Evaluation of Service Design Characteristics for Concurrent BRT and Local Bus Service in Santa Clara County and Other Urban Corridors

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1.0 INTRODUCTION

Over the past decade, dozens of transit agencies across the United States have turned to Bus Rapid Transit as a cheaper, more flexible means of augmenting their existing transit infrastructure. When implemented successfully, Bus Rapid Transit (BRT) can provide the benefits of rail transit – frequency, speed, reliability, and comfort – at a fraction of the capital and operating costs. It accomplishes this by using specialized buses travelling at frequent intervals in dedicated or mixed traffic lanes, making fewer stops with shorter dwell times to quickly transport passengers across crowded urban networks.¹

While BRT can help to significantly increase system capacity, cost efficiency, and overall mobility, it should be viewed as a single element in a complex transportation network that serves a wide variety of users and needs. The successful integration of new BRT service with other parallel modes – namely, local, all-stop bus service – is critical to the transit corridor’s long-term health and viability. The degree to which a productive balance is achieved is largely defined by decisions that are made during the service design planning process.

One major transit agency that is planning to implement BRT with local overlay service is the Santa Clara Valley Transportation Authority (VTA) in San Jose, California. Since 2008, VTA has been planning to supplement its local bus service in three major corridors with the addition of over 30 miles of BRT routes.² Since the existing local bus lines in these corridors represent several of the most heavily-used routes in the VTA system,³ the effective coordination of BRT with these local lines through intelligent service planning and design will be especially important.

1.1 Problem Statement

The operational relationship between BRT and local bus service is an important subject of research, particularly in light of the growing popularity of BRT systems. Transit agencies like VTA that are planning to introduce BRT into complex, urban networks could benefit from a set of general recommendations that focus on the design and evaluation of concurrent BRT and local bus service. Without such guidance, inadequate coordination between existing bus lines and new BRT systems could unintentionally reduce a network’s capacity to provide service for short, local trips or trips that include origins or destinations without frequent bus service. Likewise, poorly-matched service frequencies and spans can also produce a detrimental effect on overall system productivity, ridership, reliability, and customer satisfaction. It may even stem potential growth in economic productivity attributed to effective BRT.⁴ Therefore, the decisions made in the service design planning process are particularly important in corridors with complementary BRT and local bus service.

The purpose of this capstone paper is to sequentially address the following three questions:

1. What service design characteristics provide the most productive balance between concurrent BRT and local bus service?
2. What BRT and local bus service design characteristics should be implemented in the three planned BRT corridors in Santa Clara County?
3. What metrics should be used to evaluate the performance of concurrent BRT and local bus service in Santa Clara County and other similar transit systems?

For the purposes of this paper, “service design characteristics” refers to two main design considerations for both BRT and local bus lines: service frequency and span. Frequency is measured primarily in
headways (time, in minutes, between scheduled arrival times). Span is represented by the hours per day and days per week that a particular route or service is operated. These attributes were selected for the roles they play in defining the basic operational relationship between BRT and supporting local, all-stop bus service.

The first and third questions have broad implications for transit agencies that operate or are planning to operate BRT-type service. The provision of adequate service frequencies and service hour spans are among the most statistically-significant BRT ridership drivers.\(^5\)\(^6\) Systems that successfully develop and maintain productive balances between BRT and local service are more like to experience ridership growth, tenable ridership splits, shorter travel times across all parallel modes, improved service reliability, and cost efficient labor/vehicle deployment. The findings of these questions could also benefit communities without immediate access to BRT, senior citizens, and persons with disabilities that limit personal mobility.

The findings and recommendations yielded from the second and third questions are directly applicable to VTA’s planned BRT projects in Santa Clara County. Although the BRT Strategic Plan and its preferred operating characteristics have been approved by the VTA Board of Directors, the flexible nature of service frequency and span allows them to adapt as warranted by changing circumstances. This paper revisits and expands upon some of the analyses that VTA staff used to determine their preferred service design characteristics. As such, Santa Clara County and VTA may also benefit from the findings of this research.

1.2 What is BRT?

The Federal Transit Administration (FTA) defines Bus Rapid Transit as “an enhanced bus system that operates on bus lanes or other transit-ways in order to combine the flexibility of buses with the efficiency of rail.”\(^7\) The National Bus Rapid Transit Institute (NBRTI) calls it “an innovative, high-capacity, lower-cost public transit solution that can achieve the performance and benefits of more expensive rail modes.”\(^8\) Others have more succinctly dubbed it “rubber-tired light rail transit ... but with greater operating flexibility and potentially lower costs.”\(^9\)

While there is no standard set of BRT criteria and current systems vary widely in their operating characteristics, size, and amenities, the main goals of BRT are usually increased speed, reliability, and comfort. The first objective is achieved by reducing the number of stops, increasing distance between stations, constructing dedicated bus lanes, implementing signal prioritization technology, and reducing dwell times through off-board fare collection, low-floor, multi-door vehicles, and intelligent station design. The second BRT goal, reliability, is often realized with shorter headways, longer service spans, and real-time data provided by at-stop displays or mobile device applications. Finally, BRT delivers comfort through modern branding, onboard amenities like high-back seats and wireless internet, and enhanced station waiting environments.\(^10\) This list is not exhaustive, and few BRT systems include all of these components due to fiscal, political and physical constraints. As a result, agencies often tailor BRT service as needed. This adaptability within dense, existing transportation networks further demonstrates the flexibility, scalability and cost efficiency of BRT that set it apart from other modes.\(^11\)

1.3 BRT & Local Bus Service

Aside from their similar vehicles and shared ability to operate in mixed traffic lanes, BRT and local bus fill two distinctly different niches within a larger transportation network. As described in the previous section, true BRT shares more characteristics with rail transit than it does with conventional local bus service; it features modern, high-capacity vehicles operating with fewer stops, short headways and
improved travel times. Alternatively, local bus lines tend to operate with standard vehicles, more stops, less frequent headways, increased delays, longer dwell times, and fewer passenger amenities.12

BRT and local bus routes also serve different types of communities. BRT deployment is usually limited to the corridors where demand – and potential demand – for public transit is strongest. These tend to include high-density centers of residential and commercial activity. Based on Institute for Transportation Engineers (ITE) guidelines, frequent, BRT-type bus service is best suited for areas with at least 15 dwelling units per acre, 10,000 people per square mile, or 20 to 50 million square feet of non-residential activity.13 Local buses are better equipped to serve lower density, less populated areas with reduced transit demand. ITE guidelines recommend local bus service for areas with as few as five dwelling units per acre, 3,000 people per square mile, or 5 to 8 million square feet of non-residential activity.14 Of course, urban environments are far more complex than these simple categorizations, and areas with concurrent BRT and local bus service are the primary focus of this paper.

One other major distinction between BRT and local bus service is the trip and customer types that each serves. In a healthy, productive shared BRT corridor, the average BRT trip is usually longer than the average local trip, presumably because time savings and other benefits incurred by choosing BRT are magnified as trip distance increases. Specific trip length data is not readily available for many transit agencies, but some industry experts have adapted average trip lengths of 3.7 miles for conventional buses, and 4.5 miles or higher for light rail and BRT.15,16 This may also be explained by the tendency of BRT to target discretionary riders in lengthy commuting corridors, while conventional buses are used for a wide range of shorter, local trips in less dense areas.

These different characteristics outline the distinct niches that are usually served by BRT and local bus routes. Both modes, however, are mutually dependent upon each other to efficiently meet a wide variety of travel demands. It is therefore incumbent upon BRT service planners to acknowledge the importance of complementary local bus service, and select service design characteristics that will promote a healthy equilibrium between the two modes.

1.4 Brief History of BRT

The first modern BRT system – the Integrated Transit Network (RIT) in Curitiba, Brazil – was introduced in 1974 with segregated bus lanes, off-board payment, and level, multi-door access between the platform and vehicle. The RIT system was extremely well-planned with corresponding land use policies, and careful system integration with the pre-existing local and feeder routes.17 From the late 1970’s through the 1990’s, several jurisdictions in the United States introduced limited-stop bus service with dedicated lanes, but it was still seen as a niche market for smaller or mid-sized cities.18 It was not until 2000, when Bogota, Columbia opened its TransMilenio service, that the potential for BRT to support large-scale metropolitan markets was fully recognized.19

In the years that followed, the Federal Transit Administration (FTA) produced two seminal guidance documents for Bus Rapid Transit in the United States, which are reviewed in the next section – TCRP Report 90: Bus Rapid Transit Implementation Guidelines in 2003, and Characteristics of Bus Rapid Transit Decision-Making.20 By the end of 2005, Los Angeles, Boston, Oakland, Kansas City, and Las Vegas were all operating successful, large-scale BRT service. Since then, new BRT-style systems have opened in New York City, Cleveland, Seattle, Miami, Phoenix, Nashville, Salt Lake City, Eugene, Reno, and Honolulu, among others. Additional BRT service is currently planned in San Francisco, Chicago, Denver, San Jose, and many other cities across the country.21
1.5 Bus Rapid Transit in Santa Clara County

Santa Clara County and its largest city, San Jose, are located in Northern California at the south end of the San Francisco Bay. Santa Clara County covers nearly 1,300 square miles and is home to over 1.8 million residents. Dubbed the “Silicon Valley” in the 1990’s, it has since developed as an international hub for many of the tech sector’s leading industries and employers.

In an effort to accommodate this continued influx of population and jobs, the county’s Congestion Management Agency and primary transit operator, the Santa Clara Valley Transportation Authority (VTA), prepared its Bus Rapid Transit Strategic Plan in 2009. The plan identifies six potential BRT corridors in Santa Clara County and recommends three as having the “best potential to support BRT-tier service.” The three corridors determined to be most promising for near-term BRT implementation are Santa Clara/Alum Rock, El Camino Real, and Stevens Creek Boulevard.

As of the beginning of 2013, all three “near-term” BRT corridors are still in the planning stages. However, the Santa Clara/Alum Rock corridor is in final design and environmental review phases and BRT service along that section is scheduled to begin in late 2015. The other two corridors – Stevens Creek Boulevard and El Camino Real – are both still in the preliminary design phase and will likely not begin service until 2016 or later. In each of these corridors, BRT service will be phased in gradually and integrated with planned BART extensions to Berryessa and downtown San Jose.

More detailed information about the existing and planned bus service in these corridors is included in the Santa Clara County case study section.
2.0 LITERATURE REVIEW

Although BRT is a relatively new concept, many important documents have been published in the past decade that shed light on how BRT can be implemented effectively. The following section offers summary and analysis of this existing body of research as it pertains to the service design characteristics of BRT and complementary local overlay bus service. The literature reviewed includes five BRT guides and a series of technical articles and reports that provide a foundation for the paper’s methodology and analyses.

The first BRT guide, TCRP Report 90: Bus Rapid Transit, Implementation Guidelines, was published by the FTA’s Transit Cooperative Research Board (TCRP) in 2003. In terms of service frequency, Levinson et al suggest that BRT service should operate with 8-10 minute headways during peak commute periods and 12-15 minute headways during off-peak hours. When overlapped with local bus service, combined headways of 2-4 minutes during peak hours and 5-6 minutes during midday periods are recommended. Service span guidelines based on service type are also included. For BRT that operates in mixed traffic lanes, it suggests that the basic BRT service should operate 18-24 hours a day, seven days a week, and “may be augmented by conventional local bus routes.” For BRT with dedicated lanes, the guidelines recommend a service span of at least 16 hours with express service offered during weekday peak periods. The recommendations on combined frequencies are particularly salient to this paper, but its discussion of service spans focuses on BRT and Express services without accounting for local overlay service span. Finally, Levinson et al echo the important point that service patterns and levels should be based on the specific needs and constraints of each city or corridor.26

Another FTA guidebook, TCRP Report 118: Bus Rapid Transit Practitioner’s Guide, addresses similar BRT service planning considerations. This report revisits and extends the service design findings of TCRP Report 90 by including several additional operation and maintenance cost implications. This report provides additional clarification on the relationship between BRT and local bus service spans, noting that BRT may only require a 12-hour span when concurrent local bus routes are available during evenings and weekends. It also cites several examples of arterial streets in Los Angeles and other cities where BRT service has been successfully “overlaid” on the existing local bus network using the service design principles outlined in these two TCRP reports, but makes no reference to complementary service design characteristics.27

Perhaps the most comprehensive BRT guide, the FTA’s Characteristics of Bus Rapid Transit Decision-Making was published in 2004 and subsequently updated in 2009. This report presents similar findings on BRT service design, but provides further analysis. For both frequency and span, it underscores the reliability of all day service with short headways, but also acknowledges that such service may not be cost efficient, especially when periods of low demand could be served by a basic local bus overlay service. The report notes that high-frequency service can reduce the impact of service interruptions and improve brand image, but can also create additional safety and security issues. Finally, it includes a table displaying the operating characteristics – span, frequency, and stop spacing – of 45 different BRT systems around the world. Based on these examples, the report infers that service frequency is correlated to the BRT’s running way type; grade-separated or dedicated lanes can operate every 1 to 8 minutes, while arterial service in mixed traffic typically operate with 9-15 minute headways.28 These headways are more frequent than those cited in the two previous reports, but no recommendations for the frequency of concurrent local bus service are identified.

Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities, Bus Rapid Transit by Lloyd Wright of a German transportation consulting firm (GTZ) makes additional service design
recommendations. Wright argues for making BRT headways as short as possible to increase customer satisfaction. He also suggests that the quality and convenience of making transfers can be extremely important to successfully integrating BRT with other local and regional transit modes. Finally, Wright explains that headways can be affected by the size of the BRT vehicles, since smaller vehicles may require increased headways to provide adequate capacity. Conversely, identifying a desired vehicle load factor (average load divided by vehicle capacity) can help determine an appropriate service frequency to meet ridership demands. Bogota’s typical average load factors of 80 percent during peak periods and 70 percent during non-peak hours are cited as a good place to start.\textsuperscript{29}

The \textit{BRT Planning Guide} by the Institute for Transportation and Development Policy (ITDP) echoes many of the GTZ sourcebook recommendations. In terms of service frequency, it states that headways of ten minutes or less are desirable so that passengers need not consult a timetable; however, the report also concedes that overly-frequent service with low vehicle load factors can diminish the financial viability of the service and should be avoided.\textsuperscript{30} This relationship between frequency, load factors, and operating cost is an important one and will be further dissected in this paper.

One of the earliest quantitative approaches to bus service frequency optimization was Jan Owen Jansson’s \textit{A Simple Bus Line Model for Optimisation of Service Frequency and Bus Size}. Published in 1980, Jansson uses the “square root formula” to calculate appropriate headways based on travel time, trip lengths, boarding and alighting times, passenger volumes, number of buses, vehicle capacity, operational cost per bus revenue hour, and the passenger time values for waiting and riding. Jansson’s work advances previous models by emphasizing the importance of the last variable – the time cost incurred by passengers during the various trip stages. He argues that transit operators have historically underestimated these hidden user costs, and that in order to account for them, service providers should use lower capacity vehicles with shorter headways.\textsuperscript{31} There are, however, several professed limitations to this model. First, it addresses the transit supply side, but does not analyze how demand is affected, so its findings are more theoretical and the model cannot necessarily determine the optimal supply levels in a specific set of operating circumstances. Second, the value of passenger time is relative to a number of personal factors, so any calculations that include such a cost will make major assumptions and will always be accurate. Finally, the model does not account for multiple concurrent modes or different types of running ways that could affect the results. Despite these limitations, Jansson’s analyses are helpful in determining what factors should be included in the effort to determine optimal service design characteristics of BRT and local bus service.

\textit{Optimization of Headways for Bus Rapid Transit with Stop-Skipping Control} by Xumei Cheng and others provides another quantitative perspective of both service frequency optimization and the effect of stop-skipping. Chang et al include a section on existing frequency optimization research that reviews 17 different models from the last three decades. Each model, algorithm, and formula is unique in how it approaches the optimization question: almost all of the models included a variation of fleet size, vehicle size, and operating costs; most factored in passenger waiting time costs; and others focused on maximum load data, minimizing the number of transfers, or even the numbers of empty seats as a measure of productivity.\textsuperscript{32} Chen’s comprehensive summary of existing research provides additional insight into which factors can help demonstrate the productivity or inefficiency of various service design configurations.

\textit{Bus Rapid Transit Scheduling Optimal Model Based on Genetic Algorithm} by Shi Liang and others, presents a methodical, multi-faceted study on BRT frequency optimization. Like several of the previous models, Liang’s genetic algorithm seeks to minimize passenger travel time cost and bus time cost. Using China’s Gangzhou Bus Rapid Transit (GBRT) as a case study example, Liang et al divide the service day into several
decision-making periods with different levels of demand. The algorithm is then able to determine the optimal headways that produce the lowest total passenger travel time and operating cost for each period throughout the day. The use of these output factors to assess service frequency during different times of day serves to inform the research methodology of this paper.

Another report that lends itself more directly to the development of this paper’s case study evaluation methodology is The San Pablo Rapid BRT Project Evaluation, prepared by Cheryl Thole and Alasdair Cain of NBRTI and the Center for Urban Transportation Research (CUTR). Thole and Cain evaluate the performance of the San Pablo corridor before and after the implementation of BRT service based on travel time, reliability, image/identity, safety/security, and system capacity. These system outputs are measured both quantitatively through ride checks and qualitatively through customer surveys that gauge user perceptions in each of the categories. Ultimately, Thole and Cain find that the San Pablo Rapid provides reduced travel times, improved reliability, and increased corridor capacity. The report’s findings are concrete, but might be extended further to encapsulate the true corridor performance. For example, the researchers aggregate total corridor ridership by revenue service hour, but fail to assess the number of the boardings per trip, peak load factor, and average passenger trip length for both San Pablo Rapid and Line 72. Similarly, the corridor travel time analysis focuses on the reduced travel time achieved by the San Pablo Rapid as a percentage of the local bus and preceding limited stop services. The travel time of the local 72 line is only referenced as a means of comparison rather than as an output variable that should be factored into the overall corridor performance analysis. Despite these minor flaws, this report provides valuable contextual data about San Pablo Boulevard prior to and immediately following its BRT implementation. This information will be further examined and updated in the San Pablo Rapid case study and will contribute to the subsequent corridor performance evaluation.

One final report, Nicholas J. Votaw’s Does Off-Board Fare Collection Using Ticket Vending Machines and Proof-of-Payment Enforcement Make the Most Sense Along Planned VTA Bus Rapid Transit Lines 522 and 523 in Santa Clara County?, also served to define the methodology of this research effort. Votaw’s thesis answers this question by reviewing literature on the subject, preparing several case studies, gathering data, conducting interviews, and using the results to make logical inferences and recommendations for Santa Clara County. While the fare collection content is not directly relevant, Votaw’s similar purpose and methodology provides an instructive framework on how the research and analyses might be conducted, and how the main conclusions for Santa Clara County may be extrapolated. Consequently, this approach was applied in part to the analysis of service design characteristics for BRT and local bus service in Santa Clara County.

On the whole, the literature reviewed in this section provides a foundation from which this paper’s main questions on service design characteristics of concurrent BRT and local bus service may be addressed. The BRT guides comprise an extensive amount of background information on BRT service design considerations and how BRT should be integrated with other nearby modes. Most of the documents underscore the importance of service design elements like frequency and span and outlined some basic suggested parameters that provide a helpful starting point for this paper’s analyses. The technical reports on service frequency supply valuable insight on critical variables like operating costs, travel time, passenger wait time, average trip length, vehicle size, vehicle load factors, and others that can be used in this paper’s analyses of service design characteristics. Along with Votaw, these studies provide a main part of the methodological framework through which the paper’s three primary questions will be addressed. A full description of the research methodology is included in the following section.
3.0 RESEARCH METHODOLOGY

Public transportation presents a number of challenges to researchers seeking to improve ridership, mobility, or cost efficiency. No two transit systems are exactly alike. They are complex, dynamic organisms, defined by the circumstances and constraints of the areas they serve. Consequently, the planning, design, and operating decision for each must be made within the spectrum of each system’s unique geographic, political and fiscal context. Similarly, any change in ridership or perception of transit is the byproduct of dozens of different factors – which are often difficult to measure – and the associated elasticity of each factor. As a result, analyses that seek to identify specific best practices for improving ridership will likely be riddled with confounding variables and specious conclusions.

In light of these challenges, this research paper does not provide rigid, quantitative recommendations based on detailed statistical examination. As demonstrated by the literature review, the subject of service frequency optimization, in particular, using complex models, genetic algorithms, and other high-level mathematical analyses has been well-documented. Instead, information aggregated from a detailed series of case studies, supplemental agency staff interviews, the previous literature review section, and the VTA BRT Strategic Plan were used to address the following three research questions:

1. **What service design characteristics provide the most productive balance between concurrent BRT and local bus service?**
2. **What BRT and local bus service design characteristics should be implemented in the three planned BRT corridors in Santa Clara County?**
3. **What metrics should be used to evaluate the performance of concurrent BRT and local bus service in Santa Clara County and other similar transit systems?**

The specific methods and data that were required to address each of these three questions are described below:

3.1 Evaluating Service Design Characteristics of Concurrent BRT & Local Bus Service

The first question seeks to identify the service design characteristics – specifically, frequency and span ratios between concurrent BRT and local bus service – that contribute to a productive balance between the two modes. This question was addressed mainly through five carefully-selected case studies of BRT and local bus corridors in major North American cities. These case studies were supplemented by interviews with transit agency staff and literature review findings from the previous section to develop general observations and guidelines for developing successful concurrent BRT and local bus service.

