/traffic corridor where the bus rapid transit system is to be implemented (6, 7, 8, and 9).

2.4.1 Integration of Multiple Priorities, Objectives, and System Requirements

The multi-jurisdictional or multi-stakeholder element can make the process of decision-making and implementation more complex as each stakeholder usually brings its own philosophies, priorities, and agendas. In particular, the two primary stakeholders — the transit agency and the highway and traffic department — will have their own ideas on specifying requirements that BRT systems need to satisfy and there may be concurrence as well as differences between these sets of requirements. Achieving consensus, let alone agreement, among all affected stakeholders, whether political jurisdictions or other transportation organizations may at times prove to be a challenging and possibly difficult task. To have a system that works effectively requires the transit agency to achieve agreement with localities and other agencies on infrastructure, operations, and assignment of responsibilities. However, the primary objectives of transit agencies, to provide high-level, high-quality service for their customers at minimum cost, may conflict with the objectives of highway and traffic agencies whose performance is often judged more on enhancing vehicle-moving than people-moving capacity. These often-competing objectives can complicate the implementation of bus rapid transit strategies and may require significant coordination and cooperation if multiple highway and traffic agencies are involved.

2.4.2 Introduction of New Technologies

Institutionally, there may be concerns over the use of new technologies regarding their complexity and reliability. Moreover, there will need to be coordination on the selection and implementation of new technologies determining whether or not they should be selected to meet the needs of multiple stakeholders and how this could complicate BRT deployment. Insufficient understanding of the "state of the art" of technologies and how they can be used in BRT operations also needs to be recognized and addressed.

2.4.3 Organizational Adaptation to Changes Resulting From Bus Rapid Transit

Institutional issues may arise not only between organizations such as transit agencies, political jurisdictions and traffic operators, but also internally within individual organizations. Concerns over preferences in funding and use of scarce resources, the delegation of potentially added responsibilities for staff may result in intra-organizational resistance and morale issues. Unless there are additional funding sources available, increased spending on one route will usually mean decreased funding on others.

Bus rapid transit systems may require additional resources to support the service offered. Additional operations, new technologies, retrofitted/new vehicles, and new infrastructure will likely require training and maintenance. Achieving agreement on roles and responsibilities may be difficult if employees are merely required to shoulder additional duties and responsibilities for BRT without additional compensation or support.

Many agencies will need additional time to identify and integrate best industry practices for BRT. Even then, identifying and attempting to accommodate an agency's departments' needs may cause internal discord. As new strategies may affect the duties of staff, it is vital that they are consulted and strategies are selected with staff concerns in mind.

2.4.4 The Political Arena

At each stage in the process of implementing BRT, decision-making stakeholders are involved in a variety of ways that impact the specific deployment path a particular bus rapid transit system will take. The decision-makers are by definition major players in the political arena that govern the local jurisdictions in which the BRT would operate. The commitment to BRT by such major players is of crucial importance to its success.

To establish and sustain a high level of interest and commitment to BRT will likely require a political champion. Whether it is an individual or organizational entity, a political champion would aid in coalition building and sustaining interest in BRT when interest could expand and diminish over time. The strength and capability of a political champion would help determine if the project can withstand voices of opposition arising from various quarters, for example, the local business community or local residents. However, gaining such championing decision-makers often requires proof of the operational and quality-of-service benefits of BRT, but political support is usually required first to perform the testing that could result in the quantifiable benefits. Here we encounter the chicken-or-the-egg dilemma. One way out of this dilemma is to cite BRT benefits arising from several other venues, especially others in the U.S. in communities with similarities to the site in question so that valid comparisons are possible.

2.4.5 Public Relations and Marketing

The ultimate success of any new product, no matter how good its potential may be, depends largely on how information about it — both benefits and costs — is communicated. To gain support for BRT, it needs to be properly "sold" to many stakeholders including bus passengers, employees, motorists, the general public, as well as decision-makers. However, selling BRT requires setting expectations. Setting high, yet realistic expectations will be crucial for the long-term success of the system. Failure to produce what was proposed could lead to public disappointment and tarnish the sponsoring agency's name and reputation, resulting in BRT being untouchable for some period of time.

One issue that may arise from poorly executed public relations, marketing, and educational campaigns are motorists' complaints and backlash who perceive that transit is getting special, and undeserved, treatment, causing roadway delays and raise "tax-equity" issues upon seeing such a system installed for buses, such as with transit signal priority systems.

It would also be important to educate the public and passing motorists on new interactions they may have with bus rapid transit systems. Moreover, the transit agency needs to take into account its current performance, both actual and perceived by the public. Before taking on the additional responsibilities of a BRT, an agency must ensure its current operations are performing satisfactorily. Otherwise, the agency may face political and public opposition if it is perceived the agency is overextending itself beyond its capabilities.

2.4.6 Labor and Human Factors

Transit properties must consider the effects of BRT on its staff, especially bus drivers and maintenance workers. BRT may raise concerns over additional work and responsibilities, changing role of drivers, especially without assurances of additional staff, resources, and/or pay, use of Automated Vehicle Location (AVL) systems for monitoring schedule adherence and different responsibilities between BRT and non-BRT routes.

For example, for transit signal priority, bus drivers would have a direct and potentially the closest connection of all agency employees with any new technology implemented as part of a BRT. How would such employees embrace such new systems? Would it mean any change in the definition of their job? The specifics of the bus rapid transit system will determine the extent to which bus drivers need to interact with the system, that is, how much attention drivers must pay to activate and/or monitor the system. With everything the bus driver currently needs to do as part of his/her job, giving the driver additional tasks related to the operation of TSP would likely be problematic leading to a preference for either no or only minimal interaction with the driver.

Finally, drivers will likely need to switch back and forth between TSP and non-TSP routes over the course of relatively short time periods, possibly even the same day. Thus, training for new driving conditions and situations and the ability to smoothly switch between TSP and non-TSP routes could be of concern to drivers as well as transit agency management, especially in the instance where drivers have more than simply minimal interaction with the system.

2.4.7 Planning and Land Use

Large-scale public transportation projects often influence travel patterns and surrounding land uses. Bus rapid transit, intended to replicate high-level transit service, may raise concerns over how it fits into a region's overall transportation plans and how it will affect local land uses. Many BRT projects intend to strengthen and encourage higher land uses. Project sponsors will need to educate and address public concerns regarding the potential impacts of BRT on the physical environment. The public's fear of change and the "unknown" often leads to resistance and opposition toward many such projects. Finally, a BRT system's inherent flexibility, often a much-touted attribute, may, in fact, be a disadvantage. Potential developers may be reluctant to invest along BRT corridors due to its perceived lack of permanence.

2.4.8 The Physical Environment

The physical presence of a BRT system may also raise institutional challenges. Many project areas, especially in older city centers, may simply lack the physical space to easily accommodate certain BRT implementation strategies. Bus rapid transit projects may also find themselves competing with other interests for high value real estate, which may not only inflate costs, but also complicate institutional dealings. Thus, availability and acquisition of right-of-way or physical space may be an issue.

Image is also a strong marketing tool for BRT. While station area improvements are a popular BRT strategy, these improvements are typically being inserted into the existing urban design. Organizations may find it a challenge to reach agreement or consensus to develop station improvements that promote a strong image, while being acceptable to numerous local interests.

2.5 Interactions and Tradeoffs

It is essential that a systems approach be taken in the planning for and implementation of bus rapid transit systems. That is what has motivated us to include each of the four topic areas described in this section. Moreover, it is important to integrate these topic areas together to understand how they interact with each other and not think of them in isolation from one another. In this way, a much more complete and accurate depiction of the system with both its benefits and costs may be derived.

We provide here a few examples to illustrate this point. Design attributes are directly linked with operational and service plans and resulting benefits especially in terms of new ridership. For example, to reduce route travel time along a bus rapid transit corridor, there will be fewer stops/stations than would normally be used if that corridor were used for conventional local bus service. However, the further apart consecutive stops/stations are placed, the further customers would need to walk to access the stop/station. Clearly, a transit agency would plan the location of each stop/station to balance the competing objectives of reducing total travel time and attracting new riders. Having the stops spaced further apart contributes to reducing overall travel time because there would be fewer number of stops for the bus to provide boarding and alighting, however, having to walk further to access the bus may discourage potential riders from using this BRT service. In Los Angeles, MTA's Metro Rapid along Wilshire Boulevard originally sited stations approximately 75% to 80% of a mile apart. Overall travel time along the Wilshire corridor has been reduced by 25% and there has been an increase in ridership by approximately 25% with 33% of these being riders new to transit (10). However, based on public opinion about the Metro Rapid service, MTA is planning on inserting a few additional Metro Rapid stops/stations. The number and location have to be selected carefully as adding stops will attract new riders because of the reduced distance people have to walk to the stop, however, it will increase overall travel time, which itself would be a disincentive to attracting new riders.

Another interaction is among design attributes, service plans, and institutional concerns. In order to provide more rail-like level of service, an exclusive or at least near-exclusive right-of-way may be sought. Moreover, at BRT stops/stations the use of queue jumpers and/or bus bulbs may also be considered. The use of these design attributes in order to improve the level of service may, however, collide with concerns of the local business community over its opposition to the removal of or restrictions placed on parking space availability that may be necessary to accommodate such operational and service plans for BRT.

A third example to illustrate the importance of integrating these issues brings together technological aspects, operational plans, and institutional concerns. Again, on Los Angeles' Wilshire Boulevard Metro Rapid service, MTA implemented in 2000 various bus rapid transit features as elements of its Metro Rapid service including transit signal priority along the heavily traveled Wilshire-Whittier Boulevard corridor. This corridor traverses the cities of Santa Monica, Beverly Hills, and Montebello in addition to the city of Los Angeles and each of these municipalities controls signal operation within their respective jurisdictions. Thus for the Wilshire-Whittier corridor, MTA and the four signal operators are the primary stakeholders. Initially, transit signal priority was implemented only within the city of Los Angeles as the other cities wanted demonstrative proof of transit signal priorities' benefits before they relinquished control over the operation of traffic signals in their jurisdictions. To date, transit signal priority still remains implemented only in the city of Los Angeles while negotiations between MTA and the other jurisdictions continue.

3.0 DEVELOPING A FRAMEWORK FOR THE DEPLOYMENT PLANNING OF BUS RAPID TRANSIT SYSTEMS

3.1 Adopting a Systems Optimization Approach

A bus rapid transit (BRT) system differs from more traditional rail and bus services by its features that combine most of the qualities of light rail transit (LRT) with highly flexible service and advanced technologies to improve customer convenience and system reliability. BRT can thus be seen as a bus-based "rapid" transit system that combines vehicles stations, running way, and Intelligent Transportation Systems (ITS) elements into a fully integrated system with a unique identity. The planning process of a BRT system can generally be divided into three inter-correlated stages:

1) Feasibility study or major investment study in which BRT is investigated among other alternatives, such as LRT and METRO to find out the most cost-effective investment over a corridor

2) Deployment planning that determines what BRT elements will be included in the BRT system and their deployment sequence

3) Operations planning including designing routes and stations, setting timetables, scheduling vehicles, and assigning crew.

While the first and third stages are essentially planning-specific for any transit service, the second stage has special features for a BRT system due to its flexibility in incremental deployment of BRT elements. In Reference 3, the authors have set forth the planning considerations of BRT development referring mainly to Stage 1. In contrast, this report focuses on Stage 2 dealing with deployment-specific issues.

There are numerous BRT elements available for transit agencies from which to choose to equip their BRT systems. Therefore it is not a surprise to observe that currently deployed BRT systems in the U.S. and internationally exhibit various configurations, designed by transit planners based on their professional considerations and judgments. For example, Los Angeles County Metropolitan Transit Authority (LACMTA)'s Wilshire-Whittier BRT corridor includes a simple route layout, frequent service, less frequent stops, level boarding and alighting, color-coded buses and stations, bus signal priority, next bus displays and is headway based. In Orlando, the Lynx LYMMO BRT consists of exclusive bus-only lanes Automated Vehicle Location (AVL) system, passenger information kiosks at stations and a Transit TV Network.

Different system combinations of BRT elements exhibit different service levels and reflect different budgetary constraints. Upon deciding to invest in BRT, a transit agency must select that combination of elements that maximize the cost-effectiveness of deployment. Cost-efficiency and effectiveness are affected by local and site-specific factors, such as land use, transit demand, passenger behavior, transit feeder service, traffic volume and road geometry, which contribute to a deployment's degree of success. Therefore, we recommend adopting a systems approach with adequate and realistic objectives and constraints.

This paper proposes a deployment-planning framework that provides, in a series of steps, a general structure for optimal deployment of BRT systems. This framework and its formulation, once operationalized, can provide transit agencies a practical tool for determining the optimal deployment strategy, i.e., what BRT elements should be included in the system, given budgetary, institutional and other types of constraints associated with the proposed BRT corridor, along with steps to take to meet future needs based on available funding.

Given that a transit agency has decided to deploy BRT for a specific corridor, another important issue that the agency faces is how to equip this BRT system. Typically, a BRT system contains the following features:

- **Exclusivity of Running Way**

  Most BRT systems are operated on exclusive lanes or busways, but a few operate in mixed traffic on customary streets that also use other BRT features.

- **Advanced Bus Technologies**

  This includes clean fuel propulsion systems, low-floor configurations, advanced communication systems, improved access, maneuverability, improved operating efficiency, reduced emissions, and reduced weight of transit buses.

- **Improved Fleet Management Technology**

  Fleet management combines infrastructure with ITS technologies to improve travel time and reliability of bus service, as well as traffic flow for other vehicles. Strategies include: bus turnouts or curb realignments, automated vehicle location (AVL) systems for improved real time management and dispatching, and bus signal priority systems

- **Distinctive Aesthetics or Amenities**

  Enhanced shelters, stops, or stations; passenger information systems including schedules, brochures, and real-time information; and distinctive aesthetics that provide more friendly facilities and amenities.

- **Faster Fare Collection and Boarding**

  Application of prepayment methods, e.g., Smart Cards and reconfigured platform design for easier and faster passenger access.

- **Integrating Transit Development with Land-Use Policy**

  Help builds a market for transit services and reinforce Transit-Oriented Development (TOD) in areas or corridors with building site and street designs favoring transit and pedestrian usage.

- **Innovative Project Delivery Methods** (procurement, design, operation, maintenance, finance strategies)

  Development of new approaches developed and implemented for procurement, system design, construction, operations, maintenance, and financing.

Subject to budgetary, institutional and other constraints associated with the corridor, transit agencies have to cost-effectively configure their BRT systems, which must be tailored to site-specific characteristics. To achieve this goal, a systems optimization approach should be adopted with adequate and realistic objectives and constraints. A planning framework, reflecting this approach, is proposed to assist transit agencies with this task. The proposed deployment-planning framework is depicted in Figure 3-1, containing the following steps:

7) Determine possible combinations of BRT elements , while taking into account the existing transit system, feasibility of implementation, institutional issues and other considerations;

8) Assess the capital cost associated with each combination;

9) Derive feasible combinations consistent with budget constraints;

10) Evaluate each feasible combination;

11) Conduct sensitivity analyses with respect to available budget, travel demand, cost of components, etc., and

12) Recommend optimal alternatives of combinations for implementation.

The activities and corresponding methodology for each step are described below.

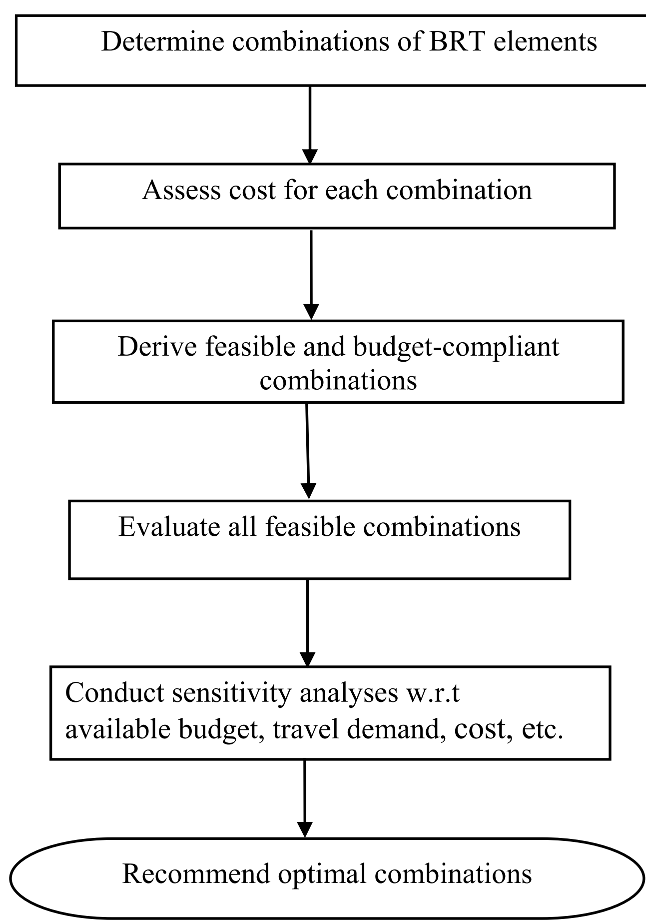


FIGURE 3-1 A Framework for BRT Deployment Planning

3.1.1 Determination of Bus Rapid Transit Element Combinations

There are numerous BRT elements available for transit agencies to select from and these may be classified into the following groupings (3): running way, bus, stop, bus route, operation policy, ITS elements and others. Under each category there are additional attributes, which are listed below:

1. Running way:
    a. Mixed traffic lane
    b. Queue jumper
    c. Bus-only lane
    d. Median busway
    e. HOV lane on freeway
2. Bus:
    a. Identity (coloring and brand name)
    b. Low-floor
    c. More doors and wider doors
    d. Larger capacity
    e. Distinctive, dedicated BRT vehicle
3. Stop:
    a. Wider spacing of stops
    b. Identity (coloring and brand name)
    c. Level boarding and alighting
    d. Amenities (shelter and benches, etc)
    e. Information kiosk
    f. Next bus displays
    g. Bus bulb
4. Bus route:
    a. Simple layout
5. Operation policies:
    a. Off-vehicle fare collection
    b. Headway-based schedule

    c. Frequent service
    d. Dynamic dispatch operation
    e. Overtaking policy
6. ITS elements
    a. AVL system
    b. Passenger information system
    c. Signal priority
    d. Electronic fare collection
    e. Lane assist technologies

In the proposed planning framework, a combination of BRT elements instead of being an arbitrary collection of elements is tailored to the needs of each transit agency using a cost-effectiveness approach and represents a stand-alone BRT system that a transit agency may wish to deploy. Therefore, determining a BRT combination involves consideration of improving the existing level of service and reducing operational cost. Some BRT elements are termed essential and must be included in the set of elements, including buses and stops with a distinctive color scheme and a unique brand name, simple route layout, wide spacing of stops and frequent service. In addition other elements can be selected from an elective set, while considering existing systems, technical feasibility, institutional constraints and other issues.

Institutional issues may be the major consideration at this stage of planning. Deployment of a BRT system often involves multiple stakeholders, such as transit agencies, municipal street departments of traffic, state departments of transportation, and planning agencies which may have different priorities, objectives and agendas. Institutional issues could prohibit some BRT elements from being implemented. For example, in cases where projects look to utilize roadway space that is currently used for on-street parking, businesses and residents may be opposed to this “loss” of parking, even if it is only during peak-periods. For transit signal priority, traffic engineers often raise safety and operational objections. Indeed, transit signal priority could lead to signal delay increases on cross-streets and incidents and accidents have caused transit signal priority to be terminated. Recent examples include BRT in Miami, and LRT in Houston. A recently completed study (9) offers guidance in anticipating future institutional problems and developing strategies to solve them. Transit planners should be aware of potential institutional issues associated with BRT elements, and then examine ways to resolve them to develop meaningful BRT combinations.

Another point is the interdependency between some elements leading often to treat these elements in pairs. For example, the use of *low-floor buses* is associated with *level boarding and alighting at stops*, and *frequent services* with *a headway-based schedule*. Implementation of *transit signal priority* often requires *far-side* or *mid-block stops*, an *AVL system* comes with *a passenger information system* and *lane assist technologies* may require *dedicated bus lanes*. Therefore, formulation of BRT element combinations should accommodate the interdependencies among elements to assure deployment efficiency.

Figure 3-2 makes a sketch of the procedure to determine the feasible and reasonable combinations of BRT elements.

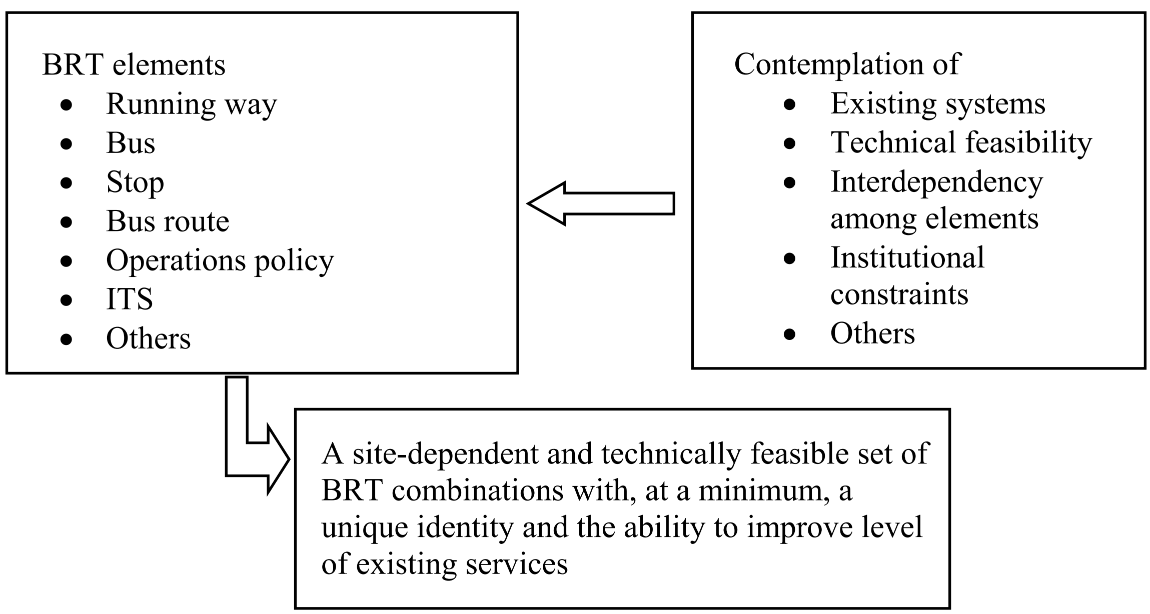


FIGURE 3-2 Determination of Combination of BRT Elements

3.1.2 Cost Assessment for Each Combination

To assess the capital cost of each combination of BRT elements, the unit cost of each element is required. Such information may be collected from agencies that have BRT projects in operation, being planned or under construction. Moreover, there exist previous BRT system studies that contain certain cost estimates (1, 3, 4, and 11). Reviewing these reports is certainly another way to obtain additional cost information. Furthermore, TCRP has an on-going project (Project A-23A) to determine the costs, impacts, and effectiveness of implementing selected BRT elements. This two-year project will be completed at October 2005. It is expected that resulting reports will provide substantial cost information useful to transit agencies.

Caution must be used when dealing with cost estimation of BRT combinations because:

1) *Costs of BRT elements may vary based on the specific technology being used.* For example, the capital cost of transit signal priority system is primarily associated with the necessary instrumentation of intersections and transit buses. Depending on the specific technology being used (e.g., 3M Opticom™ versus LA Metro Rapid TSP system) and equipped transit fleet size, the costs of prior deployments have ranged between $8,000 and $35,000 per intersection. Therefore, when estimating how much a transit signal priority system would cost for a specific implementation, technology details should be considered as much as possible. Existing infrastructure such as the traffic control system and transit fleet management system is one of the dominating factors that determine the type of transit signal priority technology.
2) *Integrated deployment of BRT elements may save significantly.* In almost all BRT deployments, ITS and bus technologies have been used in less than a fully integrated manner. For example, current bus data communication systems have not yet considered many BRT features and therefore many add-on functions and features cannot be integrated with such systems. A transit bus that is instrumented with advanced communication systems (ACS), signal priority systems, and bus arrival information functions is often equipped with three separate positioning systems. By carefully designing system concepts and selecting appropriate technologies, integrated deployment of BRT elements can be realized, which would reduce associated capital costs

significantly. In this case, cost information from other deployments may not be directly applicable.

3) *Operating and maintenance costs must be considered*. Though the proposed framework focuses on capital cost assessment, operating and maintenance costs associated with some BRT elements should also be taken into account. Some BRT elements will require a great deal of capital investment, often requiring transit agencies to shoulder the risk of having greater capital to maintain without recovering sufficient additional revenue to cover those costs. Such operating and maintenance costs may make transit agencies reluctant to embrace certain BRT elements.

3.1.3 Constraints and Feasible Combinations

Having decided to deploy BRT along a specific route, a transit agency likely has an approximate idea about its budget constraints, which will create the cost limit for financially feasible BRT element combinations from a sensitivity analysis. This analysis will show the transit agency other feasible element combinations for cases of budget under- and over-estimation.

Other computational attempts will be performed with partial implementation of selected elements to meet the budget constraint. The flexibility of BRT development plans covers both incremental deployment of BRT elements over time and incremental deployment over different route segments.

3.1.4 Evaluation of Feasible Combinations: Recommended Optimal Combination(s)

This is a key step in the proposed framework of deployment planning, including selection of performance measures, expressing these appropriately as objective functions, evaluating each BRT combination and selecting and recommending the optimal one(s).

3.1.4.1 Measures of Performance

Many performance measures have been developed and used by the transit industry in a variety of ways in response to differing transit system goals and objectives. In addition, one TCRP research project has produced a practical, user-friendly guidebook that assists transit system managers in developing a performance-measurement system or program that uses traditional and nontraditional performance measures to address customer and community issues (12). The guidebook assigns performance measures to eight primary categories, including availability, service delivery, safety and security, maintenance and construction, economic, community, capacity and travel time.

The purpose of this work is to evaluate each feasible BRT combination with their respective cost-efficiency and cost-effectiveness as is illustrated in Figure 3-3.

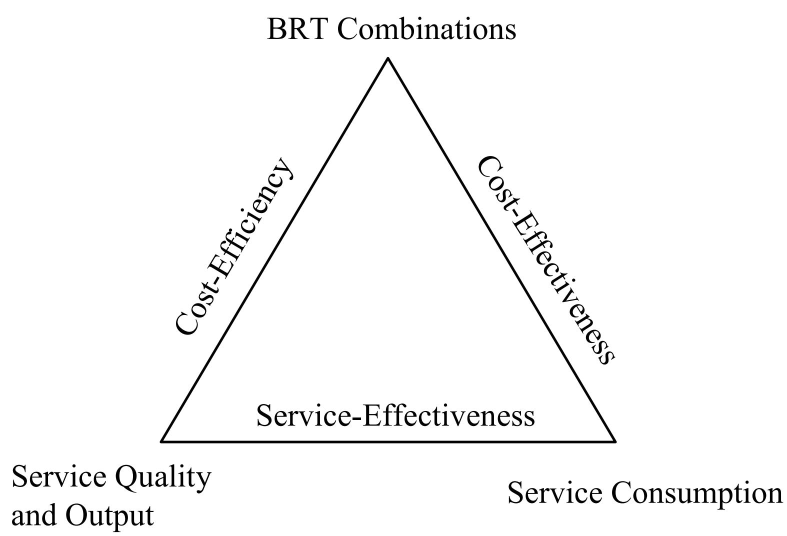


FIGURE 3-3 Cost-Efficiency versus Cost-Effectiveness of BRT Elements

A number of performance measures can be used to represent the service quality and output of a BRT system, including travel time, service reliability, service frequency and customer waiting time. Service consumption is normally represented by ridership. Transit agencies that have specific objectives they want their BRT system to achieve can easily develop their own performance measures to evaluate different BRT combinations. We propose four aggregate performance measures and objective functions that may be used by agencies seeking to improve overall level of service but without specific objectives in mind. The objective functions are relatively easy to quantify and represent the combined perspectives of passengers, the operator/transit agency and the community, which are the three primary stakeholders. However, these objective functions are only concerned with cost-efficiency of BRT-element combinations for an existing (known) passenger demand. In order to evaluate the cost-effectiveness, changes in ridership with respect to the implementation of selected BRT elements should be forecasted. This can be achieved either by a "learning curve" of an existing similar BRT system in operations, or via market research including potential system customers and non-users.

The four objective functions proposed in this work can be formulized in two equations, min Z_1 and min Z_2, across different combinations of BRT elements:

$$Z_1 = \alpha_1 \sum_{i,j \in N} Wt(i,j) + \alpha_2 \sum_{r} Esh_r + \sum_{i,j \in N} [\alpha_3 Ph(i,j) - \alpha_4 Dph(i,j)] \tag{1}$$

$$Z_2 = FS \tag{2}$$

where

N = Set of stops in a given BRT system (main and variation routes) and can be referred to as points of demand. Variations to the main BRT routes can be all routes with short-turn, skip-stop, and different start/end-point strategies;

$Ph(i,j)$ = Passenger hours between stops i and j, $i,j \in N$ (defined as passengers' riding time on a BRT vehicle on an hourly basis. It measures how much time is spent by passengers in vehicles between the two stops);

$Dph(i,j)$ = Difference in Passenger hours between $Ph(i,j)$ and the total passenger hours from i to j when only using the shortest path, $i,j \in N$;

$Wt(i,j)$ = Waiting time between stops i and j, $i, j \in N$ (defined as the amount of time passengers spend at the BRT stops while moving between stops i and j);

Esh_r = Empty Space-Hours on route r (defined as the unused seats on the BRT vehicle on an hourly basis. Empty Space-Hours measures the unused capacity on vehicles);

FS = Fleet Size (number of BRT vehicles needed to provide all trips along a chosen set of routes);

α_k = Monetary weights where $k=1, 2, 3, 4$ (see next section).