The five case study corridors were selected based on their provision of concurrent BRT and local bus service, data availability, and similarity to Santa Clara County in terms of demographics, transportation infrastructure, and land use patterns. These studies evaluate major transit corridors in Los Angeles, Oakland, Las Vegas, Kansas City and Salt Lake City. Since the purpose of the first question is to determine which service design characteristics achieve the most “productive balance” between BRT and local bus service, the data collection process for each case study focused on the system, corridor, and route inputs and outputs that quantify the ridership productivity and service balance of this relationship. These inputs included demographic information, land use characteristics, BRT and local bus system features (BRT elements, running way, vehicle sizes, amenities), and operational characteristics of both modes (headways, headway ratios, spans, stop spacing). The majority of the system input data was collected through internet research and e-mail communication with agency staff. Conversely, the output data
collected to quantify the degree to which a healthy, multimodal equilibrium has been reached included ridership trends (modal splits, growth, load factors, transfer activity, diurnal ridership distribution), travel time statistics (average travel times, average delays, average passenger trip lengths), operating costs per revenue hour, environmental impacts, and any relevant customer survey data that may be available. As much as possible, the output data was broken down by direction and time of day to provide insight as to how well the services operate together throughout the course of the day.

The data described above was aggregated into a comprehensive matrix to facilitate direct comparison and evaluation. When combined with information gleaned from the standardized staff interviews and previous literature review, this data was used to analyze the adequacy of each set of service frequency and span ratios, determine the degree to which a “productive balance” has been achieved, and inform the findings and lessons learned from each case study. These findings formed the basis of the observations and recommendations on service design characteristics for concurrent BRT and local bus service.

3.2 Service Design Characteristics in Santa Clara County’s Planned BRT Corridors

The second question attempts to identify the optimal service design characteristics for the BRT and local routes in three planned BRT corridors in Santa Clara County. Since VTA’s BRT system is still only in the planning stages, this analysis features an evaluation of existing and planned bus service characteristics. While the analysis of existing service is based upon basic performance measures, the evaluation of the planned BRT and local service frequencies and spans will use the findings of the literature review, previous case studies and the VTA BRT Strategic Plan to draw comparisons, expand upon previous analyses, and make logical inferences on potential service design characteristics in Santa Clara County’s Santa Clara/Alum Rock, El Camino Real, and Stevens Creek corridors.

In order to compare Santa Clara County with the previous case studies, the demographics, land uses, system characteristics, and selected performance measures for the three planned BRT corridors will be collected and summarized. Each case study will be reviewed to determine the extent to which the lessons learned from its section may be applied to VTA’s planned BRT corridors. The service design characteristics for successful case studies with similar indicators to the Santa Clara County corridors will be highlighted and compared to the operating plans outlined in the BRT Strategic Plan.

3.3 Evaluation Metrics for Concurrent BRT & Local Bus Service

The third question aims to further expand the general applicability of the paper’s findings by developing a series of performance measures that evaluate the success of corridors or systems with concurrent BRT and local service. The answer to this question draws from the literature review and case study findings, as well as the evaluative methods described in VTA’s BRT Strategic Plan and interviews with transit agency staff. These resources each contribute to the identification of ways in which the productivity, speed, efficiency, and balance of concurrent BRT and local bus service can be jointly measured. The resulting indicators will be based primarily on the data collected and analyzed for the previous two research questions as well as findings from the literature reviews and agency staff interviews.

The design of this methodology enables the three main research questions to be addressed through detailed case study evaluations and comparisons, literature reviews and interviews with agency staff. These sources and methodologies have been directly tied to each question’s general purpose and data requirements. Since the three questions logically flow from one to another in the order in which they are presented, the research plan methodology is carried out sequentially in the following sections.
4.0 CASE STUDY # 1 – LOS ANGELES, CA (WILSHIRE BOULEVARD)

4.1 Overview of Los Angeles

The City of Los Angeles is an enormous, sprawling metropolis located along the southern California coastline. Covering 472 square miles with over 3.8 million residents, it represents the largest city in California, and the second most populous city in the country. It is also the seat of government for Los Angeles County. The five-county Los Angeles metropolitan area spans 34,000 square miles and is home to over 18 million residents. The region enjoys a favorable year-round climate with mild temperatures and little rain, and is situated in a desert basin between the beaches of the Pacific Ocean and the foothills of the San Gabriel Mountains.36

Billed as the “Entertainment Capital of the World”, Los Angeles is a cultural mecca renowned for its prominence in the art, fashion, and entertainment industries. The region also serves as an international hub for business, trade, science, technology, medicine, education, research, media, and sports.37 A recent “Global Cities Index” measuring global economic impact ranked Los Angeles sixth behind only New York, London, Paris, Tokyo, and Hong Kong.38 Despite not being the state capital, downtown Los Angeles also trails only Washington D.C. among the largest government centers in the United States.39

Los Angeles is also known for the strong ethnic and economic diversity within its population. Based on the 2010 Census, over two-thirds of city residents identify themselves as minorities and nearly half are persons of Hispanic or Latino origin. Almost 40 percent of Los Angelinos are foreign-born and approximately 60 percent speak a language other than English at home. These percentages are dramatically higher than the national averages. The median household income in Los Angeles between 2007 and 2011 was $50,028 and 20 percent of the population live below the federal poverty level. This median household income is roughly equal to the national figure, but nearly five percentage points higher than the nationwide percent of persons that live in poverty.40

4.2 Wilshire Boulevard Corridor

Wilshire Boulevard is the major east-west arterial street that connects downtown Los Angeles with the major business, shopping and entertainment districts in Central Los Angeles, Beverly Hills, Westwood, and Santa Monica. From South Grand Avenue in the central business district to Ocean Avenue in Santa Monica, the street measures approximately 16 miles in length and operates primarily on an undivided four-lane roadway section with auxiliary turn lanes. On its busiest stretch in Westwood near I-405, the road expands to six, and briefly eight, lanes.

For large portions of its length, Wilshire Boulevard is lined by high-rise commercial and residential development. It is the most densely-built corridor in the entire western United States.41 The population density of the census tracts within the corridor is over 14,000 persons per square mile.42 The areas immediately adjacent to the main strip include large, crowded swaths of single- and multi-family dwelling units. At its eastern terminus, Wilshire Boulevard bisects downtown Los Angeles and is surrounded by dozens of office and hotel towers. The corridor’s middle portion abuts Good Samaritan Hospital, MacArthur Park, Koreatown, and the “Miracle Mile”, a densely-developed segment between Fairfax and Highland Avenues famous for its shopping, museums and the La Brea Tar Pits. Moving westbound, Wilshire Boulevard then passes through Beverly Hills, Westwood, and Brentwood. Major destinations along this section of the corridor include the Rodeo Drive in Beverly Hills, the UCLA campus in Westwood, and several prominent hotels, theaters and large medical complexes. The corridor’s westernmost
segment runs through Santa Monica’s downtown commercial district before ending at the oceanfront promenade.43 As a result of this eclectic mix of uses and the interspersed pockets of high-density commercial and residential development, Wilshire Boulevard serves a large volume and wide range of transportation demands.

Based on recent traffic counts, the most heavily-traveled sections of Wilshire Boulevard near Westwood and the I-405 interchange carry between 100,000 and 125,000 vehicles per day, making Wilshire Boulevard the busiest arterial street in a city defined by its perpetually congestion road network. Other segments of the Wilshire Boulevard Corridor carry between 20,000 and 90,000 vehicles each weekday.44 As a result of major employment growth in western Los Angeles over the last few decades, the corridor exhibits a reverse flow commute pattern with the majority of vehicles traveling westbound – away from downtown – in the morning and eastbound during the afternoon and evening periods.45

4.3 Public Transportation in Los Angeles

The Los Angeles Metropolitan Transportation Authority – or “Metro” as it is more commonly known – serves as the regional transportation planning agency (RTPA) and primary public transportation operator for Los Angeles County. In 2010, Metro provided 463 million unlinked passenger trips, the third highest total amongst all transit agencies in the United States.46 Metro operates six heavy rail subway lines, two transitway bus lines, 20 bus rapid transit lines, and 163 other express, limited-stop and local bus routes, shuttles and circulators. Additional bus service is provided by the Los Angeles Department of Transportation (LADOT), Santa Monica Municipal Bus Lines, and several dozen other local operators.

The Los Angeles Metro Rail system includes 101 stations, covers 87.7 miles, and the five subway lines record approximately 360,000 total boardings on a typical weekday. The city’s 183 bus routes provide service to nearly 16,000 bus stops across a 1,433 square mile service area. On an average weekday, they are responsible for carrying 1.15 million passengers throughout the Los Angeles metropolitan area.47

4.4 Public Transportation in the Wilshire Boulevard Corridor

As one of the busiest arterial streets in the region, the Wilshire Boulevard Corridor is served by multiple subway and bus lines. Along the eastern section of the corridor, the Red and Purple Lines provide subway rail service between Hollywood, Mid-Wilshire and downtown Los Angeles. Major bus routes operating along parts of Wilshire Boulevard include Santa Monica’s Big Blue Bus Route 2, Antelope Valley Transit’s Route 786 commuter service, and Foothill Transit’s Line 481 express service. Metro Lines 20 and 720 provide local and rapid service, respectively, along the entire length of the Wilshire Boulevard Corridor.

The Red Line provides underground rail service in Union Station, downtown Los Angeles, Hollywood, and North Hollywood. The route operates beneath or immediately adjacent to Wilshire Boulevard for a 2.5 mile stretch between Grand and Vermont Avenues. The line makes two stops on Wilshire Boulevard – Westlake/MacArthur Park and Wilshire/Vermont – before turning north on Vermont Avenue towards Hollywood and the San Fernando Valley. The Purple Line, which operates between downtown Los Angeles and Koreatown follows the same 2.5 mile stretch along the corridor, but continues below Wilshire Boulevard for an additional mile to Western Avenue to provide service to Koreatown’s Wilshire/Normandie and Wilshire/Western stops. The Red and Purple Lines account for a combined total of 158,000 average weekday boardings.48 Future plans for rail service include the 9.4 mile “Westside Extension” of the Purple Line along Wilshire Boulevard from its current terminus at Western Avenue to the just beyond the Wilshire/I-405 interchange. The extension will include eight additional stations.
serving Beverly Hills, Century City, and Westwood. As part of this extension, Line 720 will likely be reconfigured or possibly discontinued. Construction on the first of three phases is slated to begin in 2014 and be completed by 2023. The final phase is scheduled to open in 2035.

Three non-Metro bus routes operate on segments of Wilshire Boulevard. Santa Monica’s Big Blue Bus Line 2 operates between downtown Santa Monica and the UCLA campus in Westwood. The route serves a four mile segment of Wilshire Boulevard between 4\textsuperscript{th} Street and Gayley Avenue with 20-30 minute headways throughout the day.\textsuperscript{51} Antelope Valley Transit’s Route 286 provides limited-stop commuter service between Westwood, Century City, Beverly Hills, and Hollywood with stops on Wilshire Boulevard at Westwood Boulevard and from Santa Monica Boulevard to La Brea Avenue.\textsuperscript{52} Foothill Transit also operates Line 481, a peak direction commuter service with 10-20 minute headways that takes residents of El Monte, Alhambra, and Monterey Park to downtown Los Angeles and Wilshire Boulevard between Western Avenue and Figueroa Street.\textsuperscript{53}

**Line 20**

Local, all-stop bus service on Wilshire Boulevard is provided by Metro Line 20. Line 20 operates 24 hours, seven days a week between 7\textsuperscript{th} Street and Main Street in downtown Los Angeles and Wilshire Boulevard and Westwood Boulevard. Between 10:00 PM and 6:00 AM, Line 20 service extends west from Westwood to Santa Monica via Wilshire Boulevard, Ocean Avenue, and Colorado Avenue. As shown on Figure 4-1, the Line 20 trunk route follows Wilshire Boulevard in its entirety and extends into downtown Los Angeles along 7\textsuperscript{th} Street. From downtown to Santa Monica, the route measures 17.4 miles and includes 107 and 106 eastbound and westbound stops, respectively, for an average stop distance of 0.16 miles. The major trip generators along the route from east to west include the Good Samaritan Hospital, Wilten Theater, Los Angeles County Museum of Art, Armand Hammer Museum, Beverly Hills shopping district, UCLA, and Veteran’s Hospital. The route is operated with standard 40’ buses and the fare ($1.50 per trip) is collected through the onboard farebox. Passengers are encouraged to use TAP smart cards, which can be linked to personal bank accounts to ensure quick, easy fare payment.\textsuperscript{54}

Line 20 also includes many important regional transit connections. Passengers may transfer to the Purple Line at the Wilshire/Western and Wilshire/Normandie stations, and the Red or Purple Line at the Wilshire/Vermont, Westlake/MacArthur Park and 7\textsuperscript{th} Street/Metro Center stations. The 7\textsuperscript{th} Street/Metro Center station also provides connections to the Blue and Expo subway lines with service to Culver City, South Los Angeles, Compton and Long Beach. Line 20 also has several major bus connections transfer points in downtown Los Angeles, Santa Monica and at Vermont Avenue, Western Avenue, and Westwood Boulevard.\textsuperscript{55}

Line 20 local bus service operates with average headways ranging from 5 to 30 minutes. During the weekday morning peak period, the peak direction (westbound) runs with 5 to 10 minute headways, while the eastbound trips are spaced every 10 to 12 minutes. For weekday afternoon commute hours, peak direction (eastbound) headways are typically 8-10 minutes, while the westbound trips operate every 8-12 minutes.\textsuperscript{56} A more detailed description of Line 20 service frequency, including off-peak and weekend headways, is provided in the analyses sections below. A copy of the current Line 20 schedule is included in Appendix B.
Figure 4-1 – Map of Metro Line 20

Line 720

Metro Rapid Line 720 was introduced in 2000 as one of two BRT demonstration projects in the Los Angeles area. Prior to its implementation, Wilshire Boulevard was already the busiest corridor in the region and was served by five different metro bus lines – three disjointed local routes and two supplemental limited stop services. In an effort to simply and improve service, city officials and planners identified BRT similar to the system in Curitiba, Brazil as the ideal solution for the Wilshire Boulevard Corridor. Metro Rapid Line 720 service was one of the first BRT-style systems to be implemented in a major North American city.57

Line 720 service operates in mixed traffic with no dedicated bus lanes between East Los Angeles, Downtown, Central Los Angeles, Beverly Hills, Westwood, Brentwood and Santa Monica. The service is available seven days a week, and typically runs between 5:00 AM and 1:00 AM. As shown on Figure 4-2, the route begins near Commerce in East Los Angeles and follows Whittier Boulevard and 6th Street into downtown. Line 720 crosses over to Wilshire Boulevard several blocks west of downtown and traces the corridor all the way to Santa Monica's oceanfront promenade where it turns south for several blocks on Ocean Avenue and Colorado Avenue to its western terminus. The entire route measures 24.7 miles in length, and with 33 stops in each direction, the bus stops on average once every 0.75 miles. Along with the major trip generators along Wilshire listed for Line 20, Line 720 also serves the Commerce Center shopping area and the East Los Angeles Doctor’s Hospital.58

Line 720 service is mostly provided with 60’ articulated, low floor NABI buses running on compressed natural gas (CNG). The buses are uniquely branded and have a sleek, modern appearance so that they are easily differentiated from standard Metro buses. Although the route operates in mixed traffic, it is able to travel through the corridor more quickly than the local service based on its fewer stops and the implementation of Traffic Signal Priority (TSP) technology. Real-time arrival information from NextBus is also available to Line 720 passengers via telephone, internet, or at-station displays.59 Metro Rapid fares are the same as the fares charged for local service - $1.50 for a single trip and $5.00 for a day pass. Metro Rapid fares are also collected by on-board electronic fareboxes and riders are encouraged to use TAP smart cards.60

Since they share the same corridor, Lines 20 and 720 also share many of the same regional transit connections. Line 720 passengers can connect to the Red, Purple, Blue and Expo subway lines at the same stations as Line 20. Both routes share the same major bus transfer points along Wilshire Boulevard, however, Line 720 passengers may also connect to several major East Los Angeles bus routes on Whittier Boulevard at Soto Street and Atlantic Avenue.61

Line 720 operates high-frequency service with short 2-8 minute headways during weekdays. During morning commute hours, peak direction (westbound) buses arriving once every 2-4 minutes. Conversely, afternoon peak direction (eastbound) service operates with 2-5 minute headways. Saturday and Sunday daytime service is provided with 5-7 minute headways.62 More detailed service frequency is available in the following analyses sections. A copy of the current Line 720 schedule is included in Appendix B.

At present, Metro is also constructing dedicated bus lanes along a 7.7 mile stretch of the Wilshire Boulevard Corridor from west of downtown to Brentwood. During the peak commute hours, the lanes will be restricted to through traffic and only made available for buses, bicyclists, and right-turning vehicles. The project will serve as an intermediate solution to the corridor congestion issues until the future Purple Line rail extension comes online.63
Figure 4-2 – Map of Metro Rapid Line 720

4.5 Operational Analysis of Lines 20 & 720

Wilshire Boulevard represents one of the busiest and most successful transit corridors in the Los Angeles metropolitan area. A recent survey demonstrated that public transit enjoys a 20 percent mode split in the Wilshire Boulevard Corridor as compared to 8 percent for the City of Los Angeles as a whole. This section summarizes the current ridership, historical ridership, travel times, on-time performance, and operating costs of Lines 20 and 720. A detailed summary of the operational characteristics of Lines 20 and 720 is provided in Appendix A.

Ridership

Lines 20 & 720 comprise the two main bus lines on the Wilshire Boulevard Corridor. Based on the most recent data, the two routes combine to average nearly 57,000 daily weekday boardings, over 37,000 Saturday boardings, and almost 28,000 Sunday boardings. With over 40,000 average daily boardings, Metro Rapid Line 720 accounts for nearly 70 percent of the total weekday ridership, but it operates for nearly twice as many service hours as Line 20. When normalized by service hours, Lines 20 and 720 average a more balanced 61.7 and 55.4 weekday boardings per service hour, respectively. When weekday ridership data is broken down diurnally, this service ratio balance is evident during the morning commute, midday, afternoon commute, evening, and late night periods. From a historical standpoint, ridership on Line 20 has remained stagnant for the last three years, but Line 720 ridership has increased by roughly 11 percent since 2010. The fact that overall Metro bus ridership was down nearly six percent during the same period makes the continued success of Line 720 even more remarkable.

Peak Load Factor Data

The balanced ridership described above is further demonstrated by the load factor data, which measures the average peak vehicle load as a percentage of that vehicle’s maximum seated capacity. A peak load factor that is greater than one indicates the presence of standees and potential overcrowding. If a route frequently registers peak load factors of one or more, the service frequency may need to be increased. The average weekday peak load factor for Line 20 local service is 0.84, or roughly 33 passengers on a 40-seat bus. Line 720, which operates with 57-seat vehicles, carries an average weekday peak load of just over 47 passengers for a peak load factor of 0.83. The peak load factors are generally higher during the morning and afternoon peak hours, particularly in the peak commute directions. Line 720 rapid service carries a peak load factor of 1.09 in the westbound direction during the morning peak period. Conversely, a Line 720 eastbound service operates with an average peak load factor of 1.02 during the afternoon rush hours. The highest peak load factors for Line 20 occur during the middays (0.96), afternoon peak hour (0.89), and the overnight owl service (0.88). These load statistics reflect a healthy transit corridor with buses that are operating at or near full capacity. Metro service planners utilize a maximum load factor standard of 1.30 to determine when additional service—either through shortened headways, extended span or extra “fill-in” buses—is needed. This standard represents a bus carrying a full complement of seated and standing passengers. Based on this threshold, the Line 20 and Line 720 loads demonstrate strong ridership with frequent standees but do not pose high risks for overcrowding.

Travel Time

One of the main issues in the Wilshire Boulevard Corridor is congestion-related delays. Since both Lines 20 and 720 currently operate in mixed traffic lanes, they too are plagued by the corridor’s perpetual traffic problems. During periods of minimal traffic, Lines 20 & 720 can travel the length of the trunk route –
downtown Los Angeles to Westwood — in 42-43 and 37-38 minutes, respectively. However, during the afternoon peak period, Line 20 takes nearly twice as long (84-86 minutes) to cover the same distance. Line 720 fares slightly better, but still takes 65 minutes to travel the 12 mile distance. A recent National Bus Rapid Transit Institute survey measured the average speed of Line 720 as only 13.5 miles per hour. The average speeds of both routes are likely much lower during the peak morning and afternoon periods.

**On-Time Performance**

Lengthy travel times in congested corridors can often lead to major service reliability problems. Consequently, Lines 20 and 720 run “on-time” – or within five minutes of the schedule arrival times – approximately 80 and 78 percent of the time, respectively. The two routes achieve slightly higher on-time performance rates during the morning peak hours, however, the rates decrease dramatically during the afternoon and evening hours. During the afternoon rush hour, Lines 20 & 720 record respective on-time performance rates of 68 and 60 percent. Service reliability drops further during the early evening hours to 63 and 55 percent, respectively. Although these on-time performance statistics appear concerning, the extremely short headways along the corridor ensure that the next bus is never more than a short walk away and effectively negate the issue.

**Service Costs**

The final operational measure of Lines 20 & 720 is cost. The capital cost for building Line 720 in 2000 came in at just over $5 million to implement, or about $195,000 per revenue mile. Metro does not maintain route-specific operating data but estimates that Lines 20 & 720 each currently cost approximately $130 per revenue hour to operate. The overall operating costs for Metro bus lines in 2011 were estimated to be $0.64 per passenger mile and $2.68 per unlinked passenger trip.

Lines 20 & 720 also contributed to reduced environmental costs. The vehicles used on both routes run on compressed natural gas (CNG) which burns much cleaner than traditional fossil fuels. CNG vehicles are 98 percent cleaner than the traditional diesel buses that they replaced, and their usage reduces air pollution by 152,000 pounds per day.

### 4.6 Comparative Frequency Analysis of Lines 20 & 720

As demonstrated by the previous section, the operational performance of Lines 20 and 720 have helped make Wilshire Boulevard one of the nation’s more robust transit corridors. Service design characteristics such as frequency and span have invariably helped contribute to this success. Table 4-1 provides analyses of service frequencies and spans for Lines 20 and 720 by time of day. Standardized time periods have been used for purposes of comparison. Based on a common agency standard, these time periods include the morning peak hours (6:00 AM – 9:00 AM), midday (9:00 AM – 4:00 PM), afternoon peak hours (4:00 – 7:00 PM), and evening (7:00 – 10:00 PM).

**Headway Ratios**

Due to the corridor’s soaring ridership and productivity levels, the peak hour frequencies are extremely short at one bus every 4 and 10 minutes for Lines 720 and 20, respectively. Line 20 local service is provided throughout the day at 10 minute, before service decreases to roughly once every 19 minutes. The frequency on Line 720 decreases to every six minutes during middays and every nine minutes during
evenings. Based on these headways, the BRT-to-Local to ratio is 2.5 during both peak periods, 1.7 during middays, and 2.1 during evenings.

Table 4-1 – Wilshire Boulevard Corridor Frequency Analysis Summary

<table>
<thead>
<tr>
<th></th>
<th>Average Headways (Minutes)</th>
<th>Average Boardings</th>
<th>Average Peak Load Factor</th>
<th>Average Travel Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WEEKDAY TIME PERIODS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AM PEAK (6 - 9 AM)</td>
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<td>4</td>
<td>2.5</td>
<td>3,688</td>
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<tr>
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<td>6</td>
<td>1.67</td>
<td>7,189</td>
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<tr>
<td>PM PEAK (4 - 7 PM)</td>
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<td>4</td>
<td>2.5</td>
<td>4,373</td>
</tr>
<tr>
<td>EVENING (7 - 10 PM)</td>
<td>19</td>
<td>9</td>
<td>2.11</td>
<td>560</td>
</tr>
</tbody>
</table>

Primary Source: Kumar, Ashok. Transit Planner. L.A. Metro. Email to Author, 2 April 2013.

Ridership

Based on current ridership data for the two routes, the extremely short headways seem to be warranted. Lines 20 and 720 average 61.7 and 55.4 weekday boardings per revenue hour, respectively.74 These average hourly ridership figures are even more remarkable in light of the fact that they have been diluted by the large number of off-peak service hours. Although boardings per service hour cannot realistically be broken down by time period, the raw ridership data indicates that the BRT-to-Local headway ratios are reasonable. For example, Line 720 runs 2.5 times more frequently than Line 20 during afternoon rush hours and averages 2.52 times more boardings than Line 20 during the same period. Similarly, the headway ratio during the morning peak hours is 2.5 and Line 720 boards 2.72 times as many passengers as Line 20 during that time. However, the frequency distribution during the evening may be slightly skewed towards local service, as Line 720 accounts for 3.26 times as many passengers as Line 20, but only runs 2.11 times more often. Based on these ratios, Line 720 evening service could be offered every 6-7 minutes instead of the current nine minutes to achieve a more appropriate balance of service.

Peak Load Factors

The successful balance of daytime service made apparent by the normalized ridership statistics is further illustrated by the average peak load factor data for the two routes. Lines 20 and 720 maintain average weekday peak load factors of 0.83 and 0.84, respectively. More specifically, these peak load factors are 0.75 and 0.88 during the morning peak hours, 0.96 and 0.90 during middays, and 0.89 and 0.95 during the peak hours of the afternoon commute.75 The notable proximity of peak load factor data of each of the
two routes indicates that the service headways are – for the most part – appropriately configured. Although the morning peak shows a 15 percent difference between the peak load factors for Lines 20 and 720, the midday and afternoon peak periods registered differences of only six and seven percent, respectively. The average evening peak load factor for Line 720, however, is 22 percent higher than that of Line 20 evening service. Similar to the ridership analyses, this indicates that the evening current headway distributions seem to disproportionately favor Line 20 local service.

Other Indicators

The relative balance of the daytime peak load factors also implies that the service headways are well-designed in terms of how they relate to the trip type distributions within the Wilshire Boulevard Corridor. The average passenger trip lengths for Lines 20 and 720 are 3.15 and 6.26 miles, respectively, and the average passenger trip durations are 18 and 28 minutes. These figures demonstrate that the intended BRT and local trip differentiation is being fully realized. The relatively low transfer activity between the two routes – three and two percent of total boardings, respectively – may further solidify this point. One indicator that may slightly contradict these findings is the average stop spacing distance between the two routes – 0.16 miles for Line 20 and 0.75 miles for Line 720. This ratio of 4.5 local stops for each BRT stop is the highest among the five case studies and suggests that local service frequencies could be improved to better serve areas near local stops that do not have access to BRT stations.

Lastly, a recent customer survey administered to Line 20 and 720 passengers provided a number of insights on the degree to which the passenger’s travel needs are being met. On Line 20, the majority of passengers reported that the wait for the bus was 10 minutes or less. For Line 720, more than half of the respondents had to wait five minutes or less. The survey also found that 73 and 70 percent of passengers normally had access to seats on Lines 20 and 720, respectively. Therefore, the majority of these statistics seem to indicate that the existing frequencies and frequency ratios on Lines 20 and Line 720 provide adequate service levels to meet current transit demand in the corridor.

4.7 Span Analysis for Lines 20 & 720

Based on the intense and eclectic mix of uses and densities within the Wilshire Boulevard Corridor, it is important that the span of service for both Lines 20 and 720 be designed to accommodate the wide range of transit activity that results from a vibrant urban environment such as this. As previously noted, Line 20 operates 24-hour service, seven days a week, while Line 720 is out of service for roughly four hours between 1:00 AM and 5:00 AM, but is running at all other times on weekdays, Saturdays and Sundays.

Current ridership and peak load factor data clearly support the operations of both lines during all regular daytime hours, but they also seem to validate the provision of Line 20 as a 24-hour service and the short overnight break in Line 720 service. At present, Line 20 averages 836 boardings per weekday between the hours of midnight and 4:00 AM. The peak load factor for this “Owl Service” is a robust 0.88, a significant increase over 0.71, the Line 20 peak load factor from 10:00 PM to midnight. Part of this increase is explained by the fact that Line 20 is the only Metro bus service operating in the Wilshire Corridor between 1:00 and 4:00 AM. For the small sample of Line 720 trips between midnight and 1:00 AM, the average peak load factor registers as a paltry 0.44. Therefore, the decision to conserve resources by consolidating service after 1:00 AM appears to make sense based on ridership and peak load factor data.
Extensive weekend service is also necessitated by the nature of the residential development patterns and types of trip generators in the Wilshire Boulevard Corridor. The preponderance of parks, museums, theaters, shopping districts, and other major centers of weekend activity undoubtedly contributes to the strong Saturday and Sunday ridership on both lines. Based on data from the last six months, Line 20 averages 8,938 Saturday boardings and 6,505 Sunday boardings; Line 720 accounted for averages of 28,332 Saturday boardings and 21,255 Sunday boardings during the same period. Weekend peak load factor data for the two lines was not readily available for the two lines.

The recent customer survey supports the adequacy of the current service span for both routes. When asked about the Line 20 schedule, 82 percent of the passengers agreed that it met their needs. Conversely, 85 percent of Line 720 passengers were satisfied with the current bus schedule.  

4.8 Wilshire Boulevard Corridor Findings & Lessons Learned

In terms of capacity, frequency, and span of service, Metro Rapid Line 720 is likely the closest to date that any American city has come to the immense productivity of BRT systems in Bogota and Curitiba. Alongside Line 20 local service, the two Metro bus routes operating on Wilshire Boulevard combine for an astounding 57,000 average daily boardings. The hourly ridership data, average peak load factors, average passenger trip lengths, and passenger survey data further demonstrate the strong health of the current Wilshire Boulevard bus service. While the nature of development along Wilshire Boulevard and the presence of major trip generators undoubtedly represent an ideal transit environment, the intelligent, demand-responsive service planning and design of Lines 20 and 720 has also played a central role in the corridor’s success and long-term health.

For the most part, the current service frequencies for both routes appear to be adequate. The comparative frequency analysis reviewed proportional ridership data, average peak load factors, as well as several other indicators and determined that the short headways and corresponding headway ratios of 1.7 to 2.5 throughout the day are warranted by the current ridership demand for each of the routes. One exception to this finding was Line 720 evening service. The current weekday evening headways for Lines 20 and 720 are 19 minutes and 9 minutes, respectively. Based on a comparison of this headway ratio to the corresponding proportional ridership and load factor data, the frequency analysis determined that Line 720 evening intervals could be shortened by 2-3 minutes to operate every 6-7 minutes. This recommendation was independently supported by anecdotal evidence from an interview with Scott Page, Metro’s Manager of Service Planning.

As outlined in the span analysis, the provision of 24-hour local service on the main trunk route is warranted by ridership and peak load factor data. The current Line 720 hours of operation – between 5:00 AM and 1:00 AM – also seem to be appropriate in light of the diurnal peak load factor data, which shows healthy load data throughout the day and smaller loads for the first and last hour of service. Accordingly, the recommended increase in frequency does not need to be accompanied by an extension of service hours. Finally, based on the numerous entertainment and cultural destinations within the Wilshire Boulevard Corridor and strong ridership data, the current weekend spans seem to be appropriate.

Based on this research and analyses, the following lesson may be taken from the Wilshire Boulevard Corridor case study:
1. **Intelligent service design of concurrent BRT and local bus routes contributes to strong ridership productivity.** The careful monitoring of ridership and peak load factor data has enabled Metro service planners to evaluate the performance of Lines 20 and 720 and make frequency and span adjustments as necessary. This commitment to developing and maintaining balanced, highly productive service facilitates the continued growth that has occurred in the Wilshire Boulevard Corridor over the last few years.

2. **Peak load factor data is one of the most important performance metrics for service frequency and span and should be monitored regularly.** The biggest reason to increase or decrease the dimensions of service is to alleviate overcrowding or reduce the resources devoted to underperforming routes. Metro’s use of a 1.30 maximum peak load factor standard provides a clear guide for when additional frequency or span is needed to accommodate ridership demand. While Metro’s peak load standard is based solely upon vehicle capacity, other considerations such as corridor density, ridership, and customer input could also help determine what the standard should be. It could also be beneficial to develop minimum peak load standards and comparative peak load factors to further inform service design decisions in corridors with concurrent BRT and local service.

3. **Comprehensive passenger data can also help assess the adequacy of the multimodal service design in a given corridor.** Metro collects extensive data on average passenger trip lengths, average passenger trip durations, rider behavior, customer satisfaction, and other passenger-related outputs. This allows the service planners to develop a full understanding for how the corridor functions, what types of trips are being made, and what is driving ridership at all times of day in both directions. Such detailed corridor-specific information is invaluable in the effort to determine appropriate service design characteristics in busy urban corridors with varying types of transit service.

4. **Equity considerations are important but should not be the deciding factor in service design decisions.** Based on the early success of the BRT and local bus lines in Wilshire Boulevard, several dozen other corridors in the Los Angeles metropolitan area were earmarked for similar enhanced multi-tiered service. Most of these corridors had demonstrated strong ridership potential to warrant the increased frequencies and spans associated concurrent BRT and local service, but others had not and were included only to score political points and satiate equity concerns. Not surprisingly, the short headways and extended service spans that allowed Lines 20 and 720 to thrive on Wilshire Boulevard were not supported on some of the other corridors and service was eventually reduced or discontinued.\(^\text{82}\)
5.0 CASE STUDY # 2 – OAKLAND, CA (SAN PABLO AVENUE)

5.1 Overview of Oakland

Located in Northern California’s San Francisco Bay Area, the City of Oakland spans 56 square miles and is home to nearly 400,000 residents.\(^{83}\) It is situated directly across the bay from San Francisco and less than 40 miles north of San Jose. Oakland is the largest city in the East Bay and is the County Seat of Alameda County. Alameda County and its northern neighbor, Contra Costa County, share the San Pablo Avenue Corridor. The two counties account for a total population of 2.6 million and a land area of 1,455 square miles.\(^{84,85}\)

Oakland is best known for its port, the Port of Oakland, which ranks as the fourth largest container port in North America and the twentieth biggest in the world.\(^{86}\) In 2012 alone, the port was responsible for moving over 2.3 million cargo containers.\(^{87}\) In addition to the port, downtown Oakland boasts several large corporate headquarters and a number of museums, theaters, and other cultural attractions. The University of California at Berkeley, located five miles north of downtown Oakland, enrolls 26,000 undergraduate students and is perennially ranked as the top public institution in the United States.\(^{88}\)

Oakland is also well known for its diverse population. A recent study identified the City of Oakland as the most ethnically diverse city in the nation.\(^{89}\) The 2010 Census reported that 74 percent of Oakland city residents identify themselves as minorities. This figure is slightly lower in Alameda and Contra Costa Counties at 66.1 percent and 52.7 percent, respectively, but all are still well above the national average of 36.6 percent. The percents of residents that speak a language besides English at home are 40 percent, 43 percent, and 33 percent in the City of Oakland, Alameda County, and Contra Costa County, respectively. The median household incomes in the three municipalities are $51,144, $70,821, and $79,135, and the percents of residents below the federal poverty level are 20 percent, 12 percent, and 10 percent.\(^{90,91,92}\)

5.2 San Pablo Avenue Corridor

San Pablo Avenue, also known as Lincoln Highway and State Route 123, is the major north-south arterial street that connects downtown Oakland with Emeryville, Berkeley, Albany, El Cerrito, Richmond, San Pablo, Pinole, and Hercules. From City Hall in downtown Oakland to Willow Avenue in Hercules, entire San Pablo Avenue Corridor measures 19 miles in length. The trunk portion of the corridor between downtown Oakland and Contra Costa College in San Pablo covers 12 miles. For virtually its entire length, San Pablo Avenue is a four-lane median divided arterial street with auxiliary turn lanes. The road is undivided for several segments north of Albany and features on-street parking on both curbs in Berkeley and downtown Oakland.

Aside from the Oakland central business district, Doctor’s Medical Hospital in San Pablo, and several major shopping centers along the corridor, San Pablo Avenue is abutted predominantly with medium-density residential, commercial, and industrial development. The overall population density of the census tracts along the corridor is 10,770 persons per square mile.\(^{93}\) Contra Costa College, located at the northern end of the corridor, is also a major trip generator. A strong push has been made in the last decade to increase the amount of multi-family housing in the immediate vicinity of the corridor. This has led to the construction of a number of medium-density multi-family housing complexes and complementary shops and restaurants along San Pablo Avenue in Albany, Berkeley, and El Cerrito.
San Pablo Avenue serves as the primary surface arterial for travel between downtown Oakland. Since it runs directly parallel to Interstate 80, it is often used as an alternative route for congestion-weary motorists. Based on 2011 Caltrans traffic volumes, I-80 carries approximately 197,000 daily trips while San Pablo Avenue accounts for roughly 28,000 trips at the Alameda – Contra Costa County Line on a typical weekday. The majority of traffic in the corridor travels southbound towards Oakland in the morning and northbound during the afternoon rush hour. 94

5.3 Public Transportation in Oakland

The Oakland area represents a major regional hub for public transportation. All five BART rail lines travel through portions of Oakland and provide service to 17 BART stops in Alameda and Contra Costa Counties. Additional rail service in the area is operated by the Altamont Corridor Express (ACE) and Amtrak’s Capital Corridor commuter line. The primary bus operators in Alameda and Contra Costa Counties include the Central Contra Costa Transit Authority (CCCTA or “County Connection”), Western Contra Costa Transit Authority (“WestCAT”), Soltrans, Dumbarton Express, WestCAT, Tri Delta Transit, Union City Transit, Livermore Amador Valley Transit Authority (LAVTA or “Wheels”) and AC Transit. There are also three major ferry terminals near downtown Oakland. 95

The Alameda-Contra Costa Transit District – or “AC Transit” as it is more commonly known – serves as the primary public transportation operator for the City of Oakland and the unincorporated western portions of Alameda and Contra Costa Counties. In 2010, AC Transit provided 61.2 million unlinked passenger trips, which placed it among the top 30 transit properties in the country. 96 AC Transit currently operates 114 bus routes, which serve 5,600 stops in the agency’s 365 square mile service area. 97

5.4 Public Transportation in the San Pablo Boulevard Corridor

As the primary arterial street between Oakland, Berkeley, and the northeast Bay Area, San Pablo Avenue features a variety of public transit services. Rail service in the corridor is available at the El Cerrito and El Cerrito del Norte BART Stations. Both of these stations are within a quarter-mile of the main arterial street and serve as important transfer points for many of the buses that operate on San Pablo Avenue. From these two BART stations, passengers have one-seat access to Oakland, San Francisco, and points throughout the East Bay and Peninsula areas.

The buses offering extended service in the corridor include Transbay Lines L and LC, Late night Lines 800 and 802, local Lines 72 and 72-M, and the BRT-style Line 72-R. The two transbay lines – Lines L and C – originate in downtown service and provide direct service via I-80 to Albany, El Cerrito and San Pablo on weekday afternoons. These two routes operate on San Pablo Avenue for 4.5 miles between Central Avenue in Albany and Church Street in San Pablo, but most of the trips do not permit local passengers. Lines 800 and 802 both operate daily between midnight and 6:00 AM. Line 800, seemingly one of the longer routes in the Bay Area, runs from downtown San Francisco to downtown Oakland, Berkeley, Albany, and Richmond. It operates on San Pablo Avenue for several miles between University Avenue in Berkeley and MacDonald Avenue in Richmond for almost five miles. Line 802 also operates overnight, covering the portion of San Pablo Avenue between Oakland and Berkeley that is not covered by Line 800. These special bus lines provide overnight coverage along San Pablo Avenue to supplement the daytime service on Lines 72, 72-M, and 72-R. 98
Lines 72 and 72-M

Lines 72 and 72-M combine to provide local, all-stop bus service from Oakland to Richmond almost exclusively along San Pablo Avenue. As shown in Figure 5-1, the two routes are identical from Jack London Square in downtown Oakland to El Cerrito. In Richmond at MacDonald Avenue, Line 72-M splits off to the west to serve the Richmond BART/Amtrak Station and Point Richmond, while Line 72 continues north on San Pablo Avenue to Contra Costa College in San Pablo and Hilltop Mall in Richmond. From Line 72 measures roughly 14.5 miles in length and includes approximately 85 stops in each direction for an average stop distance of 0.17 miles. The current Line 72/72-M schedules are included in Appendix C.

Although the two lines are separate, the schedules are interwoven on the shared trunk line between Jack London Square and MacDonald Avenue to provide shorter, balanced headways. For the most part, each route operates every 30 minutes and the two routes combine along San Pablo Avenue to provide 15 minute headways for almost the entire day. Both services operate seven days a week from 5:00 AM to 1:00 AM. As mentioned in the previous section, local San Pablo Avenue service between 1:00 AM and 5:00 AM is available via Lines 800 and 802. Lines 72 and 72-M also enjoy extensive connections with regional transit centers such as the Oakland Amtrak Station, Jack London Square Ferry Terminal, 12th Street BART Station, Uptown Transit Center/19th Street BART Station, El Cerrito Plaza BART Station, El Cerrito del Norte BART Station, and – for Line 72-M – the Richmond BART/Amtrak Station. These connections provide critical transfers to regional rail, bus and ferry lines.

Lines 72 and 72-M are both operated with standard 40’ buses and the standard AC Transit fare ($2.10 per trip) is collected through an onboard farebox. Passengers are encouraged to use smart cards (Clipper Cards) to ensure quick and easy fare payment.

Line 72-R

Line 72-R – or the San Pablo Rapid – was introduced in 2003 to improve transit service in the high-ridership San Pablo Avenue Corridor. As shown in Figure 5-1, this BRT-style service follows the same route as Line 72 and uses many of the same stops between Jack London Square in downtown Oakland and Contra Costa College in San Pablo. Line 72-R measures 14 miles in length, approximately 12 of which are on San Pablo Avenue. The route makes 27 stops in each direction, which equates to one stop every 0.54 miles. The San Pablo Rapid utilizes shorter headways than the local routes, but its span is somewhat limited. It runs on weekdays from 6:00 AM to 8:00 PM, but does not operate on Saturdays or Sundays. The Line 72-R schedule is headway-based with buses arriving every 12 minutes throughout the day. A copy of the current schedule for Line 72-R is included in Appendix C.