3.1.4.2 Individual Objectives

The objective functions set forth takes into account three perspectives: the passengers, the operator and the community. A good BRT route is defined as an attractive one from all the three perspectives.

The first straightforward objective is to minimize the total waiting time of the passengers. This is strictly the perspective of a BRT user. The formulation of this objective takes the following form:

$$\min \quad \alpha_1 \sum_{i,j \in N} Wt(i,j) \tag{3}$$

where α_1 = monetary value of one-hour waiting time.

The second objective is to minimize the total unused seat capacity as to allow for a more viable BRT service. This is strictly the perspective of the operator who wishes to see more usage of the available BRT seats. The following is the formulation of this objective:

$$\min \alpha_2 \sum_r Esh_r \tag{4}$$

where α_2 = the equivalent of one hour average monetary revenue divided by the average number of hourly boarding passengers. This objective is to minimize the total monetary value of the unused seat capacity.

The third objective is to minimize the total loss if all the BRT passengers are switched to the shortest path. This objective attempts to take into account the comparison between the BRT route and its best competitor, which is usually the private car, or in certain cases taxi, subway, railway or aircraft. This objective represents the perspectives of the government and the BRT passengers, and takes the following form:

$$\min \ \Delta = \sum_{i,j \in N} [\alpha_3 Ph(i,j) - \alpha_4 Dph(i,j)] \qquad (5)$$

where α_3 = equivalent of one-hour difference in average (BRT bus) cost between riding the shortest (can be perceived as done by a private car) path and the BRT route, and α_4 = monetary value of one hour in-vehicle time. The value of Δ is the total monetary loss (or saving, if it is negative) if all the BRT passengers are switched to the shortest path, where $\alpha_3 Ph$ = total monetary loss, with respect to cost only, if all the BRT passengers are switched to the shortest path, and $\alpha_4 Dph$ = total monetary value of the time saved if all the BRT passengers are switched to the shortest path.

The fourth objective is to minimize the number of BRT vehicles to carry on the determined frequencies (timetables). This is strictly the operator perspective who wishes to perform all the BRT trips using the minimum number of vehicles. This objective takes the form:

$$\min \ FS \qquad (6)$$

Objectives (3), (4), and (5) are all in passengers hours cost and therefore for simplicity, could be summed up to min Z_1 as it is shown in Eq. (1). Objective (6) stands alone to some extent and it is termed min Z_2 as in Eq. (2).

3.1.4.3 Steps in Calculating Z_1 and Z_2

There are seven steps required to calculate all four objective functions, if the high-level macroscopic evaluation method is used:

1) Calculate average origin-destination (O-D) demand for peak, off-peak and daily in the BRT system (main route with variations) for each feasible (complied with budget constraint) BRT element combination using survey or experienced-based methods;
2) Calculate peak and off-peak period frequencies of the BRT vehicles using given minimum frequencies (policy-headway based) and desired occupancies (load factors) for these periods,
3) Calculate Wt and Esh for peak, off-peak and daily periods;
4) Calculate Ph and Dph for peak, off-peak and daily periods using average travel time information for each BRT route variation and its best competitor(s);
5) Determine required fleet size for peak and off-peak periods using the information of BRT average travel times;
6) Evaluate the cost of $\alpha_1 Wt$, $\alpha_2 Es$, Δ, Z_1 and Z_2 based on cost estimates of α_k, $k = 1, 2, 3, 4$;
7) Compare different feasible (complied with budget constraint) BRT element combinations to establish recommendations using the components of Z_1 and Z_2.

The input for the objective functions analysis consists of:

1) A given BRT route and its variations;
2) Average O-D demand for peak, off-peak and daily;
3) Average travel times for peak and off-peak, for each direction;

4) Average round trip times for peak and off-peak periods;
5) BRT vehicle capacity;
6) Desired BRT vehicle occupancy (load factors) for peak and off-peak periods;
7) Minimum frequency (inverse of policy headway) for peak and off-peak periods;
8) Minimum relevant average travel time of best (shortest time) BRT competitor.

In the subsequent section the analysis of the objective functions is interpreted using a detailed example.

3.1.4.4 Evaluation Method

Various methods can be used to evaluate the impact of individual BRT combinations where microscopic simulation emerges as one of the promising directions. Microscopic simulation technology provides the ability to simulate the detailed movements of individual vehicles in a traffic network according to behavioral models attempting to mimic actual driver decisions and actions. A properly calibrated and validated simulation program can model and represent efficiently traffic networks. Therefore, microscopic simulation can be used to assess the cost-efficiency of each BRT element or combination of elements. Although most currently available microscopic traffic simulation software, such as Paramics, and VISSIM have limited pre-programmed functionality to represent and simulate all BRT elements, efforts can be made to expand the functionality through development of a set of plug-in Application Programming Interface (API) modules. The enhanced microscopic simulation software is competent for the cost-efficiency evaluation task.

The task can also be conducted in a high-level macroscopic way if the intent is to get first-cut quick-response estimates of the impacts of individual BRT combinations. This section introduces how to calculate the four objective functions, Equations 3-6, in a macroscopic and simplified way.

Calculation of the objective function Z_1 is based on the so-called load profile. It is a histogram describing the number of passengers on board the BRT vehicle vs. the BRT route length (in time units). The first element in Z_1 is Wt, the total wait time hours both at the BRT system stops and during transfers. In order to calculate this element the frequency of BRT vehicles is determined using the maximum load point method (12) during the time covered by the passenger demand matrix:

$$F_r = \max\left[\frac{L_r}{d_o}, F_{\min}\right] \tag{7}$$

where F_r = the service frequency of the BRT route *r*; L_r = maximum passenger load on route *r*; d_0 = desired occupancy (load factor) on each BRT vehicle, and $F_{\min}$ = minimum frequency (inverse of policy headway) required. If $F_r = F_{\min}$, the load profile will have no effect on the frequency determination.

The expected wait time for passengers on the BRT route is half of the BRT vehicle headway where passengers arrived randomly to the transit stop and the headway are distributed in a deterministic manner (14):

$$w_r = \frac{1}{2F_r} \tag{8}$$

where w_r = expected waiting time for passengers on route *r*. Hence, Wt can be easily calculated.

The second element in Z_1 describes the total empty-space hours (when d_0 equals the number of seats on the BRT vehicle). This element represents an unproductive measure for the operator (e.g. unused seat capacity). Its formulation is:

$$Esh_r = \max(L_r, F_{\min} \cdot d_0) \cdot t_r - Ph_r \tag{9}$$

where t_r = the overall travel time on route *r* between its start and end, and Ph_r = the total passenger hours on route *r*.

The third element of the objective function Z_1 is Δ based on *Ph* and *Dph*. The *Ph* represents the total passenger hours on the BRT route. The *Dph* represents the passenger-hour difference between the BRT route and the shortest (automobile) path. By taking into account the impact of each BRT element, if any, on bus operating speed, dwell time, traffic delay and intersection delay, it is possible to estimate the average travel time for the BRT route with a specific configuration. The Δ can then be calculated accordingly.

The second objective function, Z_2, is an estimate for the fleet size required to satisfy passenger demand. The method used for evaluating the fleet size is based on deficit function theory (15), which provides techniques to assign the minimum number of BRT vehicles to carry out a given timetable. A deficit function is simply a step function, which increases by one at the time of each trip departure and decreases by one at the time of each trip arrival. Such a function may be constructed for each terminal in a multi-terminal transit system. The sum of the maximal deficit function values over the schedule horizon and across all the terminals is the minimum number of vehicles required. The maximal value of the deficit function can be reduced by introducing deadheading (empty) trips into the schedule, as well as shifting the departure times within bounded tolerances (16). This work may not include all the detailed procedures of deficit function theory and will concentrate rather on estimating the minimum fleet size required for a fixed schedule (shifting of departure times is not allowed).

3.1.4.5 Recommended Optimal Combination(s)

With the calculated performance measures for each BRT element combination, an optimal combination of BRT elements can be selected and be recommended for deployment. However, since we often have more than a single objective function (or performance measure, there may not exist an unambiguously optimal BRT combination of elements due to tradeoff characteristics among the objectives. Hence, this analysis may end up with a set of Pareto-optimal combinations, a family of BRT combinations, which is optimal in the sense that no improvement can be achieved in any objective without degradation in another or others. Based on these non-dominated combinations, a multiple-criteria decision-making process should be used to evaluate and select the compromise solution. This is illustrated schematically in Figure 3-4. Any combination within the dotted line region is considered an optimal combination because 1) any combination outside the region is dominated by at least one combination within this region, where by “dominated” we mean that *both* objective functions are minimized and 2) no combination inside this region is dominated by any other combination inside the region.

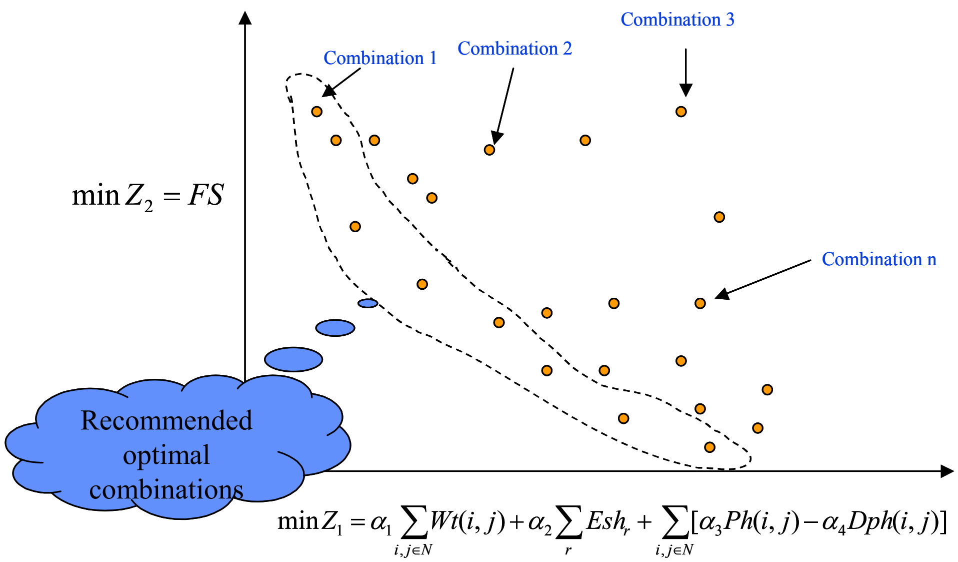


FIGURE 3-4 Schematic Diagram Identifying (dashed line) Recommended Optimal Combination(s)

4.0 CASE STUDY: THE METRO RAPID BUS RAPID TRANSIT SYSTEM IN LOS ANGELES

In June 2000, the Los Angeles County Metropolitan Transportation Authority (MTA) and the City of Los Angeles Department of Transportation (LADOT) began its demonstration of its new bus rapid transit service along two of the city’s most heavily traveled urban-suburban corridors in terms of ridership. This service was named *Metro Rapid* and was part of a demonstration program that consisted of “a new, fast, high-quality bus service” along these two corridors, each traveling in the east-west direction: The Wilshire-Whittier

Boulevards corridor and the Ventura Boulevard corridor. Figure 4-1 depicts the route map for the Wilshire-Whittier Metro Rapid corridor that extends from the Pacific Ocean on the west for twenty-seven miles east to the city of Montebello going through downtown Los Angeles. This map also indicates connections to other parts of Los Angeles County's rail network, that is, its heavy rail Red Line heading north and its light rail transit Blue Line heading south from the highlighted Wilshire-Whittier line. This route map, however, does not depict the "VA Hospital" stop lying between "Barrington" and "Westwood".

4.1 Mid-City/Westside Transit Corridor Study

The western half of the Wilshire-Whittier corridor is part of an area in Los Angeles designated the *Mid-City/Westside Transit Corridor Study*. The Mid-City/Westside Study Area is located in western Los Angeles County and encompasses approximately 112 square miles, bounded approximately by the Pacific Ocean on the west; Sunset Boulevard and the Hollywood Freeway (US 101) on the north; Hope Street and Figueroa Street on the east; and Slauson Avenue and Manchester Boulevards on the south. Portions of the City of Los Angeles, unincorporated areas of Los Angeles County (e.g., Baldwin Hills), and the Cities of West Hollywood, Beverly Hills, Santa Monica, and Culver City are within the Study Area. The Mid-City/Westside Transit Corridor is shown in Figure 4-2 and also depicts another corridor within the area, the Exposition Boulevard corridor, in which light rail transit has been chosen as the locally preferred alternative over bus rapid transit and other alternatives.

The focus of this case study is on that portion of the Wilshire-Whittier corridor lying within the Mid-City/Westside Study Area consisting of approximately eighteen miles from the Pacific Ocean on the west to the Los Angeles Central Business District (CBD) on the east and consisting of twenty bus stops. In June 2001, the MTA Board adopted bus rapid transit for the Mid-City/Westside Transit Corridor Study, that is, that portion of the corridor between the Pacific Ocean and Western Ave on the east (See Figure 4-2), as the Locally Preferred Alternative. The MTA completed environmental clearance for the Mid-City/Westside Transit Corridor Study BRT project in August 2002.

Based on an MTA evaluation of its performance, Metro Rapid has been hailed as a success by MTA and because of this success by way of the Mid-City/Westside Transit Corridor Study, MTA and the Federal Transit Administration (FTA) are looking to further enhance transit on Wilshire Boulevard by providing larger buses and a dedicated transit lane to keep buses moving during periods of heavy traffic congestion. These enhancements will be discussed in Section 4-3 (17, 18, and 19).

FIGURE 4-1 Route Map for Wilshire-Whittier Boulevards Metro Rapid Demonstration Program

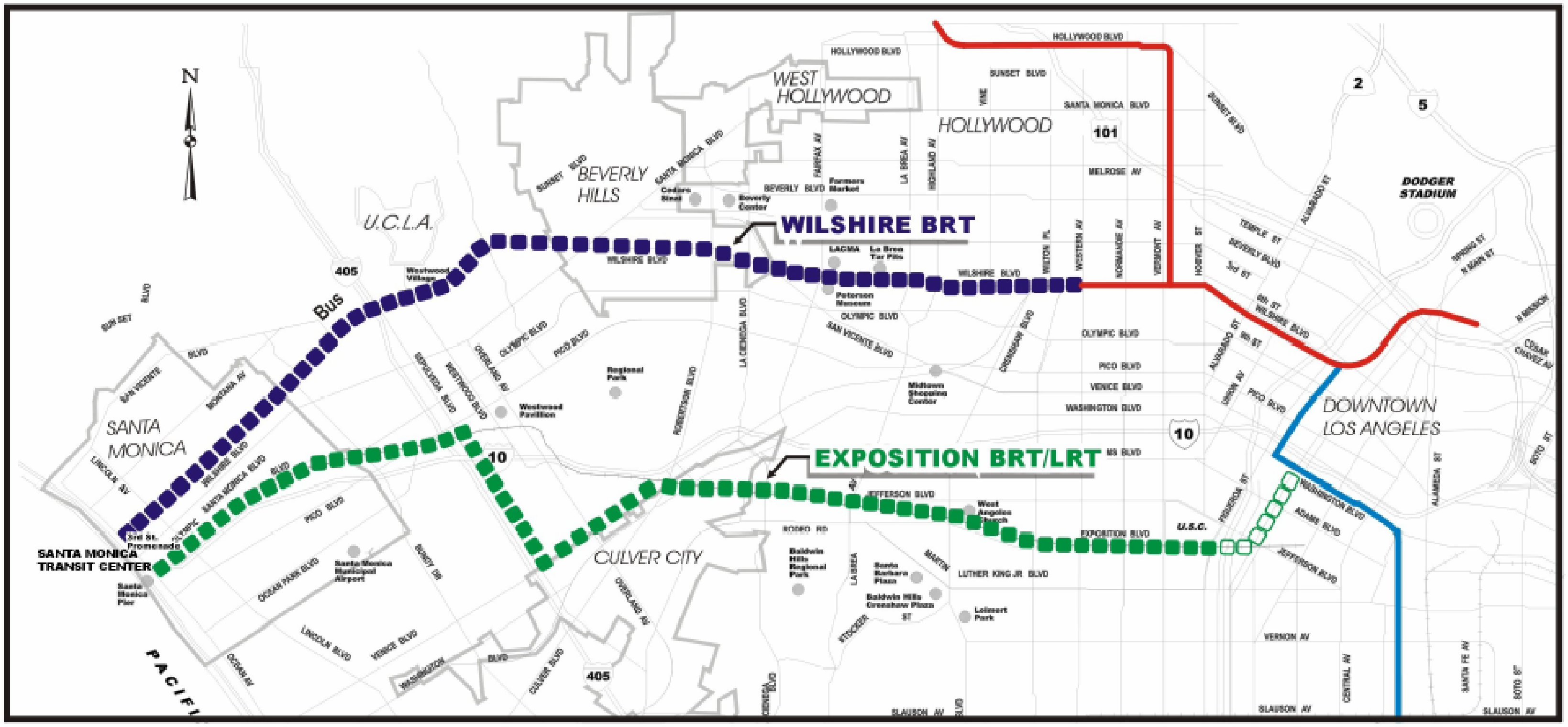


FIGURE 4-2 Mid-City/West side Transit Corridor

4.2 Pre-Metro Rapid Service and Planning for Wilshire

Before the implementation of Metro Rapid, MTA lines 18, 20 and 320 provided local bus service in the project area. Using previous timetables, the combined peak period average speed of this service was approximately 12 miles per hour, which is very similar to the current running speeds of the BRT system in Curitiba, Brazil. It took approximately 65-69 minutes to complete the journey from Wilshire/Western to the end of the line in Santa Monica.

The bus rapid transit line on Wilshire is an outgrowth of coordinated efforts by the City of Los Angeles and the Los Angeles County Metropolitan Transportation Agency to improve bus transit along this corridor. Based on input from passengers of the local bus lines through surveys and traffic studies conducted by the Los Angeles DOT, MTA learned that

- The public was dissatisfied with slow bus service
- The average speeds for MTA buses along the corridor had declined by 12% since the mid-1980s, and
- LADOT found that a bus was stopped 50% of the time that it was in service.

The Metro Rapid Program was initiated in March 1999 by the MTA's Board of Directors following an initial feasibility study. Staff was directed by the Board to conduct the administration's feasibility study in response to a visit to Curitiba, Brazil, by MTA and City of Los Angeles officials. The Curitiba urban design and public transportation model has been widely praised internationally for its success and has been a major force in the Federal Transit Administration's (FTA) creation of a national bus rapid transit initiative.

The feasibility study recommended that MTA, in partnership with the City of Los Angeles, conduct a demonstration along two to three major arterials that had strong ridership and favorable characteristics for BRT development. The operating experience accompanied by a performance evaluation would provide a basis for further BRT development.

Twelve key attributes were associated with the Curitiba System (See Table 4-1). Six of these, along with bus signal priority, were included in the Phase I Demonstration. The remaining six attributes (e.g., special lanes and high-capacity buses) would be deployed in the Phase II System Expansion (or as now called Mid-City/Wilshire BRT Enhanced Project, discussed in Section 4.3). The main objective of the Metro Rapid Bus Demonstration program was to offer rail-type frequent and high-quality transit services connecting the terminus of the Red Line to major destinations in outlying areas.

TABLE 4-1 Key Attributes of Curitiba Bus Rapid Transit System Compared to Los Angeles' Metro Rapid

Curitiba Key Attributes	Metro Rapid	
	Phase I Demonstration	Phase II Expanded System
Simple Route Layout	Yes	Yes
Frequent Service	Yes	Yes
Headway-based Schedules	Yes	Yes
Less Frequent Stops	Yes	Yes
Level Boarding and Alighting	Yes	Yes
Color-coded Buses and Stations	Yes	Yes
BUS-SIGNAL PRIORITIES		
Exclusive Lanes	No	Yes
Higher Capacity Buses	No	Yes
Multiple Door Boarding and Alighting	No	Yes
Off-Vehicle Fare Payment	No	Yes
Feeder Network	No	Yes
Coordinate Land Use Planning	No	Yes

4.3 Metro Rapid Bus Demonstration Program ─ Phase I

MTA implemented their "Phase I" Metro Rapid along the Wilshire corridor, designated as Line 720, which consisted of the following changes to service from the previous local bus service:

- Invested in low floor buses for level boarding
- Invested in signal priority software and hardware
- Equipped stops with *Next Bus* message information signs
- Reduced the number of stops from 135 to 30, spaced approximately 75% to 80% of mile apart as part of its simple route layout
- Implemented a new operation policies:
    - Faster buses can and are even encouraged to pass slower buses
    - Passengers are encouraged to alight the bus from the backdoor
- Placed bus stops generally on the far side of intersections; local stops remain on near side of intersection.
- Reduced headway to 2.5 minutes during peak periods, that is, between 7 and 10 AM and between 4 and 7 PM.
- Introduced prepaid fare payment (although passengers can still pay the driver)
- Color-coded Metro Rapid buses and stops/stations using red and white with "Metro Rapid" designated on each bus and a symbol above the word "Rapid" to represent fast movement. Use of this design and colors on vehicles and stations help to promote and instill a unique identify of the service in passengers' minds.

The Wilshire/Whittier Metro Rapid lines began service in June 2000, coinciding with the opening of the extension of the Metro Rail Red Line north to the San Fernando Valley. All seven of the Phase I attributes were fully operational at start-up except for the Metro Rapid stations where temporary stops were utilized. In September 2000, an additional 23 trips were added during peak periods with a resulting 10% increase in ridership within just three days, indicating a strong latent demand still remaining. The *Next Bus* displays were installed at selected stations in 2001. Pictures of the Metro Rapid bus and stops/stations, which convey its unique identity are shown in Figures 4-3 and 4-4.

FIGURE 4-3 Metro Rapid Bus: Unique Identity

FIGURE 4-4 Metro Rapid Bus Stop: Unique Identity

4.3.1 Elements of the Metro Rapid Bus

Running way

Buses operate in mixed traffic, usually in the curb lanes wherever they are available. This permits curbside passenger boarding and alighting.

BRT Services

The Wilshire-Whittier Metro Rapid runs from Santa Monica to the city of Montebello. There are 30 stations along the entire 27-mile route and 20 stations along the portion of the route that is the focus of this case study. Service was initially provided at 3-minute intervals during peak periods and at 10-minute intervals during off-peak and on weekends. As ridership increased, the westbound peak headway was reduced to 2-1/2 minutes.

Metro Rapid BRT service is complemented by local bus service on the Wilshire Boulevard corridor. Local bus service generally alternates with Metro Rapid service resulting in approximately 50 buses per hour on Wilshire, exclusive of overlapping bus routes.

Vehicles

Buses, manufactured by North American Bus Industries (NABI), are low-floor vehicles with a seating capacity of 40 passengers, compressed natural gas (CNG) buses. The buses have a special exterior paint design of red and white that is easy to distinguish from other buses as well as from MTA's other local buses traveling on the Wilshire corridor and is coordinated with the color scheme of stop/station design. The buses also have a special interior image. They are equipped with bus signal priority transponders, automatic vehicle location and automatic passenger counters systems.

Stations

Exclusive Metro Rapid bus stops are located on the far-side corner of intersections, whereas local stops are located on the near-side. A *Next Bus* display indicates when the next bus will arrive. Shelter, landscaping, station art, and seats are provided. Stations and buses share visual cues including color and graphics.

Transit Priority Signal System (TPS)

A bus priority system along the portions of the Wilshire Boulevard corridor located within the city of Los Angles gives buses running behind schedule additional green signal time. Traffic signals within the city of Los Angeles constitute approximately one-half of the signals along the corridor between the Pacific Ocean and the Los Angeles CBD that is the focus of this case study. The other half run through the cities of Santa Monica and Beverly Hills. The reader is referred to subsection 2.5 for a discussion of the tradeoff between the technical and institutional issues associated with implementing transit signal priority along only a portion of the corridor. A key objective was to maintain uniform headways between successive buses. The signal green time along the bus routes may be advanced or extended up to 10% of the signal cycle whenever a bus approaches. (Cycle lengths range from about 70 to 90 seconds, with longer cycles in a few locations). At certain major intersections, the green light may be extended only in every other cycle. To prevent drivers from speeding up to extend the green time, early buses are not given priority.

The system is based on communications between antennae loops embedded in the pavement and transmitters mounted on buses. The automatic bus detection using loops and transponders was designed to reduce bus delay, maintain bus spacing, and simultaneously minimize impact on cross traffic. Each signalized intersection in the project is equipped with loop detectors that serve as Automatic Vehicle Identification (AVI) sensors. These sensors, embedded in the pavement, receive a radio-frequency code from a small transponder installed on the underside of each vehicle. Buses equipped with unique transponders are detected when traveling over the loop detectors. These loops are connected to a sensor unit within the traffic signal controller at each intersection, which transmits the bus identification number to the Transit Priority Manager (TPM) computer in the city's Automated Traffic Surveillance and Control (ATSAC) Center at City Hall East for tracking and schedule comparison. Once the bus identification and location are received by the TPM, the computer determines the need for traffic signal priority. If the bus is early or ahead of the scheduled headway, no traffic signal priority treatment is provided. However, if the bus is late or beyond the scheduled headway, then the downstream traffic signal controller will provide signal priority to help the bus catch-up with the scheduled headway. In addition, real-time data links from the MTA dispatch center to the ATSAC center are used to obtain the daily bus assignment for schedule comparison.

Traffic signal control at each intersection is provided by a Model 2070 controller that is equipped with a state-of-the-art software program developed by the City of Los Angeles specifically for this project. Once the Model 2070 traffic signal controller receives a request from the Transit Priority manager, it implements one of four types of traffic signal priority actions depending upon the point in time when the signal controller receives the commands, relative to the background cycle. The four types of traffic signal priority actions are the following:

- "Early Green" priority is granted when a bus is approaching a red signal. The red signal is shortened to provide a green signal sooner than normal.
- "Green Extend" priority is granted when a bus is approaching a green signal that is about to change. The green signal is extended until the bus passes through the intersection.
- "Free Hold" priority is used to hold a signal green until the bus passes through the intersection during non-coordinated (free) operation.
- "Phase Call" brings up a selected transit phase that may not normally be activated. This option is typically used for queue jumper operation or a priority left turn phase.

Operations and Maintenance

Bus schedules for Metro Rapid BRT service use vehicle spacing, that is, headway rather than time points. Bus drivers are encouraged to drive fast and overtake slower vehicles, including slower buses. Lane supervisors monitor service. Maintenance policies include new enhanced daily cleaning of vehicles, zero tolerance of vehicle defacement (e.g., seat inserts) and enhanced station maintenance and cleaning. A satellite operation control center, developed specifically for the Metro Rapid program, provides a graphic display of bus operations for management.

4.3.2 Evaluation of Metro Rapid Bus ─ Phase I

The Metro Rapid Demonstration program had seven basic objectives:

1. Reduce passenger travel times
2. Increase service reliability
3. Increase corridor ridership
4. Attract new riders
5. Improve fleet and station appearance
6. Improve service effectiveness, and
7. Build positive community relations

The program has been successful in achieving these objectives. Operating speed, service quality, ridership, and customer response have all exceeded expectations, with very little or no negative impact on the rest of the system and general traffic. Some of these results are discussed in detail in the following section (10).

4.3.2.1 Operating Speed

The Metro Rapid program introduced several attributes specifically designed to improve service operating speeds. These included transit signal priority, level boarding/alighting with low-floor buses, headway- rather than timetable-based schedules, fewer stops, far-side intersection location of stations, and joint active management of the service operation from the Transit Operations Supervisors (TOS) in the field and the MTA Bus Operations Control Center (BOCC). Since the start of service, Metro Rapid has achieved several major improvements in operating speeds. Travel time savings of about 25% were recorded in the corridor (See Table 4-2). Overall bus travel speeds increased from 11 to 14 mph [18 to 23 kph] on Wilshire Boulevard. The impacts to cross-street traffic were minimal, typically averaging about 1 second of delay per vehicle per cycle.

TABLE 4-2 Metro Rapid Changes in Travel Time

Speed improvement	Wilshire─Whittier Corridor
Overall Speed Improvement	29%
Eastbound (Range)	31% (18-40%)
Westbound (Range)	28% (21-32%)

The City of Los Angeles DOT conducted independent research regarding the attributes that contributed to the speed improvement and found that the transit signal priority system accounted for approximately one third of the improvement and the other elements, e.g., wider stop spacing, accounted for the remaining two thirds of the benefit. Corridor segments with transit signal priority operate faster than segments without priority, especially when ridership loads are considered. To further increase bus speeds along the

Wilshire/Whittier corridor, transit signal priority needs to be extended to the segments in Beverly Hills, East Los Angeles, Montebello, and Santa Monica.

Metro Rapid operated faster in mixed arterial traffic than the Curitiba Express lines in exclusive lanes. This is attributed to Curitiba's closer station spacing and externally controlled vehicle speed governors. Depending on the time of day and direction of travel, Metro Rapid speeds average between 14 and 30 mph [23 and 48 kph] compared to Curitiba's average speed of 13.8 mph [22 kph]. Several segments the Wilshire Metro Rapid line operated significantly more slowly because of other factors:

1. Traffic congestion caused major delays for Line 720 through downtown Los Angeles.
2. Very high ridership loads result in extended dwell times and slower operations between downtown Los Angeles and Western Avenue. The higher-capacity buses and multiple-door boarding in Phase II will reduce dwell times significantly, further improving operating speeds.

4.3.2.2 Service Quality

The key elements of service quality that were considered important were reduction in bus bunching (headway ratios), average passenger wait times, and passenger standing loads. Line 720 Wilshire/Whittier headway ratios show considerable bus bunching, especially during peak periods when the buses are very frequent. Average passenger wait times are typically less than five minutes except during afternoon peak periods, especially westbound, when wait times can exceed the typical headway. High daily ridership results in high average loads for much of the day. The passenger-perceived average loads were even higher due to the variability induced by the high headway ratios (bus bunching).

4.3.2.3 Ridership

MTA has estimated the ridership on the two Metro Rapid corridors using both point-check data and data from automated passenger counters. Although the two methods return somewhat different results, there is agreement that ridership has increased dramatically on both corridors by approximately 25% to 33% (See Table 4-3).

TABLE 4-3 Ridership Changes Due to Project Implementation

Total Unlinked Ridership	Wilshire/Whittier Corridor Before	Wilshire/Whittier Corridor After
Local	39,708	55,946
Limited	23,785	---
Metro Rapid	---	28,207
Total Ridership	**63,493**	**84,153**
% Corridor Ridership		
Local	63%	66%
Limited/Metro Rapid	37%	34%
Net Increase	---	20,666
% Increase	---	32.6%

The increase in the Wilshire/Whittier corridor appears to result from major growth in both Metro Rapid and local ridership, with the percentage of riders using Metro Rapid dropping slightly from the historic limited-stop service. This is possibly due to (a) the wider stop spacing for Metro Rapid, (b) the old limited-stop service was only limited-stop for a portion of the route and operated in local service for long segments, and (c) some people transfer between the Metro Rapid and local buses along the corridor. The Wilshire/Whittier Metro Rapid appeared capacity constrained in the morning peak period, and an additional 23 trips were introduced in September 2000, to alleviate the problem. This resulted resulting in an immediate increase in ridership for the overall Metro Rapid line.

Passenger surveys indicated that one third of the overall increase was from new riders (patrons who never rode transit before), one third was from current riders riding more often, and one third was from riders of other MTA transit switching to service in these corridors.

4.3.2.4 Operating and Capital Costs

A principal advantage of Metro Rapid service is that its operating and capital costs are considerably lower than those for rail. Capital costs are summarized in Table 4-4. The overall demonstration cost for stations and bus signal priority was $8.3 million, or slightly less than $200,000 per route mile. The Metro Rapid capital program involved three areas: station development, bus signal priority, and vehicle acquisition.

- The station program was designed, fabricated, and installed at a cost of approximately $100,000 per mile.
- The bus signal priority system cost was approximately $20,000 per intersection.
- NABI, 40-foot, CNG, low-floor buses from current fleet procurement orders were used to operate the Metro Rapid routes.

Operating costs are shown in Table 4-5. The overall annualized (12-month) marginal operating cost of Metro Rapid Demonstration service approximates $12.7 million – slightly under $300,000 per route mile.

TABLE 4-4 Capital Cost for Metro Rapid on Wilshire Corridor

Capital Element	Wilshire-Whittier	
	Units/Miles	Cost
Stations	25.7 miles	$2,441,000
Bus Signal Priority	25.7 miles	$2,569,000
TOTAL DEMONSTRATION	---	$5,010,000

TABLE 4-5 Operating Cost for Metro Rapid on Wilshire Corridor

	Annual Operating Cost			
Corridor	Pre-Rapid	Post-Rapid	Net Change	% Change
WILSHIRE-WHITTIER				
Lines 18/318	$10,563,000			
Lines 20/21/22/320/322	$14,964,000			
Line 18		$8,312,000	($2,251,000)	-21.3%
Lines 20/21		$10,261,000	($4,703,000)	-31.4%
Metro Rapid 720		$14,137,000	$14,137,000	N/A
Combined Corridor	$25,527,000	$32,710,000	$7,183,000	28.1%

4.3.3 Desired Improvements

The Phase I Demonstration program has proven successful in increasing speeds, improving reliability, and attracting riders. However, several areas emerged where additional refinements are desirable:

(1) Continue to improve bus operating speeds by completing the transit signal priority installation along the corridor outside of the city of Los Angeles (in Beverly Hills and Santa Monica).

(2) Introduce exclusive bus lanes where feasible and give priority to arterial segments with chronic, debilitating, traffic congestion delay.

(3) Provide more passenger capacity along Wilshire/Whittier Boulevards by introducing larger vehicles during peak periods rather than increasing service frequency.
(4) Reduce station dwell times by testing and introducing off-vehicle fare collection systems such as “proof of payment” and introducing high-capacity buses to manage standees within standards and avoid gross aisle congestion delays.

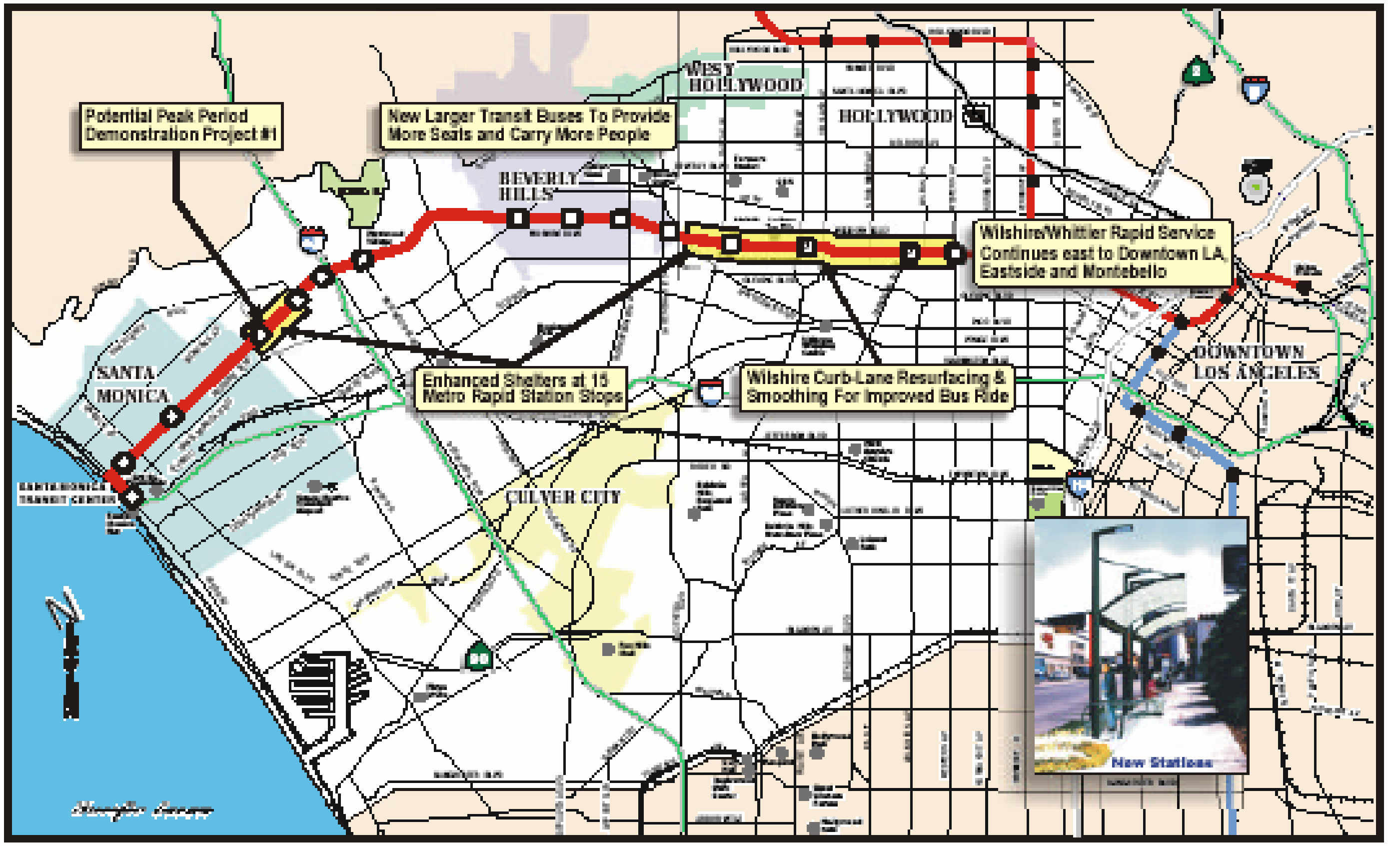
Accordingly, MTA has proceeded with Phase II of the Metro Rapid Bus Demonstration that is described in the following section under the new identifier of Mid-City/Wilshire BRT Enhanced Project (20 and 21).

4.4 Mid-City/Wilshire Bus Rapid Transit Enhanced Project

Since the opening of Metro Rapid service on Wilshire Boulevard in June 2000, bus ridership has increased more than 25 percent. Metro Rapid travel times have been reduced up to 25 percent compared to local Metro service along Wilshire Boulevard due to Metro Rapid’s features. Currently there are approximately 80,000 boardings each day along the route including Metro Lines 18, 20, 21, 22, and Metro Rapid Line 720, and a total of approximately 100,000 boardings per day when other bus operators are included, making it one of the heaviest-used bus transit corridors in the nation. In spite of this, many buses travel at less than eight miles per hour along segments of the route because of heavy traffic congestion. The latent demand for faster transit service along this corridor is evident by the tremendous overcrowding on Metro Rapid along the majority of the project area route.

The Wilshire BRT Enhanced Project (Figure 4-5) focuses on the western portion of the route specifically between Western Ave on the east and the Pacific Ocean on the west in the City of Santa Monica. These enhancements will, referred to as Phase II of the Metro Rapid Bus Project in Table 4-1, build upon the successes of the existing Metro Rapid features by adding the following project elements that are expected to contribute greatly to the success of a mature BRT system (Table 4-6), and further reduce travel time (Figure 4-6 and 4-7) (17 and 19):

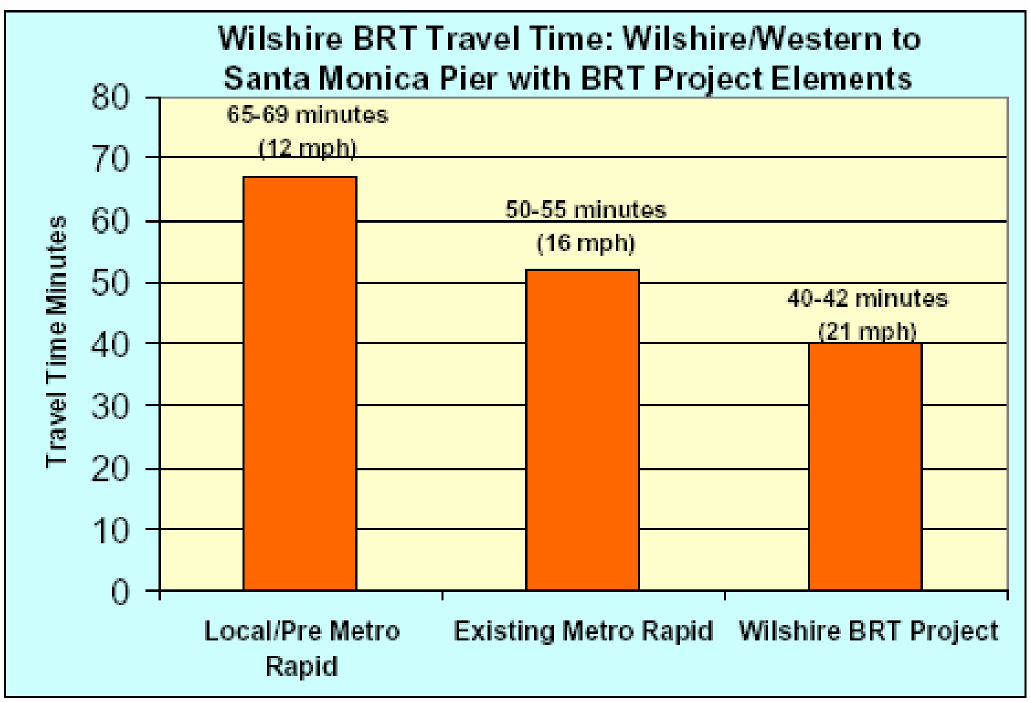
FIGURE 4-5 Wilshire Bus Rapid Transit Enhanced Project



The Wilshire Bus Rapid Transit Corridor runs from the Wilshire/Western Metro Red Line Station to the Santa Monica Pier.

Further enhancements:

- Curb lane bus operation
- Demonstration peak period lanes on certain segments in coordination of cities
- Smoother ride on rebuilt concrete lanes
- Smartcard fare payment
- Ticket vending machines at bus stops to reduce boarding time
- Enhanced traffic signal system
- New larger buses to increase bus capacity and reduce crowding in rush-hour periods
- multiple-door entry and exit
- New bus designs for greater passenger comfort
- Maintains all existing landscaped medians
- Maintains all left turn pockets



The Metro Rapid has improved travel times in the project area by 25 percent. The Wilshire BRT will further improve travel times by another 25 percent. The same trip will now be about 15 minutes shoret than today's Metro Rapid and almost 30 minutes shorter than local buses.

FIGURE 4-6 Additional Expected Reduced Travel Times with Wilshire Bus Rapid Transit Enhanced Project

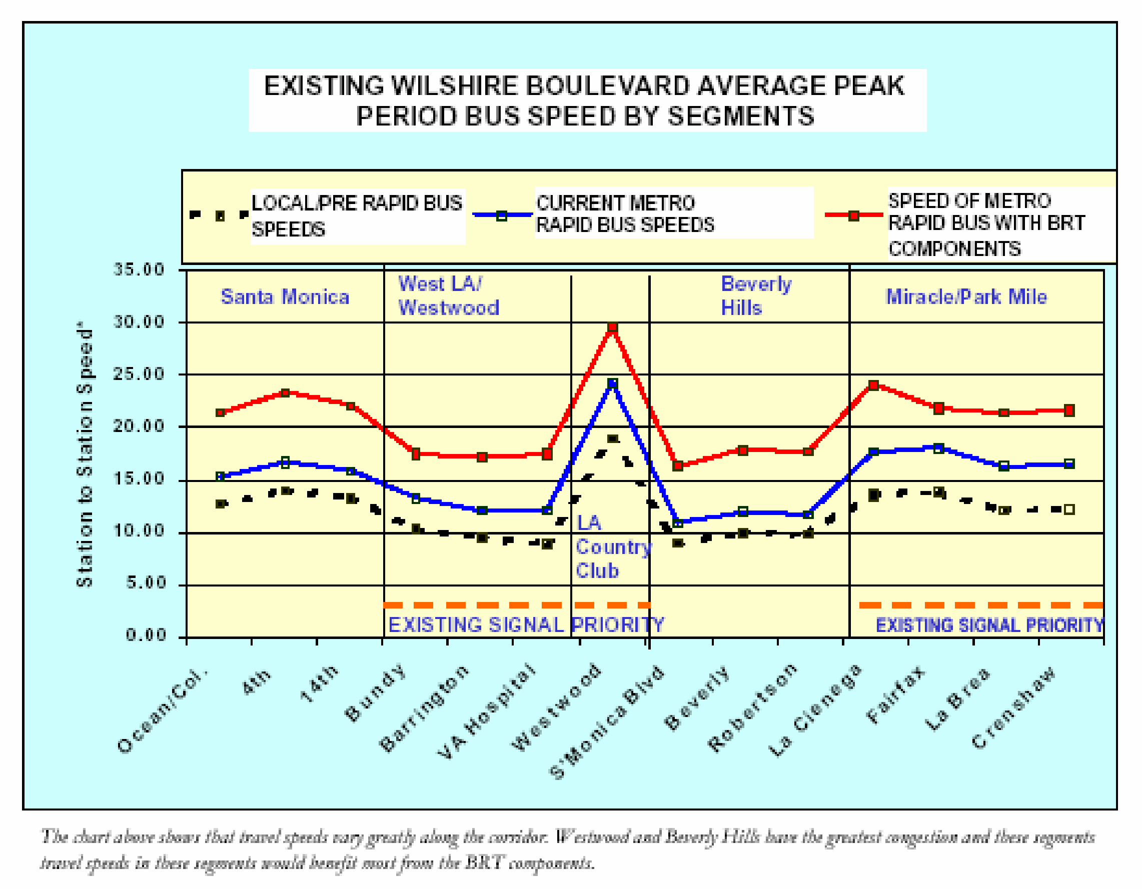


FIGURE 4-7 Additional Expected Travel Speed Increases with Wilshire Bus Rapid Transit Enhanced Project

TABLE 4-6 Key Features of Existing Metro Rapid Compared with Enhanced BRT Project

KEY FEATURES	Existing Metro Rapid	Enhanced Project
Simple Route Layout	X	X
Frequent Service	X	X
Headway-based Schedules	X	X
Less Frequent Stops	X	X
Level Boarding and Alighting	X	X
Bus Signal Priority	X	X
Next Bus Displays	X	X
Higher Capacity Vehicles		X
Multiple Door Boarding and Alighting		X
Point of Sale Fare Pre-Payment		X
Fare Payment Machines		X
Curb Lane Repair for Smoother Ride		X
Station Areas with Larger Canopies		X
Station Area Landscaping		X
Information Kiosks		X
Operations and Maintenance Facility		X
Exclusive Peak Hour Bus Lanes on segments of the route as supported by local jurisdiction		X

The features of the Wilshire BRT Enhanced Project are discussed more fully in the following sections. Table 4-7 provides a comparison of the project elements that would be incorporated into each neighborhood segment.

TABLE 4-7 Proposed Improvements by Neighborhoods

	Wilshire Center	Park Mile	Miracle Mile	Beverly Hills	Westwood	County of LA	West Los Angeles	Santa Monica
New Higher Capacity Bus Transit Vehicles	X	X	X	X	X	X	X	X
Enhanced Station Areas, Shelters and Landscaping	X	X	X	X	X	X	X	X
Curb Lane Repair & Reconstruction	X	X	X					
Bus Stopping Pads	X	X	X		X	X	X	
Parking Facilities		X	X					
Bus Maintenance Facility	Located in Downtown Los Angeles							
Peak Period Dedicated Transit Lanes	Subject to further testing & approvals by each city jurisdiction.							

4.4.1 Bus Rapid Transit Elements

Vehicles

Currently there are approximately 95 vehicles in Metro Rapid service on the Wilshire corridor. These buses are 40-foot, low-floor, 40-passenger capacity, North American Bus Industries (NABI), compressed natural gas (CNG) buses. They have a special red and white exterior paint scheme that is easy to distinguish from Metro's other buses as well as other agency's buses and is coordinated in color with the stations. They are equipped with bus signal priority transponders, automatic vehicle location, and automatic passenger counters (Table 4-8).

As an interim step, 45-foot long vehicles ("Compo bus") may be introduced. These vehicles operate on Compressed Natural Gas (CNG). They are five feet longer than existing vehicles thereby increasing capacity by about 15 percent.

The next generation of buses is "articulated". These vehicles are approximately 60 feet in length and provide 50 percent more capacity than current 40-foot buses. They also operate on Compressed Natural Gas or Electric/Hybrid technology, and are designed to provide three doors, for faster boarding and alighting. Ridership projections indicate that single-articulated (60-foot-long) buses would be able to accommodate demand in the beginning years of service. These vehicles would provide an average seated capacity of 65 passengers, with space available for another 13 to 30 standees.

TABLE 4-8 Benefits Associated with New Vehicles

New features	Benefit
Higher Capacity Vehicles	The vehicles will have at least 50 percent more carrying capacity thereby reducing overcrowding.
Multiple Door Boarding	The vehicles will have three doors instead of two, to allow faster boarding and exiting. All doors will be used for both boarding and alighting.
Circulation Layout	The internal layout of the vehicle will be designed to minimize bottlenecks near doors allowing passengers to enter and exit easily and quickly.
On Board Fare Validators	Smart card fare validators will allow passengers to enter through any door and validate their fare. Exact cash fare will be accepted through the front door only.
Variable messaging on-board vehicle	"Next stop messaging" will give information about next stop and transfer points.

BRT Stops/Stations

The Wilshire BRT enhancements would upgrade existing Metro Rapid shelters at 15 stops along the route. All stations would be configured as split platforms and located on either side of Wilshire Boulevard to serve westbound or eastbound travel demand. A total of 30 shelters will be upgraded along the route. Most stations will be in the same location as the existing Metro Rapid shelters. The distinctive "gates" will be expanded to provide three gates where possible. Each “gate” will frame one of the doors of the new 60-foot articulated buses.

Similar to Light Rail Transit, BRT riders would be able to enter or exit the transit vehicles from any door. Shelters will have three gates aligned with the three doors of the future 60-foot articulated buses facilitating multiple door boarding. Smart Card fare media would be read by validators located on-board the bus at each of the three doors. Transit riders would debit fares by waving the Smart Card at the validator upon boarding and exiting the vehicle.

A typical BRT station would consist of a canopy with lighting to protect passengers from sun and rain, boarding gates to act as guides to the vehicle’s entry points, and amenities including:

- Kiosk with transit and district maps
- Bus schedule displays
- Real time bus arrival information (next bus sing)
- Emergency/information phone
- Ticket vending machine nearby
- Seating and lean bars at stops
- Landscaping
- Public art
- Bicycle facilities (racks and/or lockers)
- Enhanced cross walks
- Enhanced lighting
- Distinctive pavement marking

4.4.2 Wilshire Boulevard Curb Lane Reconstruction

Curb lane reconstruction on Wilshire Boulevard between Western Avenue and San Vicente Boulevard in Wilshire Center, Park Mile and Miracle Mile districts will allow both transit vehicles and motorists a more comfortable and safer ride. The current roadway condition includes potholes and a severe cross slope. Vehicles traveling in the curb lane experience severe bumps at each cross street, coupled with jolts from cracked pavement and potholes. Buses experience frequent damage to undercarriages and unpleasant ride quality for transit riders. Reconstructing and smoothing the curb lane along this segment will mean the curb lane will be better utilized and will allow for a more comfortable transit service experience. In addition, concrete bus pads will be installed at Rapid Bus Stops in West Los Angeles, which are currently not large enough to accommodate 60-foot long vehicles (10).

Signal Priority

The Metro Rapid Bus has helped to increase speeds through the use of transit signal priority that have helped to increase traffic flow on Wilshire in mixed traffic with minimal impacts to north-south traffic. Currently, signal priority is implemented along the Wilshire corridor that lies within the city of Los Angeles. Additional signal priority is being sought in Beverly Hills, Santa Monica and the Veterans Administration's property that is operated by the County of Los Angeles.

Peak Period Bus Lanes

The MTA has proposed a three-stage demonstration of dedicated bus lanes in the peak period (7:00am to 9:00am and 4:00pm to 7:00pm) along selected segments of Wilshire Boulevard — the curb lane — if supported by the local city/jurisdiction. These three stages will be implemented in a series of field tests and evaluations based on a comparison of before and after values of particular performance measures. In off-peak hours and on weekends, the entire route would operate in mixed flow traffic, just as it does today. During peak periods, selected segments would operate as "Bus Only" lanes, subject to the approval of each city/jurisdiction. Areas of Wilshire Boulevard recommended for exclusion for consideration as peak period dedicated segments include Westwood (Comstock to Selby) and Santa Monica (Centinela to Ocean).

There are still significant rush hour periods when general traffic and transit buses are slowed to less than five miles per hour. The implementation of a transit lane during these peak periods will keep the transit buses moving and provide an incentive for more people to choose transit and help stabilize the number of cars on the road. Overall, the bus lane will allow four to five times the people-moving capacity of a general-purpose lane during these periods of heavy congestion.

The MTA Board specified that any dedicated bus lanes should not be implemented as a component of the project unless approved by the local City or County jurisdiction. Each stage is expected to be field tested for a period of six months together with being evaluated.

- Stage I: Between Centinela and Federal Avenues -- To measure the effectiveness of an exclusive curbside BRT lane operation during AM and PM peak periods by improving Metro Rapid's existing system service along this portion of Wilshire Boulevard. Right-turning vehicles will be allowed to enter the BRT lane and use it as a shared lane prior to the intersection. Buses will be allowed to exit the BRT lane to avoid potential delays caused by right-turning vehicles. This portion of Wilshire Boulevard contains two Metro Rapid stops at Barrington and Bundy Avenues. Prior to the start of this stage of the demonstration, curbside parking was allowed during both morning and afternoon peak periods. Thus, during the period of performance for Stage 1, there will be no need for curbside traffic diversion, though parking spaces will be lost.

- Stage II: Between La Brea and San Vicente -- To analyze potential impacts caused by through traffic diversion to parallel streets due to conversion of a curbside travel lane to an exclusive BRT lane during peak periods. This portion of Wilshire Boulevard contains two Metro Rapid stops at Fairfax and La Brea Avenues.

- Stage III: Between Western and La Brea: Similar to Stage II except that the curbside lanes within this portion of Wilshire Boulevard are 10½ feet wide, narrower than the transit lane standard. Thus, in addition to a through traffic diversion analysis, demonstration of an electronic guidance system would be included in this project. This portion of Wilshire Boulevard contains three Metro Rapid stops at La Brea, Crenshaw, and Western Avenues.

The Stage I Demonstration Project is currently in operation and has a 6-month period of performance. Stages II and III would presumably occur in the 2005-2006 time frame. For purposes of this case study analysis, we focus on the site of the Stage III Demonstration Project because of its near-term focus significance to and for MTA (22).

The MTA's goal is to implement BRT service, via peak-period exclusive lanes, from Western Avenue to Centinela Avenue. Such upgraded service would be a seamless part of the Wilshire-Whittier Metro Rapid service. However, only by success of the Demonstration Program and local concurrence will the full project be implemented.

Parking Facilities

The MTA normally constructs park and ride lots as a part of new transit lines to encourage high ridership and provide a place for transit patrons to leave their cars when they board a bus or train. No parking lots have been explicitly provided for this purpose along the Wilshire BRT route: 1) because of the density of the Wilshire corridor; and 2) because it the MTA's intent not to attract additional automobile trips into the corridor.

However, the MTA owns two sites (one at the southwest corner of Wilshire and Crenshaw Boulevards, and the other at the northwest corner of Wilshire Boulevard and La Brea Avenue) that could be used on an interim basis pending the ultimate development or disposition of these MTA properties. These parking facilities would provide parking for the Wilshire BRT project, as well as parking for those with existing lease agreements with the MTA.

Crenshaw Parking Facility

The MTA-owned Wilshire/Crenshaw site is 1.6 acres. This site contains a surface parking lot with 135 parking spaces that are currently leased to the Los Angeles Unified School

District (LAUSD), and a vacant lot. This site also surrounds a 0.2-acre residential parcel on three sides, which is currently privately owned and occupied as a single-family residence that would be acquired for the project.

The future parking facility would provide 167 spaces. Proposed for this site are enhanced paving in the crosswalks, landscaping and a new local bus stop with a curvilinear steel shelter.

La Brea Parking Facility

The MTA-owned Wilshire/La Brea site is 1.23 acres. The western portion of the site contains a self-service parking lot with approximately 50 spaces, and a newsstand. An unstriped parking lot is north of this lot. The two lots provide parking to surrounding commercial and residential uses. The eastern portion of the site contains an existing building, with a Metro Customer Service Center and a consignment store.

The future facility would involve the resurfacing and repaving of the two parking areas to provide a total of 74 parking spaces. The property would be brought into code compliance and landscaping would be added to the site. The MTA would maintain existing lease agreements; the newsstand owner/patrons use some spaces, while surrounding businesses and residences use other spaces. Additional spaces and bicycle parking facilities would be available for transit patrons. Access would be provided via Detroit Street.

Maintenance and Storage Facilities

The Wilshire BRT system will require a bus storage and maintenance facility. The facility would provide maintenance for the Wilshire BRT and Metro Rapid Bus systems. The existing Division 10 maintenance facility was chosen for this purpose. This facility is located in the City of Los Angeles. It is approximately 20.2 acres and has been in operation since 1984.

The proposed expansion would add approximately 8.6 acres to the existing facility. The site would be expanded through land acquisition and by including a triangular shaped area south of the Metro Link tracks, for a total of 28.8 acres. The completed facility would allow for parking and servicing of approximately 500 buses; approximately 100 additional buses above the 400 vehicles that are presently serviced at this facility.

All project elements are scheduled to be in service by November 2005.

BRT Service Characteristics

Bus operations of the Wilshire BRT are based on existing Metro Rapid service per MTA Line 720. In essence, the same Metro Rapid routes would be operating but would be able to take advantage of the dedicated bus lanes during the peak period. Similar to the level of Metro Rapid service in operation now, service frequencies would range from two to five minutes in the peak period and five to ten minutes in the off-peak period.

Existing local bus service will continue to run on Wilshire Boulevard (MTA 20 series and Santa Monica Municipal Bus Line 2). A summary of operating characteristics for the Wilshire BRT is provided in Table 4-9.

TABLE 4-9 Wilshire Bus Rapid Transit Operating Characteristics

Transit Service	Existing Wilshire/Whittier Metro Rapid Bus routes use BRT lanes from Santa Monica City limit to Western Avenue. Assumes similar service frequencies to existing Metro Rapid service, approximately 2-5 minute headways in peak and 5-6 minutes in off-peak.
Operations	Single-articulated buses (60 feet long) would be used. Average dwell time of 30 seconds is assumed, which may require facilitated boarding/alighting methods such as proof of payment fare collection and boarding/alighting through both front and rear doors.
Max speed	35 mph
Average speed	19.2 mph along BRT segment, including stops and delays at intersections; 16.2 mph average from downtown Santa Monica to downtown Los Angeles. Off-peak speeds average 14.2 mph.
Signal preemption	For transportation model purposes, partial signal preemption assumed at major intersections and full preemption assumed at minor intersections.
Transit running time	57.6 minutes during peak and 70 minutes during off-peak from downtown LA (5th/Grand) to downtown Santa Monica.

Source: Manuel Padron Associates, 2001

4.4.3 Project Implementation Approach

Current Status

The Wilshire BRT project was environmentally cleared in August 2002 with construction bids accepted in Spring and Summer 2003. The project is scheduled to be open for service on or before November 2005 (10).