The Line 72-R service runs with 40’ low floor ultra low sulfur diesel (ULSD) Van Hool A330 buses. Several Intelligent Transportation Systems (ITS) were implemented on the San Pablo Rapid service. These include Transit Signal Priority (TSP), Automated Vehicle Locator (AVL), Automated Passenger Counting (APC), and at-station real-time information displays that inform passengers when the next bus will be arriving. These improvements essentially represent a minimal BRT investment in upgrading from standard service.

Line 72-R fares are the same as the fares charged for local service - $2.10 for a single trip, collected via onboard farebox with cash of the Clipper Card. Bus-to-bus transfers cost additional $0.25 while bus-to-BART connections are $1.85. Connections from Line 72-R to Transbay Lines L or LC are free. Since they share the same corridor, Lines 72 and 72-R also share many of the same regional multimodal connections described in the previous section.
5.5 Operational Analysis of Lines 72 & 72-R

The San Pablo Avenue Corridor has served as an integral component of the transit infrastructure in western Alameda and Contra Costa Counties for decades. This section summarizes the current ridership, travel times, on-time performance, and operating costs of Lines 72, 72-M and 72-R. A detailed summary of the operational characteristics of Lines 72, 72-M and 72-R is provided in Appendix A.

**Ridership**

In 2012, Lines 72, 72-M, and 72-R combined to average 14,715 boardings per weekday, or approximately 37 boardings per revenue hour. Lines 72-R and 72 are ranked seventh and tenth, respectively, among all AC Transit routes in terms of average weekday boardings. Line 72-R does not operate on weekends, but local service on Lines 72 and 72-M averaged a fairly strong combined ridership of 39 boardings per revenue hour on Saturday and 33 boardings per revenue hour on Sundays.107

Of the 14,715 weekday boardings, local service on Lines 72 and 72-M account for over half of the corridor ridership with 7,976 combined daily boardings in 2012. These two lines also averaged 34.7 weekday
boardings per revenue hour. By comparison, Line 72-R rapid service drew an average of 6,739 weekday boardings or 40.7 boardings per revenue hour. These figures represent a combined 1.7 percent increase in weekday ridership over the last three years with the local lines demonstrating a 4.5 percent increase since 2010. Lines 72 and 72M have shown considerable weekend ridership growth during this period with increases of 16 percent on Saturdays and 24 percent on Sundays. Line 72-R rapid service, however, slipped 2.9 percent from 2010 levels. Despite this, these trends compare favorably with the systemwide ridership, which decreased by 2.7 percent on weekdays and 0.1 percent on Saturdays during the same period. Sunday ridership, however, increased by 5.2 percent. Based on these ridership statistics, the minor decrease in rapid ridership is puzzling, but overall bus ridership productivity in the San Pablo Avenue Corridor seems to be healthy and on the rise.

Load Factor Data

The average weekday peak load factors for Lines 72 and 72-M are 0.70 and 0.67, respectively. When combined, the peak load factor for local service along San Pablo Avenue is roughly 0.69. This number equates to 22 passengers on a 32-seat bus. Line 72-R rapid service, similarly, averaged a weekday peak load factor of 0.71. The highest weekday peak load factor for local service occurred during the midday period (0.79), while the highest period for Line 72-R was the morning peak (0.83). Not surprisingly, the highest directional load splits were the peak morning southbound trips heading to Oakland and the peak afternoon northbound trips to San Pablo, which exhibited peak load factors with 0.90 and 0.83. These statistics reflect strong ridership, but are not high enough to warrant serious concern for overcrowding.

Travel Time

As a heavily-traveled corridor for trips between Oakland, San Pablo, and points between, San Pablo Avenue experiences a great deal of congestion-related delays, particularly during weekday peak periods and when I-80 is severely backed up. Since both local and rapid buses travel in mixed traffic lanes, both are subject to these delays. For example, on the trunk section of Line 72 between Jack London Square and Contra Costa College, late night buses can traverse the entire route with minimal traffic in roughly 58 minutes. During the afternoon peak period, however, Line 72 local trips can take between 80 and 85 minutes to complete the route. Similarly, Line 72-R rapid service can cover the same distance in 43 minutes during off-peak periods, but takes as long as 73 minutes during the afternoon peak period. Therefore, while the rapid service can shave up to 17 percent off the total end-to-end travel time, congestion during the peak hours reduces time savings and makes service planning more difficult for all three routes.

On-Time Performance

As a result of the delays described in the previous section, the local and rapid bus lines operating in the San Pablo Avenue Corridor experience major service reliability issues. Line 72-R rapid service arrives within five minutes of its schedule approximately 84 percent of the time on weekdays. The reliability of the local service in the corridor, however, is much worse. Line 72 operates “on-time” roughly 67 percent of the time on weekdays, 53 percent of the time on Saturdays, and 76 percent of the time on Sundays. This poor on-time performance for local service is cause for concern and likely has a detrimental effect on ridership and customer satisfaction.
Service Costs

One last operational performance measure of the AC Transit bus lines in the San Pablo Avenue Corridor is cost. The capital expenditure required to construct the San Pablo Rapid in 2003 was roughly $3.2 million or $228,571 per mile. This cost was relatively low in comparison to other BRT project because the Van Hool vehicles purchased were the same as those used on many other AC Transit routes. While AC transit staff did not have route-specific operating cost data, it estimated that Lines 72, 72-M, and 72-R each cost approximately $177 per revenue hour to operate. At the system level, AC Transit also reports bus operating costs of $1.52 per passenger mile and $4.97 for each unlinked passenger trip.

Data on the effects of the San Pablo Rapid on environmental costs is not readily available, all of the AC Transit routes on the corridor are operated with ultra-low sulfur diesel (ULSD) vehicles. Buses that use this type of propulsion emit 97 percent less sulfur than previous “low sulfur diesel” models.

5.6 Comparative Frequency Analysis of Lines 72 & 72-R

Since the San Pablo Avenue Corridor represents one of the busier transit corridors in the East Bay, it is imperative that the headways for its local and rapid bus lines be appropriately designed. This section evaluates the degree to which the current service headways match up with ridership splits, peak load data, and several other important factors. For comparison purposes, the two local routes – Lines 72 and 72-M – are combined as Line 72 in these analyses, but their balanced ridership and load factor statistics seem to suggest that matching 30 minute headways provide adequate service frequency.

Headway Ratios

The service design of Lines 72 and 72-R seems to create a productive balance between the local and rapid bus lines. The rapid service operates every 12 minutes throughout the entire day. The Line 72 schedule runs about every 15 minutes for most of the day with slightly more frequent service during the peak hours and slightly longer headways during the evenings. Based on the exact average headways shown in the table, the headway ratio is 1.33 during the morning peak hours and 1.25 during the midday and afternoon peak periods. These headways have been maintained since the inception of the San Pablo Rapid service in 2003. Since the 72-R rapid service only operates until 8:00 PM on weekdays and does not operate on Saturdays or Sundays, no headway comparisons are available for weekday evenings or weekends. A summary of the headway ratios and corresponding operational data is show in Table 5-1.

Ridership

Comparative ridership data for the local and rapid routes suggests that the headways could be modified to more accurately balance passengers between the two routes. Line 72 draws an average of 35 boardings per revenue hour, which is roughly 17 percent fewer than the 41 boardings per revenue hour recorded by Line 72-R rapid service. When the ridership is broken down by time of day, however, the local routes attract 22 percent more boardings than the rapid service during the morning peak hours and five percent more during middays. Thus, data for boardings per revenue hour implies that the rapid service could benefit from shorter headways, but the diurnal ridership data finds that the local service should be provided more frequently. This discrepancy between boardings per revenue hours and overall ridership may be explained by the large difference in service hours between the local and rapid bus lines.
Table 5-1 – San Pablo Avenue Corridor Frequency Analysis Summary

<table>
<thead>
<tr>
<th>Time Periods</th>
<th>Average Headways (Minutes)</th>
<th>Average Boardings</th>
<th>Average Peak Load Factor</th>
<th>Average Travel Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM Peak (6 - 9 AM)</td>
<td>16</td>
<td>12</td>
<td>1.33</td>
<td>1,451</td>
</tr>
<tr>
<td>Midday (9 AM - 4 PM)</td>
<td>15</td>
<td>12</td>
<td>1.25</td>
<td>3,816</td>
</tr>
<tr>
<td>PM Peak (4 - 7 PM)</td>
<td>15</td>
<td>12</td>
<td>1.25</td>
<td>1,288</td>
</tr>
<tr>
<td>Evening (7 - 10 PM)</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>896</td>
</tr>
</tbody>
</table>

Primary Source: Der, Howard. Planning Data Administrator. AC Transit. Email to Author. 2 April 2013.

Peak Load Factors

The questions raised through the analysis of ridership data are clarified somewhat by the peak load factor data. For weekdays, Lines 72 and 72-R maintain average peak load factors of 0.69 and 0.71, respectively. During the morning and afternoon peak periods, Line 72-R rapid service exhibits 10 and 5 percent greater load factors than the local lines, while during middays, the local service is marginally higher. Despite these minor fluctuations, these proportions seem to demonstrate a reasonable balance of headways between the two services. Headways throughout all three periods for both services fall below the Bogota average peak load factor standards of 0.80 during peak periods and 0.70 during off-peak service that were discussed in the literature review.

Other Indicators

Another potential indicator of the adequacy of the current headways is average passenger trip length. BRT is typically designed to serve longer trips, while shorter trips could be made using the local bus. Consequently, a corridor with longer average BRT trip lengths represents a healthy, productive relationship between the two services. Based on 2012 trip statistics for the local and rapid services, Line 72-R serves and average trip length of 4.2 miles, while Lines 72 and 72-M average 4.0 and 3.5 miles, respectively. This minor differentiation is likely due to the fact that most trips in the San Pablo Avenue Corridor are relatively short and very few passengers travel the entire length of the corridor. A review of stop spacing also shows that the corridor has approximately three local stops for every BRT stop. This is one of the lowest ratios among the five case studies and indicates that the balance of service frequencies could be further shifted towards BRT with minimal consequences for riders in the San Pablo Avenue Corridor.
Data on average passenger trip durations, transfer activity, and customer satisfaction was requested but not available. It is therefore not included in the frequency analysis.

5.7 Span Analysis for Lines 72 & 72-R

Land uses and densities within a corridor often play a central role in determining the span of service that is provided. Since the areas adjacent to the northern three-quarters of San Pablo Corridor are characterized primarily by low-intensity residential and industrial development, the demand for extended rapid service hours is likely insufficient. That overnight service is only provided hourly by two completely different routes (Lines 800 & 802) supports this assertion. By this logic, the current weekday spans of 6:00 AM to 8:00 PM for rapid service and 5:00 AM to 1:30 AM for local service appear to be reasonable.

A review of corridor ridership and peak load factor data also seems to – for the most part – support the current service spans. Weekday late night ridership data indicates that the Line 72 trips occurring after 10:00 PM draw just 22 boardings across the entire length of the route. The average peak load factor for these trips is 0.36, well below the loads measured during the other portions of the day. The data for mornings before 6:00 AM is slightly higher, with 27 boardings per trip and a peak load factor of 0.44. These numbers imply that current ridership demand during early mornings and late nights does not necessitate an extension of service hours during those periods. This finding is supported by TCRP Report 118, which notes that BRT spans as low as 12 hours may be reasonable if sufficient local service is provided during evening and overnight periods.

Local service provided by Lines 72 and 72-M currently operates from 5:00 AM to 1:30 AM on Saturdays and Sundays, while the rapid Line 72-R does not run on weekends. As mentioned in the operations analysis section, the average weekend ridership is 39 boardings per revenue hour on Saturday and 33 boardings per revenue hour on Sunday. Weekend peak load factor data was not readily available and is therefore not included in this portion of the analyses. These ridership numbers are strong, but less than impressive considering that Line 72-R is out of service so the local routes are the only service available. Despite the mediocre hourly ridership data, the growth in weekend ridership over the last three years – up 16 percent on Saturdays and 24 percent on Sundays – may warrant additional consideration for extended weekend service. If the trend continues, weekend service could be gradually increased through headway adjustments or the gradual implementation of Line 72-R weekend service.

5.8 San Pablo Avenue Corridor Findings & Lessons Learned

With two of the ten most popular routes in the AC Transit system, San Pablo Avenue is one of the most productive corridors in the Alameda and Contra Costa Counties. On an average weekday, the three Line 72 routes register 14,715 boardings, a 1.7 percent increase over the previous three years. The growth of local service on Lines 72 and 72-M has been particularly dramatic during this three year period, increasing 4.5 percent on weekdays and 16 percent and 24 percent on Saturdays and Sundays, respectively. These two local routes and Line 72-R rapid service maintain 34.7 and 40.7 boardings per revenue hour, respectively. Along with strong average peak loads of 0.69 and 0.71 for local and rapid service, respectively, this ridership data demonstrates the overall health and success of the San Pablo Avenue Corridor, despite its minimal investment in BRT.

The current headways for Lines 72, 72-M, and 72-R have been in place for nearly a full decade and seem to foster a productive balance between local and rapid bus service. Under the current schedules, the San Pablo Rapid operates with 12 minute headways while one of the two local lines arrives once every 15
minutes. The resulting headway ratios of roughly 1.25 to 1.33 correspond well with the ridership splits and contribute to the effective service balance. Although the findings of the comparative ridership evaluation were not conclusive, the average peak load factor data and average passenger trip lengths demonstrate that the current frequencies are providing adequate service levels to meet the various travel demands within the San Pablo Avenue Corridor. This finding was supported by anecdotal evidence collected during interviews with AC Transit staff.\textsuperscript{125}

With a few minor exceptions, the current service spans on Lines 72, 72-M, and 72-R provide adequate hours of operation to satisfy current demand. The San Pablo Avenue Corridor is comprised mostly of low-density residential development, so it is not surprising that ridership and peak load factors are relatively low during evening and weekend periods. Therefore, the decision to not operate the San Pablo Rapid during weekends or weekday evenings appears to be justified. Moreover, a review of local service ridership and peak load data on the first weekday trips in the early morning and last trips late at night indicates that the provision of service during those periods may not be warranted by current demand.

Based on the research and analyses described above, the following lessons can be gleaned from the San Pablo Avenue Corridor example:

1. **Budgetary constraints frequently supersed good service design.** Based on the observations of AC Transit staff, it is apparent that the biggest issue facing their transit planners and schedules is the budget. They have designed and implemented a strong transit infrastructure in the San Pablo Avenue Corridor, but their ability to improve and expand service to accommodate normal ridership growth is undermined by a perpetual shortage of resources. While most agencies face similar challenges, it seems to be more pronounced for AC Transit.\textsuperscript{126}

2. **Headway-based BRT schedules are often prone to bunching and inconsistent headways.** Bunching occurs when the intervals between consecutive buses becomes on a headway-based schedule become skewed due to traffic patterns and individual driver behavior. This issue occurs most on longer routes with headway-based schedules like the San Pablo Rapid, because the buses are not required to follow specific arrival and departure times at each timepoint. This affects service reliability and convenience and can reduce the effectiveness of the intended service frequency ratios. To address this issue, AC Transit recently began enforcing several timepoint along the route to ensure proper spacing and maintain the desired frequency ratios.\textsuperscript{127} GPS technology can also be helpful in reducing bunching patterns.

3. **Headways on one portion of the route may not be appropriate for another portion of the route.** Although this analysis treats routes as single entities with singular characteristics, it is important to note that different parts of the same route may perform better with different frequencies that can be provided by branching routes or shortening selected trips. In the San Pablo Avenue Corridor, the Richmond corridor, served by the northern branch of Line 72-M is an example of this. Although it might benefit from a marginal increase to frequency along this portion of the route, this could only realistically occur if additional trips were also deployed along the trunk portion of the route and possibly on the Contra Costa College branch as well. The cost of these additional necessary improvements is prohibitive.

4. **Average waiting times and overall customer convenience are also important factors in service design decisions.** Several members of the AC Transit staff intimated that – financial constraints notwithstanding – Line 72-R rapid service would benefit substantially from an increase in service
frequency from one bus every 12 minutes to one bus every 15 minutes. This recommendation is not necessarily supported by ridership or peak load factor data, but is instead would be implemented to improve customer convenience and reduce average wait times.¹²⁸

5. **Schedule coordination between BRT and local service is less important with high-frequency service and irregular headway ratios.** Despite the clear interaction between the two routes, AC Transit schedulers have never specifically coordinate service between Line 72 and Line 72-R. This is due to the relatively high service frequencies of the two routes, and the unusual 1.25 headway ratio, which makes it virtually impossible to provide a consistent sequencing of rapid and local service.¹²⁹
6.0 CASE STUDY # 3 – LAS VEGAS, NV (LAS VEGAS BOULEVARD NORTH)

6.1 Overview of Las Vegas

The City of Las Vegas is a large, rapidly-growing metropolis built in a desert basin amidst the Spring Mountains of southern Nevada. Covering a land area of 136 square miles with just under 390,000 residents, Las Vegas is the largest city in the state and serves as the county seat of Clark County.130 Clark County itself is home to two million residents over 7,891 square miles.131 Although Las Vegas city proper includes only a portion of the downtown area, the term “Las Vegas” typically includes the large portions of unincorporated areas south of downtown that include McCarron Airport and the Las Vegas Strip.132

Las Vegas is a uniquely American city made famous for its entertainment, shopping, and dining attractions. The city’s seemingly endless array of casinos, resorts, restaurants, and retail centers make it one of the most popular tourist destinations in the world. In 2012 alone, Las Vegas hosted 21,615 conventions, 39.7 million tourists, and generated $9.4 billion in gaming revenues for Clark County. The city’s most famous area is the Las Vegas Strip, a 4.2 mile section of Las Vegas Boulevard South just south of downtown where the majority of the city’s casinos, resorts, and shopping are located.133

Over the last two decades, the populations of Las Vegas and Clark County have grown dramatically. Since 1990, the number of residents in the City of Las Vegas has doubled and the Clark County population has jumped by 155 percent.134 The city also features a great deal of ethnic and economic diversity. The 2010 Census reported that 52.1 percent of Las Vegas residents identify themselves as minorities. Nearly one-third of the population speaks a primary language other than English. The median household income in Las Vegas is $54,174 and approximately 15 percent of the population falls below the federal poverty line. Based on these statistics, Las Vegas has significantly more diversity and foreign-born persons than the national average, and a median household income that is slightly above the figure for all Americans.135

6.2 Las Vegas Boulevard North Corridor

Las Vegas Boulevard is the city’s major north-south arterial street running parallel to Interstate 15 through the entire Las Vegas metropolitan area. It runs through the southern unincorporated areas of Enterprise and Paradise, the Las Vegas Strip, downtown Las Vegas, North Las Vegas, Nellis Air Force Base, and the Las Vegas Motor Speedway. The street is divided between Las Vegas Boulevard North and Las Vegas Boulevard South near downtown at Fremont Street, and the northern half of the corridor measures roughly 7.5 miles in length. Las Vegas Boulevard North is constructed as a four-lane, median-divided arterial with auxiliary turn lanes, and dedicated curbside bus lanes for about 4.5 miles along the northernmost segment of the corridor.

Las Vegas Boulevard North represents one of the busiest corridors in the region and provides an important connection for residents of North Las Vegas traveling to downtown Las Vegas and the Las Vegas Strip. Based on the most recent traffic data, it carries roughly 29,000 daily trips near downtown and 17,000 vehicles on an average weekday in North Las Vegas.136 The southern end of the corridor is located in close proximity to the dense central business district. The rest of the corridor, most of which is located in North Las Vegas, runs through low-density residential, commercial and municipal areas. The major trip generators along this portion of the corridor include two large casinos (Jerry’s Nugget and Silver Nugget), several government buildings, shopping centers, and Nellis Air Force Base. The overall population density of the census tracts immediately adjacent to the corridor is 7,908 persons per square mile.137
6.3 Public Transportation in Las Vegas

The Regional Transportation Commission of Southern Nevada (RTC) serves as the primary transit operator and Metropolitan Planning Organization (MPO) for all of southern Nevada. RTC carried approximately 61 million unlinked trips and covered 211 million passenger miles in 2012. The agency’s 53 bus routes cover a total service area of 280 square miles. Based on 2009 ridership, RTC ranks as the nineteenth most productive bus operator in the country.

The 53 routes operated by RTC include two special downtown/strip routes (SDX & Deuce), seven express bus routes, 31 local residential routes, and 13 limited service “Silver Star” routes intended for senior citizens. The SDX and Deuce combine to provide express service from the southern edge of the Las Vegas metropolitan area to the Strip and downtown Las Vegas. Almost all of the routes that service the downtown and strip areas converge at the Bonneville Transit Center, which serves as the city’s primary transit hub.

6.4 Public Transportation in the Las Vegas Boulevard North Corridor

With nearly 2.6 million boardings in 2012, Las Vegas Boulevard North is one of the busiest transit corridors in the region. Most of the corridor is lined on both sides by extensive low-density residential development. These areas are home to large populations of minority, low-income, and transit-dependent individuals, many of whom work at the resorts, restaurants, and other businesses in the downtown area and on the Las Vegas Strip. Therefore, the performance of transit in the Las Vegas Boulevard North Corridor plays an instrumental role in supporting the health and productivity of the regional economy.