Proposed Construction Packages

The MTA Board approval of the Wilshire BRT LPA specifically stated that project implementation would be subject to local jurisdictional approval. To address specific jurisdiction-by-jurisdiction concerns, the MTA is planning to implement the project via seven construction "packages", as follows:

1. Curb Lane Repair and Reconstruction, Stations and Signals within City of Los Angeles
2. New Stations in Beverly Hills
3. New Stations in Santa Monica
4. New Station at VA Hospital
5. Demonstration Program for each transit lane
6. Bus Storage and Maintenance Facility in Downtown Los Angeles
7. Parking Facilities (at Crenshaw and La Brea MTA-owned sites)

Note, that these seven packages are not typical BRT elements, as understood in our theoretical framework. However, in reality institutional and budgetary constraints may divide the projects into segments other then the main BRT elements.

In the next segment we briefly address each construction package.

Wilshire Boulevard Curb Lane Repair and Reconstruction in the City of Los Angeles
The majority of the construction activities (lane repair/reconstruction and installation of concrete bus pads) would occur along a four-mile segment of Wilshire Boulevard, between Western Avenue and San Vicente Boulevard. Lane reconstruction would not occur from San Vicente Boulevard to Ocean Avenue (West Los Angeles and Santa Monica) since the curb lane is in good repair in these areas. Bus pad reconstruction is proposed in West Los Angeles between Westwood Station and Bundy Station, to provide for enlarged transit vehicles. Bus pads in Beverly Hills and Santa Monica are already in place to support such vehicles.

The intent of the curb lane reconstruction between Western Avenue and San Vicente Boulevard is to provide a level travel surface for the buses, and in turn a more comfortable ride for bus passengers. The area to be reconstructed would be at the intersections and at mid-blocks between the intersections. Construction would consist of the following components:

- Reconstruction of travel lanes and bus pads on Wilshire Boulevard (between Western Avenue and San Vicente Boulevard)
- Installation of bus pads only at station locations from Westwood Boulevard to Bundy Drive
- Installation of station shelters and station landscaping along the entire Wilshire BRT route (from Western Boulevard to Ocean Avenue)
- Installation of additional infrastructure for elements such as communications and signaling

Construction of the curb lane improvements between Western and San Vicente is expected to occur in three phases. Under each phase, different groups of three to four street block segments would be affected.

Station Installation

During roadway reconstruction, 30 curbside shelters would be installed (one eastbound and one westbound shelter at 15 different intersections).

Stations and Signals in Beverly Hills and Santa Monica

Separate discussion will be held with the cities of Beverly Hills and Santa Monica to reach agreement on the introduction of transit signal priority and BRT stations and peak-period curb lanes where appropriate. Implementation of any of these project elements would only occur following council approval in these two cities.

Station at VA Hospital

The Metro Rapid system is currently serving the Veteran's Administration (VA) Hospital via the existing Metro Rapid bus pullout at Bonsall Drive. As part of the Wilshire BRT Project, this stop would be upgraded to full BRT standards to accommodate articulated buses. Separate discussions will be held with the County of Los Angeles and the Veteran's Administration regarding upgrades to the VA Hospital station.

Bus Storage and Maintenance Facility

This design package of the implementation approach for the Wilshire BRT Project will constitute a separate construction package.

Parking Facilities

Two parking facilities would be upgraded as part of the Wilshire BRT project. The final implementation package(s) would therefore entail the construction of these two sites.

4.5 Data Collection

Our case study focused on ridership during peak periods of the Metro Rapid Bus during weekdays and so we collected data during the days of the week and times of the day that represented peak travel times, and average and heavy passenger loads. MTA's staff recommended that each weekday between 7 AM and 10 AM was morning peak and between 4 PM and 7 PM were afternoon peak travel times. Data was collected during morning and afternoon peak periods on two typical weekdays (Monday and Thursday) selected in consultation with MTA to represent average and crush passenger volume load days, respectively. The raw data was then reduced and entered into an Excel spreadsheet in preparation for data analysis[2].

We collected data by making observations about the number of passengers boarding and alighting each bus and the passenger load for each bus upon its departure from the bus stop together with the bus arrival and departure time and bus identification number, that is, the bus' run number. Again, our focus was on that part of the Wilshire-Whittier Metro Rapid line between Santa Monica and Downtown Los Angeles consisting of twenty bus

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[2] We collected data on Monday, April 7 and Thursday, April 10 during 7-10am and 4-7pm.

stops along this approximately 20-mile long corridor, consisting of, heading from west to east:

- 5th/Colorado
- 4th
- 14th

Santa Monica

- Bundy
- Barrington
- VA Hospital
- Westwood

Los Angeles

- Santa Monica
- Beverly
- Robertson
- La Cienega

Beverly Hills

- Fairfax
- La Brea
- Crenshaw
- Western

Los Angeles

- Normandie
- Vermont
- Alvarado
- Witmer
- 5th/Grand (Downtown Los Angeles)

Los Angeles

During the morning peak periods we collected data on Metro Rapid buses heading in the west direction while in the afternoon we collected data on Metro Rapid buses heading in the east direction. This directionally-dependent data collection protocol was based on information provided to the team by MTA. We hired students from UCLA to serve as data collectors and while our plan called for data to be collected at as many as possible of the 20 Metro Rapid Bus stops along the corridor between the western terminus and the Los Angeles CBD on the east, the exact number of these bus stops for which data was collected was specifically determined on the actual data collection days to account for contingencies that occurred, such as last minute cancellations and schedule changes by a few of the students. As a result, we were not able to collect data at each of the twenty Metro Rapid bus stops during each of the designated directional peak periods, however, most bus stops were covered.

Data collectors used a passenger volume count template to gather information. The log was designed to minimize the amount of writing necessary (See Appendix I to view the template).

Among the twenty Metro Rapid bus stops were a few where heavy passenger loads were expected during either the morning or afternoon peak periods. For example, in the morning, heading westward, Vermont, Western, and Fairfax Avenues were stops with heavy loads. Heading eastward in the afternoon, Westwood Boulevard has a very heavy load. To accommodate these large passenger volumes, MTA inserts additional buses at those locations during those times on an as needed basis depending on level of demand, a process that is referred to as Dynamic Dispatch and Deployment by MTA. MTA positions staff at these Metro Rapid stops who then communicate with a dispatcher who sends additional buses that are parked and waiting nearby. Accordingly, for purposes of our data collection, we positioned at least two and sometimes three people at these locations to collect data and minimize the amount of data that went uncollected due to the demands of counting large volumes of passengers and large number of buses arriving and departing.

Passengers included each individual who either boards or alights from the bus. Since we are interested in how crowded the bus gets with passengers during the peak time periods, minors were also counted if he/she took up a seat or stood on their own, i.e., except for children who were held by a parent or guardian.

4.6 Data Analysis

This section presents the analysis results of the data collected from the survey. The major purpose was to obtain ridership and O-D demand pattern of the Wilshire Metro Rapid corridor. Other information, such as headways and dwell times were also estimated as side products.

4.6.1 Number of Boarding and Alighting Passengers

Due to the limited resource, the survey could not cover the whole segment of interest (west half of the corridor, 20 stops). The data were only collected on either day for half of the segment. Therefore, in order to obtain a complete estimate of boarding and alighting passengers at each individual stop, a Monday/Thursday ridership ratio was used to convert the recorded passenger counts of one day to the estimates of the counts for the other day. The ratio was about 1.1457, calculated based on the observed passenger counts on the six stops (4^{th}, Bundy, Westwood, Fairfax, Western and Vermont) where data were collected on both days. In addition, adjustments have been made where appropriate dealing with the issues such as missing count of buses and late arrival or early leave of the surveyors.

Table 4-10 provides the estimated number of boarding and alighting passengers at each stop, and the same results are illustrated by Figures 4-8 to 4-11.

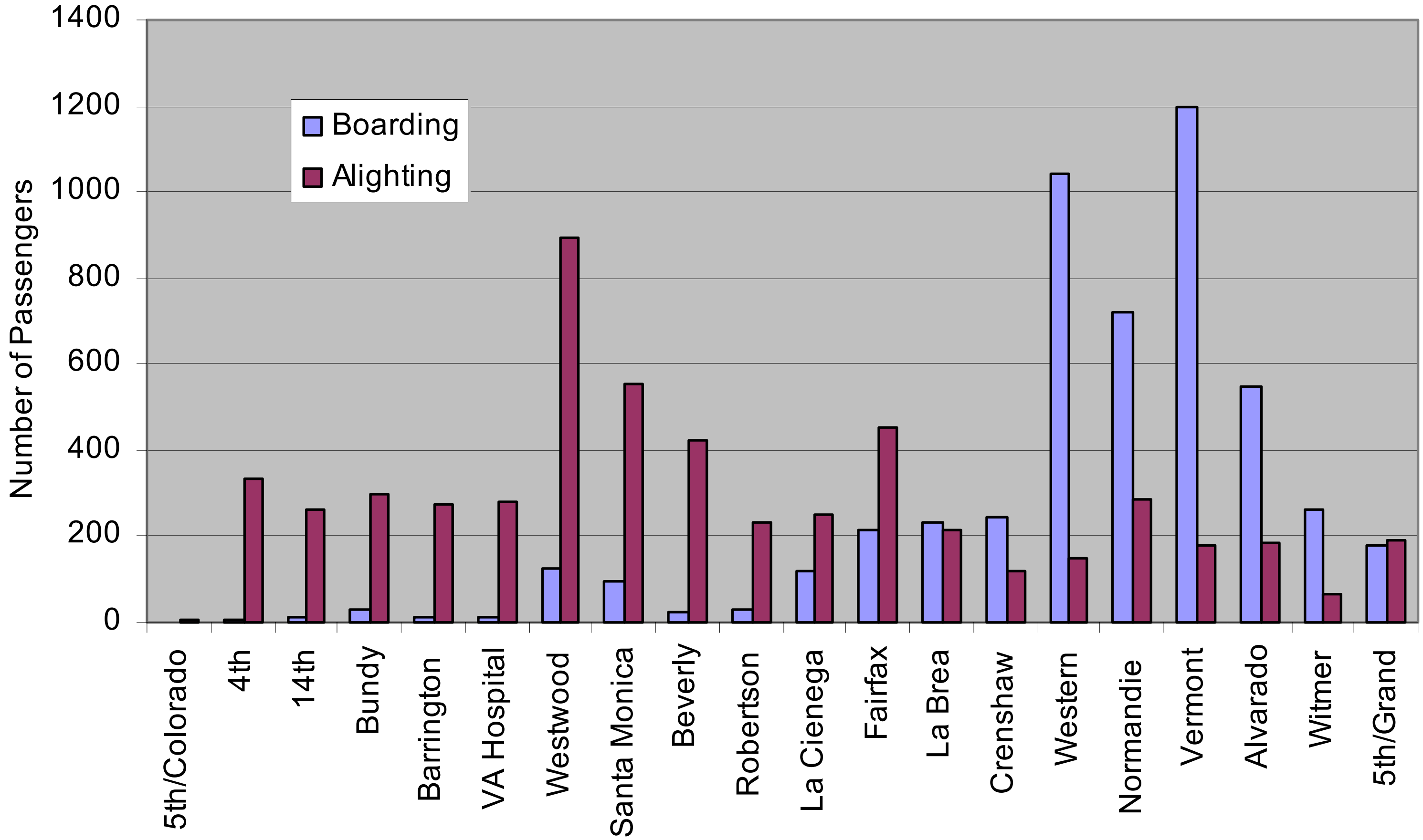

FIGURE 4-8 Number of Boarding and Alighting Passengers at Stops (Monday, Westbound, 7:00 am -10:00 am)

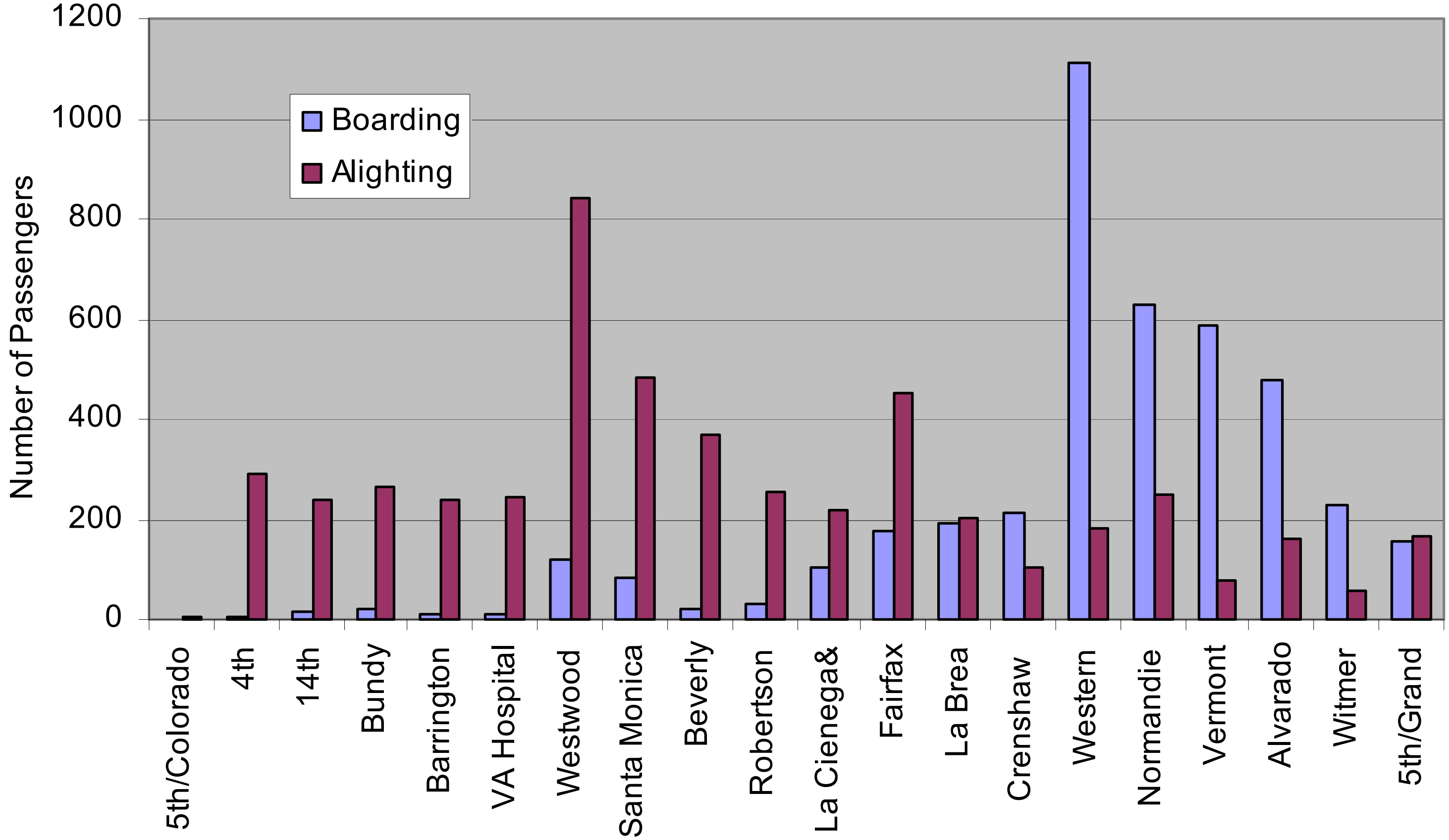

FIGURE 4-9 Number of Boarding and Alighting Passengers at Stops (Thursday, Westbound, 7:00 am -10:00 am)

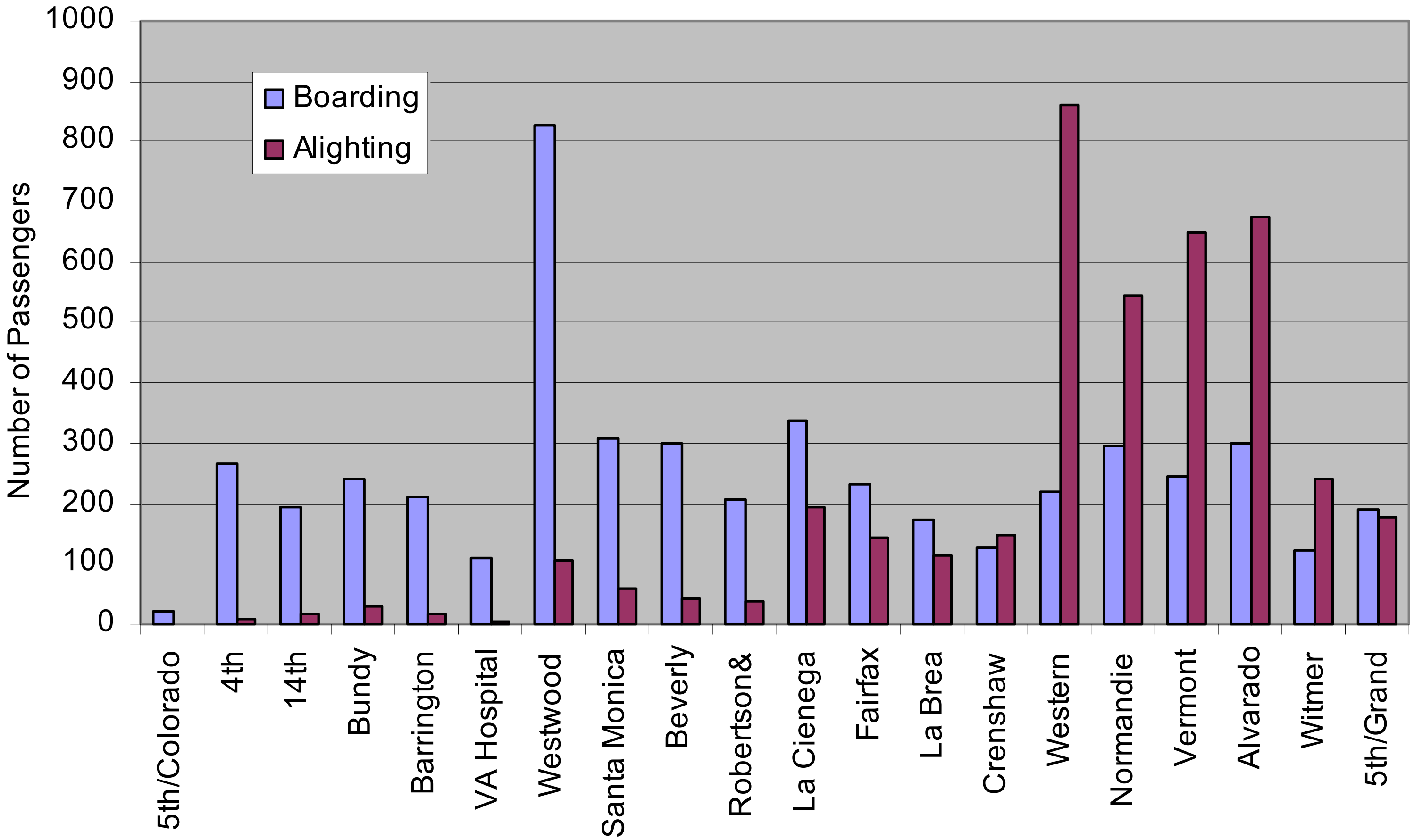

FIGURE 4-10 Number of Boarding and Alighting Passengers at Stops (Monday, Eastbound, 4:00 pm -7:00 pm)

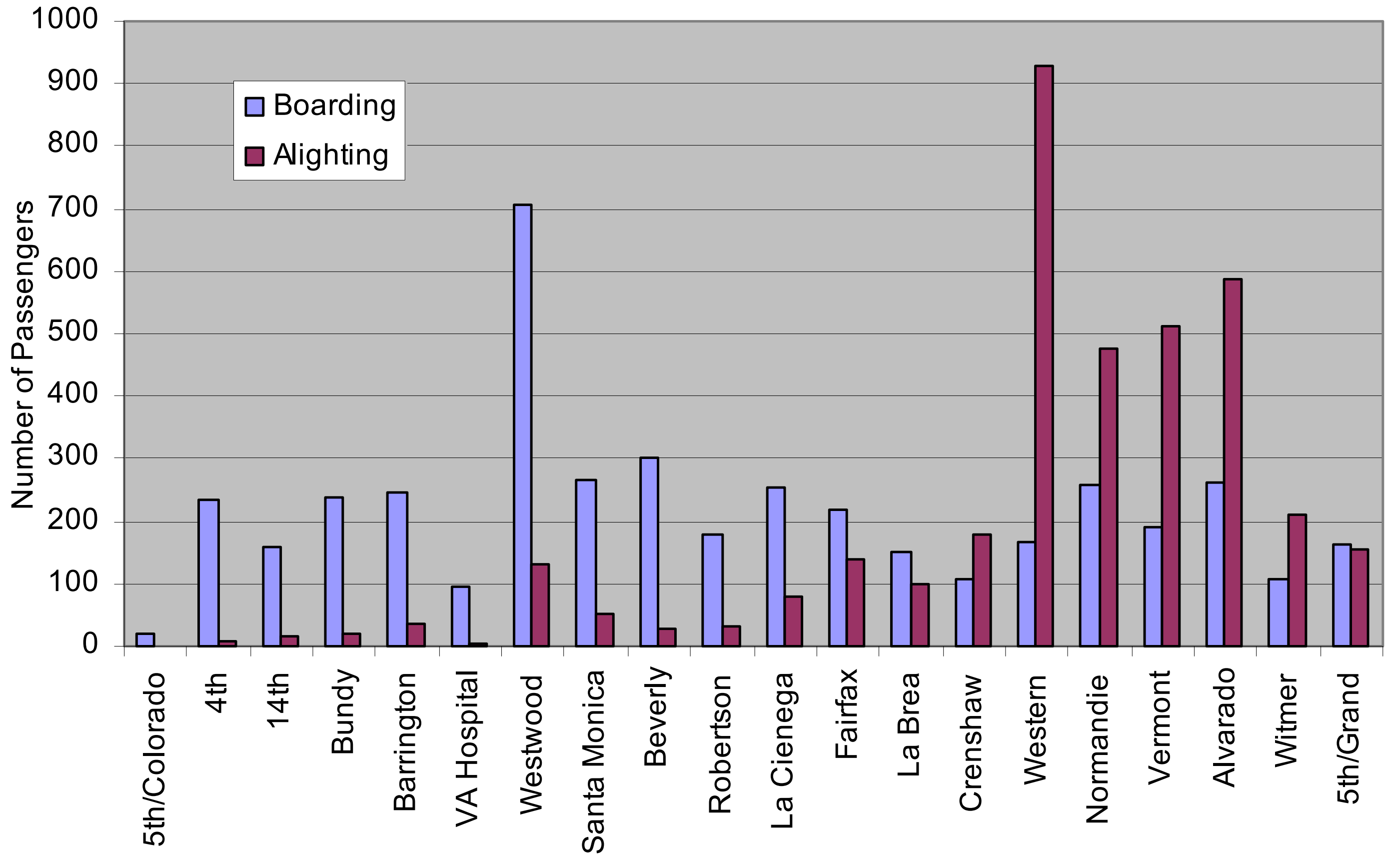

FIGURE 4-11 Number of Boarding and Alighting Passengers at Stops (Thursday, Eastbound, 4:00 pm -7:00 pm)

4.6.2 O-D Trip Tables

Given total numbers of boarding/alighting passengers at individual stops, estimating O-D trip tables is essentially the same as the conventional O-D distribution problem with trip generation/attraction at traffic zones in the so-called four-step travel demand analysis procedure. However, most of the widely-used estimation procedures there need prior O-D information to work with or calibrate the models. Since such information was not available, we adopted a simple O-D estimation procedure based on the assumption that number of alighting passengers is proportionally divided among all the possible origins according to the respective number of boarding at these origins.

As we only collected data for half of the Wilshire corridor (20 stops out of 31), the total boarding is not equal to the total alighting in Table 4-10. To estimate the O-D, we created an additional dummy stop, named as east stops, to equalize the boarding and alighting.

The resultant O-D tables are presented in Tables 4-11 to 4-14. Note that although these tables are consistent with the numbers of boarding and alighting collected from the field, they are not uniquely determined by those data and thus may not represent the true situation.

4.6.3 Headways

The Metro Rapid is operated with a headway-based schedule. The average headway and headway distribution at each stop represent intensity and reliability of the service. Figure 4-12 presents the two-day average headways at individual stops. It reveals a tendency that headways become larger and larger as buses run farther along the route. As examples, Figures 4-13 to 4-24 show the headway distributions at Westwood, Santa Monica, Western, Normandie, Vermont and Alvarado, the busiest stops along the corridor. These figures reflect the schedule reliability of the service at the stop level.

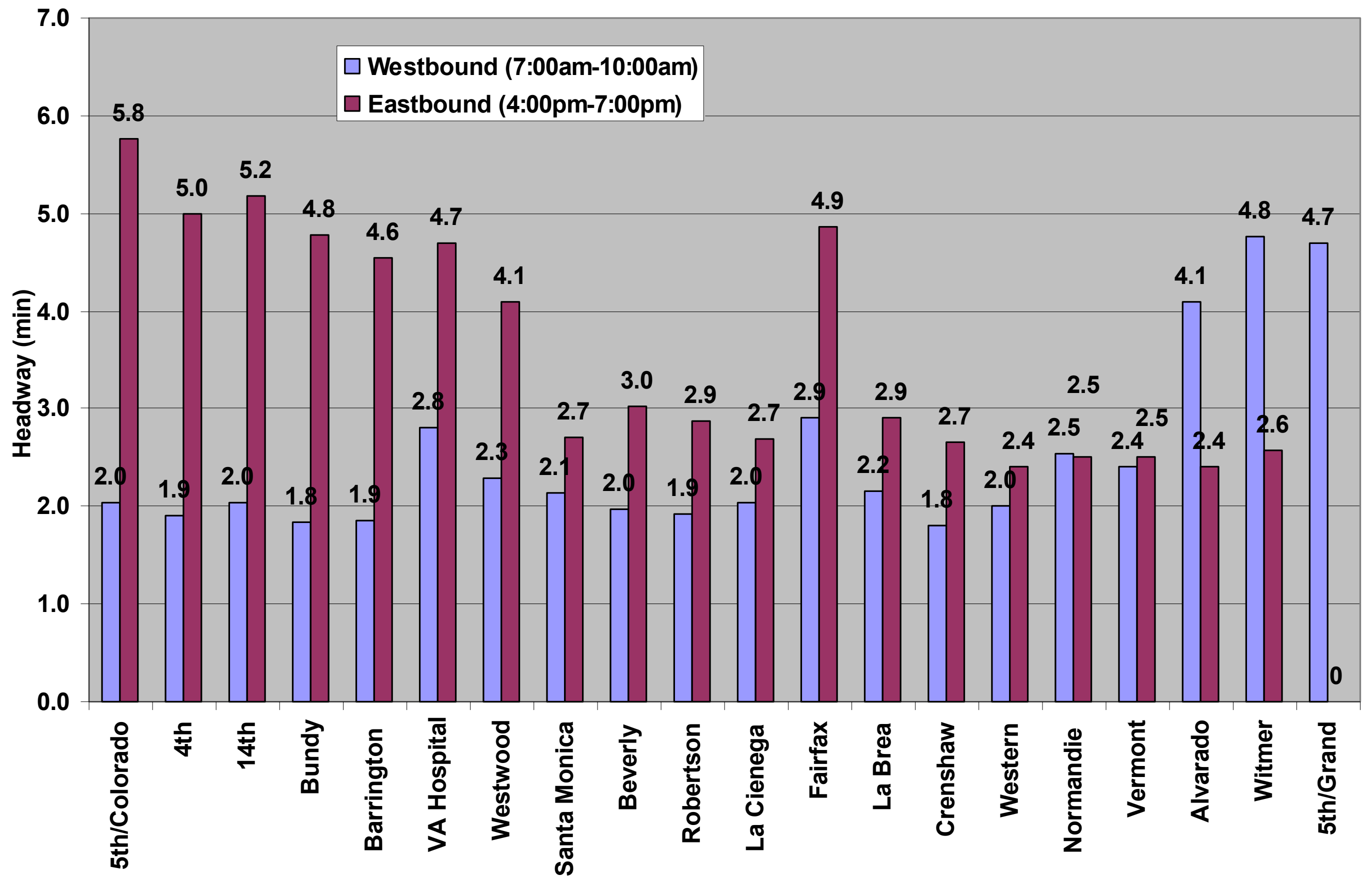

FIGURE 4-12 Two-Day Average Operational Headways at Stops

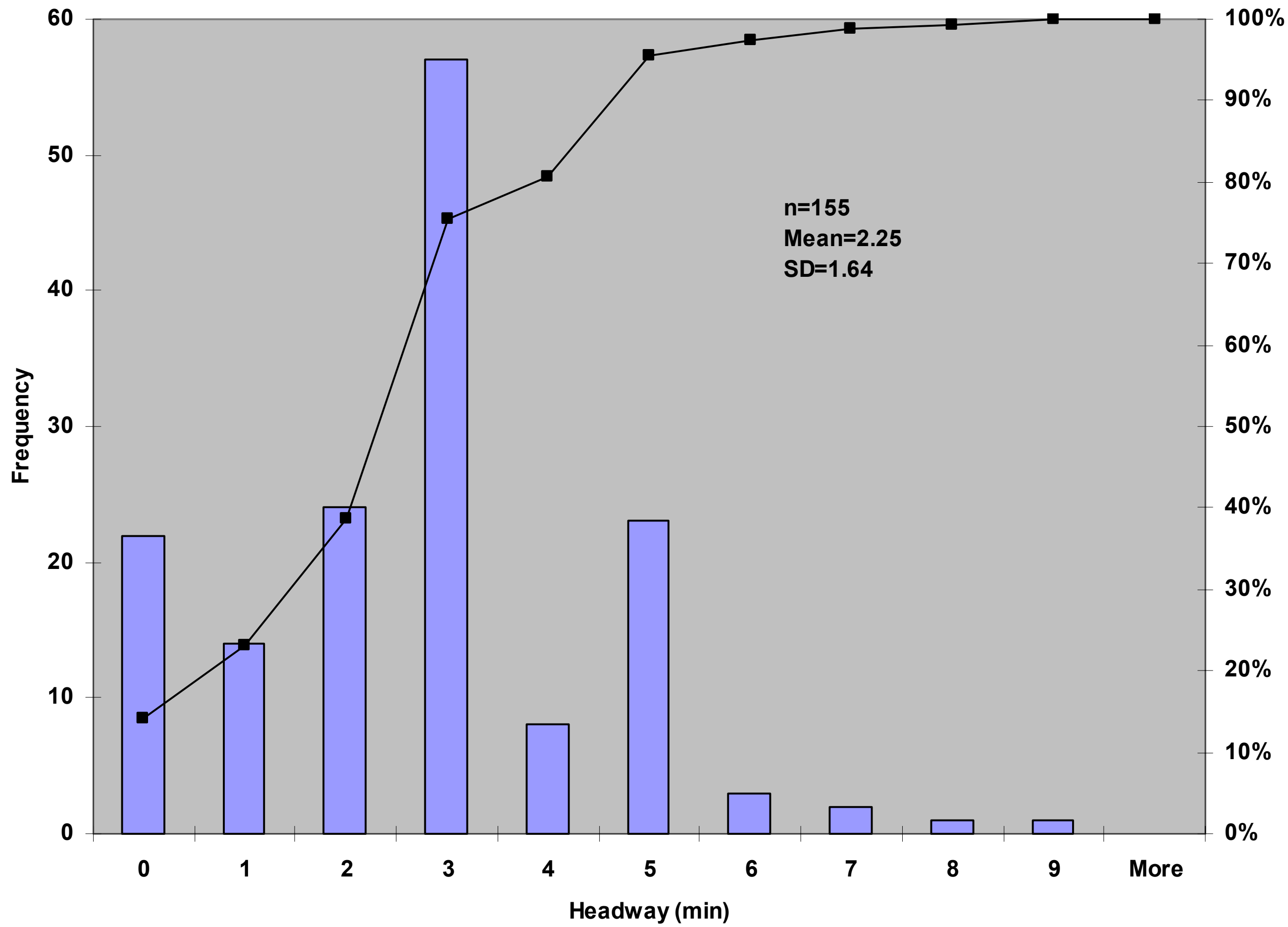

FIGURE 4-13 Headway Distribution at Westwood (Westbound, Monday and Thursday, 7:00am-10:00am)

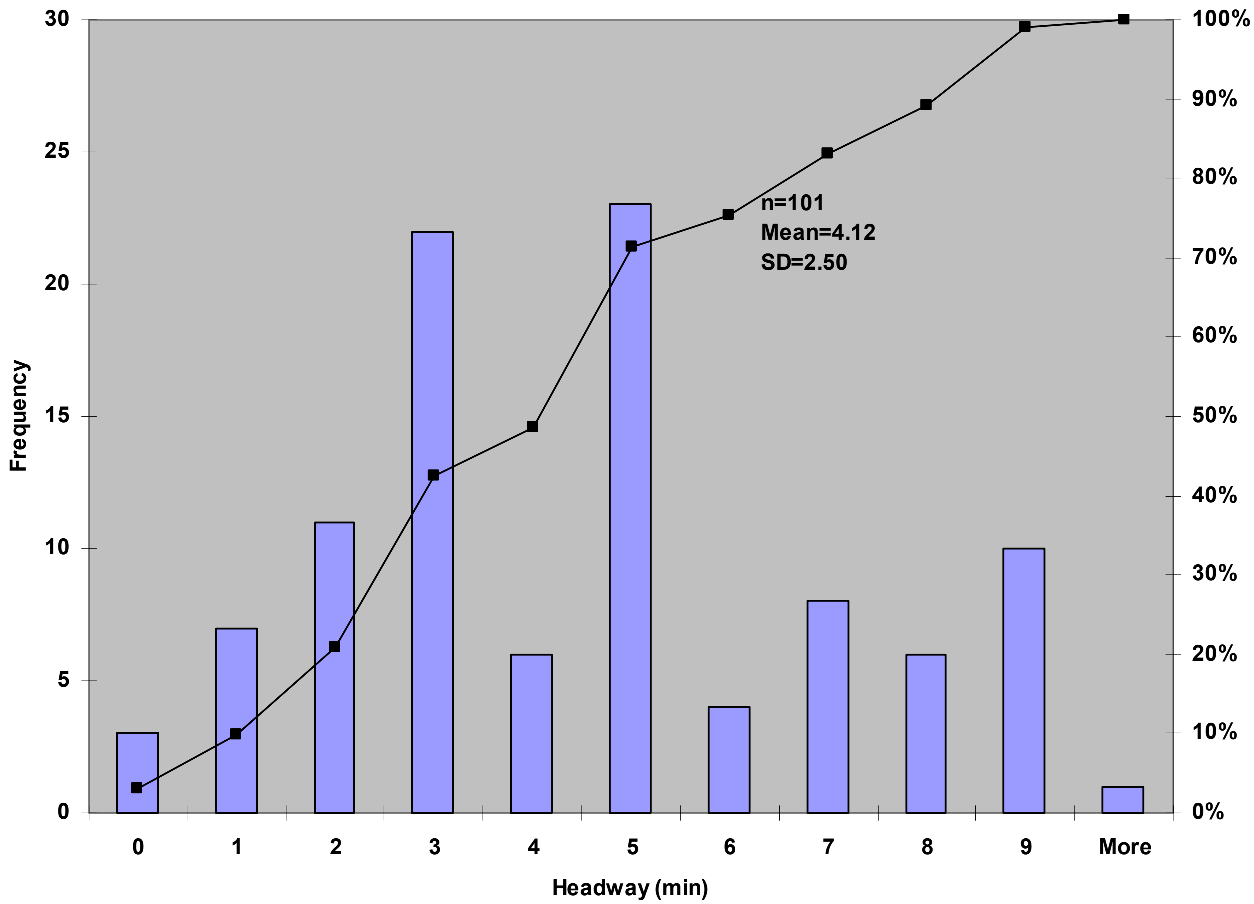

FIGURE 4-14 Headway Distribution at Westwood (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

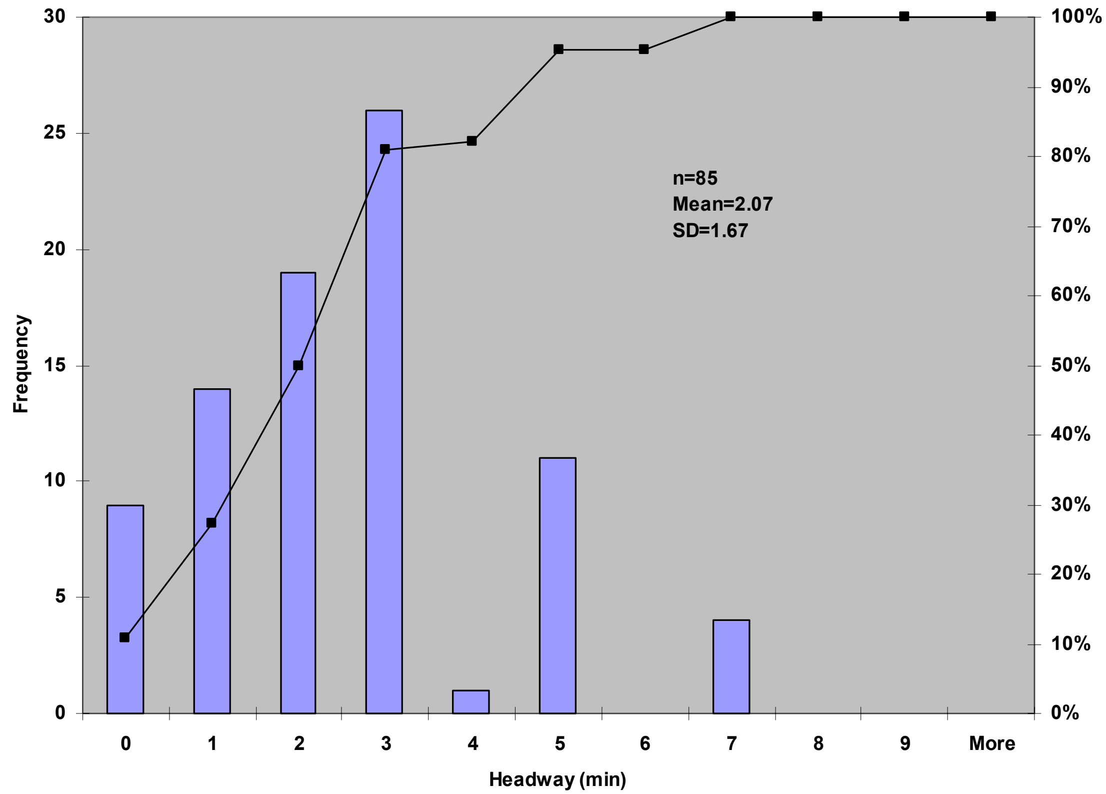

FIGURE 4-15 Headway Distribution at Santa Monica (Westbound, Monday and Thursday, 7:00am-10:00am)

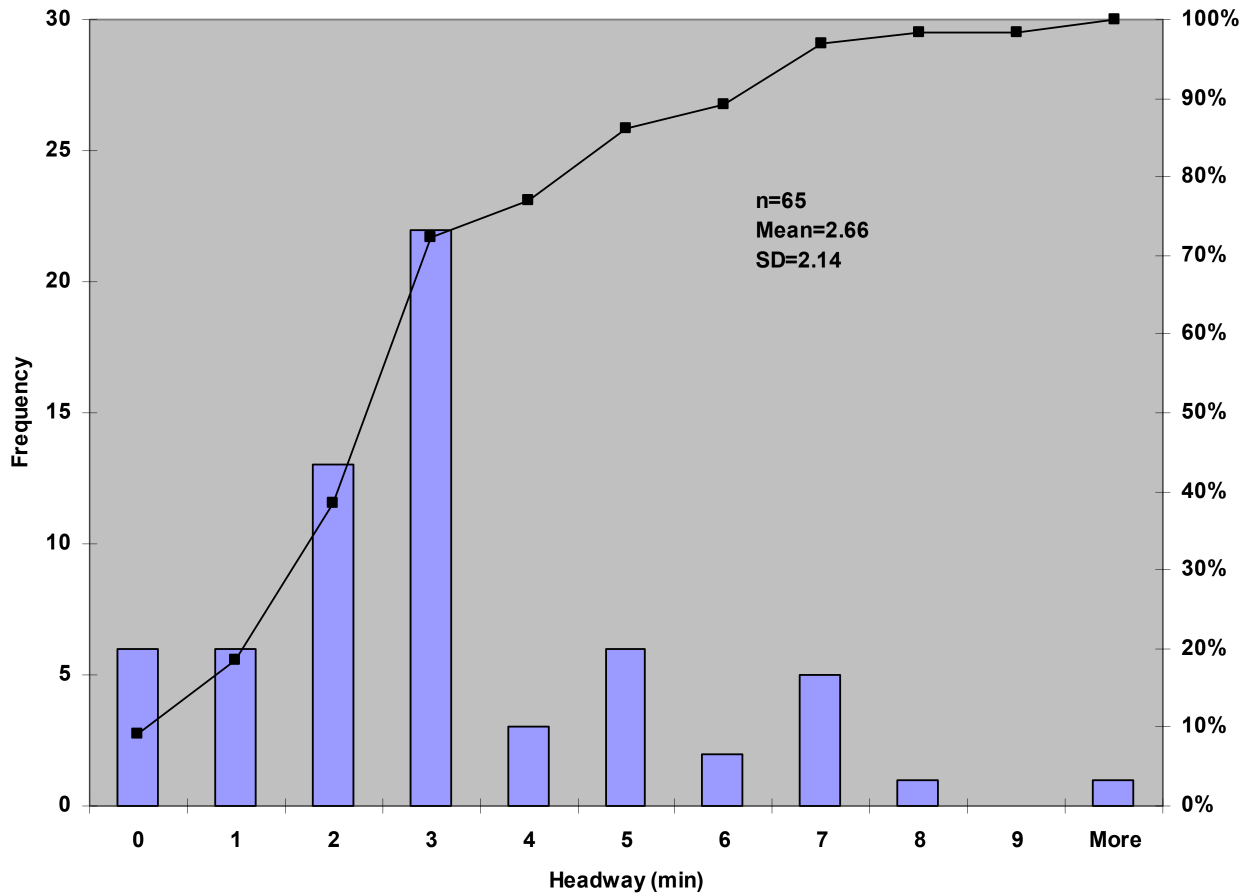

FIGURE 4-16 Headway Distribution at Santa Monica (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

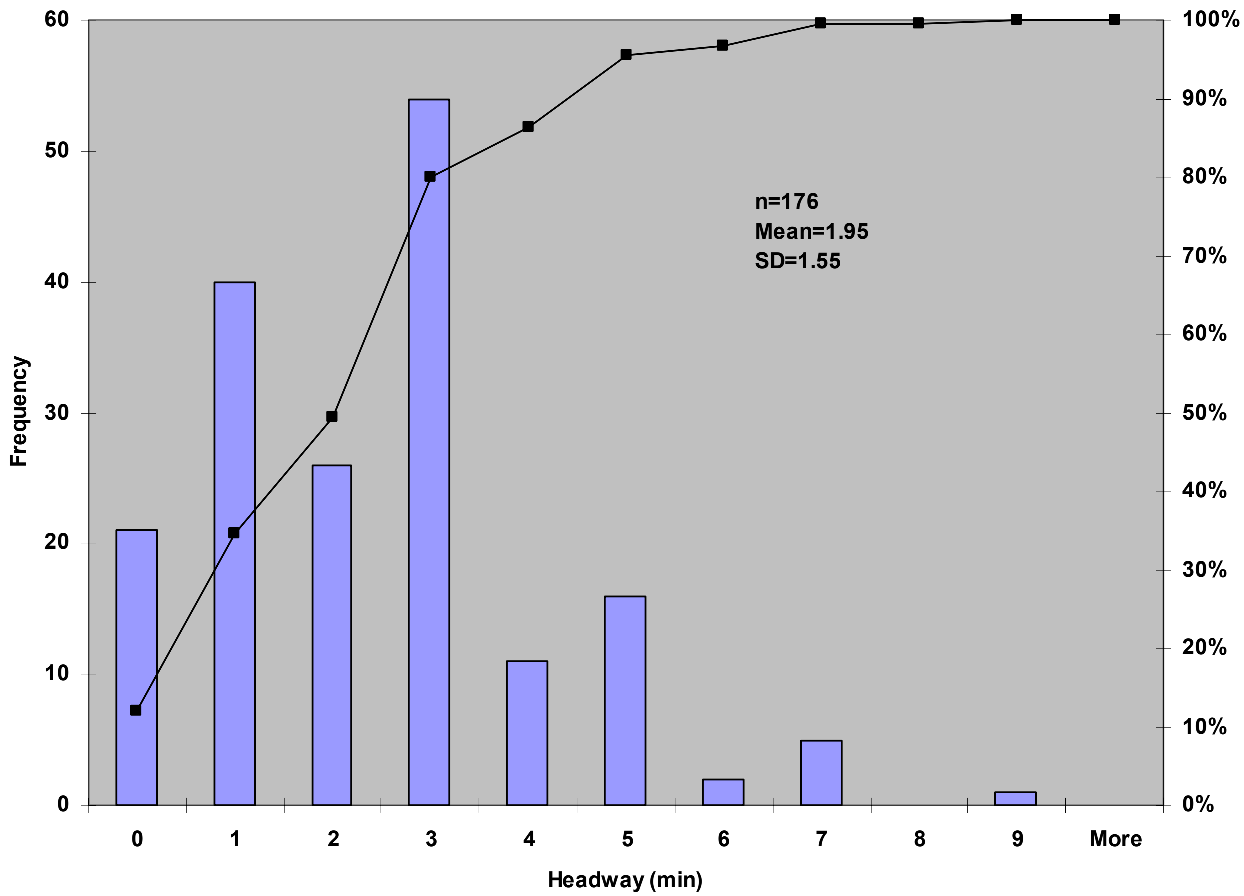

FIGURE 4-17 Headway Distribution at Western (Westbound, Monday and Thursday, 7:00am-10:00am)

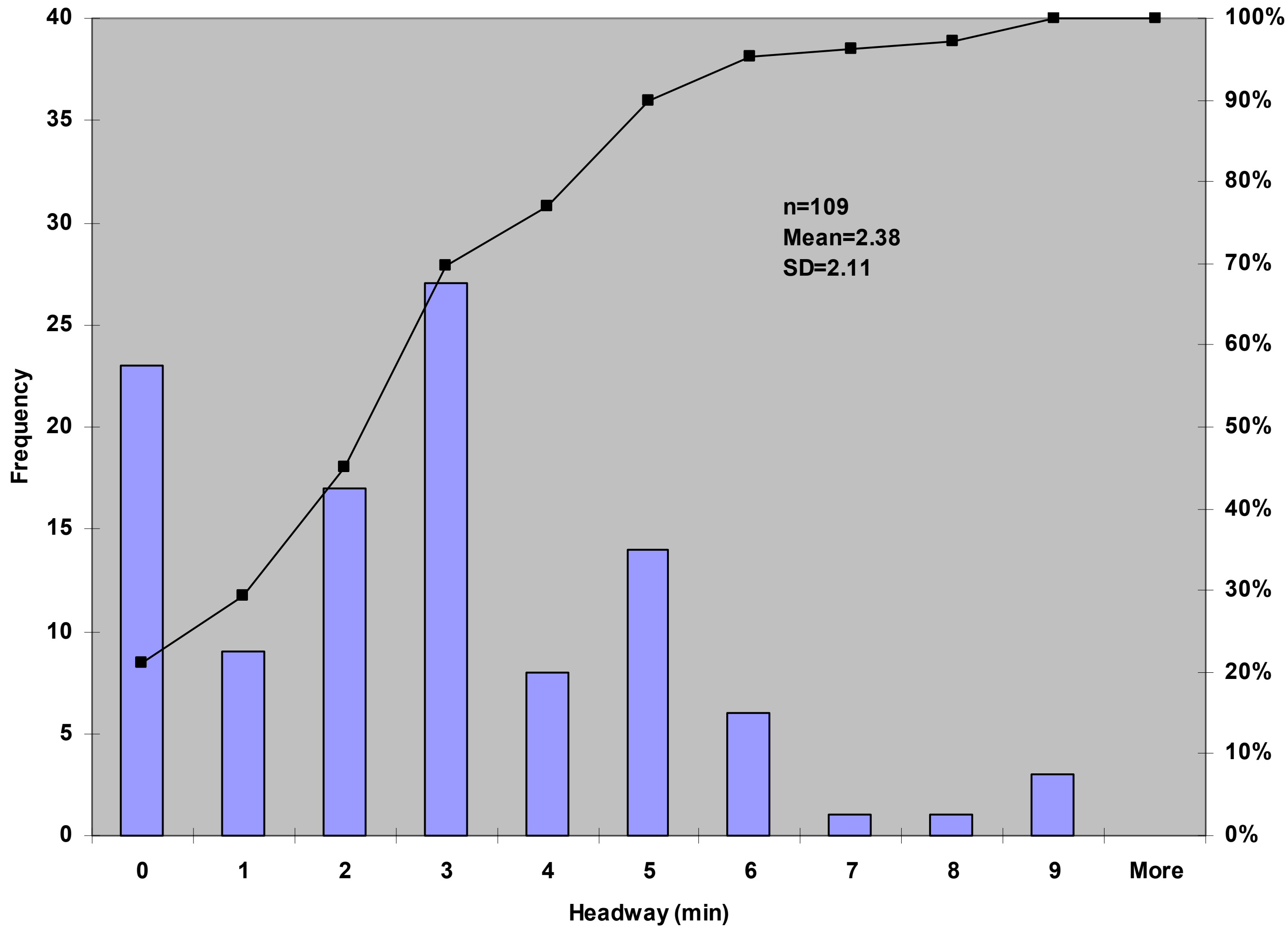

FIGURE 4-18 Headway Distribution at Western (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

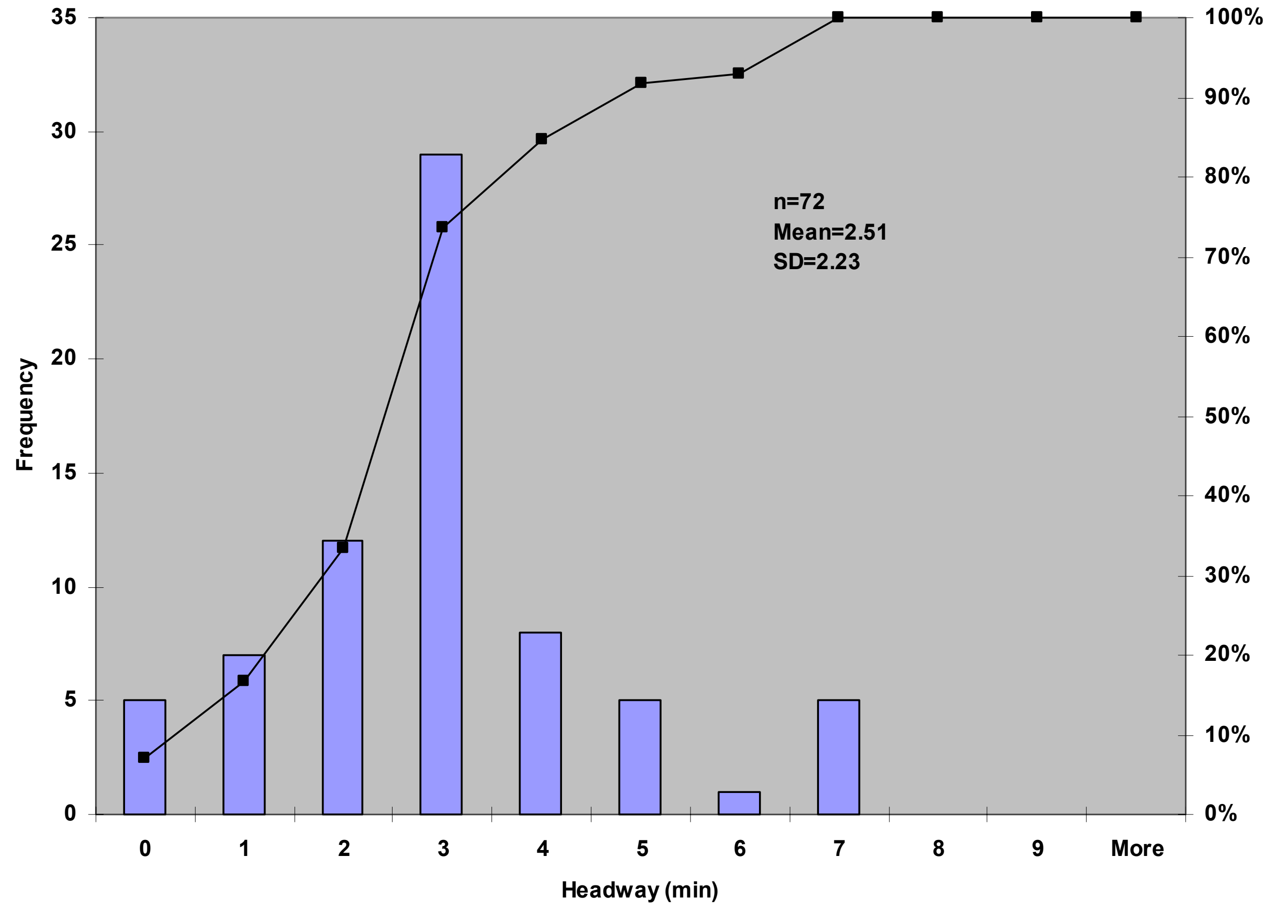

FIGURE 4-19 Headway Distribution at Normandie (Westbound, Monday and Thursday, 7:00am-10:00am)

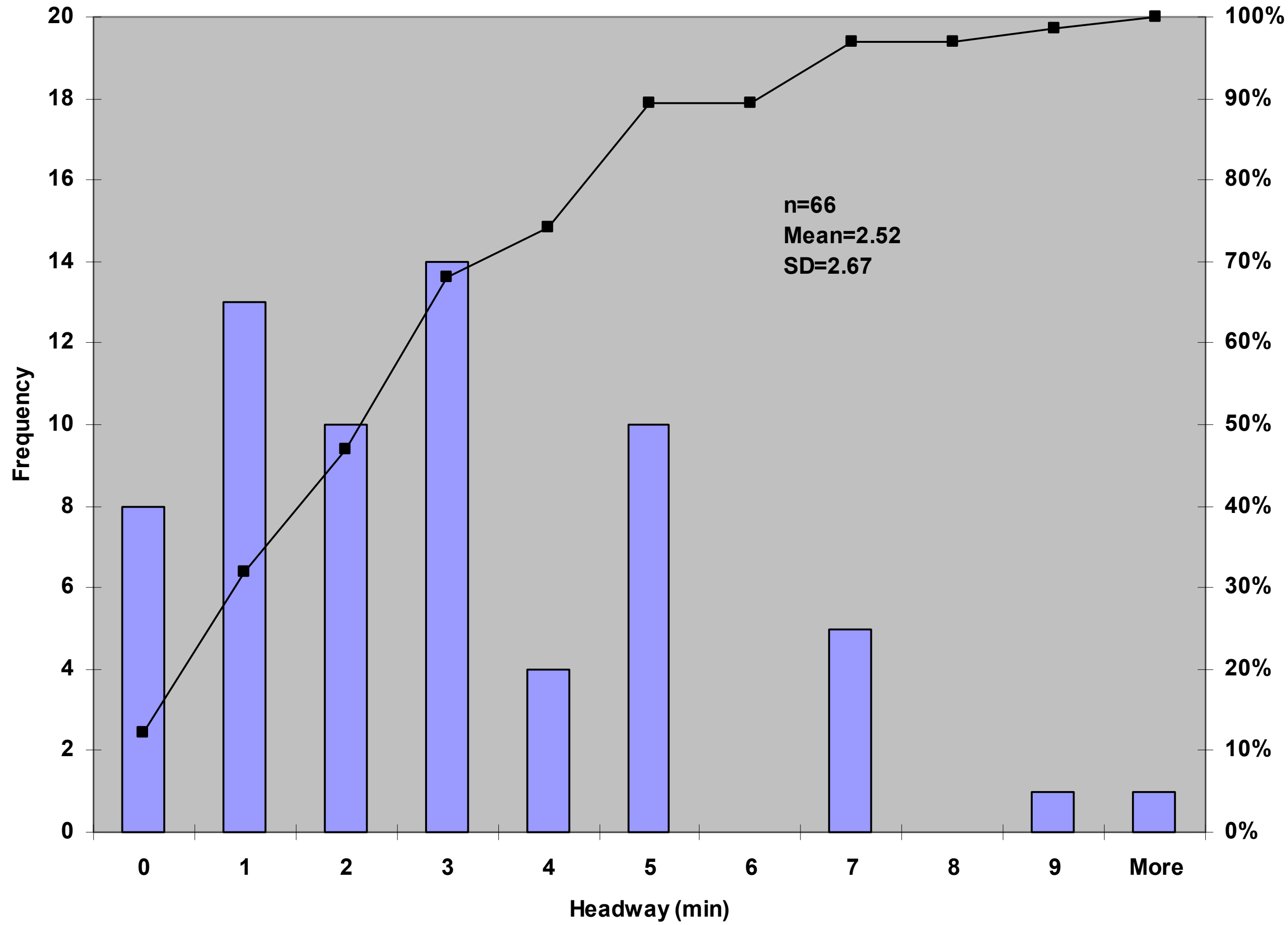

FIGURE 4-20 Headway Distribution at Normandie (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