The southern end of the Las Vegas Boulevard North Corridor connects with the Bonneville Transit Center. This connection enables passengers from North Las Vegas to travel virtually anywhere in the Las Vegas metropolitan area. The two bus routes that provide service from Las Vegas Boulevard North to the downtown Las Vegas and the Bonneville Transit Center are Line 113 and the Metropolitan Area Express (MAX).

Line 113

Line 113 has provided local service along Las Vegas Boulevard North for decades. The Line 113 route travels almost exclusively along Las Vegas Boulevard North from the Bonneville Transit Center in downtown Las Vegas to Nellis Air Force Base on the northeast fringe of the Las Vegas metropolitan area. The total length of the route is approximately 7.5 miles, and with 30 stops in each direction, the bus stops about once every quarter mile. A map of Line 113 is included as Figure 6-1.

Line 113 service is provided 24 hours a day, seven days a week. It operates once every 30 minutes throughout the course of the day with slightly longer headways during late night and overnight periods. The route currently operates with 50 minute headways between 1:00 AM and 5:00 AM, however, RTC is planning to decrease service to run hourly during that period as part of the July 2013 service changes. A copy of the current schedule for Line 113 is included in Appendix D.

Line 113 passengers can transfer to many of the other major bus routes within the region at the Bonneville Transit Center near downtown. Additional transfers to lines in North Las Vegas can be made at North Civic Center Drive (Line 110), North Pecos Road (Line 111), North Nellis Boulevard (Line 115), and several other cross streets along the route (Lines 203, 209, 210, 214E, 215, 218 and 219).
The local service is operated with 60-foot buses and the standard fares of $2.00 per trip or $3.00 for a two-hour pass apply. Passes purchased for residential trips are also valid on Express and Downtown/Strip Express routes. At the stops that Line 113 shares with the MAX, fares must be purchased at the Ticket Vending Machines (TVM) on the station platforms. The on-board fare boxes may be used at non-shared Line 113 stops where TVM’s are not available.\textsuperscript{145}

\textit{MAX}

The MAX BRT service was implemented as an FTA Demonstration Project in 2004 to enhance service along the heavily-travelled Las Vegas Boulevard North Corridor. MAX features dedicated curbside lanes for a 4.5 mile stretch at the northern end of the corridor. South of Civic Center Drive, the MAX operates in mixed flow traffic lanes. The MAX uses 62-foot, low-floor, articulated Civis vehicles that run on hybrid diesel-electric power. With their sleek design, unique branding, and four entry doors, the MAX vehicles look more like light rail trains pulling up to a platform than they do traditional buses. Additional BRT elements that have been implemented on the MAX service include enhanced stations, off-board fare collection at TVM’s, queue jump lanes, Traffic Signal Priority (TSP), Automatic Passenger Counters (APC), Real-Time Information, and Optical Guidance Systems (OGS) to ensure precise docking at the platforms.\textsuperscript{146}

The MAX follows the same route as Line 113 along Las Vegas Boulevard North from the Bonneville Transit Center in downtown to the intersection of Las Vegas Boulevard North and Craig Road adjacent to Nellis Air Force Base. With 11 stops in each direction over the length of the 7.5 mile corridor, MAX buses average one stop every 0.68 miles. All MAX stops are shared with Line 113, but only about half of the Line 113 stops are also served by the MAX. The major connections described above for Line 113 can also be made by MAX passengers.\textsuperscript{147}

MAX service operates seven days a week with an approximate span of 5:00 AM to 7:00 PM. The rapid service arrives once every 30 minutes throughout the course of the day. The schedule is integrated with the Line 113 schedule so that alternating buses arrives every 15 minutes at the shared stops within the corridor.\textsuperscript{148} A copy of the current MAX map and schedule is included in Appendix D.

\textbf{6.5 Operational Analysis of Line 113 & MAX}

The Las Vegas Boulevard North Corridor represents a critical link for the transit-dependent populations living in North Las Vegas and the numerous employment and activity centers in downtown Las Vegas and along the Las Vegas Strip. This section summarizes the current ridership, travel times, on-time performance, and operating costs of Line 113 and MAX service. A detailed summary of the operational characteristics of Line 113 and the MAX is provided in Appendix A.

\textit{Ridership}

The most recent daily ridership statistics for Line 113 and the MAX show that the two routes combine to average just over 5,000 boardings on a typical weekday. Line 113 is responsible for 2,673 of these daily boardings while the MAX accounts for the remaining 2,392. Based on 2012 data, Line 113 and the MAX averaged 66 and 60 weekday boardings per revenue hour, respectively. On Saturdays, the two lines drew 62 and 55 boardings per hour. Finally, Sunday ridership data indicates that Line 113 local service and the MAX rapid service recorded 57 and 48 boardings per revenue hour, respectively.\textsuperscript{149}
Overall ridership productivity in the Las Vegas Boulevard North has fluctuated greatly over the last decade. Since the introduction of MAX BRT service in 2004, the peak annual corridor ridership was achieved in 2008 with 3.7 million boardings. As a result of service reductions in 2010, ridership fell to 2.7 million annual boardings and was reported at 2.6 million in 2012. The 2008 peak and subsequent drop in 2010 is consistent with systemwide ridership statistics, however, RTC routes as a whole have registered a 10 percent increase in annual ridership since 2010 while the Las Vegas Boulevard North Corridor has remained stagnant. Lingering effects from the 2010 service reductions may be responsible for the lack of ridership growth in the corridor over the last three years. Despite this trend, 2012 boardings per revenue hour for Line 113 and the MAX are up 3.1 percent and 5.3 percent, respectively, from their performance in 2011.150

Load Factor Data

RTC peak load factors are calculated by stop and not by time period, so diurnal peak load factors are not available. The overall average weekday peak load factors for Line 113 and the MAX are 0.54 and 0.78, respectively. These figures equate to average peak load sizes of 31 and 24 for local and rapid services, respectively. The highest loads for both routes in both directions are typically found along the southern half of the Las Vegas Boulevard North Corridor.151 Based on these figures, the local Line 113 service buses are running half-empty and well below their capacity for large portions of the day.

Travel Time

Both Line 113 and the MAX travel along identical routes on Las Vegas Boulevard North between Nellis Air Force Base and the Bonneville Transit Center. However, Line 113 vehicles operate in mixed flow traffic lanes for the entire length of the corridor, while MAX BRT service has access to dedicated curbside lanes for a 4.5 mile segment along the northern portion of the route. As a result of these dedicated lanes, fewer stops, and traffic signal priority systems at key intersections, the MAX is able to travel from end-to-end over 20 percent more quickly than Line 113.152

On-Time Performance

The travel time savings described in the previous section translate to service reliability and on-time performance. The MAX, with its dedicated lanes, fewer stops, and TSP technology, arrives within five minutes of its scheduled arrival time roughly 90 percent of the time. Line 113 on-time performance statistics are slightly lower, with 87 percent of the local service trips arriving within the five minute window. RTC also measures service reliability with a 10-minute benchmark and the MAX and Line 113 arrived within this timeframe 98 percent and 95 percent. For both standards, the MAX is at or slightly above the systemwide average, while Line 113 falls 1-3 percent below it.153

Service Costs

The capital investment for the initial construction of the MAX was $20.3 million or $2.6 million per mile. These costs are relatively low compared to other BRT systems with dedicated bus lanes due to the fact that RTC utilized existing “breakdown” lanes and did not have to make any right-of-way acquisitions.154 The operational cost of Line 113 and the MAX are both estimated at $101.53 per revenue hour.155 In 2011, RTC reported systemwide average operating costs of $0.97 per passenger mile and $3.35 per unlinked trip.156
The enhanced Civis vehicles that are used to operate the MAX BRT service run on diesel-electric hybrid propulsion and therefore incur reduced environmental costs. A special electric motor allows the vehicles to accelerate more smoothly than traditional diesel buses and attain the air quality emissions that are comparable to those of Compressed Natural Gas (CNG). The vehicles also use the energy supplied by regenerative braking to operate the climate control system on each bus. These features enable MAX vehicles to produce lower emission levels and consume less energy.\textsuperscript{157}

6.6 \textbf{Comparative Frequency Analysis of Line 113 & MAX}

The schedules for Line 113 and MAX service are integrated and balanced to provide 15 minute headways throughout the day. This configuration was introduced in 2010 as a way to reduce service costs and promote equity with other regional corridors while maintaining frequent service along the Las Vegas Boulevard North Corridor. Prior to 2010, the MAX had run with 12 and 15 minute headways. Line 113 local service has always operated primarily with one bus every 30 minutes.\textsuperscript{158} This section evaluates the efficacy of the current service headways in terms of how well they correspond with existing ridership, peak load factors, and other important indicators. A summary of the analysis is included as Table 6-1.

\textit{Headway Ratios}

As described above, the local Line 113 and MAX rapid service are scheduled with offset 30 minute headways that provide 15 minute combined headways at stations that are shared by both routes. This translates to a headway ratio of 1.00 during the morning peak, midday, and peak rush hours. MAX service does not operate after 8:00 PM so there is no evening headway ratio. Weekend service maintains the same combined 15 minute headways but is not included in this analysis.

\textit{Ridership}

An annual ridership comparison between Line 113 and the MAX depict a surprising imbalance. In 2012, Line 113 accounted for 1.7 million annual boardings, while the MAX registered just 865,747. These figures represent a complete reversal from 2010, when the MAX drew nearly 1.8 million annual boardings compared to 928,915 boardings on Line 113.\textsuperscript{159} These trends coincide with the 2010 service changes that effectively reduced MAX service by half and made Line 113 the more popular route.\textsuperscript{160}

Daily ridership data provides additional insight into the proportional relationship between local and rapid service along Las Vegas Boulevard North. Line 113 and MAX service average 2,673 and 2,392 weekday boardings, respectively, or 53 and 47 percent of the total daily boardings in the corridor, but this is largely due to the additional evening and late night service offered by Line 113. By time of day, MAX service accounts for roughly 53 percent of corridor ridership during the morning peak period, 55 percent of the midday boardings, and 59 percent of the afternoon peak period boardings.\textsuperscript{161} These statistics demonstrate that when both lines are in service during the daytime, MAX is the more productive route and could be offered at more frequent intervals than the local service.

\textit{Peak Load Factors}

RTC does not calculate peak load factors by time of day, but the average weekday peak load factors for Line 113 and the MAX are 0.54 and 0.78, respectively.\textsuperscript{162} These values are slightly skewed, however, by the vehicle types used on the two routes and the seating capacities of each. Line 113 operates with 60-foot vehicles whose interiors are filled with seats and can accommodate up to 58 seated passengers. MAX
uses 62-foot vehicles that include several large areas for standees and have only 31 seats.\textsuperscript{163} Therefore, since the two services feature identical frequencies, the actual average peak loads – 24 for Line 113 and 31 for MAX – provide a more apt comparison. Based on these statistics, the MAX headways could be marginally increased during the daytime to facilitate more balanced service equilibrium.

Table 6-1 –Las Vegas Boulevard North Corridor Frequency Analysis Summary

<table>
<thead>
<tr>
<th>WEEKDAY TIME PERIODS</th>
<th>Average Headways (Minutes)</th>
<th>Average Boardings</th>
<th>Average Peak Load Factor</th>
<th>Average Travel Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line 113</td>
<td>MAX</td>
<td>Ratio (MAX:113)</td>
<td>Line 113</td>
</tr>
<tr>
<td>AM PEAK (6 - 9 AM)</td>
<td>30</td>
<td>30</td>
<td>1.00</td>
<td>386</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>MIDDAY (9 AM - 4 PM)</td>
<td>30</td>
<td>30</td>
<td>1.00</td>
<td>1,016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>41</td>
</tr>
<tr>
<td>PM PEAK (4 - 7PM)</td>
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<td>1.00</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>39</td>
</tr>
<tr>
<td>EVENING (7 - 10 PM)</td>
<td>21</td>
<td>-</td>
<td>-</td>
<td>333</td>
</tr>
</tbody>
</table>

Other Indicators

Although exact route-specific average passenger trip lengths were not available, the average trip length for the entire RTC system is 3.5 miles. Based on staff estimates and anecdotal evidence, the average trip lengths for both Line 113 and the MAX in the 7.5 mile Las Vegas Boulevard North Corridor are comparable to the system average.\textsuperscript{164} Likewise, the ratio between the average stop spacing for the two routes is the lowest of the five case studies at just over 2.5 local stops per BRT station. These statistics demonstrate the lack of intended differentiation of the two services. Perhaps most telling is the fact that the vast majority of passengers at the shared BRT stations simply board the next bus that arrives regardless of whether it is Line 113 or the MAX.\textsuperscript{165}

These statistics and descriptions are not consistent with a corridor that is effectively meeting the wide-ranging travel demands of its constituents. That a recent corridor analysis rated the overall transit service as level of service “C” is further proof of the detrimental effect of the 2010 service reductions on the Las Vegas Boulevard North Corridor.\textsuperscript{166}
6.7 Span Analysis for Line 113 & MAX

Transit planning in a city like Las Vegas presents a number of unique challenges. One such challenge is providing adequate service spans for all of the late-night and overnight activities resulting from the city's round-the-clock entertainment and gaming industries. In the Las Vegas Boulevard North Corridor, Line 113 operates 24 hours a day, seven days a week to fill this niche. Alternatively, MAX service offers limited hours of operation, from 5:00 AM to 7:00 PM on most days. Prior to the 2010 service reductions, MAX buses ran until 10:00 PM on both weekdays and weekends.\(^{167}\)

Based on current ridership data, the 24-hour span for local service appears to be warranted. Line 113 averages nearly 189 boardings each weeknight between 10:00 PM and midnight. Between midnight and 5:00 AM on weekdays, the service picks up an average of over 300 passengers. On weekends, the local route averages 192 and 243 boardings during the same late night and overnight time periods.\(^{168}\)

Since Line 113 provides service to all of the stops along Las Vegas Boulevard North, the provision of both services during the late night and overnight periods would be fairly redundant. Despite this, the MAX averages roughly 58 boardings in its first hour of weekday service (5:00 AM to 6:00 AM) and 137 boardings during its last hour of operation (6:00 PM to 7:00 PM). On weekends, the MAX rapid service averages 74 and 125 boardings during these same initial and final hours of operation. By comparison, Line 113 averages fewer boardings during all of these periods except early weekday mornings. Line 113 ridership also increases substantially immediately before and after MAX service begins and ends.\(^{169}\) Therefore, although Line 113 provides adequate early morning and evening service along Las Vegas Boulevard North, the ridership potential does exist for expansions to BRT operating hours during those times. This finding is consistent with the BRT guidelines of Levinson et al, which recommend a minimum BRT weekday span of 16 hours.\(^{170}\)

6.8 Las Vegas Boulevard North Corridor Findings & Lessons Learned

Las Vegas Boulevard North represents one of the most important arterials in the Las Vegas metropolitan area and also perhaps one of the most conducive to public transit. As demonstrated by the operations analyses, Line 113 and the MAX have historically enjoyed a strong ridership base, but have performed inconsistently over the last few years. Ridership gains between 2005 and 2009 were offset by a substantial reduction in MAX service frequency in 2010 that led to a 23 percent dip in annual boardings. As proof of the corridor’s resiliency, ridership on the two routes has stabilized and begun to recover over the last three years, but is still well below its previous productivity.\(^{171}\) It is therefore reasonable to assume that with a healthy economy, additional resources, and potential service improvements, the Las Vegas Boulevard Corridor could at least return to the productivity levels that it achieved between 2005 and 2009.

Prior to 2010, MAX service operated with 12 and 15 minute headways as compared with its current schedule that runs one bus every 30 minutes to provide combined 15 minute headways with Line 113. The findings of the comparative frequency analysis indicate that the reduced MAX service frequency is not adequate for the current corridor ridership. An evaluation of the ridership balance and peak load factors for each of the two routes suggests that the MAX headways might be increased to one bus every 20 to 25 minutes or even restored to their previous frequencies to create a more optimal balance with Line 113.

The necessary provision of a 24-hour span of service along Las Vegas Boulevard North is fulfilled by the all-stop local Line 113. This overnight demand is supported by recent ridership figures and should be
continued. The review of MAX service hours, however, noted that the rapid service demonstrates solid ridership performance during its first and last hours of service each day. Ridership during the final hour of service – between 6:00 PM and 7:00 PM - was particularly strong and exceeds the number of Line 113 boardings during the same period. Considering the wide array of nighttime activities in downtown Las Vegas and the Strip, it comes as no surprise that the demand likely exists for extending MAX BRT evening service by two or more hours.

Based on this research and analyses, the following lessons may be taken from the Las Vegas Boulevard North Corridor:

1. **Cost and equity considerations can regularly undermine successful service planning and design.** This appears to have been the case in 2010, when RTC decided to reduce MAX service frequency to save money and reallocate resources to other underserved corridors. In the regional context, the resources may have been deployed more efficiently elsewhere, but that does not mean that the shorter MAX service intervals were unwarranted. It is therefore important to acknowledge that service planning and design do not exist in a vacuum, and the biggest reason for not providing adequate headways or service hours is usually a lack of the necessary resources.

2. **It is important to properly distinguish the different roles of BRT and local service.** The current service design of the Line 113 and MAX is fairly unique. The two routes essentially operate together as one route with 15 minute headways and slightly different operating characteristics on every other trip. Accordingly, the average BRT passenger trip length is similar to that of the Line 113 local service, and passengers will usually take the first bus that arrives at their station regardless of which service it is. In a healthy corridor, the headways and ratio of service will be designed to incentivize the use of more efficient BRT service for longer trips while still providing the local route at reasonable intervals for shorter trips.

3. **Simplify the relationship between BRT and local service as much as possible.** Despite the shortcomings described above, the Line 113 and MAX schedule and its combined 15 minute headways are very easy to understand. However, the complexity of this arrangement becomes apparent with the fare collection process. MAX fares are collected off-board at TVM’s, while Line 113 fares are deposited into an onboard farebox. Depending on the station and time of day, a different method of payment must be used, which is confusing to passengers and may dissuade them from riding altogether. There has also been an exceptionally high incidence of fare evasion on the MAX. As a result, RTC is working to simplify the fare collection process, and may remove TVM’s altogether in favor of the traditional onboard fareboxes.  

4. **Detailed operating performance data should be collected regularly and monitored to inform the service design process.** RTC does an exceptional job of monitoring its ridership statistics, but detailed data for several other important service indicators was not readily available. Average peak load factor data broken down by direction and either hourly or by time of day would be of particular interest to frequency and span decisions. Other helpful data might include average trip lengths broken down by route, and time of day, on-time performance by time of day, and route-specific customer surveys.
7.0 CASE STUDY # 4 – KANSAS CITY, MO (TROOST AVENUE)

7.1 Overview of Kansas City

Kansas City is a large Midwestern city located in the state of Missouri on the border with Kansas at the confluence of the Missouri and Kansas Rivers. The Kansas City metropolitan area spans parts of Jackson, Clay, Cass, and Platte Counties and is the largest city in the state of Missouri. The 2010 U.S. Census estimated the Kansas City population as 463,202 across a total land area of 315 square miles. These figures make it the largest city in the state of Missouri.\(^\text{173}\)

Downtown Kansas City span roughly three square miles near the city’s center and is bounded three major interstate highways – I-35 on the north and west, I-70 on the north and east, and I-670 on the south. The downtown area features higher densities and a greater mix of uses than are found in other parts of the city. Downtown Kansas City is particularly famous for its parks, fountains, upscale shopping, upscale shopping districts, and live jazz music.\(^\text{174}\) In a 2012 feature, Forbes magazine included Kansas City on a shortlist of “America’s Best DOWTowns”\(^\text{175}\).

Based on 2010 Census figures, Kansas City’s population is comprised of 45.1 percent minorities, but only 7.7 percent of its residents are foreign-born and only 11.9 percent speak a primary language other than English. Based on these statistics, Kansas City has more diversity than the national average but far fewer foreign-born persons. The median household income in Kansas City is $45,246 – or roughly $6,000 below the national average - and 18.2 percent of the population lives below the federal poverty threshold.\(^\text{176}\)

7.2 Troost Avenue Corridor

Troost Avenue is a minor north-south arterial street that runs along the eastern edge of downtown Kansas City. The street is parallel to Highway 71 from Admiral Street in the north to Bannister Road in the south. It is an undivided two–lane road with auxiliary turn lanes and sidewalks. The total length of Troost Avenue from downtown to South Kansas City is just over 10 miles.