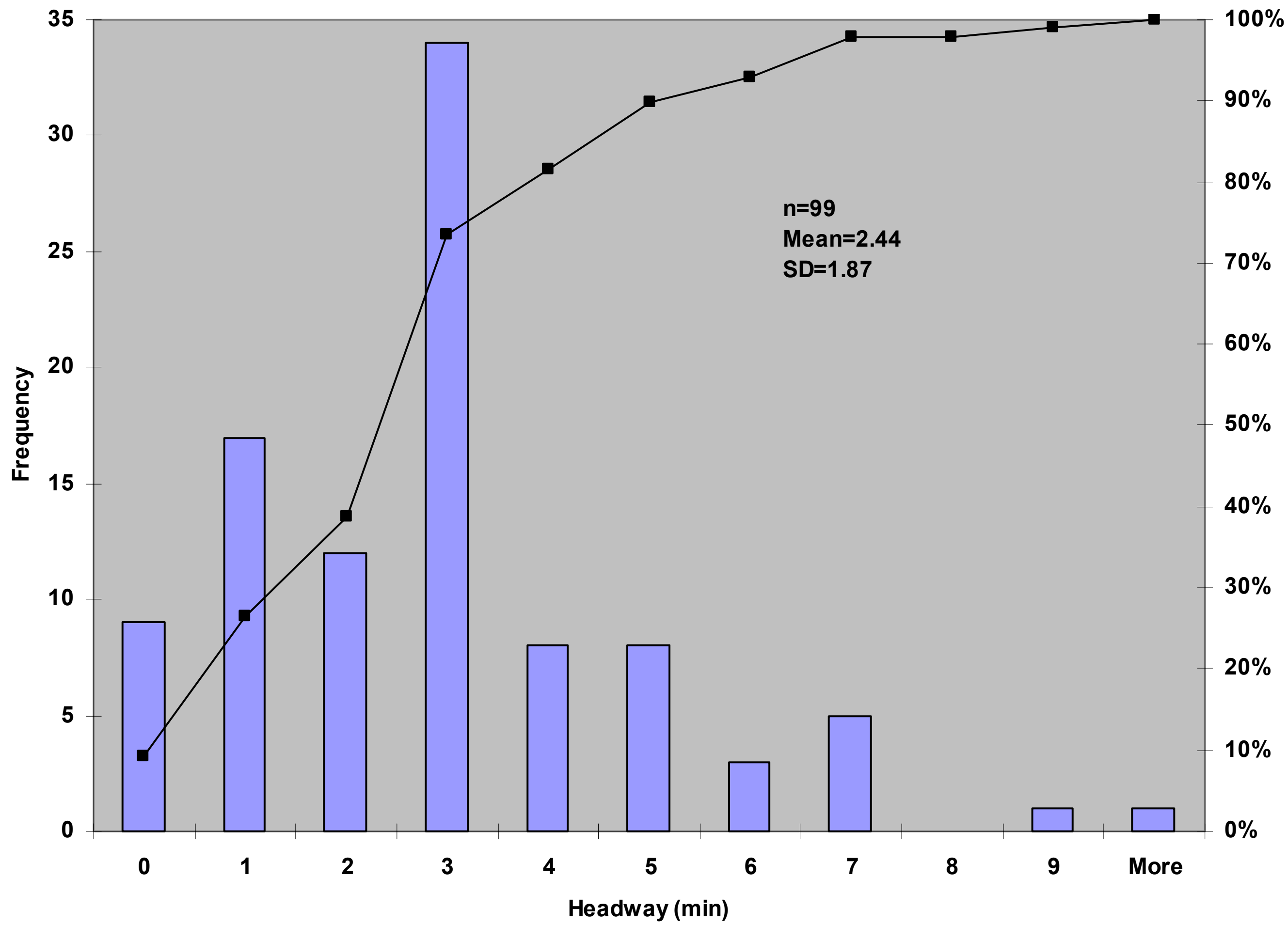

FIGURE 4-21 Headway Distribution at Vermont (Westbound, Monday and Thursday, 7:00am-10:00am)

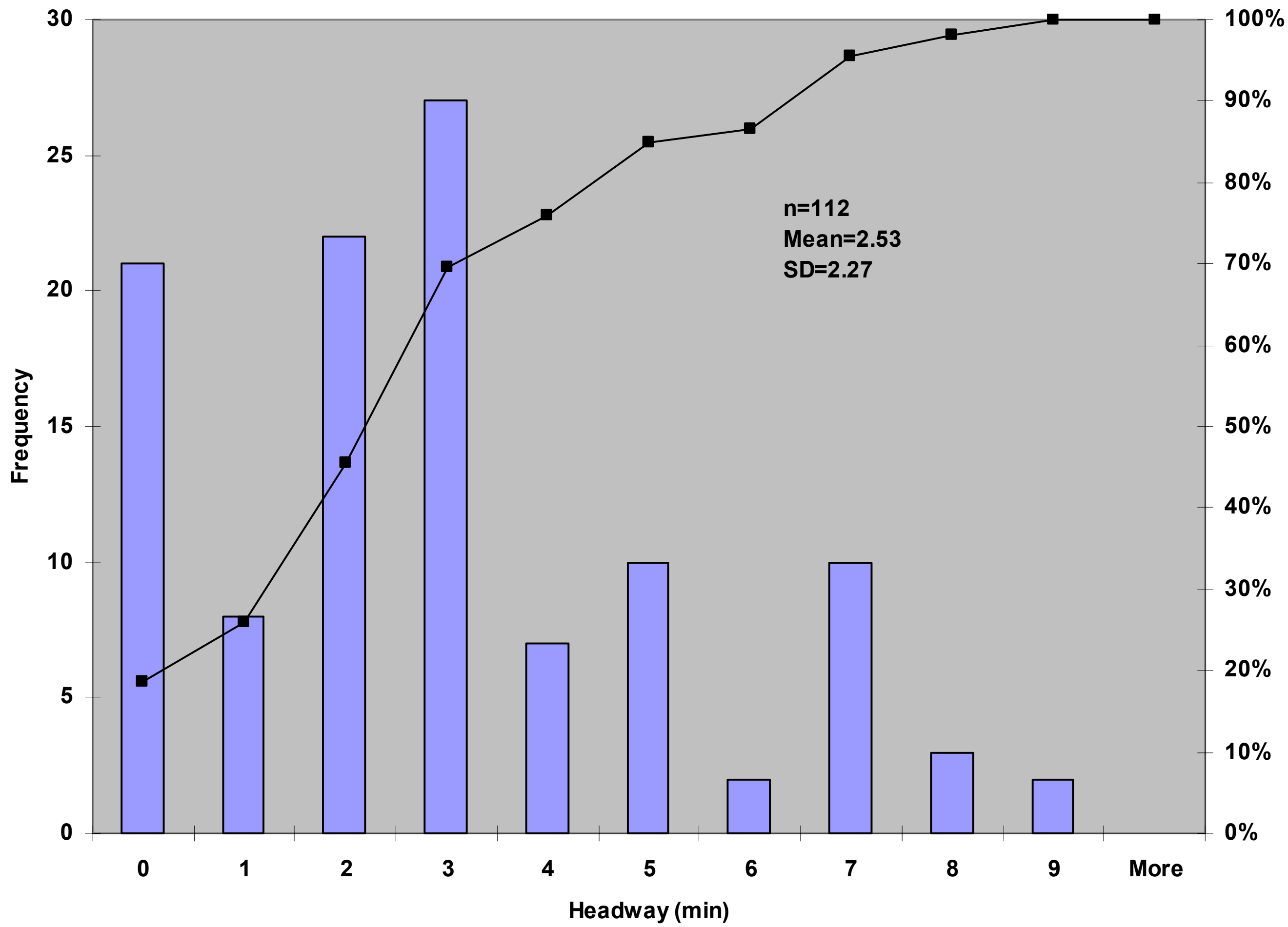

FIGURE 4-22 Headway Distribution at Vermont (Eastbound, Monday and Thursday 4:00pm-7:00pm)

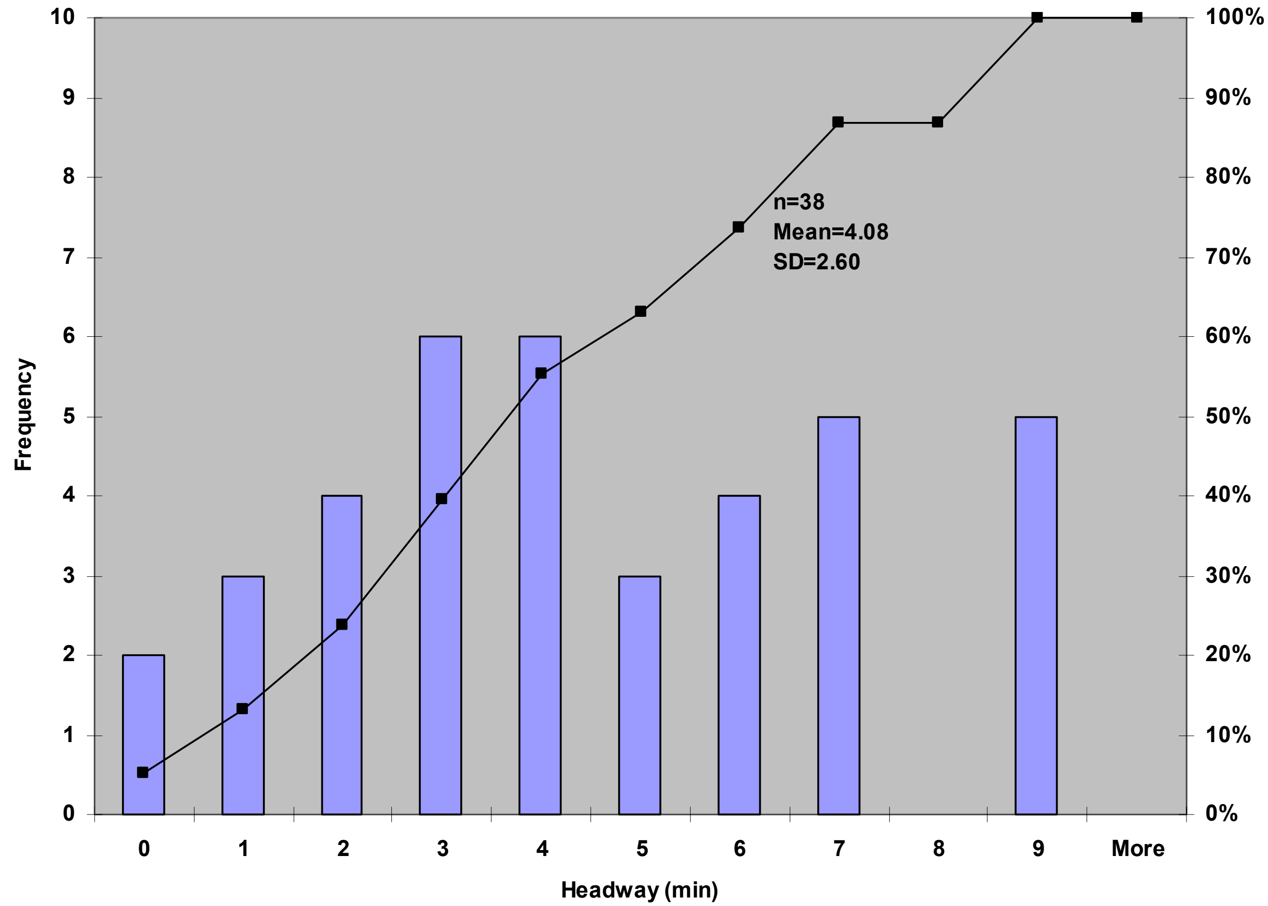

FIGURE 4-23 Headway Distribution at Alvarado (Westbound, Monday and Thursday, 7:00am-10:00am)

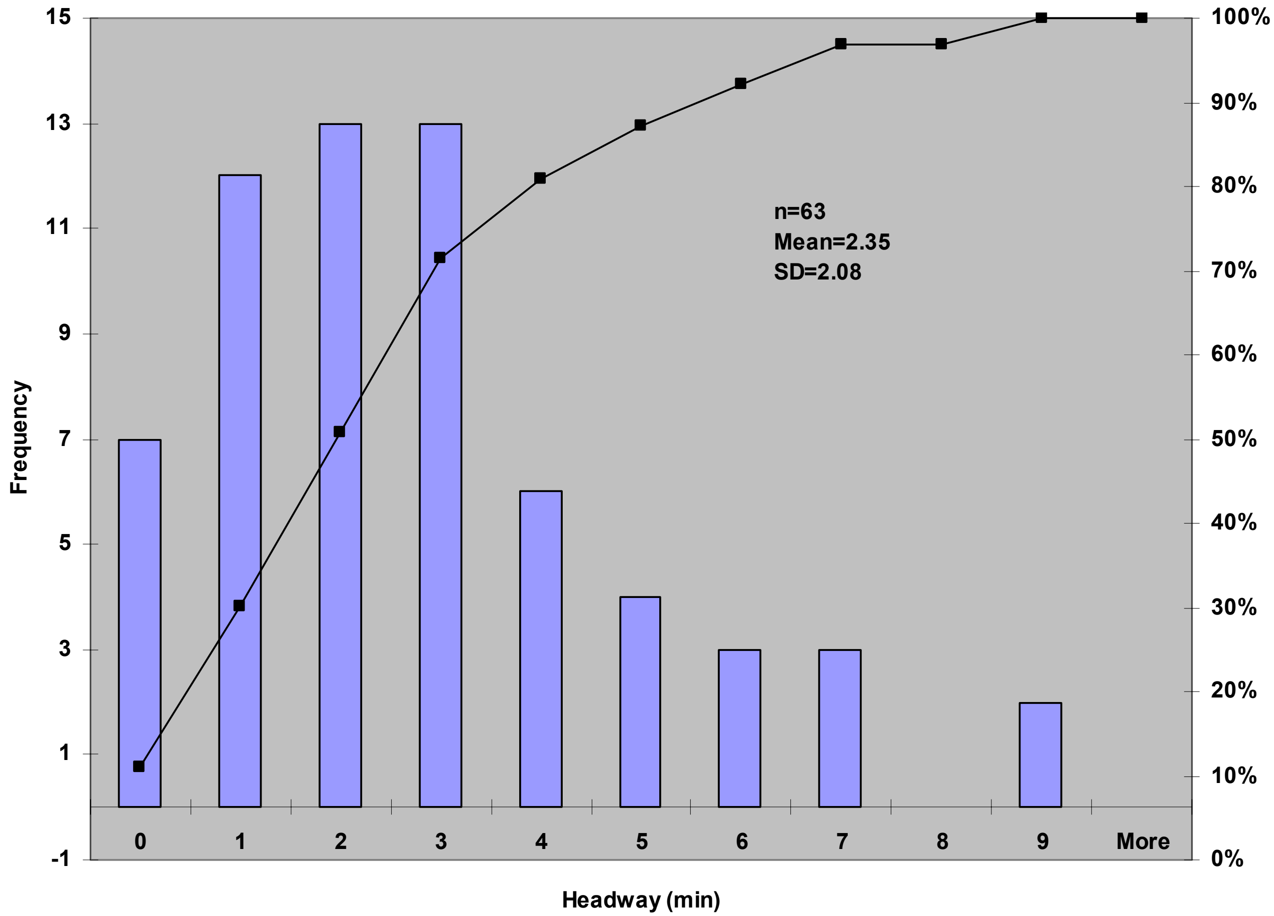

FIGURE 4-24 Headway Distribution at Alvarado (Eastbound, Monday and Thursday 4:00pm-7:00pm)

4.6.4 Dwell Time

Dwell time is another important measure of transit performance. With the survey data, we estimated average dwell times at individual stops, shown in Figure 4-25.

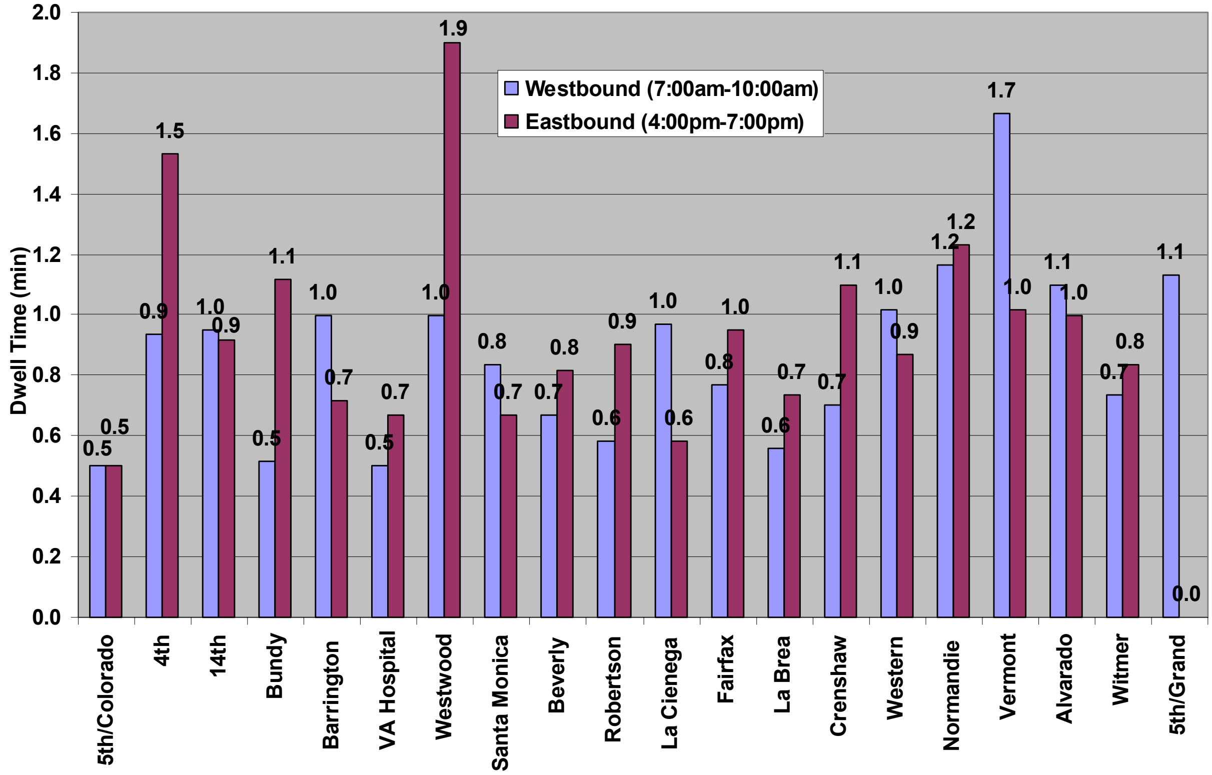

FIGURE 4-25 Two-Day Average Dwell Times at Stops

Figures 4-26 through 4-37 illustrate the dwell distributions at Westwood, Santa Monica, Western, Normandie, Vermont and Alvarado. Note that, as the survey was not designed for this purpose, the arrival and departure times of buses were recorded in minute, not in second. Therefore, the estimates of dwell times presented are not entirely accurate. In fact, for example, when a bus was recorded arriving and departing at the same time, we assumed the dwell time was 0.5 minute.

Figure 4-38 presents the breakdown of average trip time for the west segment of the route. It is shown that in average Metro Rapid buses spend 25% and 21% of the total trip time at stops for westbound and eastbound trips respectively.

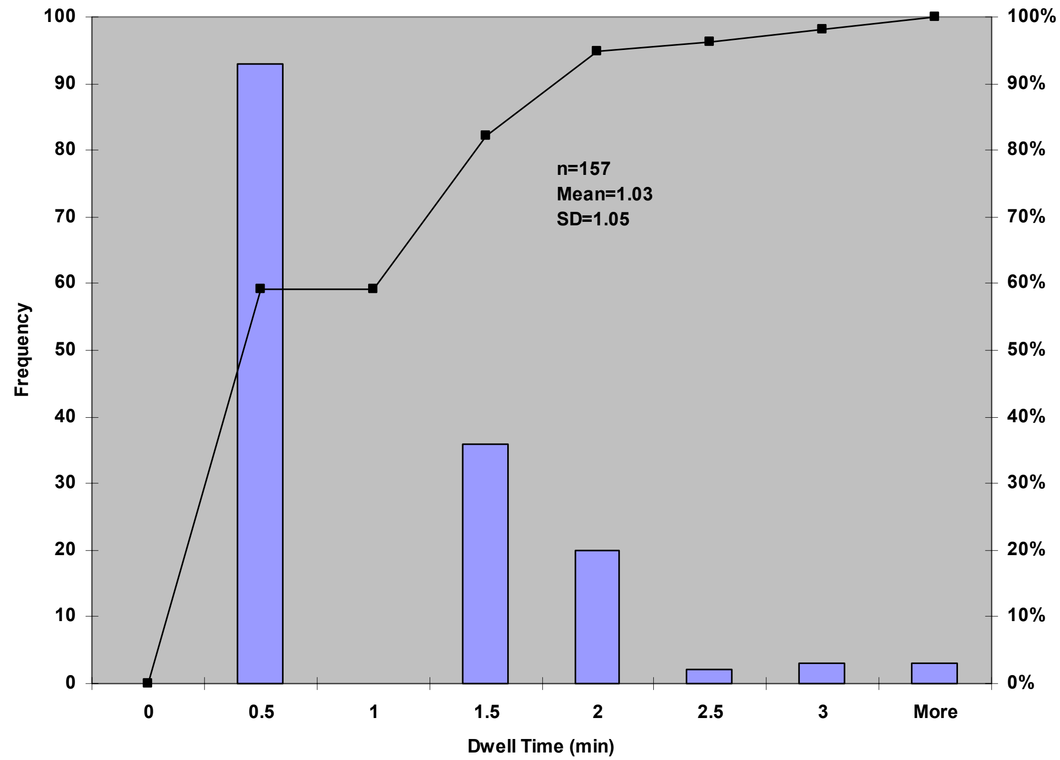

FIGURE 4-26 Dwell Time Distribution at Westwood (Westbound, Monday and Thursday 7:00am-10:00am)

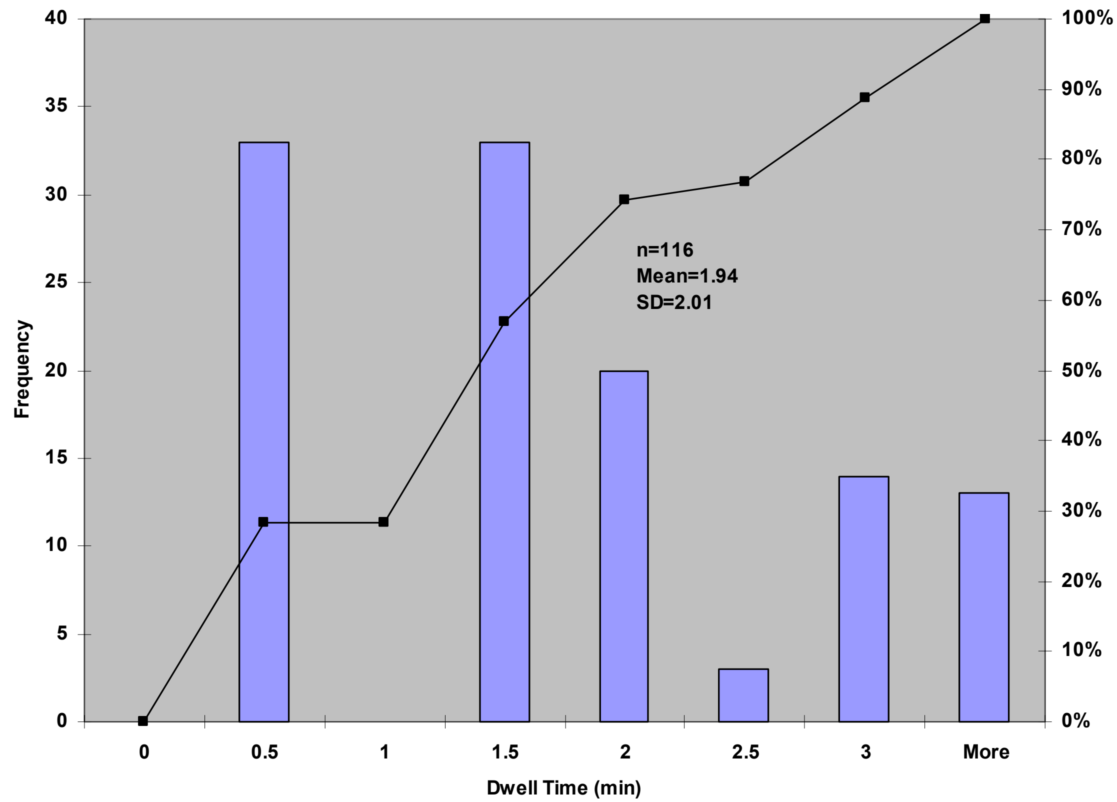

FIGURE 4-27 Dwell Time Distribution at Westwood (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

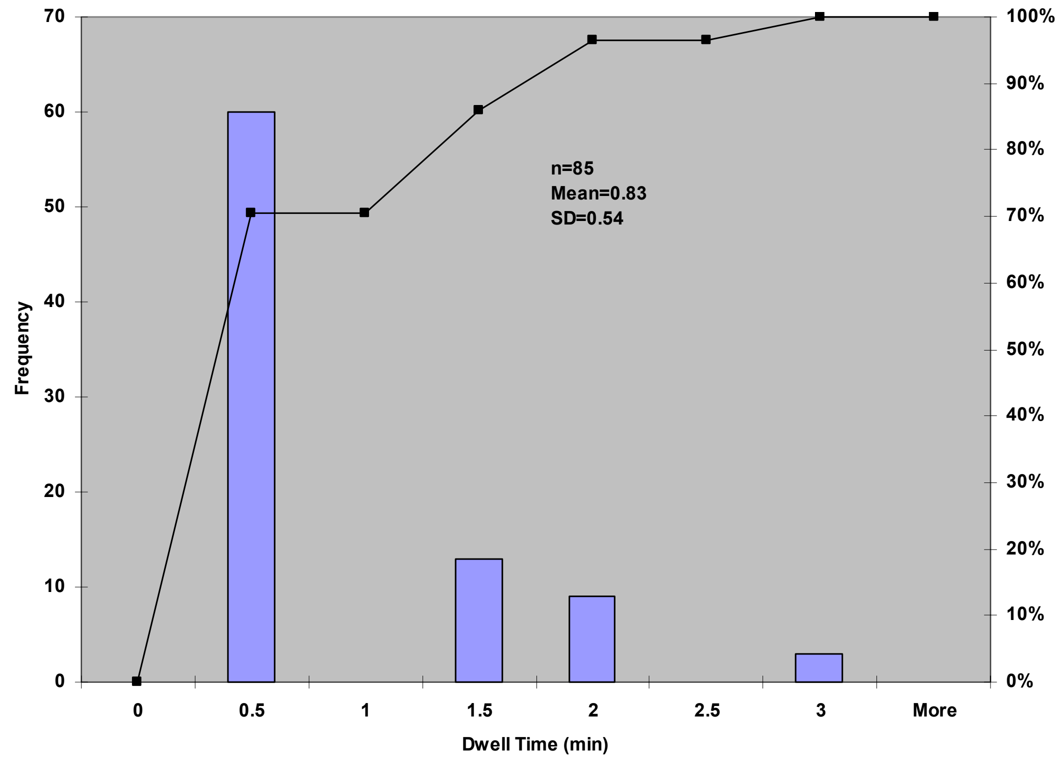

FIGURE 4-28 Dwell Time Distribution at Santa Monica (Westbound, Monday and Thursday 7:00am-10:00am)

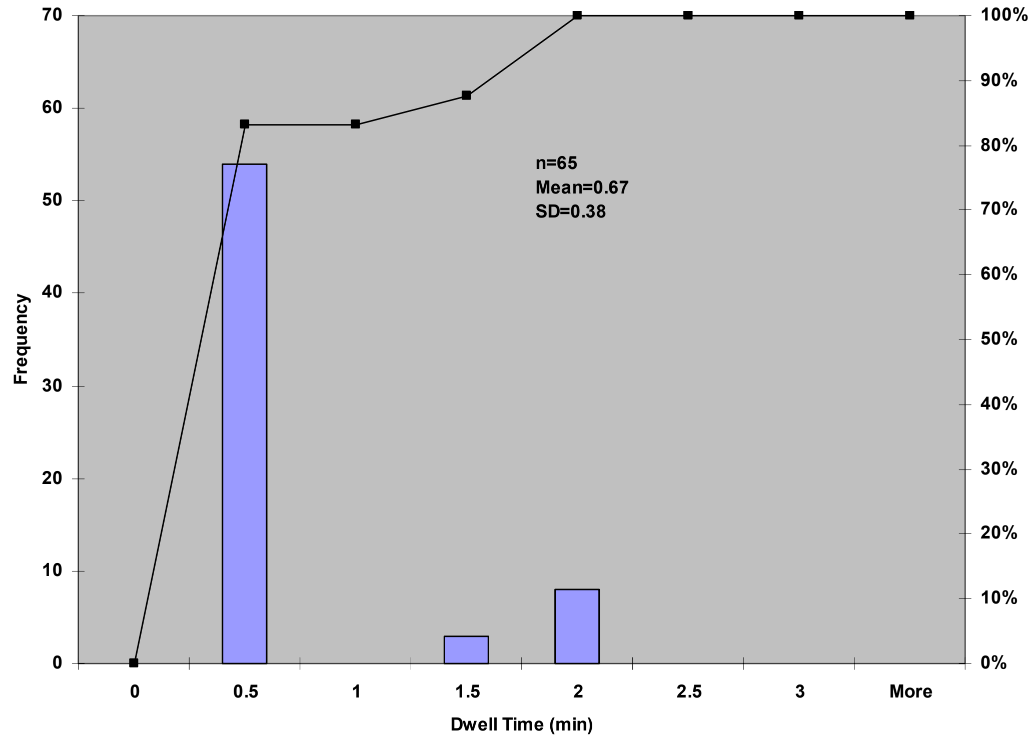

FIGURE 4-29 Dwell Time Distribution at Santa Monica (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

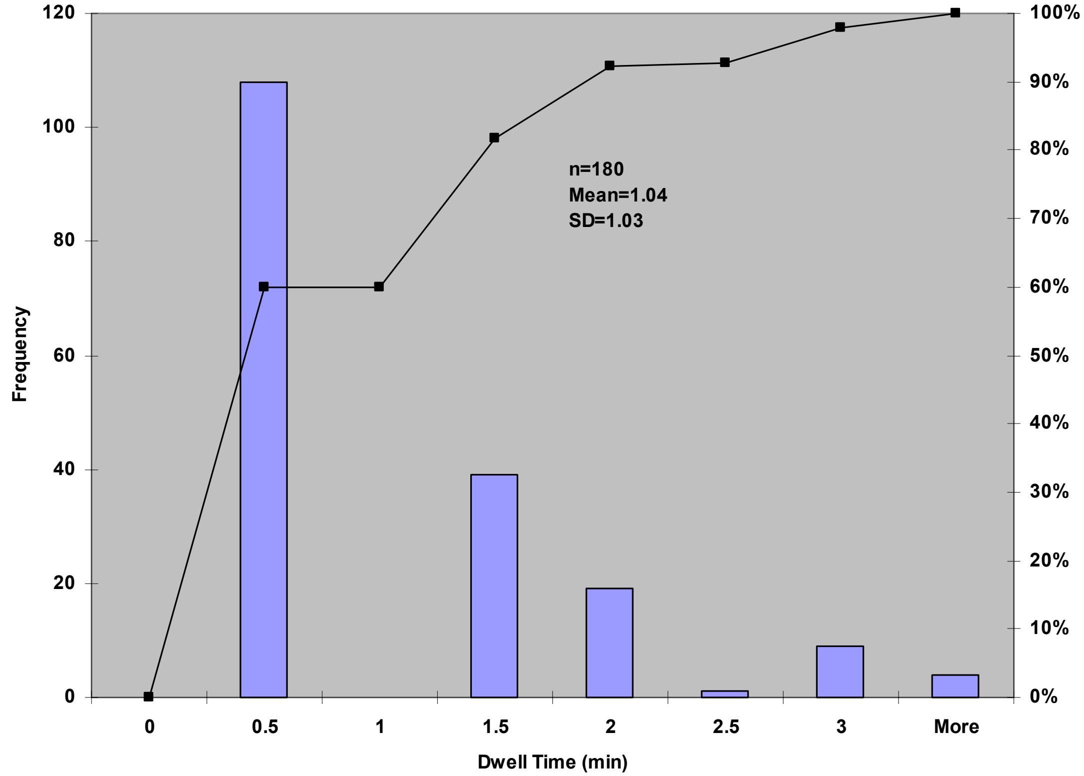

FIGURE 4-30 Dwell Time Distribution at Western (Westbound, Monday and Thursday 7:00am-10:00am)

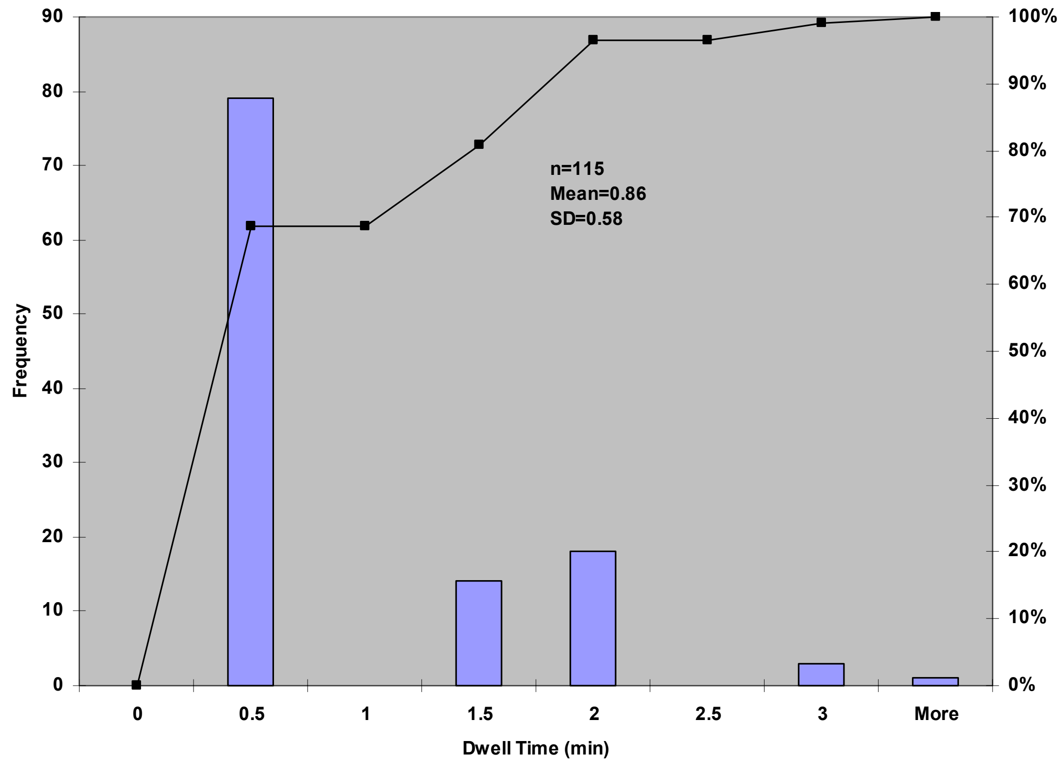

FIGURE 4-31 Dwell Time Distribution at Western (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

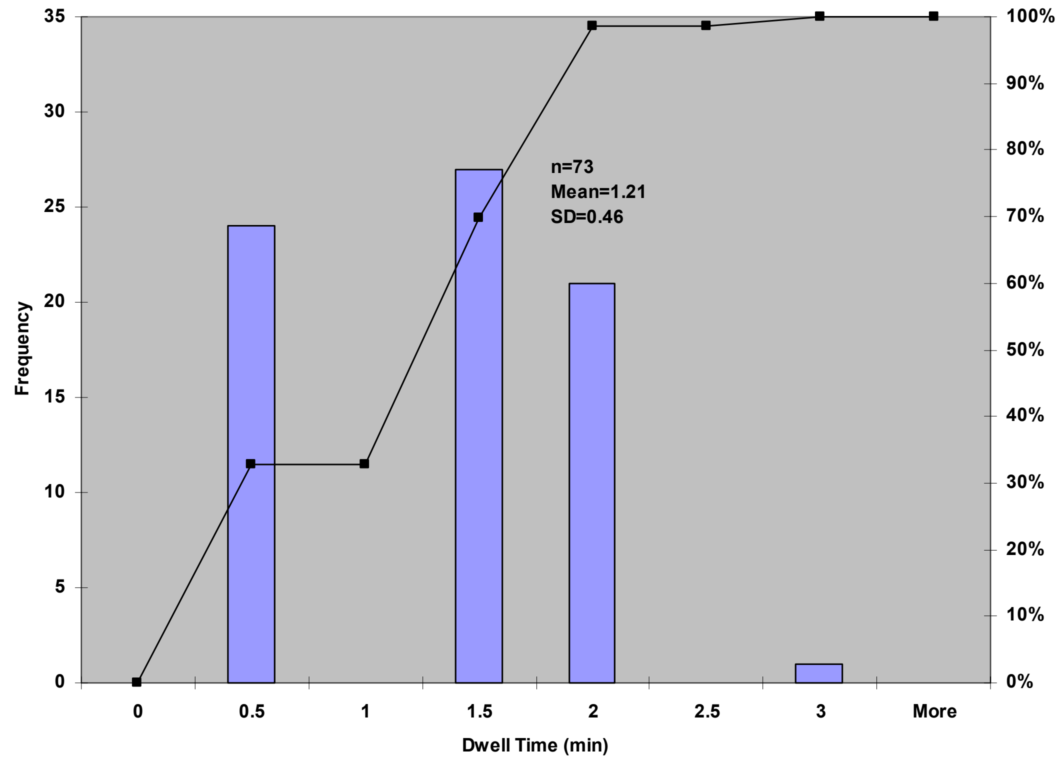

FIGURE 4-32 Dwell Time Distribution at Normandie (Westbound, Monday and Thursday 7:00am-10:00am)

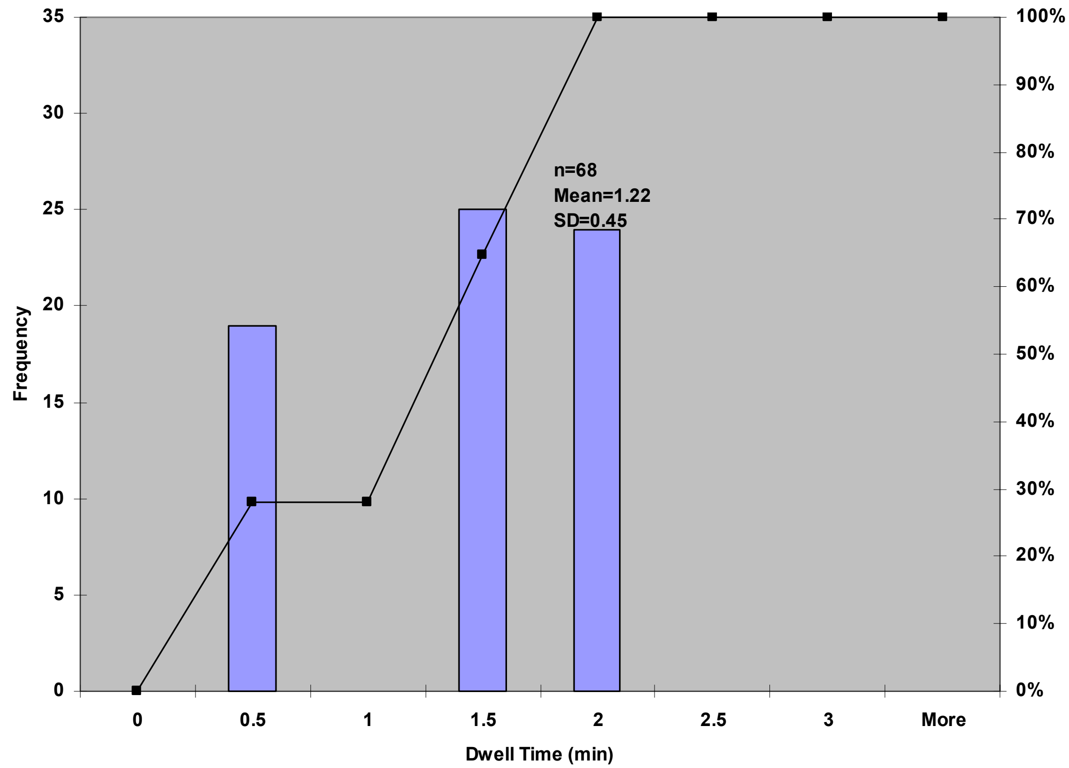

FIGURE 4-33 Dwell Time Distribution at Normandie (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

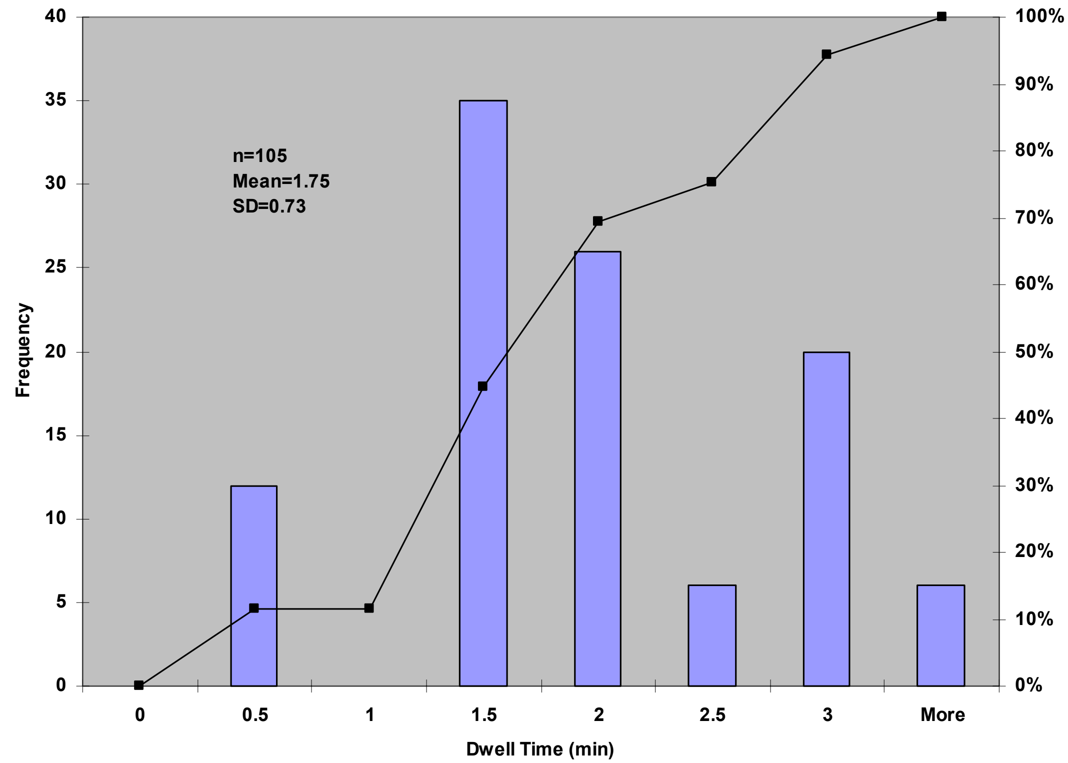

FIGURE 4-34 Dwell Time Distribution at Vermont (Westbound, Monday and Thursday 7:00am-10:00am)

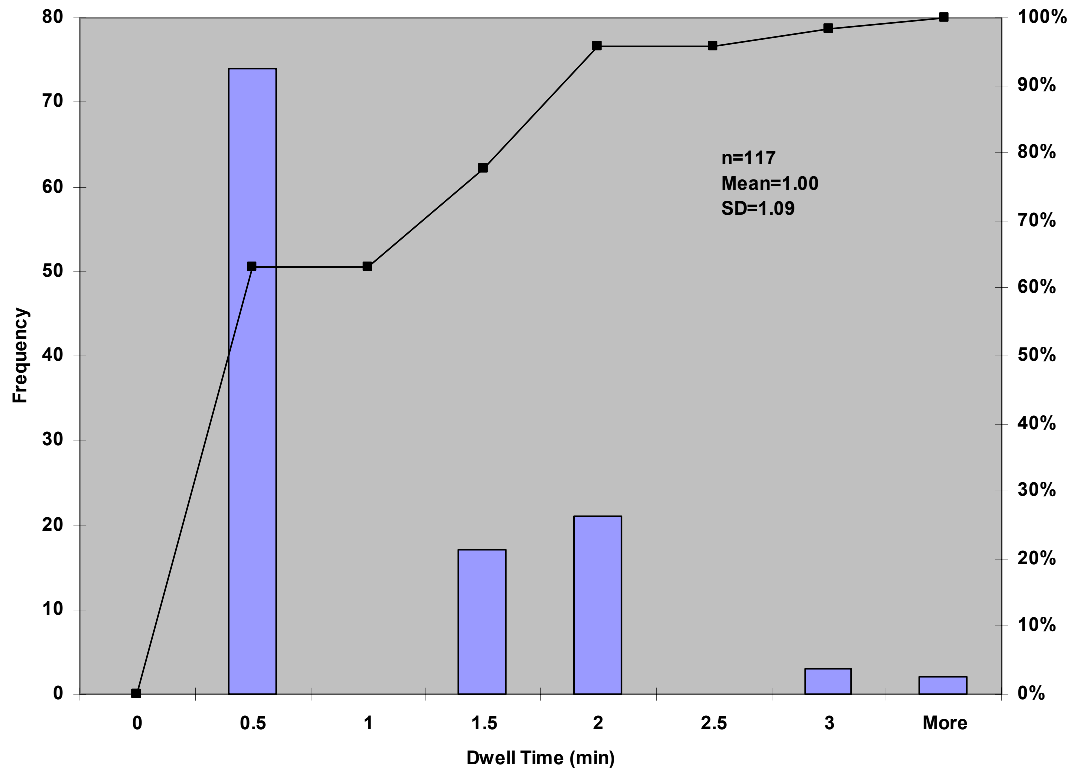

FIGURE 4-35 Dwell Time Distribution at Vermont (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

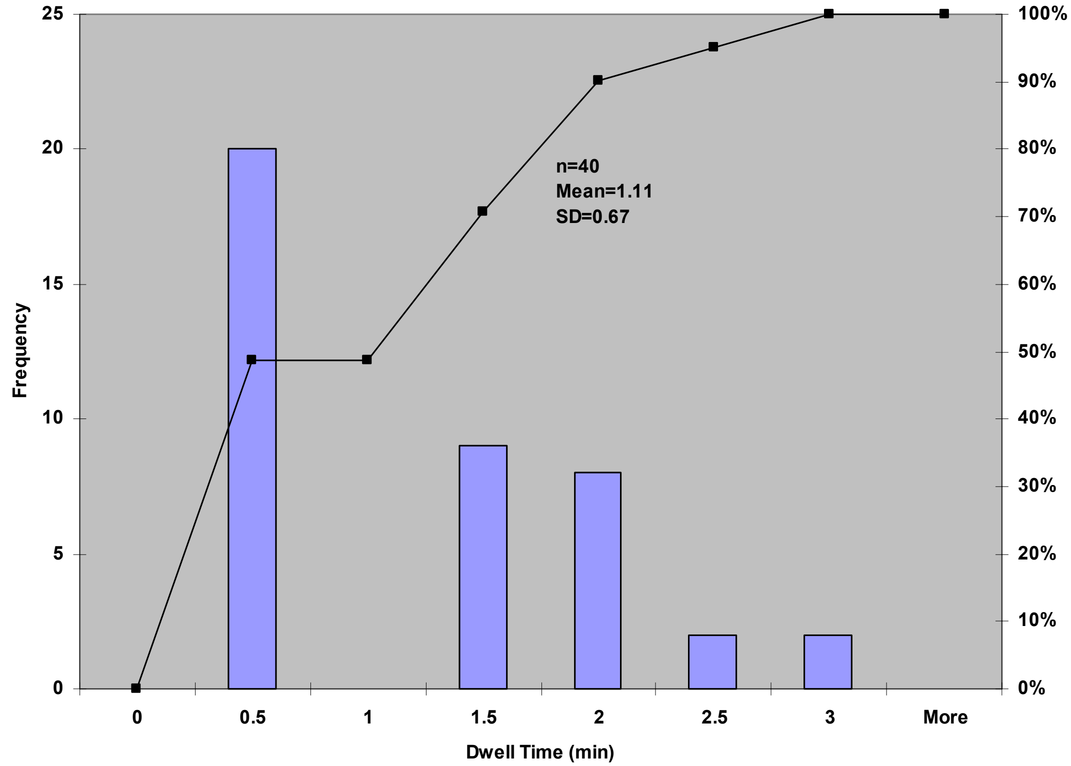

FIGURE 4-36 Dwell Time Distribution at Alvarado (Westbound, Monday and Thursday 7:00am-10:00am)

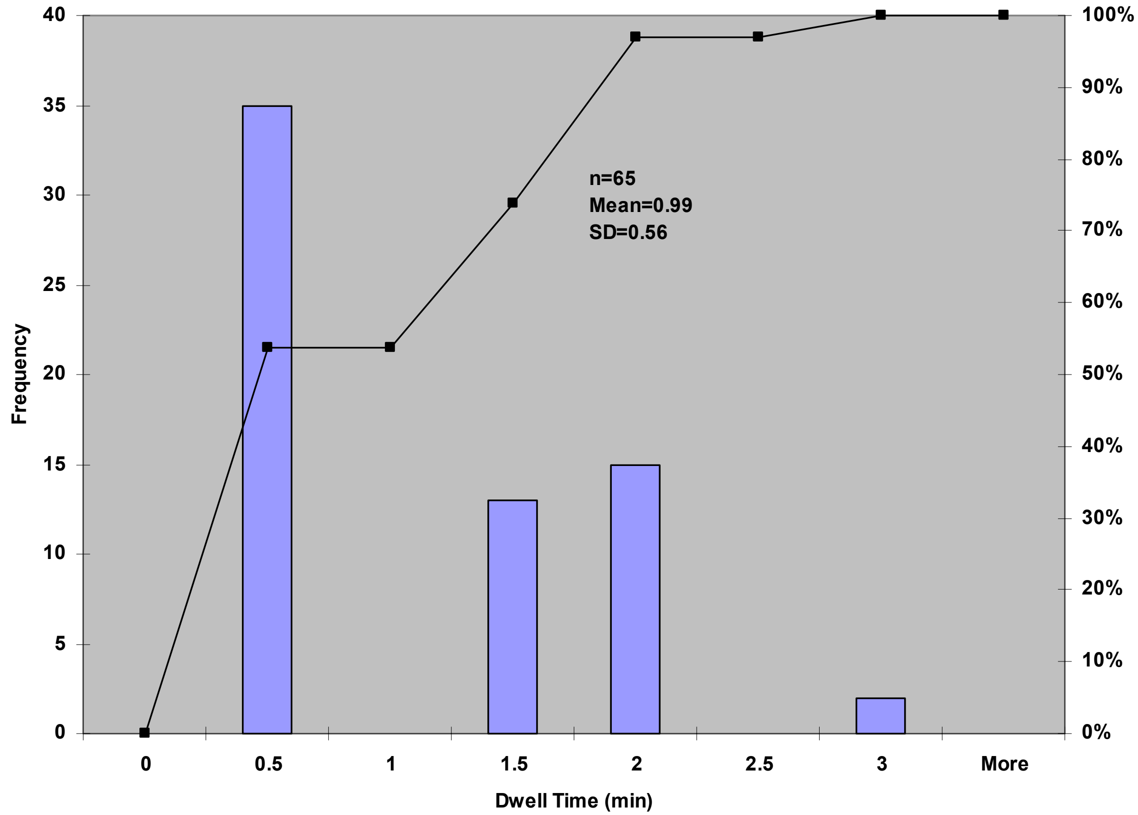

FIGURE 4-37 Dwell Time Distribution at Alvarado (Eastbound, Monday and Thursday, 4:00pm-7:00pm)

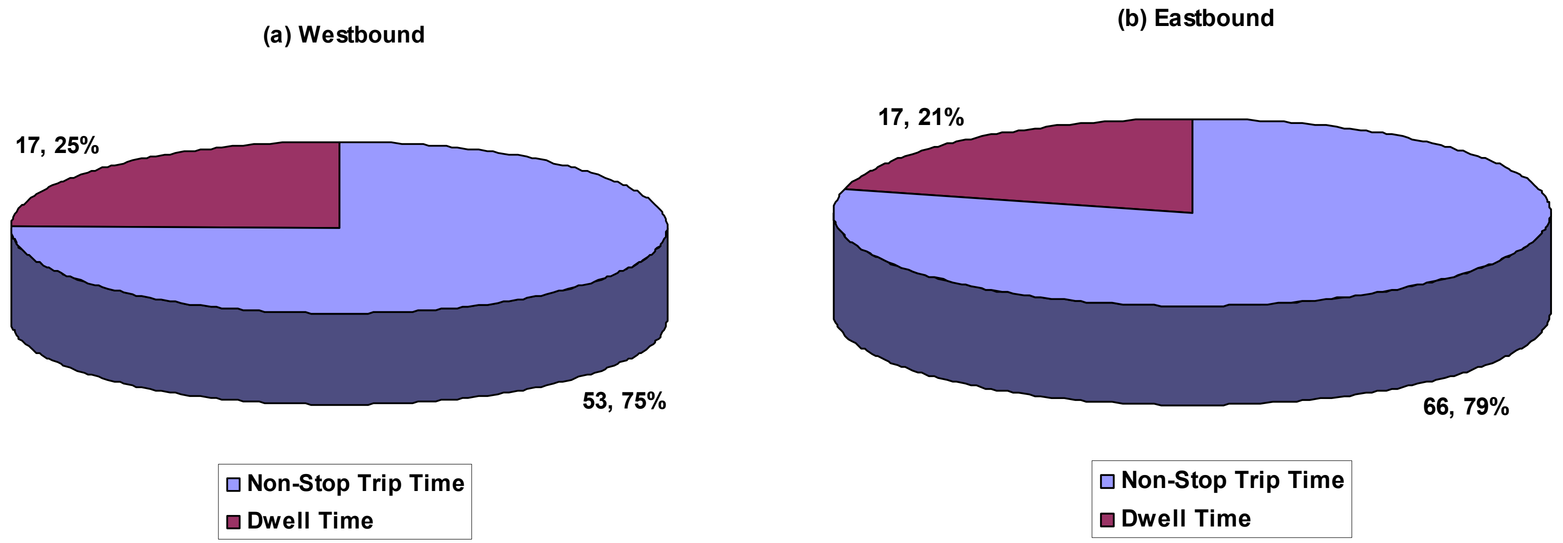

FIGURE 4-38 Trip Time Breakdown

TABLE 4-10 Number of Boarding and Alighting Passengers at Stops

Monday

Westbound

		5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	Total
7:00-8:00	Boarding	0	1	4	8	3	4	38	61	8	7	37	110	115	89	434	309	508	247	127	69	2180
	Alighting	2	102	106	110	163	95	285	170	121	83	83	175	68	29	40	85	94	72	32	79	1995
8:00-9:00	Boarding	0	2	6	14	3	5	48	21	7	13	49	72	77	85	364	254	461	173	71	56	1782
	Alighting	3	129	80	120	60	97	359	238	149	84	88	161	93	48	67	113	48	55	14	69	2073
9:00-10:00	Boarding	0	2	4	10	4	6	39	11	7	9	32	33	42	70	244	156	231	128	62	52	1142
	Alighting	2	103	76	66	53	91	249	144	153	63	77	115	56	40	39	88	35	55	21	40	1567
Total	Boarding	0	5	15	32	10	15	125	93	23	29	118	215	234	244	1041	719	1200	549	260	176	5104
	Alighting	7	334	262	296	276	282	893	552	423	230	248	451	217	117	146	286	177	182	66	188	5635

Eastbound

		5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson&	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	Total
4:00-5:00	Boarding	8	108	75	86	81	44	354	143	107	88	167	78	37	41	85	116	96	104	54	79	1950
	Alighting	0	3	8	6	5	5	41	17	17	16	134	48	35	58	396	211	227	229	77	69	1601
5:00-6:00	Boarding	9	94	72	96	66	40	299	93	125	71	99	85	93	46	63	101	99	94	32	69	1745
	Alighting	0	2	7	11	4	0	39	19	13	9	31	38	48	50	293	175	240	226	92	56	1353
6:00-7:00	Boarding	5	64	45	60	66	27	172	70	68	47	74	67	42	41	71	79	49	102	37	40	1226
	Alighting	0	2	1	12	8	0	26	25	11	13	29	58	31	39	170	158	182	219	71	52	1106
Total	Boarding	22	266	192	242	213	111	825	306	300	206	340	230	172	128	219	296	244	300	123	188	4921
	Alighting	0	7	16	29	17	5	106	61	41	38	194	144	114	147	859	544	649	674	239	177	4060

Thursday

Westbound

		5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega&	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	Total
7:00-8:00	Boarding	0	1	2	5	3	4	38	53	7	13	32	52	72	78	502	270	225	216	111	60	1744
	Alighting	2	89	97	95	142	83	265	149	106	85	72	159	59	25	57	74	24	63	28	69	1743
8:00-9:00	Boarding	0	2	6	8	3	4	47	19	6	12	43	81	81	74	385	222	212	151	62	49	1466
	Alighting	3	113	89	104	52	84	326	208	130	101	77	167	96	42	70	99	31	48	12	60	1911
9:00-10:00	Boarding	0	2	6	6	3	5	33	9	6	9	28	45	37	61	226	136	152	112	54	45	976
	Alighting	2	90	52	68	46	79	249	126	134	67	67	125	49	35	55	77	22	48	18	35	1444
Total	Boarding	0	4	14	19	9	13	118	81	20	34	103	178	190	213	1113	628	589	479	227	154	4186
	Alighting	6	292	238	267	241	246	841	482	369	254	216	451	204	102	182	250	77	159	58	164	5099

Eastbound

		5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	Total
4:00-5:00	Boarding	7	94	44	86	85	39	330	125	91	77	79	105	32	41	68	101	74	91	47	69	1684
	Alighting	0	3	6	6	17	4	53	15	17	14	24	48	31	82	358	184	232	200	67	60	1420
5:00-6:00	Boarding	8	82	65	97	93	35	219	81	137	62	113	63	81	41	45	88	60	82	28	60	1540
	Alighting	0	2	4	6	5	0	49	17	6	8	31	53	42	49	308	153	226	197	80	49	1285
6:00-7:00	Boarding	4	56	48	56	68	24	159	61	75	41	62	50	37	25	55	69	57	89	32	35	1103
	Alighting	0	2	7	6	12	0	30	22	3	11	24	37	27	46	262	138	54	191	62	45	979
Total	Boarding	19	232	157	239	246	97	708	267	303	180	254	218	150	107	168	258	191	262	107	164	4327
	Alighting	0	6	17	18	34	4	132	53	26	33	79	138	100	177	928	475	513	588	209	154	3683

TABLE 4-11 O-D Trip Table (Monday, Westbound, 7:00am-10:00am)

	5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	East Stops	Total Boarding
Ocean/Colorado	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4th	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
14th	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
Bundy	0	18	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32
Barrington	0	4	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
VA Hospital	0	4	3	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15
Westwood	0	27	22	26	25	26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	125
Santa Monica	0	12	9	11	11	11	39	0	0	0	0	0	0	0	0	0	0	0	0	0	0	93
Beverly	0	2	2	2	2	2	8	5	0	0	0	0	0	0	0	0	0	0	0	0	0	23
Robertson	0	2	2	2	2	2	8	5	4	0	0	0	0	0	0	0	0	0	0	0	0	29
La Cienega	0	9	8	9	9	9	31	20	15	8	0	0	0	0	0	0	0	0	0	0	0	118
Fairfax	0	16	13	15	14	15	52	34	26	14	16	0	0	0	0	0	0	0	0	0	0	215
La Brea	0	15	12	15	14	14	50	32	25	14	15	30	0	0	0	0	0	0	0	0	0	234
Crenshaw	0	15	12	14	13	14	48	31	24	13	15	29	15	0	0	0	0	0	0	0	0	244
Western	0	60	49	59	55	57	200	129	100	55	61	119	61	36	0	0	0	0	0	0	0	1041
Normandie	0	39	32	38	36	37	130	84	65	36	40	78	40	23	41	0	0	0	0	0	0	719
Vermont	0	56	46	55	52	54	187	121	94	51	58	112	58	33	60	163	0	0	0	0	0	1200
Alvarado	0	21	18	21	20	21	72	46	36	20	22	43	22	13	23	62	90	0	0	0	0	549
Witmer	0	8	6	7	7	7	25	16	13	7	8	15	8	4	8	22	32	66	0	0	0	260
5th/Grand	0	4	4	4	4	4	15	10	7	4	5	9	5	3	5	13	19	39	23	0	0	176
East Stops	0	9	7	9	8	8	29	19	15	8	9	17	9	5	9	25	37	76	44	188	0	531
Total Alighting	7	334	262	296	276	282	893	552	423	230	248	451	217	117	146	286	177	182	66	188	0	5635