The Troost Avenue Corridor consists mainly of low- and medium-density residential, industrial, and commercial development. There are a variety of mid-rise office buildings, K-12 schools, vocational colleges, churches, small businesses, manufacturing plants, shopping centers, and modest multi-family housing complexes, particularly near downtown Kansas City. Major trip generators along the corridor include the University of Missouri’s Kansas City Campus (UMKC), Rockhurst University, the Stowers Institute for Medical Research, Truman Medical Center, and a large field office for the U.S. General Services Administration (GSA). The rest of the Troost Avenue Corridor is lined with large residential tracts of single family homes on small half-acre lots. The overall population density of the census tracts within the corridor is 4,073 persons per square mile.\(^\text{177}\)

7.3 Public Transportation in Kansas City

The Kansas City Area Transportation Authority (KCATA) is the main transit agency for a 400 square mile service area that includes parts of seven different counties in both Missouri and Kansas. KCATA operate roughly 66 bus lines that serve over 5,700 stops throughout the region. The bus system boasts an average weekday ridership of 50,000 boardings and recorded 15.2 million boardings in 2012.\(^\text{178}\) The system also accounts for 62 million passenger miles and 16 million unlinked passenger trips each year.\(^\text{179}\) The Mid-America Regional Council (MARC) serves as the MPO for the Kansas City metropolitan area.\(^\text{180}\)
The KCATA Metro bus system includes two BRT-style, Metro Area Express (MAX) routes, 11 express lines, 48 local bus routes, and five Metroflex demand-response service routes. The most popular route in the system is the Main Street MAX, a BRT service that opened in 2005 to provide service along the busy Main Street Corridor between downtown Kansas City and the suburbs of Brookside and Waldo to the south. A second MAX route, the Troost MAX, was added in 2011. 181

One other major transit operator, Johnson County Transit, provides weekday commuter service across large portions of the Kansas City metropolitan region. “The JO”, as its more commonly known, runs three standard routes with all-day service, eight express routes with commute period service, and four demand-responsive “Flex” service lines. 182 JO routes record approximately 2,200 total trips on an average weekday. 183

7.4 Public Transportation in the Troost Avenue Corridor

The residential areas along Troost Avenue tend to include higher percentages of low-income households and are consequently more dependent on public transportation. As a result, Troost Avenue is the second busiest transit corridor in the Kansas City metropolitan area, behind only the Main Street Corridor. 184 As part of the Smart Moves Regional Transit Vision first developed by MARC in 2002, Troost Avenue was identified as one of nine regional corridors in Jackson and Cass Counties that are critical to the health of the regional transit system. The plan designates the northern half of Troost Avenue for “urban transit service” and calls for “major fixed route service” on the southern half. 185

Five major bus routes serve the Troost Avenue Corridor. Two of the routes are provided by Johnson County Transit (Lines 556 & 575) and three are operated by KCATA (Lines 25 & 108, Troost MAX). Line 556 operates north-south service every 30 minutes on a route between southwest Kansas City, Kansas and the University of Missouri at Kansas City. The route makes two stops on a short section of Troost Avenue near the UMKC campus– at Cleaver Street and 55th Street. Line 575 operates hourly, also originating across the state line in Kansas City, Kansas near 127th street before traveling north and east to its northern terminus at Troost Avenue and 75th Street. 186 Line 108 is a Metro route that operates mostly parallel to Troost Avenue on Indiana Avenue, but as it nears downtown Kansas City, it switches over to follow Troost Avenue from 18th Street to 11th Street near downtown. It runs primarily with 30 minute headways on weekdays and Saturdays, and 60 minute headways on Sundays. While Lines 108, 556 and 575 operate service along small segments of Troost Avenue, the majority of service along the full length of the Troost Avenue Corridor is provided by Line 25 and the Troost MAX.

Line 25

Local, all-stop service along the Troost Avenue Corridor is provided by Line 25. As shown on Figure 7-1, the route begins in downtown Kansas City, Missouri, travels several blocks east on 11th and 12th Streets, before turning south on Troost Avenue for roughly nine miles to its southern terminus at President Avenue/83rd Street. Line 25 is 9.5 miles in length and with over 100 stops in each direction it can stop on average once every 0.13 miles. The route operates seven days a week from 5:00 AM to 7:30 PM on weekdays and 5:30 AM to 7:00 PM on Saturdays and Sundays. Half-hour headways are run on weekdays and Saturdays, while trips are provided once every hour on Sunday. 187 A copy of the current Line 25 is included in Appendix E.
Figure 7-1 – Map of Line 25

Metro passengers riding Line 25 can also make free connections with several other important regional bus routes. The most important transfer points on Line 25 are located in downtown Kansas City at Oak and 11th Streets (City Hall), and at Grand Boulevard and 12th Street. These stops provide transfer points for over twenty other KCATA bus routes, including the Main Street MAX. Additional major transfer points for Line 25 on Troost Avenue include 22nd Street (Line 123), 27th Street (Line 27), Armour Boulevard (Lines 35 & 54), 39th Street (Line 39), 55th Street (Line 155), 63rd Street (Line 163) and 75th Street (Line 175). Passengers can also connect with the Troost MAX at designated Line 25 stops.188

Line 25 operates with standard 40-foot buses in the same lanes as regular traffic. Standard Metro fares of $1.50 are collected onboard.189

**Troost MAX**

Based on the success of its predecessor, the Main Street MAX, the Troost MAX was introduced in 2011 to provide enhanced, BRT-style service on one of the most popular corridors in the Kansas City metropolitan region. The Main Street MAX was opened in 2005 as the first project to use funds from the FTA's popular “Very Small Starts” funding program. It included fewer stops, faster service, and an improved passenger experience. The recently-opened Troost MAX embraced many of these elements and expanded them to the region’s second-most popular transit corridor.190 It features new BRT-style vehicles, enhanced waiting environments, fewer stops for quicker service, and at-station real-time information displays.191

The Troost MAX, or the “Green Line”, operates on a route similar to Line 25. As shown on Figure 7-2, the trunk portion of the MAX route begins in downtown Kansas City, follows Holmes and Charlotte Streets about eight blocks south before tracing Troost Avenue 7.5 miles south to 75th Street. The section north of 75th Street comprises the trunk portion of the Troost MAX route. Every third weekday trip and every other weekend trip extend south on Troost Avenue to Bannister Road before turning east for three miles to the intersection of Bannister Road and Drury Avenue in South Kansas City. The trunk portion of the route on Troost Avenue serves downtown, the Financial District, the Government District, the Crossroads District, Hospital Hill, Midtown, and the Bannister District. The major trip generators along the Troost Avenue Corridor are all served by the Troost MAX BRT service along with downtown attractions such as City Hall and the Sprint Center. In total, the Troost MAX covers 13.3 miles and makes about two dozen stops in each direction. The average stop distance of the Troost MAX is 0.57 miles.192

The Troost MAX operates seven days a week. On weekdays, the MAX runs from 4:30 AM to 1:00 AM, and on weekends, the service is available between 5:30 AM and 12:30 AM. Troost MAX service headways are 10 minutes during the morning peak, midday, and afternoon peak periods. Weekend Troost MAX service is operated once every 30 minutes.193 A copy of the current MAX schedule is included in Appendix E.

The Troost MAX uses special low-floor, two-door 40-foot hybrid vehicles manufactured by Gillig. They are uniquely branded so that passengers can differentiate MAX vehicles from other local routes. Fares are collected onboard, and the standard KCATA Metro fares apply. Transfers between Metro routes are free of charge.194
Figure 7-2 – Map of Troost MAX

7.5 Operational Analysis of Line 25 & Troost MAX

Due to its proximity to downtown and the demographics of its adjacent neighborhoods, Troost Avenue is one of the most productive transit corridors in the Kansas City metropolitan region. This section summarizes the current ridership, travel times, on-time performance, and operating costs of Line 25 and Troost MAX service. A detailed summary of the operational characteristics of Line 25 and the Troost MAX is included in Appendix A.

Ridership

Prior to the implementation of the MAX in 2011, Metro bus service along Troost Avenue was provided almost exclusively by Line 25, which recorded 1.95 million weekday boardings in 2010. In 2012, the two routes combined to draw 1.99 million weekday boardings, an increase of roughly 2.6 percent. For a corridor that is likely still adjusting to the recent introduction of MAX service, this growth is a positive indicator for its overall health and productivity.195

Of the nearly two million boardings in the corridor in 2012, the Troost MAX accounted for over 1.5 million, or 75 percent of weekday ridership in the corridor. This discrepancy is likely due to the fact that the MAX runs three times as often as Line 25 and offers extended evening service hours. When normalized by service hours, the gap is less pronounced. On an average weekday, Line 25 boards 42 passengers per service hour. The Troost MAX averages 48 boardings per revenue hour. On a typical weekend, Line 25 and the Troost MAX draw 2,250 and 3,776 boardings, respectively.196

Load Factor Data

Peak load factor data for Line 25 and the Troost MAX further demonstrate the high productivity of the Troost Avenue Corridor. The most recent overall average weekday peak load factors for Line 25 and the Troost MAX are 0.72 and 1.21, respectively. Based on the seated vehicles capacities of 40 on Line 25 and 37 on the Troost MAX, these figures translate into average peak loads of 29 and 44 passengers. The biggest loads are found on the southbound Troost MAX during the afternoon peak period (1.59), but the service record astonishingly strong average peak load factors of roughly 1.40 throughout the morning rush hours, midday and evening periods.197 If accurate, these numbers reflect extremely strong ridership trends and suggest that significant overcrowding may be occurring throughout the day on the Troost MAX.

Travel Time

Line 25 and the Troost MAX travel along a similar routing as they head south from downtown Kansas City through the Troost Avenue Corridor. While selected MAX trips extend further south and east, the trunk portions of the two routes can be compared to determine travel time savings. During periods of light traffic in the early morning hours, Line 25 and the Troost MAX can travel the trunk portion of the route in 34 minutes and 30 minutes, respectively. During the morning peak hours, the two services require about 42 minutes and 35 minutes to cover the same distance. In the midday and afternoon peak periods, Line 25 and the MAX take 44 minutes and 40 minutes, respectively. These figures represent approximate time savings of 9 to 17 percent for Troost MAX passengers.198
**On-Time Performance**

Due to the relative predictability of travel times in the Troost Avenue Corridor, the two lines demonstrate strong on-time performance. The Line 25 local service arrives within five minutes of the schedule times approximately 91 percent of the time. Similarly, the Troost MAX arrives on time just over 90 percent of the time. KCATA does not track on-time performance statistics by time or type of day, so a more detailed breakdown of service reliability was not available.199

**Service Costs**

The initial construction and implementation phases for Troost MAX service required approximately $30.2 million in capital funds. The costs of operation for Line 25 and the Troost MAX are both estimated as $55.49 per revenue hour. In 2011, KCATA reported systemwide average operating costs of $1.21 per passenger mile and $4.42 per unlinked trip.200

MAX service has been lauded for its use of green features and technology. The Troost MAX vehicles all utilize hybrid diesel-electric propulsion, and operate using only battery power at speeds below 25 miles per hour. This type of vehicle significantly reduces nitrous oxide emissions and exhibits fuel efficiency that is 10 to 20 percent better than typical diesel buses. Additional green station features such as solar-powered lighting and rain gardens, further reduce energy costs and environmental impact.201

### 7.6 Comparative Frequency Analysis of Line 25 & Troost MAX

Since the introduction of MAX service on Troost Avenue in 2011, passengers along the corridor have enjoyed weekday service frequencies of at least one bus every 10 minutes. The Troost MAX was designed to imitate the service design of the Main Street MAX, which was required to maintain ten minute headways or better to conform to FTA “Very Small Starts” funding requirements.202

In order to maintain service levels for local trips in the corridor as well as areas that are not within walking distance of a Troost MAX stop, the local, all-stop route, Line 25, was maintained with 30 minute weekday headways. The headways are typically not offset so the local bus that runs every half hour operates every 30 minutes is immediately followed by one of the rapid buses that run every 10 minutes. This section evaluates the degree to which the current service frequencies on Line 25 and the Troost MAX are providing productive, balanced service. A summary of the analysis is included as Table 7-1.

**Headway Ratios**

As noted in the previous sections, Line 25 and the Troost MAX primarily operate with weekday headways of 30 minutes and 10 minutes, respectively. This configuration – which equates to a 3.0 headway ratio – is evident during the morning peak, midday, and afternoon peak periods. Since local service does not operate later than 7:00 PM, no evening headway ratio is available. On Saturdays, both Line 25 and the Troost MAX operate with 30 minute headways. Sunday Troost MAX service operates with 30 minute headways while Line 25 local trips arrive hourly.

**Ridership**

The previous operational analyses demonstrated that the corridor has obtained modest ridership gains since 2010 – when Line 25 was the only available route. The new configuration uses shorter headways...
and longer spans to emphasize the Troost MAX as the preferred, baseline service. Accordingly, the 2012 annual ridership statistics showed that over three quarters of the total corridor boardings are attributed to the MAX service. Weekday hourly ridership is slightly more comparable, but the Troost MAX still tips the balance with 14 percent more boardings per service hour.

Despite this imbalance, a comparison of weekday ridership by time of day on each of the two services actually finds that the rapid MAX service is underemphasized by the current headways. During the morning rush hours, the ridership ratio of the Troost MAX to Line 25 is 3.38 as compared with the headway ratio of 3.0. The ridership ratios during the midday and afternoon peak periods are 3.48 and 3.23, respectively. The difference in these ratios indicates that a small increase in frequency of the Troost MAX may be warranted.

Although weekend ridership data by time of day is not available, the daily ridership statistics also suggest that shorter MAX frequencies would be beneficial. Line 25 and the Troost MAX account for 42 percent and 58 percent of Saturday boardings, respectively, but they both operate with 30 minute headways. Similarly, the Troost MAX registers 2.4 times as many Sunday boardings as Line 25 local service, but only runs twice as frequently. In both of these instances, the daily ridership figures suggest that the MAX frequencies should be improved to better accommodate current ridership demand.

### Table 7-1 – Troost Avenue Corridor Frequency Analysis Summary

<table>
<thead>
<tr>
<th>WEEKDAY TIME PERIODS</th>
<th>Average Headways (Minutes)</th>
<th>Average Boardings</th>
<th>Average Peak Load Factor</th>
<th>Average Travel Time (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM PEAK (6 - 9 AM)</td>
<td>30</td>
<td>10</td>
<td>3.00</td>
<td>335</td>
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<td>MIDDAY (9 AM - 4 PM)</td>
<td>30</td>
<td>10</td>
<td>3.00</td>
<td>1,008</td>
</tr>
<tr>
<td>PM PEAK (4 - 7 PM)</td>
<td>30</td>
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<td>3.00</td>
<td>388</td>
</tr>
<tr>
<td>EVENING (7 - 10 PM)</td>
<td>-</td>
<td>30</td>
<td>-</td>
<td>512</td>
</tr>
</tbody>
</table>

*Primary Source: Stout, Randy. Transit Planner, KCATA, Email message to author, 22 March 2013.*

**Peak Load Factors**

As detailed in the operational analysis, the peak load factor data for Line 25 and the Troost MAX reveals that the MAX service is bearing a staggeringly disproportionate amount of the corridor ridership. Based on the latest average peak load factor data, the two routes are averaging weekday peak load factors of 0.72 and 1.21, respectively. When classified by time of day, Line 25 and the Troost MAX demonstrate respective peak load factors of 0.73 and 1.40 during the morning peak hours, 0.88 and 1.37 during
middays, and 0.92 and 1.59 during the afternoon peak period. Typically, Metro staff uses a maximum average load standard of 1.30 to determine when additional service is needed.\textsuperscript{203} Therefore, if accurate, these substantial imbalances present immediate cause for concern that the current 10-minute Troost MAX headways are entirely insufficient. However, since this data represents only a single month and could be skewed by any number of factors, a more significant sample size should be reviewed to determine if the apparent overcrowding on the Troost MAX does, in fact, warrant major headway improvements.

\textit{Other Indicators}

One other indicator of overall corridor health is average passenger trip lengths. In the Troost Avenue Corridor, there is a distinct differentiation of trip types. The average trip length for Line 25 passengers is 1.4 miles. The Troost MAX average passenger trip length is over twice as long at 3.6 miles.\textsuperscript{204} These figures are particularly relevant in light of the corridor’s travel patterns. Since there are relatively few major trip generators along Troost Avenue and the most popular areas are relatively far apart, the vast majority of trips made in the corridor are throughput trips.\textsuperscript{205} This observation is supported by the average stop spacing ratios of the two routes, which at four local stops for each BRT station, are among the highest of the five case studies.\textsuperscript{206} Since these longer trips are more efficiently served by the Troost MAX, it may make sense to provide shorter headways on the MAX service to better accommodate the large amounts of throughput passengers.

\textbf{7.7 Span Analysis for Line 25 & Troost MAX}

Based on their success with the Main Street MAX, KCATA transit planners sought to replicate its service dimensions for the design of the Troost MAX. This included the hours of operation, which are nearly identical for both MAX services. Both the Main Street MAX and the Troost MAX operate from roughly 4:30 AM to 1:00 AM on weekdays, and from around 5:30 AM to 12:30 AM on weekends. Conversely, the introduction of the Troost MAX in 2010 resulted in a reduction to the span of service for Line 25, which now only operates from 5:00 AM to 7:30 PM on weekdays, 5:30 AM to 7:00 PM on Saturdays, and 6:00 AM to 7:00 PM on Sundays.\textsuperscript{207}

An evaluation of weekday ridership and load factor data suggests that the current service spans are mostly adequate but that minor modifications could be implemented. For Line 25, the first hour of weekday service in the early morning and the last hour service in the evening demonstrate average loads of 10 and 7 passengers, respectively. The first and last hours of weekday Troost MAX service carry average loads of 9 and 5 passengers, respectively.\textsuperscript{208} These relatively low loads imply that the spans of both routes could potentially be shortened by a small amount. Since the Troost Avenue Corridor lacks the densities and mix of uses that are found in the Main Street Corridor and features more low-density residential areas, it follows that a slightly shorter span than that of the Main Street MAX might be appropriate.

Weekend spans on both routes may also warrant some reconsideration. Based on 2012 ridership figures, Saturday Line 25 and Troost MAX service average 1,609 and 2,238 average daily boardings. On Sundays, the two routes draw 641 and 1,538 average daily boardings.\textsuperscript{209} More detailed weekend ridership data broken down hourly or by time of day is not currently available, but the relatively low Sunday ridership totals are somewhat concerning. Further review of service hours on early Sunday morning on both routes and late Sunday night on the Troost MAX may be beneficial.
7.8 Troost Avenue Corridor Findings & Lessons Learned

The Troost Avenue Corridor is one of the most productive transit corridors in the Kansas City metropolitan area. With the addition of the BRT-style Troost MAX in 2011, the type and amount of service provided in the corridor have changed dramatically, but the ridership has continued to grow. Moreover, the high peak load factors are indicative of the solid ridership base that exists in the traditionally low-income and transit-dependent Troost Avenue Corridor.

As currently designed, the Troost MAX runs three times as frequently as its local counterpart. However, a comparison of ridership by time of day, boardings per service hour, average peak load factors, and average passenger trip lengths suggest that the Troost MAX headways could actually be run slightly more frequently, if the resources became available. By operating 8-9 minute weekday MAX headways instead of the current 10 minute headways, a more appropriate balance between the two routes could be realized and improved service for the longer trips that tend to define the travel patterns in the Troost Avenue Corridor could be provided. Similar findings were identified for weekend service frequencies, which implied that increased MAX frequencies could be beneficial.

The analysis of service spans in the Troost Avenue Corridor found that minor adjustments to the current spans could be made. Namely, early morning weekday service on both routes and late evening service on the Troost MAX should be closely reviewed to evaluate their necessity. Likewise, the early morning and late evening Sunday service may not be warranted based on current demand. Unlike the Main Street Corridor which it attempts to emulate, the Troost Avenue Corridor may not have sufficient densities or mix of uses to support the same extended hours of operation.

In addition to these service design findings and recommendations, the following lessons can be taken from the Troost Avenue Corridor case study:

1. **Stick with what works, whenever possible, but be aware of unique circumstances that may exist.** Comparable nearby BRT routes can provide rare insight and serve as a model for similar rapid services that follow. The service design of the Troost MAX was largely based upon its predecessor, the Main Street MAX BRT service. The two routes currently operate with similar vehicles, comparable stop spacing, and identical frequencies and spans. The service dimensions of the Troost MAX have proven to be mostly effective, but the distinctly different travel and land use patterns on Troost Avenue may require some additional customization of the frequencies and spans.

2. **Agencies must deploy labor and vehicular resources as equitably and efficiently as possible.** An interview with KCATA agency staff revealed that adequate demand exists for improving combined headways for the two Troost Avenue Corridor routes. Despite this observation, staff concluded that the marginal ridership gains that would result from such an improvement would not be worth it. Instead, the labor and vehicle hours could be implemented with more productivity in other heavily-traveled corridors with additional latent ridership potential.

3. **BRT can work as baseline service with shorter frequencies and longer spans than the local route.** Unlike most corridors with concurrent BRT and local service, the Troost Avenue Corridor relies upon the rapid Troost MAX service to provide baseline service during evenings and weekends. This is the opposite of most shared corridors, which provide extended evening and weekend service with the local service to ensure maximum service coverage. This unusual configuration is
likely due to the low operating costs of BRT and local services in Kansas City, which allow extended BRT service at a reduced hourly expense. A review of annual ridership, diurnal ridership, peak load factor data and average trip lengths further demonstrates the necessity and productivity of this unique configuration.

4. **Additional Considerations may also factor heavily in service design decisions.** As a recipient of FTA funding under the “Very Small Starts” program, MAX service is required to operate with 10 minute headways or better. Since federal funding is vital to the operation of the service, any finding that headways should be reduced would be an unrealistic recommendation.211
8.0 CASE STUDY # 5 – SALT LAKE CITY, UT (3500 STREET)

8.1 Overview of Salt Lake City

Salt Lake City is the capital of the state of Utah, and is located in the northern part of the state on the southeast edge of the Great Salt Lake. With just under 190,000 residents and a total land area of 111 square miles, Salt Lake City is the largest city in Utah. The city is located at the intersection of Interstates 15 and 80, and is surrounded on the north and east by the Wasatch Mountains.