TABLE 4-12 O-D Trip Table (Thursday, Westbound, 7:00am-10:00am)

	5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	East Stops	Total Boarding
Ocean/Colorado	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4th	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
14th	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14
Bundy	0	10	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	19
Barrington	0	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9
VA Hospital	0	3	3	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13
Westwood	0	25	21	25	23	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	118
Santa Monica	0	10	8	10	9	9	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	81
Beverly	0	2	2	2	2	2	7	4	0	0	0	0	0	0	0	0	0	0	0	0	0	20
Robertson	0	3	2	3	3	3	10	6	5	0	0	0	0	0	0	0	0	0	0	0	0	34
La Cienega	0	8	7	8	7	7	28	17	13	9	0	0	0	0	0	0	0	0	0	0	0	103
Fairfax	0	13	11	13	11	12	45	27	21	14	13	0	0	0	0	0	0	0	0	0	0	178
La Brea	0	12	10	12	11	11	41	25	19	13	12	26	0	0	0	0	0	0	0	0	0	190
Crenshaw	0	12	10	12	11	11	43	26	20	14	12	27	13	0	0	0	0	0	0	0	0	213
Western	0	61	53	61	56	58	219	131	101	70	62	138	66	35	0	0	0	0	0	0	0	1113
Normandie	0	32	27	32	29	30	114	68	53	37	32	72	34	18	50	0	0	0	0	0	0	628
Vermont	0	26	22	26	24	25	93	55	43	30	26	58	28	15	41	77	0	0	0	0	0	589
Alvarado	0	20	17	20	18	19	71	43	33	23	20	45	21	11	31	59	26	0	0	0	0	479
Witmer	0	8	7	8	7	8	29	17	13	9	8	18	9	5	13	24	11	34	0	0	0	227
5th/Grand	0	5	4	5	5	5	18	11	8	6	5	11	6	3	8	15	7	21	10	0	0	154
East Stops	0	25	21	25	23	23	89	53	41	29	25	56	27	14	39	74	33	104	48	164	0	913
Total Alighting	6	292	238	267	241	246	841	482	369	254	216	451	204	102	182	250	77	159	58	164	0	5099

TABLE 4-13 O-D Trip Table (Monday, Eastbound, 4:00pm-7:00pm)

	5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	East Stops	Total Boarding
Ocean/Colorado	0	7	1	1	0	0	1	0	0	0	1	1	0	0	3	2	2	1	0	0	1	22
4th	0	0	15	16	6	1	25	7	4	3	16	10	7	9	48	27	27	22	5	3	14	266
14th	0	0	0	12	4	1	19	6	3	3	12	7	6	7	37	20	20	17	4	3	11	192
Bundy	0	0	0	0	6	1	26	8	4	3	15	10	8	9	49	28	28	23	6	3	15	242
Barrington	0	0	0	0	0	1	23	7	4	3	14	10	7	8	44	25	25	21	5	3	12	213
VA Hospital	0	0	0	0	0	0	12	4	2	2	7	5	4	4	23	13	13	11	3	2	7	111
Westwood	0	0	0	0	0	0	0	29	17	13	64	39	29	35	197	109	108	90	22	13	60	825
Santa Monica	0	0	0	0	0	0	0	0	7	5	26	16	11	13	76	42	41	35	8	5	22	306
Beverly	0	0	0	0	0	0	0	0	0	5	22	16	12	13	74	42	42	36	9	5	24	300
Robertson	0	0	0	0	0	0	0	0	0	0	17	11	8	9	53	29	29	25	6	4	16	206
La Cienega	0	0	0	0	0	0	0	0	0	0	0	19	14	17	98	53	51	43	10	6	27	340
Fairfax	0	0	0	0	0	0	0	0	0	0	0	0	10	12	67	39	38	33	7	4	19	230
La Brea	0	0	0	0	0	0	0	0	0	0	0	0	0	9	50	29	30	26	6	4	17	172
Crenshaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	41	24	24	21	4	3	11	128
Western	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	62	60	52	11	7	28	219
Normandie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	111	95	21	13	55	296
Vermont	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	122	28	18	76	244
Alvarado	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	51	164	300
Witmer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	92	123
5th/Grand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	188	188
East Stops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Alighting	0	7	16	29	17	5	106	61	41	38	194	144	114	147	859	544	649	674	239	177	861	4921

TABLE 4-14 O-D Trip Table (Thursday, Eastbound, 4:00pm-7:00pm)

	5th/Colorado	4th	14th	Bundy	Barrington	VA Hospital	Westwood	Santa Monica	Beverly	Robertson	La Cienega	Fairfax	La Brea	Crenshaw	Western	Normandie	Vermont	Alvarado	Witmer	5th/Grand	East Stops	Total Boarding
Ocean/Colorado	0	6	1	1	1	0	2	0	0	0	0	1	0	1	3	1	1	1	0	0	1	19
4th	0	0	16	10	12	1	28	6	2	3	6	9	6	10	48	22	20	18	4	3	9	232
14th	0	0	0	7	8	1	20	5	2	2	4	7	4	7	36	16	14	13	3	2	6	157
Bundy	0	0	0	0	13	1	33	7	3	3	7	10	7	11	56	26	24	21	5	3	10	239
Barrington	0	0	0	0	0	1	35	8	3	3	7	11	8	12	62	28	25	23	5	3	11	246
VA Hospital	0	0	0	0	0	0	14	3	1	1	3	4	3	5	25	11	10	9	2	1	4	97
Westwood	0	0	0	0	0	0	0	25	11	12	24	38	24	43	210	95	86	76	17	11	36	708
Santa Monica	0	0	0	0	0	0	0	0	4	5	9	15	10	17	82	37	33	30	7	4	14	267
Beverly	0	0	0	0	0	0	0	0	0	5	11	17	12	18	93	42	39	35	8	5	17	303
Robertson	0	0	0	0	0	0	0	0	0	0	7	10	7	12	57	26	23	21	5	3	10	180
La Cienega	0	0	0	0	0	0	0	0	0	0	0	15	10	16	83	38	34	31	7	4	15	254
Fairfax	0	0	0	0	0	0	0	0	0	0	0	0	9	16	77	35	31	28	6	4	13	218
La Brea	0	0	0	0	0	0	0	0	0	0	0	0	0	10	54	25	23	21	5	3	10	150
Crenshaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	42	19	17	16	4	2	7	107
Western	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	54	41	43	9	5	17	168
Normandie	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92	95	20	12	39	258
Vermont	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	108	23	14	45	191
Alvarado	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	47	137	262
Witmer	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	80	107
5th/Grand	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	164	164
East Stops	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Alighting	0	6	17	18	34	4	132	53	26	33	79	138	100	177	928	475	513	588	209	154	644	4327

4.7 Application of Deployment Planning Framework

In this section we demonstrate the use of the proposed deployment planning framework by exercising it on a site-specific case: LACMTA's Wilshire BRT corridor.

As described in Section 4.1, LACMTA has deployed the following BRT elements for their corridor: simple and single route layout without any route variations, frequent and headway-based service, less frequent stops, level boarding and alighting, color-coded buses and stations, bus signal priority and Next Bus displays. LACMTA has plans to expand their BRT system for part of this corridor along a 13-mile segment of the entire 27-mile long corridor between the Los Angeles CBD and the Pacific Ocean.

The following BRT elements are considered for the system expansion:

a. Bus signal priority (extended over existing deployment)
b. Exclusive lanes
c. Articulated buses
d. Multiple door boarding and alighting
e. Stop enhancements
f. Electronic fare payment
g. Precision docking

Given these seven BRT elements the deployment-planning framework can be used to determine cost-efficient combinations of elements for the system's expansion.

Our original objective was to exercise the deployment planning framework by means of two approaches. First, we planned to use simulation and perform a series of "what-if" analyses to assist in our understanding of the impacts for individual bus rapid transit system elements and various feasible combinations of these elements. Simulation can best capture the complexities of bus rapid transit systems. The selected tool was SmartBRT, a microsimulation and evaluation tool under development at PATH designed specifically to capture characteristics of bus rapid transit infrastructural and operational concepts and the interaction between BRT and other elements of the transportation system. The other approach was to perform a macroscopically-based and analytically-driven evaluation of the Wilshire Metro Rapid corridor.

In addition to the attention devoted to capturing the details of BRT systems SmartBRT includes traffic simulation, which is based on Paramics, with extensions using the Paramics API (Application Program Interface). Paramics is a widely used program for modeling large scale traffic networks. However, Paramics itself cannot represent the variety of BRT elements in the scope of SmartBRT. Work was performed to extend Paramics with models of bus stops (passenger and bus arrival), passenger motion (boarding, alighting, seating, transferring), and bus motion (release from terminal, lane selection, behavior when approaching signals and stops) in the context of BRT technologies and policies (signal priority, headway, payment mechanisms, door usage). In order to realistically mimic bus motion and operation, one of the inherent and core functions of Paramics that describes vehicle behavior has to be overridden, which has proved to be a difficult and time-consuming task. Consequently, the development of SmartBRT was delayed, and when we exercised the deployment planning framework, work on SmartBRT had not yet been completed to the extent that was necessary to serve this project. This limitation leaves us with the macroscopic approach, which we present in the subsections 4.7.1 through 4.7.5. Nevertheless, the macroscopic approach has provided adequate results to address the project's objective.

4.7.1 Combinations of Bus Rapid Transit Elements

The possible combinations considered are:

- Alternative A: Elements a, b, c, d, e and f (see above)
- Alternative B: Elements a, b, c, d, e, f and g

Alternative B contains all seven candidate elements while Alternative A doesn't include element g (precision docking). Precision docking is a low-speed automated positioning of buses relative to the curb or loading/unloading platform at bus stops under direct bus driver supervision. It offers precisely controlled lateral positioning with tolerances of 1 to

2 cm to allow boarding and alighting of passengers as easily as for rail transit vehicles, reducing dwell times at bus stops and improving accessibility for mobility-impaired passengers, especially those in wheelchairs). Precision docking is an emerging ITS bus technology and the BRT Consortium and the national Transit Intelligent Vehicle Initiative Committee have identified it as a critical technology for both BRT and other transit services.

- Alternative C: Elements a, b, e and f
- Alternative D: Elements a, b, e, f and g

Compared with Alternatives A and B, these two alternatives exclude element c - the costly element of articulated buses, and element d - the associated element of multiple door boarding and alighting.

- Alternative E: Elements a, c, d, e and f
- Alternative F: Elements a, c, d, e, f and g

Similarly, these two alternatives are created without element b - exclusive bus lanes.

- Alternative G: Elements a, b, c and d

There are certainly other possible combinations of elements. However, most of them are likely to be dominated in terms of efficiency by the above combinations.

4.7.2 Cost Assessment for Each Combination

4.7.2.1 Unit Costs of Bus Rapid Transit Elements

The unit costs of each element under consideration were estimated as follows:

- Bus signal priority

The capital cost of bus signal priority is primarily associated with the necessary instrumentation of intersections and transit buses. Typically cost data is reported in terms of average dollars per intersection. Depending on the specific technology being used and equipped transit fleet size, capital cost varies widely. Prior deployments indicate cost ranges between $8,000 and $35,000 per intersection. The average cost of LADOT's signal priority system is $15,000 per intersection (23), covering control software, specific loop detectors, transponders, dynamic passenger information signs and other hardware. It should be cheaper to expand the TSP system to cover the entire corridor (given that it is feasible to do) since the costs associated with equipping buses and software development will be saved. However, due to lack of detailed information about signal control systems on the intersections within parts of the Wilshire corridor in jurisdictions outside the city of Los Angeles, it is hard to determine whether additional hardware replacement (such as controllers) and software change are indeed required. Therefore, the unit cost of $15,000 per intersection is maintained.

- Exclusive lanes

Communities opposed construction of two exclusive parallel bus lanes operating 24 hours/day in the median lane of Wilshire Boulevard. Nonetheless, a peak-period curb bus-only lane is institutionally feasible through the cities of Los Angeles and Beverly Hills only. The total repair and reconstruction cost was estimated to be six million dollars (19).

- Articulated buses

Single-articulated (60-foot-long) buses can provide an average seating capacity of 65 passengers, with space available for another 13 to 30 standees. Such buses operate on Compressed Natural Gas (CNG) or Electric/Hybrid technologies, and are designed to provide three doors for faster boarding and alighting. Based on bus manufacturers' quotes, each bus costs approximately $800,000. The fleet size is approximately 100 buses.

- Stop enhancements

BRT stops will provide shelter for passengers, boarding gates, wayfinding maps, security telephones, a bus schedule display, electronic "Next Bus" arrival message, etc. The stop enhancement to the existing Metro Rapid stops will cost around $600,000 each (10).

- Electronic Fare Payment

Smart Card fare media would be read by validators located on-board the buses at each of the doors. Transit riders would debit fares by using their Smart Card upon boarding and exiting the vehicle. The cost for such an electronic fare payment system is about $13,000 per unit (24).

- Precision docking

The costs of equipping buses for precision docking are estimated to be $15,000 each in the relatively near term (when only hundreds of buses would be equipped, rather than thousands), and the cost per bus stop is estimated to be $500 for installation of reference markers.

With the above unit costs, it is straightforward to obtain the following cost estimates. Note that the cost estimates do not include project contingency and professional services like engineering, construction management and specialty consultants.

4.7.2.2 Cost Estimates of Bus Rapid Transit Combinations

With the above unit costs, it is straightforward to obtain the following cost estimates (Table 4-15). Note that the cost estimates do not include project contingency and professional services like engineering, construction management and specialty consultants.

TABLE 4-15 Cost Estimates of Combinations of Bus Rapid Transit Elements

Alternative	BRT Elements	Cost ($M)
A	a, b, c, d, e, f	99.9
B	a, b, c, d, e, f, g	101.4
C	a, b, e, f	19.9
D	a, b, e, f, g	21.4
E	a, c, d, e, f	93.9
F	a, c, d, e, f, g	95.4
G	a, b, c, d	86.6

4.7.3 Constraints and Feasible Combinations

The budget limit for implementing the sets of BRT elements is considered as given with the amount of $90M[3]. Therefore the financially feasible alternatives are C, D and G. Moreover, by refining Alternative E through excluding the element e - stop enhancement, and making it financially feasible, a new Alternative H is created. This alternative includes the BRT elements a, c, d and f, and the total cost is $83.9M.

In summary, the feasible alternatives are C, D, G and H. Since Alternative D surely outperforms Alternative C, only Alternatives D, G and H are subject to an evaluation process.

4.7.4 Evaluation of Feasible Combinations of Bus Rapid Transit Elements

A high-level macroscopic evaluation approach should serve the purpose of demonstrating the use of the proposed framework. Therefore, we use the methodology described in Section 3.3 to evaluate the alternatives for the morning peak (7:00am-10:00 am).

[3] This is not an actual budget limit for LACMTA for this project. The number was set only for the purpose of exercising the framework. If the number was high enough, there would be no trade-off between elements.

4.7.4.1 Effectiveness of Each Bus Rapid Transit Element

- Bus signal priority (a)

Substantial variability exists in the effectiveness of an existing bus signal priority system, due to differences in system design, signal priority strategy, traffic condition, and the synergy and integration with other preferential treatments. Nonetheless, reduction of transit delay at signalized intersections is generally reported between 20% and 50%. According to LADOT's estimation (23), approximately 20% of the total bus running time was spent waiting at traffic signals along the Wilshire corridor.

- Exclusive lanes (b)

The peak-only dedicated lanes between Western Avenue and Santa Monica City limits (if done) would reduce peak running time by an additional two to four minutes (19).

- Articulated buses (c)

Single-articulated (60-foot-long) buses can provide an average seated capacity of 65 passengers, with space available for another 13 to 30 standees. The current 40-foot-long buses have 39 seats each.

- Multiple door boarding and alighting (d)

Given that passengers are allowed to board and alight through all of three doors of the articulated buses, the bus dwell time is expected to be reduced by 10% to 30%. If coupled with using Smart Card fare media - by 20% to 40%.

- Electronic Fare Payment (f)

Once passengers become familiar with the electronic fare payment system, it can further reduce bus dwell times by 5%-10% (estimate).

- Precision docking (g)

Precision docking improves the amenity value and status of bus transit, by making it more like rail transit. This is particularly difficult to quantify, but in the long term it should be manifested as a ridership increase (25).

Precision docking also reduce the "dead time" that the bus spent at the stops as well as unit passenger boarding and alighting times. It is further estimated that precision docking reduces bus dwell times by 20%-30%, if implemented together with stop enhancement for level boarding and alighting and electronic fare payment.

4.7.4.2 Evaluation of Feasible Combinations

We may use the two objective functions interpreted in section 3.3 to seek for the optimal combinations across different combinations of BRT elements. Because in this case study, there was only one BRT route and no variation in consideration, we rather used a simplified formulation (Equation 1) as below:

$$\min Z_1 = \alpha_1 \sum_{i,j \in N} WT(i,j) + \alpha_2 ESH + \alpha_3 \sum_{i,j \in N} PH(i,j) \tag{1}$$

$$\min Z_2 = FS \tag{2}$$

$PH(i,j)$ = Passenger hours between nodes *i* and *j*, $i, j \in N$ on the BRT route;

$WT(i,j)$ = Waiting time between nodes *i* and *j*, $i, j \in N$;

ESH = Empty space-hours on the BRT route;

FS = Fleet size (number of BRT vehicles required to provide all trips along the chosen set of routes);

$\alpha_{1,2,3}$ = Monetary weights. In particular, α_1 is monetary value of one-hour waiting time; α_2 is average revenue per passenger hour and α_3 is monetary value of in-vehicle travel time;

Objective Z_1 is to minimize the total cost of passenger waiting time, passenger travel time, and empty seat hours. Based on data from the literature (1, 10, 26, and 27), it is estimated and assumed that $\alpha_1 = 80$, $\alpha_2 = 0.8$ and $\alpha_3 = 8$ US$ per passenger hour. The values of the objective functions for each combination were calculated using the survey data described in Section 4.2.5 and are appearing in Table 4.2.

TABLE 4-16 Evaluation Results of Combinations of Bus Rapid Transit Elements

	Passenger travel time (pass-hrs)	Passenger waiting times (pass-hrs)	Empty Seats Hours (pass-hrs)	Z_1	Z_2 [4]
Alternative D	1999	94	1614	23966	138
Alternative G	2025	139	1639	28648	84
Alternative H	2075	139	1665	29065	86

4.7.5 Recommend Optimal Combination(s)

The results in Table 4-16 are also shown in Figure 4-39.

[4] The fleet sizes reported here were calculated by using the service frequency determined by maximal passenger load, round trip time, and assumed 20-minute layover time. The actual fleet size should be larger.

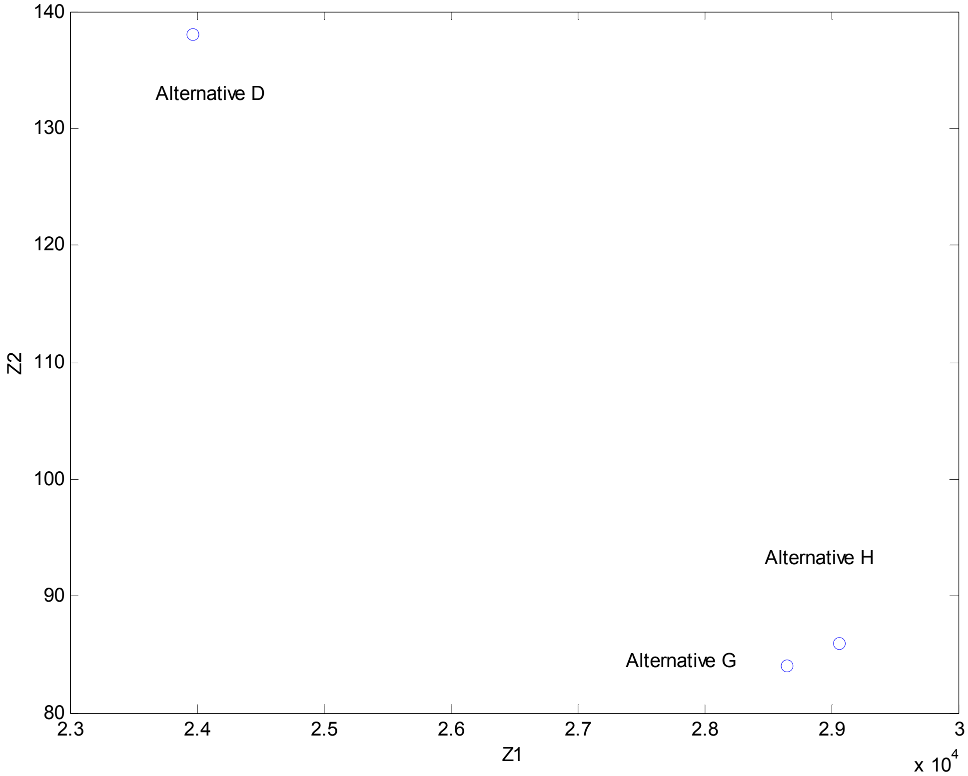

FIGURE 4-39 Values of Objective Functions of Bus Rapid Transit Combinations

It can be seen from the above figure that Alternative H is dominated by Alternative G where both G and D are two non-dominated or Pareto optimal solutions. Although the capital cost of Alternative D is much less than Alternative G, it requires much larger fleet size, which may lead to higher operating and maintenance costs. Therefore, transit agencies should look carefully on the trade-off between these two objectives and based on their preference and non-quantitative consideration decide on which alternative (among the recommended G and D) to deploy.

5.0 CONCLUSIONS AND NEXT STEPS

5.1 Conclusions

Bus rapid transit systems differ from more traditional transit services by its features that combine elements associated with other forms of mass transit such as light and heavy rail transit with highly flexible service and advanced technologies to improve customer convenience and system reliability. Bus rapid transit systems can thus be seen as a bus-based "rapid" transit system that combines vehicles stations, running way, and intelligent transportation systems technologies into a fully integrated system with a unique identity. The planning process of a BRT system can generally be divided into three inter-related stages:

- Feasibility study or major investment study in which bus rapid transit is investigated compared with other transit alternatives to find out the most cost-effective investment over a corridor
- Deployment planning that determines what BRT elements will be included in the BRT system and their deployment sequence
- Operations planning including designing routes and stations, setting timetables, scheduling vehicles, and assigning crew.

While the first and third stages are essentially planning-specific for any transit service, the second stage deals with the special features associated with a bus rapid transit system due to its flexibility in incremental deployment of elements. We have taken a systems optimization approach and developed the theoretical foundation for a deployment-planning framework that fills a gap in the overall planning process for bus rapid transit systems.

5.2 Next Steps

In this section we discuss three issues dealing with the next steps for the bus rapid transit deployment-planning framework, as follows:

- Time-phased deployment of bus rapid transit

- Systematic transit market research toward cost-effectives deployment
- Expansion of bus rapid transit corridor network

5.2.1 Time-Phased Deployment of Bus Rapid Transit

This report has developed a deployment planning framework for BRT enabling transit agencies to determine an optimal configuration of BRT elements given budgetary, institutional and other types of constraints. It is noted however that deployment phasing issue (step-by-step implementation on a time scale) is not addressed in this work though it is one of the critical issues that deserves careful exploration in order to achieve a cost-effective deployment.

With different deployment phases in terms of infrastructure, operation, testing, control and supervision, BRT system can evolve from some primary type, like operating on mixed-traffic lanes with bus signal priority, to be high-end automated system. With budgetary, institutional and technological constraints, a specific BRT implementation will often need to be deployed in several phases or stages. However, there is no rigorous way to determine how many phases the BRT system needs to evolve to its eventual state, and in each stage what BRT elements should be included. Indeed, in reality these questions are answered based on experience and expert judgments. For instance, LACMTA has deployed BRT services on the Wilshire corridor in two stages: Phase I and II based primarily on prior experience and expert judgment. Under a contract with the Federal Transit Administration in concert with the U.S. BRT Consortium, a consultant created a brochure depicting four phases for BRT system deployment that seems to follow a rather artificial “one-size-fits-all” approach to BRT deployment. Instead, the phases or stages of BRT deployment should be decided after a careful systematic analysis. When and which BRT element should be implemented is a tradeoff between the costs associated with it, ease of implementation (physical constraints and institutional issues) and resultant benefits.

A systematic methodology that consists of both quantitative and qualitative analyses can be developed to address the issue. The quantitative analysis may include a simplified mathematical model to determine optimal deployment stages, with identifying and incorporating those variables that are quantifiable. As the benefits and costs associated with one phase of deployment is obviously dependent on decisions made in previous phases, the model must dynamically optimize over a flexible time-dependent choice set, and element-dependent choice set and determine the optimal phases of deployment, which can tell how many stages the deployment plan may need, what BRT elements should be included in each stage, and when each stage should be implemented. This way, the resultant BRT deployment plan will adapt the implementation more effectively to local conditions, such as travel demand, local physical conditions and available budget. For those variables not easily quantifiable, such as societal and institutional issues, qualitative analysis methods may be applied that comprise expert knowledge and experience, literature reviews and appropriately designed and administered surveys of BRT operators.

It is expected that the proposed systematic methodology will help transit agencies deal with the deployment phasing issue and understand the characteristics that each phase of a BRT system can offer and the capital cost associated with it. These results are of immediate interest to transit agencies for deployment of cost-effective BRT systems.

5.2.2 A Systematic Transit Market Research Towards Cost-Effective Deployment

BRT is expected to provide significantly faster operating speeds, greater service reliability, and increased convenience, matching the quality of rail transit when implemented in appropriate settings. However, improved level of service (LOS) does not necessarily mean an increase of ridership. To ensure a successful implementation of BRT, market research is needed to understand better about its current and potential customers, their behavior, and their needs so that optimal deployment plans (sets of BRT elements and phases of deployment) and marketing strategies can be determined and implemented.

Not all transit agencies presently conduct rigorous market research due to the lack of established framework and appropriate tools. It is proposed to use stated preference or revealed preference surveys and other market data and quantitative analysis techniques, such as discrete choice models, to better understand consumer knowledge, needs, preferences, barriers and opportunities to change transit travel behavior with a specific focus on bus rapid transit. Market research should play an important role in planning customer-oriented transit services that have various elements and can be deployed incrementally. Undoubtedly, the elements that most address the needs of the customers would increase attractiveness of BRT and thus should be implemented with the highest priority. For example, bus operations in many U.S. cities have an image problem and BRT advocates have expressed the opinion that BRT systems should establish a separate identity from current bus operations to “maximize its potential to attract additional riders.” (28) Such an ‘image benefit’ is not new to the transit industry as it has been used to justify constructing light rail transit rather than bus systems. However, no evidence has been put forward that such effects do occur (29). Moreover, a recent study (27) concludes that there is no evident preference for rail travel over bus when quantifiable service characteristics such travel time and cost are equal. In view of this, there is a doubt whether the impact of a distinctive identity of BRT has been overstated, which definitely needs to be examined. Through market research, the relative importance of LOS characteristics can be determined, including travel time, waiting time, reliability, fare, access/egress walking time, bus stops and number of transfers. The contribution or impact of each BRT element to major measures of BRT performance is under study through current research at PATH and an on-going project (Project A-23A) funded by TCRP. Based on these results, it would be straightforward to decide which elements should be implemented in order to achieve higher ridership.

Travel needs and behaviors vary across different passenger groups. It is thus important that BRT system deployment plans should be targeted for particular market segments. Knowledge gained from the market research will also be useful for predicting ridership and designing cooperative fare strategies for BRT.

5.2.3 Expansion of Bus Rapid Transit Corridor Network

The success and popularity of initial BRT demonstration programs has made some transit agencies consider expanding their BRT programs and deploying more BRT lines. For example, LACMTA has approved the implementation of the Metro Rapid Expansion Program that calls for the development of a total of 23 Metro Rapid lines. The 23 Metro Rapid lines have been prioritized into four implementation phases. It is estimated that each phase of the program will take three years to implement between 5 and 6 Metro Rapid bus lines.

Along with the proliferation of BRT systems, two issues deserve careful exploration in order to achieve network-wide efficiency of deployment and operation.

The first issue is concerned about identification of potential BRT corridors and prioritization of implementation of these corridors. This issue is essentially a network design problem that has been long studied in the context of road traffic network and to some extent in transit network design. Therefore, the models and methodologies that have been developed in that field can be borrowed and modified to address the issue, considering the unique features of transit operations and passenger behaviors, such as the "common line" problem (30), smart access and egress to BRT lines, and smart operational tactics and strategies. .

The other issue is about fare strategies for transit services including BRT lines. Transit properties have historically experienced low levels of farebox recovery. They resorted to service expansion to maximize subsidies. Although agencies recognize the factors for fare determination, there exists no systematic methodology to investigate every option of fare programs and determine cooperative and discriminatory fare strategies across different types of transit services (normal bus and BRT lines), groups of customers and times of day. It would be of interest to develop and apply such a systematic methodology such that the transit system can be operated more efficiently at the same time the revenue can be maximized.

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Check Appropriate Boxes:

Bus Stop: ____

Day: ☐ Monday ☐ Thursday

Time Period: ☐ 7-10 AM ☐ 4-7 PM

APPENDIX I
Wilshire Metro Rapid Bus Observational Log

Record Number	Bus Arrival Time (hh:mm)	Number of Passengers Alighting (Getting off)	Number of Passengers Boarding	Bus Run Number	On-board passenger load estimate when bus departs Check Off (√) Appropriate Cell					Bus Departure Time (hh:mm)
					Few	About Half Full	Full (no standees)	Full (with some standees)	Fully Loaded (Packed) If packed, # of passengers left at stop	
1	0709 or 7:09									0709 or 7:09
2	5:23 or 17:23									5:23 or 17:23
3										
4										
5										
6										
7										
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