Salt Lake City is laid out in a strict grid pattern with higher densities concentrated in the corridors adjacent to Interstates 15, 80 and 215. The downtown area comprises a small cluster of high-rise buildings just east of the junction of Interstates 15 and 80. It includes the state capitol, multiple state, county, and city government offices, and several corporate headquarters. Although the regional economy has historically been characterized by steel, mining, and railroad operations, modern Salt Lake City primary industries include commerce, utilities, transportation, energy, health services, technology and education. The city is also home to the Church of Jesus Christ of Latter-day Saints and is strongly influenced by Mormon religious customs and traditions.

Compared to other similar cities and the nation as a whole, Salt Lake City has relatively low diversity and higher percentages of low income residents. Roughly 34.3 percent of Salt Lake City residents identify themselves as racial or ethnic minorities, down from the national average of 36.6 percent. The percent of foreign-born persons and persons that speak a language other than English at home are 17.8 percent and 27.2 percent, respectively. The median household income for Salt Lake City is $44,501 and 17.9 percent of the population lives below the federal poverty line. By comparison, the national median household income is $52,762 and 14.3 percent of Americans live in poverty.

8.2 3500 South Corridor

3500 South is a major east-west arterial street located about five miles southeast of downtown Salt Lake City. The road runs through the heart of West Valley City, from the Magna district to just east of Interstate 215, and measures almost nine miles from end to end. One mile east of Interstate 215, the road briefly turns northeast and becomes 3300 South.

The lane configurations on 3500 South vary across its length. The western half of the corridor – the four miles between Magna and 5700 West – features one lane in each direction, a bi-directional center turn lane, auxiliary right turn lanes, wide setbacks, and very few traffic signals. The corridor’s eastern sections are much wider, ranging from four to six lanes in width with auxiliary turn lanes, sidewalks, and two miles of dedicated center bus lanes.

The 3500 South Corridor can be divided into several distinct sections. The westernmost segment consists primarily of low-density residential neighborhoods, churches, schools, and the occasional shopping center. East of 4800 West, the frontage along 3500 South changes dramatically to almost exclusively commercial uses including several large shopping malls, professional offices, hotels, the Pioneer Valley Hospital, and the Maverik Center, a 12,000-seat sports arena. The overall population density of the census tracts within the corridor is 4,230 persons per square mile.
8.3 Public Transportation in Salt Lake City

Public transportation in Salt Lake City and the entire Wasatch Front region is operated by the Utah Transit Authority (UTA). Providing bus and rail service across 1,600 square miles in seven counties with 1.8 million residents, UTA routes cover one of the largest service areas in the country. Services provided by UTA include light rail, commuter rail, fixed-route bus lines, and paratransit.218 In 2012, the UTA system recorded over 42.8 million boardings.219

UTA rail services include three TRAX light rail lines and the FrontRunner commuter rail service. The 35.3-mile, 41-station TRAX system features the red, blue, and green routes, which run along outlying suburbs to the east, west, and south of downtown before converging in the central business district. Operating seven days a week between 5:30 AM and 11:30 PM, the three TRAX lines registered over 13 million boardings in 2010.220 FrontRunner commuter rail service was introduced in 2008 on a 44-mile north-south alignment between Salt Lake, Davis and Weber Counties. The service operates on weekdays and Saturdays and will extend south to Provo in the future.221

UTA also offers 66 standard fixed-route bus lines, one BRT route, and 15 demand-responsive paratransit routes. The buses provide daily and season service to parts of six different counties. In 2010, the UTA bus system accounted for 22 million trips on 650 vehicles. The BRT 35 MAX route was introduced in 2008 in the southeastern part of the Salt Lake City metropolitan area.222

8.4 Public Transportation in the 3500 South Corridor

The 3500 South Corridor includes large percentages of low-income, transit-dependent populations.223 It is served by two major UTA bus routes and several important regional light rail connections. All three TRAX light rail lines include stops at or near the 3500 South Corridor. The West Valley Central TRAX Station is located immediately adjacent to the intersection of 3500 South and 2700 West. This station is the southern terminus of the TRAX Green Line, which runs from West Valley City northeast to downtown Salt Lake City and west to Salt Lake City International Airport. The other major regional transit hub, the Millcreek TRAX Station, is at the east end of the 3500 South Corridor where it transitions into 3300 South. The Millcreek TRAX Station is served by both the Red and Blue Lines, which both operate between downtown, South Salt Lake, South Jordan, and Sandy. Connections to the FrontRunner Commuter Rail service may also be made via the Red and Blue TRAX Lines.224 The majority of trips in the corridor are made eastbound towards the Millcreek TRAX Station in the morning and westbound away from the station in the afternoon.225

Within the 3500 South Corridor, UTA also provides local bus service with Line 35 and BRT-style service with the 35-M or “MAX”. A small section of the corridor is also served by Line 240.

Line 35

Local east-west bus service on 3500 South is provided by Line 35. The trunk route begins on 3500 South at 8400 West and serves all stops along the corridor, including minor deviations at the West Valley TRAX Station and Carlisle Street. The route’s eastern terminus is the Millcreek TRAX Station, and its total length is 11.8 miles. The route includes 57 stops in each direction for an average stop spacing distance of 0.21 miles. At the western end of the corridor, the route also provides limited, one-way service on a loop through Magna. On weekdays, this loop is served by eastbound trips before 2:00 PM and westbound trips from that time to the end of the day.226 A map of Line 35 is included as Figure 8-1.
Line 35 service is provided with 30 minute headways on weekdays and 60 minute headways on Saturdays and Sundays. Local service is offered on weekdays from approximately 5:00 AM to 10:00 PM. Line 35 Saturday service operates between 6:00 AM and 8:30 PM, and on Sundays it is available from 9:00 AM to 8:00 PM. A copy of the map and schedule for Line 35 is included in Appendix F.

Line 35 runs with standard 40-foot buses in mixed traffic lanes. The standard one-way pass fare of $2.50 applies to Line 35 and includes free transfers. Line 35 passengers can connect to the TRAX light rail routes at the West Valley City and Millcreek Stations. These stations also serve as major bus hubs with connections to Lines 33, 41, 227, 232, 240, 248, 509, and 513. Additional bus connections can be made with Lines 39, 217 and 218 at cross streets throughout the corridor. Most of the corridor’s main attractions – including Pioneer Valley Hospital, Valley Fair Mail, and the Maverick Center – can be reached via Line 35.

**Line 35-M**

In response to the traditionally strong ridership performance of Line 35, UTA introduced Line 35-M – the “MAX” – as a regional pilot project in 2008. The enhanced BRT service utilizes specially-branded, low-floor, three-door Van Hool A300 buses and travels in a dedicated median bus-only lane for a two-mile
section between 3600 West and Redwood Road, and in mixed traffic lanes through the rest of the corridor. In addition to the dedicated bus lanes, the MAX also makes fewer than half as many stops as Line 35 and operates on a headway-based schedule to reduce overall travel times. The MAX also features enhanced stations, traffic signal prioritization and collision avoidance technology.\textsuperscript{230}

The MAX follows a nearly identical routing as Line 35 from Magna to the Millcreek TRAX Station via 3500 South. Like Line 35, the MAX provides limited, one-way local service to a loop through Magna at its western end, but these stops are only served by eastbound trips before 2:00 PM and westbound trips thereafter. With 14 eastbound stops and 15 westbound stops across its 10.8-mile length, the average stop spacing distance for the MAX is 0.74 miles.\textsuperscript{231} A map of the Line 35-M route is included as Figure 8-2.

On weekdays and Saturdays, the MAX operates headway-based service with shorter frequencies and longer spans than the local Line 35 service. Weekday and Saturday MAX service is provided every 15 minutes from 5:30 AM to 12:30 AM with trips departing every 15 minutes. The MAX currently does not operate on Sundays.\textsuperscript{232} A copy of the MAX map and schedule is included in Appendix F.

Another characteristic of the MAX that ensures rapid service is its off-board fare collection system that relies on proof of payment. Although the standard UTA bus fares apply, fares for the MAX are paid at TVM machines on the station platforms. Along with the three-door vehicles this speeds up the boarding process and reduces overall dwell times.\textsuperscript{233} MAX transfers are free of charge and the same connections and attractions in the 3500 South Corridor that were previously listed for Line 35 may also be reached via the MAX.\textsuperscript{234}

8.5 Operational Analysis of Lines 35 & 35-M

As discussed above, the 3500 South Corridor was selected as the Salt Lake City’s first BRT corridor based on its increased transit dependency, relatively high productivity, and consistently strong operational performance.\(^{235}\) This section summarizes the current ridership, travel times, on-time performance, and operating costs of Line 35 and 35-M/MAX service. A detailed summary of the operational characteristics of Lines 35 and 35-M is provided in Appendix A.

Ridership

Before 2008, Line 35 had long served as the primary east-west bus service in the 3500 South Corridor. While the corridor was already one of the most successful in the region, ridership began to increase dramatically with the introduction of MAX service. In the year prior to the opening of the MAX in September 2008, the corridor averaged just 3,585 average weekday boardings. With concurrent BRT and local service, that figure rose steadily to 4,035 in 2009, 4,326 in 2010 and 4,415 in 2011 before dipping slightly in 2012. Total 3500 South Corridor average weekday ridership in 2012 was up almost 19 percent from pre-MAX levels and over 5 percent higher than the average weekday boardings in 2009. This compares somewhat favorably with total UTA bus system ridership, which has only increased 2.3 percent since 2007 and dropped 2.5 percent since 2009. Despite these trends, the growth in corridor ridership has been somewhat underwhelming given the level of investment that has been made. The lack of increase in discretionary riders – or those that have other options besides transit – has been particularly disappointing.\(^{236}\)

Although the overall corridor has demonstrated steady, slow ridership growth over the last few years, the weekday ridership splits have become more and more skewed towards MAX service. As a result, average weekday ridership on Line 35 has gradually decreased by over 20 percent from 1,259 weekday boardings in 2008 to 1,001 average weekday boardings in 2012. Conversely, weekday ridership on the MAX service has grown by 10 percent during the same four-year period, from 2,966 average boardings in 2008 to 3,253 average weekday boardings in 2012. Saturday ridership on Line 35 is down 21 percent since 2009, while the MAX has increased by 1.4 percent over the same period. Line 35 Sunday service has increased by 11 percent since 2009.\(^{237}\) Thus, while overall ridership productivity seems to be demonstrating modest positive growth trends, Line 35 ridership is decreasing on both weekdays and Saturdays.

Load Factor Data

The average weekday load sizes for Line 35 and the MAX are 11.4 and 15.5 passengers, respectively. Based on the 38 available seats on the local vehicles and the 34 available seats on the BRT vehicle, these translate to average load factors of 0.30 and 0.46. Not surprisingly, the highest weekday loads are recorded during the afternoon peak hours, with 0.37 on Line 35 and 0.58 on the MAX. The average loads for Line 35 are particularly low during the morning peak and evening periods. On Saturdays, the average load factors are 0.29 for Line 35 and 0.42 for the MAX. Sunday load data indicates that Line 35 has an average load factor of 0.50.\(^{238}\) It should be noted that these figures represent the average loads at not the average peak loads, so they will likely be lower than expected. While there seem to be no risks for overcrowding, the Line 35 load factors are lower than might be expected.
Travel Time

Line 35 and the MAX service both share a nearly identical routing on 3500 South between Magna and the Millcreek TRAX Station. Without traffic, the trunk portion of the route can be covered by both routes in 34-38 minutes. However, as a result of its fewer stops, dedicated lanes, traffic signal prioritization, special low-floor, multi-door vehicles, and off-board fare collection, the MAX is able to navigate the corridor from one end to the other more quickly than its local counterpart. The MAX time savings are particularly evident during the midday, afternoon peak, and evening periods during which the MAX is able to cover the length in the 3500 South Corridor 13-14 percent more quickly than Line 35.239

On-Time Performance

The on-time performance data for these two routes demonstrates the high service reliability that can be achieved with frequent, headway-based service. Based on an “on-time” standard of within five minutes of the scheduled arrival time, roughly 87 percent of Line 35 local weekday trips are on time. Conversely, the MAX weekday service is on time almost 94 percent of the time. On weekends, the two routes average on-time performance percentages of 75 percent and 94 percent, respectively. On Saturdays, the reliability of Line 35 drops considerably during the midday and late afternoon periods, when only 70 percent and 59 percent of the trips are on-time, respectively.240 The strong service reliability performance of the MAX is likely due to its headway-based service, which does not require drive to adhere to a strict schedule and allows them to skip stops if no passenger boardings or alightings are requested.

Service Costs

The capital cost for the initial MAX implementation in 2008 was roughly $7 million.241 UTA operating expense data indicates that both Line 35 and the MAX service cost approximately $34.29 per hour to operate. Unlike several other agencies, UTA includes non-revenue hours in this calculation, which means that the average cost is lower than it would be if it were based solely on revenue hours.242 Based on NTD data, UTA reports systemwide average bus operating costs of $124.46 per revenue hour, $0.87 per passenger mile, and $5.00 per unlinked passenger trip.243 These expenses are comparable to or less than all of the other agencies cited in this report.

Limited environmental cost data is available for Line 35 and the MAX. The current vehicles feature diesel propulsion, but staff will likely recommend eco-friendly buses for the next fleet update in 3-5 years.244,245

8.6 Comparative Frequency Analysis of Lines 35 & 35-M

The original intent of the Line 35-M, MAX service was to provide rapid, high-frequency bus service which would serve as the backbone of service within the 3500 South Corridor. The MAX stops were selected based on automated passenger count (APC) data from Line 35 and other spacing considerations. In theory, this service design would permit 80 percent of trips in the corridor to be made between MAX stations, while Line 35 could provide added coverage for the less busy stations in between.246

In the years leading up to MAX implementation, Line 35 operated with 20 and briefly 15 minute headways. This bolstered corridor ridership and provided for a smooth transition to MAX BRT service.247 As described in previous sections, the MAX is mostly run on 15 minute intervals, while Line 35 operates every half-hour to meet the needs of the transit-dependent 3500 South Corridor. The headways are offset so that the local bus arrives in between the first and second and third and fourth MAX trips each hour. These
frequencies are coordinated to match up with light rail trains at the Millcreek TRAX Station. This section evaluates the degree to which the current service frequencies on Line 35 and the MAX are providing productive, balanced service in the 3500 South Corridor. A summary of the data is provided on Table 8-1.

**Headway Ratios**

As described above, Line 35 and the MAX operate with 30 and 15 minute weekday headways, respectively. These frequencies, which equate to a headway ratio of 2.0, remain constant throughout the day during both peak and off-peak hours. This same headway ratio is maintained on Saturdays, but MAX does not run on Sundays and Line 35 operates only once every hour.

**Ridership**

The corridor has achieved modest overall gains in ridership over the last few years, but has not yet lived up to expectations. The balance between the two routes has also become increasingly towards MAX service since 2009. In 2012, Line 25 accounted for less than 24 percent of average weekday boardings within the corridor. Thus, although the introduction of MAX service has resulted in marginal ridership increases, the lack of substantive growth and apparent imbalance may be cause for general concern.

**Table 8-1 – 3500 South Corridor Frequency Analysis Summary**

<table>
<thead>
<tr>
<th>WEEKDAY TIME PERIODS</th>
<th>Average Headways (Minutes)</th>
<th>Average Boardings</th>
<th>Average Load Factor</th>
<th>Average Travel Time (Minutes)</th>
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<td>30</td>
<td>1.00</td>
<td>58</td>
</tr>
</tbody>
</table>

*Primary Source: Jamison, Johanna. Grants Specialist. UTA. Email message to author, 22 April 2013.*

The schedule configuration between the routes with respective 30 and 15 minute headways is maintained throughout the day. This creates a relatively clean, easy-to-understand schedule, but does not fluctuate to the changes in ridership demand that occur throughout the course of the day. For purposes of simplicity, this is an acceptable trade-off, but a ridership comparison by time of day indicates that it may not be adequately meeting the needs of the corridor. For example, during the morning and midday periods, the MAX-to-Line 35 ridership ratios are 2.87 and 2.84, respectively, while the headway ratio is
2.0. During the afternoon peak and evening hours, the ridership ratios are 3.59 and 5.57, respectively. The figures indicate that the relative demand for MAX service exceeds the current frequency levels, particularly during afternoons and evenings. The boardings per revenue hour data for weekdays – 21.2 for Line 35 and 35.6 for the MAX – provide further evidence of this finding.\textsuperscript{250}

To a lesser extent, the dominance of MAX service continues on Saturdays when the same 30 and 15 minute headways are utilized. Lines 35 and the MAX average 23.5 and 32.3 Saturday boardings per revenue hour. The raw ridership data is less convincing, however, as it finds that the total Saturday ridership on the two routes equate to a ridership ratio of 1.48. This is markedly less than the Saturday headway ratio of 2.0 and is even more puzzling in light of the fact that the MAX operates for roughly 4.5 hours longer than Line 35. Fortunately, the load data comparisons provide some additional clarification on the Saturday service balance. As noted in previous sections, the MAX does not operate on Sundays and therefore no headway comparison can be made.

\textit{Load Factor Data}

As noted in the operational analysis, problems of overcrowding on this corridor are virtually nonexistent and therefore UTA tends to rely more heavily on average load factor data instead of peak load factor data. A comparison of average load data on Line 35 and the MAX seems to indicate that the headway configurations are mostly appropriate, but a minor improvement in MAX headways on weekdays and Saturdays could be beneficial.

Overall average weekday load factors for Line 35 and the MAX are 0.30 and 0.42, respectively. MAX loads are 26 to 41 percent greater than Line 35 loads throughout the day. Some of the largest discrepancies are found during the peak hour periods: the two routes maintain average load factors of 0.25 and 0.40 during the morning peak period, and 0.37 and 0.58 during afternoon rush hours. The evening period also demonstrates the greater MAX loads with load factors of 0.25 and 0.43 for the two services. On Saturdays, the load factors on Line 35 and the MAX are 0.29 and 0.42, respectively.\textsuperscript{251}

Although these load factor comparisons seem to support the idea of increased MAX frequencies on weekdays and Saturdays, it is important to note that they are based upon seated vehicle capacities and do not factor in standees. Since MAX vehicles can accommodate about a dozen more standees than Line 25 buses, the load values as a percentage of total vehicle capacity may actually be slightly closer than these numbers would suggest. Regardless, the MAX service with 15 minute headways is still carrying larger absolute loads and would likely benefit from slightly shorter intervals.

\textit{Other Indicators}

Additional indicators for the adequacy of current Line 35 and MAX headways include stop spacing, average passenger trip lengths and passenger survey data. The average stop spacing on the two routes – 0.74 miles and 0.21 miles, respectively – is comparable to the four other case studies and does not suggest that the relationship between the BRT and local service need to be shifted in one direction or the other. The average passenger trip lengths on the two routes, however, are remarkably close to each other. The average passenger trip lengths on Line 35 and the MAX are 5.3 miles and 5.4 miles, respectively.\textsuperscript{252} Essentially, this means that there is very little trip differentiation between the two routes and most passengers will just take the next available bus instead of waiting for either the local or rapid service. If a passenger is traveling a long distance and a local bus arrives first, the potential MAX time savings likely do not exceed the additional seven minutes or more of waiting time the MAX would require. This could
change, however, with shorter MAX headways or improved time savings. Lastly, the customer service data indicates that MAX passengers have lower incomes and are more transit dependent than most other UTA riders. This supports the previous observation that the MAX has been unable to capture the coveted discretionary ridership that it was designed to attract. Therefore, these indicators suggest that the current headway configurations could be improved from a service provision and ridership productivity standpoint with a minor 3-5 minute increase in MAX service frequencies on weekdays and Saturdays.

8.7 Span Analysis for Lines 35 & 35-M

Ridership and load factor data seems to demonstrate that the majority of transit demand on the 3500 South Corridor – and perhaps Salt Lake City as a whole – occurs during the weekday and Saturday daytime hours. Since the corridor includes large low-density residential areas and has relatively few late night activity centers, this finding is not surprising. The dramatic drop off in demand on Sundays – likely due to the area’s large Mormon population – is also a unique characteristic that affects service planning considerations. As a result of these factors, the current spans of service for Line 35 are 5:00 AM to 10:00 PM on weekdays, 6:00 AM to 8:30 PM on Saturdays, and 9:00 AM to 8:00 PM on Sundays. The MAX operates a longer span on weekdays and Saturday – between 5:30 AM and 12:30 AM – but does not run on Sundays.

These hours of operation appear to be adequate based on ridership and load factor data. On weekdays, the average load factors for Line 35 and the MAX during the early morning period are 0.30 and 0.37, respectively. The evening average load factors are 0.25 and 0.43, respectively. However, a review of the first and last weekday trips shows that ridership does begin to drop off, particularly for the early morning westbound trips and late evening eastbound trips. Based on these statistics, the only potential span change would be minor reductions to Line 35 service during these directions and times.

On Saturdays, demand for early morning and late night service appears relatively low. Many of the trips prior to 9:00 AM and after 8:00 PM average less than 10 boardings. In terms of operational efficiency, these resources might be better deployed elsewhere, but additional analysis would likely be required, especially before reducing Saturday evening service. For Sunday, Line 35 exhibits strong boarding statistics throughout the day, including its first and last hours of service. Despite the reduced demand for transit on Sundays, the reliance on Line 35 as the only Sunday service appears to work well. If anything, the ridership on the first and last trips suggest that the hours could potentially be extended to 8:00 AM to 9:00 PM.

8.8 3500 South Corridor Findings & Lessons Learned

As one of the most productive transit corridors in the Salt Lake City region, the 3500 South Corridor was tabbed as the area’s first BRT corridors in 2008. Since then, the concurrent Line 35 and MAX services have demonstrated a slow increase in overall ridership, but have fallen short of expectations, particularly amongst discretionary riders. The ridership splits and average load comparisons between Line 35 and the MAX have also become increasingly skewed towards the MAX over the last few years. These findings suggest that there may be room for improvement in the service design of the two routes.

Based on ridership splits, load data, and the other indicators described above, a minor increase in weekday and Saturday MAX frequencies could prove beneficial. MAX headways of 10 or 12 minutes would more adequately serve current ridership demand patterns and provide a clearer distinction
between BRT and local service. Based on cost and logistical considerations, however, this improvement may not be feasible.

For the most part, the weekday spans seems to be appropriate, but the weekend service hours might benefit from some minor modifications. Hourly ridership and load factor data for the MAX on weekdays and Saturday indicate that early morning westbound and late evening eastbound local trips demonstrate the lowest productivity and could be reduced. However, on Sundays, when Line 35 runs but the MAX does not, the local service span could be extended by an hour in the early morning to 8:00 AM and late evening to 9:00 PM to meet current ridership demands.

In addition to the above findings and recommendations regarding current headways and spans, the following lessons can be taken from the 3500 South Corridor case study:

1. **Public input should also be actively sought and incorporated into all service design decisions.** The original plan for MAX implementation included the partial or complete removal of Line 35 service. During the public input process, many community members expressed concerns about the lack of local service in the 3500 South Corridor and consequently, full Line 35 service was maintained. The route continues to operate seven days a week, and although its share of corridor ridership has dwindled in recent years, it provides a valuable local, all-stop service, particularly during weekday peak hours and Sundays.

2. **Ridership gains from increased service frequency must be substantial enough to outweigh the potential costs.** UTA staff has performed analyses of MAX ridership and determined that an increase of MAX frequency from a bus every 15 minutes to one trip every 10 minutes would increase daily ridership by roughly 800 riders per day. However, the costs of such increase are prohibitive and additional logistical concerns also would make such an improvement difficult to implement.

3. **Scheduled connections with other major regional transit systems can also be a significant factor in frequency decisions.** One of the biggest factors in determining Line 35 and the MAX headways is the connection to light rail trains at the Millcreek TRAX Station. Since the two TRAX lines that serve this station run on 15 minute headways – or one train every 7.5 minutes in both directions – the Line 35 and MAX schedules must be carefully coordinated to meet every train or every other train. Therefore, if MAX service frequencies were improved beyond the current 15 minute headways, they would likely need to run every 7.5 minutes, which would be much too expensive.

4. **Important cost metrics that can be used in service design decisions include cost per hour, cost per mile, and cost per passenger.** These indicators are used by UTA staff to evaluate the efficiency of existing routes and to calculate the costs and benefits of potential modifications to service frequencies and spans. Since budgetary constraints are the most common factor in service design decisions, these metrics could be useful in measuring and monitoring the efficiencies and inefficiencies of existing and proposed service dimensions.
9.0 PLANNED BRT & LOCAL BUS SERVICE IN SANTA CLARA COUNTY

9.1 Overview of Santa Clara County

Santa Clara County, and its county seat, San Jose, are located in Northern California at the southern end of the San Francisco Bay. Santa Clara County covers roughly 1,300 square miles and is home to over 1.8 million residents.\(^\text{258}\) San Jose is the tenth-largest city in the United States and the third-largest in California, behind only Los Angeles and San Diego.\(^\text{259}\)

Over the last few decades, Santa Clara County has grown dramatically as it has developed into a global epicenter of business and high technology. Comprising the southern portion of the so-called “Silicon Valley”, Santa Clara County is home to 6,600 technology companies and over 650,000 tech sector jobs.\(^\text{260}\) The area’s biggest private employers include several of the most prolific names in technology and computing – IBM, Apple, Cisco, eBay, Adobe and Hitachi.\(^\text{261}\) A 2012 study ranked Santa Clara County as the best-performing metropolitan area in the country in terms job growth, wage growth, and high tech GDP growth.\(^\text{262}\) Other large economic drivers in Santa Clara County include local government, several large colleges and universities, multi-national banking and health services.

The demographics of Santa Clara County feature a high-percentage of ethnic and racial minorities and a wide range of incomes. Based on 2010 Census figures, roughly 65 percent of Santa Clara County residents identify themselves as ethnic or racial minorities as compared to the national average of 36.6 percent. Almost 40 percent of residents are foreign-born, and more than half speak a language other than English at home. These are much higher than the national figures of 12.8 and 20.3 percent, respectively. The percent of Santa Clara County residents that live below the federal poverty threshold is 9.2 percent while the national average is 14.3 percent. Finally, the median household income of Santa Clara County is one of the highest in the nation at just under $90,000.\(^\text{263, 264}\)

9.2 Overview of Santa Clara County’s Planned BRT Corridors

As described in the introduction and outlined the Bus Rapid Transit Strategic Plan, there are three planned BRT corridors in Santa Clara County: Santa Clara/Alum Rock, Stevens Creek, and El Camino Real.

Santa Clara/Alum Rock Corridor

Stretching east to west from downtown San Jose to the Capitol Avenue and south to Eastridge Mall, the Santa Clara/Alum Rock Corridor will be the first in the South Bay to implement full-scale BRT service. Santa Clara Street, which becomes Alum Rock Avenue east of U.S. Route 101, is a major east-west arterial that connects the San Jose central business district with large, sprawling residential areas in east San Jose. Including the segments of Capitol Avenue and Capitol Expressway between Alum Rock Avenue and Eastridge Mall, the corridor measures just over seven miles long. For most of its length, Santa Clara Street and Alum Rock Avenue run as a four-lane arterial street with auxiliary turn lanes and on-street parking. West of Route 101, Alum Rock Avenue features several large median sections and shared center left turn lanes. Capitol Avenue is a four-lane divided roadway with the Alum Rock-Santa Teresa light rail tracks running in the median, and the Capitol Expressway is a six-lane divided throughway with only five intersections over the two-mile segment between Capitol Avenue and Eastridge Mall. A future extension of the light rail from its current terminus at the Alum Rock Transit Center to Eastridge Mall is also planned.\(^\text{265}\)
The western end of the Santa Clara/Alum Rock Corridor is lined with the high-rise office buildings and a myriad of other commercial uses in downtown San Jose. Major destinations along this section of the corridor include San Jose City Hall, HP Pavilion and San Jose Diridon Station. The main San Jose State University campus and several large corporate headquarters are also within walking distance. Moving east towards Capitol Avenue, the densities taper sharply outside of downtown and the street is lined with one- and two-story commercial uses with adjacent low-density residential development. This pattern continues on Capitol Avenue with single family dwelling units along the frontage near Capitol Expressway. Capitol Expressway is mostly separated from its surrounding low-density residential neighborhoods, but near Tully Road it runs immediately adjacent to Eastridge Mall, Raging Waters Park, and the Reid-Hillview Regional Airport. The total population density of the census tracts along the Santa Clara/Alum Rock Corridor is 10,769 persons per square mile.\[^{266}\]

**Stevens Creek Corridor**

On the opposite side of downtown from the Santa Clara/Alum Rock Corridor, Stevens Creek Boulevard – or West San Carlos Street, as it is identified east of Bascom Avenue – runs east to west towards De Anza College and Route 85 in Cupertino. Although the corridor extends west beyond Route 85 and east of downtown, the trunk portion of the corridor runs between downtown San Jose and De Anza College and is roughly 8.6 miles in length. For most of its running length, Stevens Creek Boulevard is a six-lane, median-divided arterial with auxiliary turn lanes and curbside bicycle lanes. Within the incorporated area of the City of San Jose, Stevens Creek Boulevard becomes West San Carlos Street and is reduced to a four-lane, median divided arterial. This roadway section is continued through downtown San Jose with the city’s two main light rail lines operating in the median right of way.

The corridor’s eastern end is located in the southern part of downtown San Jose. This area includes the San Jose Convention Center, San Jose State University, the Children’s Discovery Museum, the San Jose Center for Performing Arts, and several high-rise office buildings and hotels. This area includes some of the highest development concentrations in the region. West of downtown, Stevens Creek Boulevard is lined with low-density commercial uses that bisect large residential neighborhoods. Two of the largest mixed-use trip generators in the corridor – Valley Fair Shopping Mall and Santana Row – are located immediately west of Interstate 880 at the intersection of Stevens Creek and Winchester Boulevard.\[^{267}\] The western half of the corridor is comprised mostly of low-density commercial development interspersed with multi-family residential complexes. The two biggest destinations along the western side of the Stevens Creek Corridor are Vallco Shopping Mall and De Anza College. The overall population density of the corridor is 7,589 persons per square mile.\[^{268}\]

**El Camino Real Corridor**

El Camino Real – translated as the “Royal Road” – spans 600 miles from San Diego to Sonoma and is California’s oldest and most historically-significant highway. Although the construction of Interstate 101 and other parallel routes have diminished its significance over the last half century, El Camino Real – or State Route 82 – still serves as a vital north-south arterial between San Francisco and San Jose.\[^{269}\] One of the busiest sections of the current El Camino Real Corridor is a 16.6-mile segment between Palo Alto and downtown San Jose. From University Avenue in Palo Alto to The Alameda in Santa Clara, El Camino Real is primarily a six-lane, median-divided arterial with auxiliary turn lanes. The section of the corridor between Santa Clara and downtown San Jose shrinks to four lanes and alternates between median-divided and shared center turn lane configurations.
Between Palo Alto and San Jose, El Camino Real and the parallel Caltrain Corridor serve as the dual backbones of development. Accordingly, many of the commercial activity centers in the cities of Palo Alto, Mountain View, Sunnyvale, and Santa Clara are located adjacent to the El Camino Real Corridor. The frontage of El Camino Real is devoted almost exclusively commercial and retail uses which are backed by lower-density residential areas. The major trip generators near the northern segments of the corridor include Stanford University and Medical Center in Palo Alto, San Antonio Shopping Center, and downtown Mountain View. In Sunnyvale and Santa Clara, the corridor is adjacent to a series of large shopping centers, the Santa Clara Caltrain Station, and Santa Clara University. The El Camino Real Corridor ends near the HP Pavilion in downtown San Jose where the Alameda becomes Santa Clara Street and joins the Santa Clara/Alum Rock Corridor described above. The overall population density of the census tracts within the corridor is 6,528 persons per square mile.  

9.3 Overview of Public Transportation in Santa Clara County  

There are several private and public transit operators that provide service in Santa Clara County, but the Santa Clara Valley Transportation Authority (VTA) is the largest by far. VTA has operated transit service in Santa Clara County since 1976 and has served as the county’s Congestion Management Agency (CMA) since 1995. VTA currently operates 71 regular bus routes, 3 light rail lines, and the Outreach paratransit service. In FY 2012, the VTA bus and light rail systems accounted for 42.4 million trips and recorded an average of over 137,000 weekday boardings.

The three lines in the VTA light rail system serve 62 stations and cover 42.2 miles of track. The two main lines converge in downtown San Jose and extend outwards to serve parts of Mountain View, north Sunnyvale, north Santa Clara, north San Jose, east San Jose, south San Jose, and Campbell. The light rail system comprises the backbone of regional transit in the South Bay and averages nearly 32,000 boardings on a typical weekday.

VTA also operates 71 bus routes that serve approximately 3,800 bus stops across the 346-square mile service area. Bus service is provided via 18 core routes, 18 local routes, 18 community bus routes, 18 express lines, and four limited-stop routes. VTA buses operate in Palo Alto, Mountain View, Los Altos, Sunnyvale, Santa Clara, Saratoga, Campbell, Los Gatos, Fremont, Milpitas, Morgan Hill and Gilroy. The bus system accounts for 105,000 average weekday boardings and drew a total of 32 million boardings in FY 2012.

9.4 Public Transportation in Santa Clara County’s Planned BRT Corridors

Served primarily by Lines 22, 23, 323 and Rapid 522, the Santa Clara/Alum Rock, Stevens Creek, and El Camino Real Corridors provide important connections between downtown San Jose and the surrounding areas of east San Jose, Cupertino, Santa Clara, Sunnyvale, and Palo Alto. These routes include three of the top four most productive routes in the system in terms of average weekday boardings and provide connections to several major regional transit hubs. The following section includes a description of each route as well as a summary of its future operating characteristics upon full BRT buildout.

As shown on Figure 9-1, Line 22 currently operates between the Palo Alto Transit Center and Eastridge Mall via El Camino Real, The Alameda, Santa Clara Street, Alum Rock Avenue, King Street, Tully Road and the Capitol Expressway. The route provides local, all-stop service along this route and operates 24 hours a day, seven days per week. Line 22 trips arrive once every 12 minutes on weekdays, every 15 minutes on weekends, and every 20-60 minutes between 7:00 PM and 5:00 AM. The total length of Line 22 is 24.7
miles and the average stop spacing is 0.23 miles. The route typically operates with 60-foot articulated buses and the standard $2.00 per trip fare is collected via onboard farebox. Based on the Preferred Operating Plan from VTA’s BRT Strategic Plan, Line 22 would continue to operate 24-hour service along its existing route from the Palo Alto Transit Center to Eastridge Mall, but its weekday headways would be decreased from 12 minutes to 15 minutes.280

Figure 9-1 – Map of Line 22


Figure 9-2 – Map of Line 23

Line 23 provides local service from De Anza College in Cupertino to the Alum Rock Light Rail Station via Stevens Creek Boulevard, Valley Fair Shopping Mall, downtown San Jose, and the Santa Clara/Alum Rock Corridor. The local service operates seven days a week, between 5:00 AM and 1:00 AM on weekdays and 6:00 AM and 1:00 AM on weekends. Line 23 currently operates with the same frequency as Line 22 – 12 minute weekday service, 15 minute weekend service, and 20-60 minute headways during evenings and late night periods. The Line 23 route is 13.5 miles long with an average stop spacing of 0.20 miles. It operates with standard 40-foot buses and the standard fare applies. As part of the BRT implementation, the Line 23 route will be shortened and the eastern terminus of the route will be moved from Alum Rock Transit Center to San Jose State University in downtown San Jose. Like Line 22, Line 23 weekday service frequencies will be reduced from 15 minutes to 12 minutes, but the route’s current service span would be maintained. The route’s 15 minute Saturday headways would also be continued, but Sunday service would be reduced from once every 15 minutes to once every 20 minutes. A map of the existing Line 23 route is shown as Figure 9-2.

![Figure 9-3 – Map of Line 323](image)


Designed as a precursor to BRT, Line 323 was introduced along Stevens Creek Boulevard in 2012 to provide faster, more direct service along the busy Stevens Creek Corridor. As shown in Figure 9-3, the Line 323 route runs from De Anza College in Cupertino to downtown San Jose via Stevens Creek Boulevard, San Carlos Street, and 1st and 2nd Streets. The route differs from Line 23 in that it bypasses the Valley Fair Transit Center and terminates in downtown San Jose instead of continuing through the Santa Clara/Alum Rock Corridor. Line 323 currently operates on weekdays between 6:00 AM and 7:30 PM with 15 minute headways. The limited stop service observes only 14 stops in each direction along its 9.5 miles route for an average stop spacing of 0.68 miles. The route uses standard 40-foot vehicles and the regular bus fare of $2.00 per trip applies. Over the next two years, Line 323 service will gradually be extended to weekday evenings and weekends to build up ridership in preparation for BRT implementation. The VTA BRT Strategic Plan calls for Line 323 to become the new BRT 523 service with rapid service from De Anza College to Alum Rock Transit Center and Eastridge Mall, although it may be temporarily routed to the planned Berryessa BART station as part of the BART integration project. This service would be expanded to run every 10 minutes on weekdays and every 15 minutes on weekends with extended service spans. It would also feature new low-floor, diesel hybrid articulated BRT vehicles, enhanced stations, station bulb outs, traffic signal prioritization, real time transit data, and dedicated bus lanes in selected segments.
The BRT 523 is slated to operate in dedicated lanes on Alum Rock Ave for a 1.4 mile stretch west of Capitol Avenue. Although plans on the Stevens Creek Boulevard are still being refined, the route will likely operate in dedicated lanes for a 2.5 mile segment near Valley Fair Shopping Mall and a 1.7 mile stretch on the west end of the route near De Anza College. 287

The VTA route that most closely resembles BRT service is the Rapid 522, which runs between Palo Alto and east San Jose. As shown in Figure 9-4, the Rapid 522 follows a similar routing as Line 22, from the Palo Alto Transit Center to the Eastridge Mall via El Camino Real, The Alameda, Santa Clara Street, Alum Rock Avenue, Capitol Avenue and Capitol Expressway. The service runs on a headway-based schedule with 15 minute headways between 5:00 AM and 9:00 PM on weekdays and from 8:00 AM to 7:00 PM on Saturdays. 288 With 30 stops in each direction along its nearly 25-mile route, the Rapid 522 averages one stop every 0.83 miles. The Rapid 522 service utilizes a mix of standard 40-foot buses and specially-branded, low-floor, articulated vehicles. Additional BRT-type features include traffic signal prioritization and queue jump lanes. 289 The Preferred Operating Plan in the BRT Strategic Plan upgrades the Rapid 522 to the BRT 522 with 10 minute headways on weekdays, 15 minute weekend service, and extended service hours. The improvements will also include new, low-floor, diesel hybrid articulated BRT vehicles, enhanced stations, station bulb outs, real time transit data, and dedicated bus lanes in Santa Clara and San Jose. 290 Based on current plans, the BRT 522 will travel in dedicated median lanes along the 1.4 mile Alum Rock Avenue segment and on El Camino Real for at least three miles in the City of Santa Clara and potentially longer. 291

Figure 9-4 – Map of Rapid 522

A map showing the routes that will serve all three of the planned BRT corridors is included as Figure 9-5. A summary of the operating characteristics based on the changes associated with BRT implementation described above is shown in Table 9-1. Additional information on the three planned BRT corridors is provided in Appendix A.
9.5 Operational Analysis of Existing Service

Although the existing service on the three corridors falls short of true BRT, an operational analysis provides insight into how well the existing routes are meeting the needs of the corridors they serve. As noted above, the Santa Clara/Alum Rock, Stevens Creek, and El Camino Real are included among the healthiest and most productive transit corridors in the entire South Bay.
Line 22 is the most productive bus route in the VTA system. With local, all-stop service throughout both the El Camino Real and Santa Clara/Alum Rock Corridors, Line 22 averages over 14,500 riders each weekday and 37.6 boardings per revenue hour. The route’s solid ridership performance also continues on weekends with 37.3 boardings per Saturday revenue hour and 37.5 boardings per revenue hour on Sundays. Over the last few years, however, Line 22 ridership has gradually decreased as Rapid 522 service has gained more ridership traction. The current average weekday peak load factor for Line 22 is 0.39 – including 0.34 during the morning peak hours, 0.37 during middays, 0.41 during the afternoon rush hours, and 0.43 during evening and overnight periods. The route’s average speed is 12.5 miles per hour. Line 22 buses arrive “on time” – that is, no more than three minutes early or five minutes late – roughly 84 percent of the time. The articulated vehicles that are used for Line 22 service cost approximately $138.36 per revenue hour to operate. Based on these indicators, the Line 22 is shown to be a reliable, productive, well-designed local bus service.

The second-highest ridership productivity in the bus system belongs to Line 23, which operates all-stop service in the Stevens Creek and Santa Clara/Alum Rock Corridors. Line 23 accounts for nearly 9,000 passenger trips each weekday and averages 36.8 boardings per revenue hour. On Saturdays and Sundays, the route draws 36.4 and 31.9 boardings per revenue hour, respectively. Since Line 23 operates with standard buses while Line 22 uses larger, articulated vehicles, the average peak load factors for Line 23 are actually higher than those of Line 22. The overall weekday average peak load factor is 0.55. When measured by time of day, the route records average peak load factors of 0.57 and 0.64 during the midday and afternoon peak periods, respectively. Line 23 buses record average speeds of 10.7 miles per hour, but arrive on time approximately 87 percent of the time. The standard 40-foot buses that are used for Line 23 service cost $120.46 per revenue hour to operate. These statistics demonstrate the strong operational performance of Line 23 local service.

With an average weekday ridership of roughly 1,000, Line 323 draws the least amount of passengers among the 18 “core” bus routes. It operates primarily in the Stevens Creek Corridor and averages only 18 boardings per weekday revenue hour, slightly below the VTA bus system average. However, Line 323 has trended upward since its inception in July 2012, despite only operating on weekdays across a 12-hour span. The demand for this limited existing Line 323 service bodes well for the planned future expansion of the route. In fact, Line 323’s average peak load factors of 0.49 and 0.45 for the midday and afternoon peak periods are comparable to some of the more popular core routes. The overall average weekday peak load factor for Line 323 is 0.45. The average speed of Line 323 buses is 12.3 miles per hour, and they arrive on time approximately 90 percent of the time. Line 323 uses standard buses, which cost $120.46 per revenue hour to operate. Although Line 323 currently operates with low overall ridership, it has demonstrated clear growth in its first year of service, suggesting that route productivity could increase markedly with the provision of additional, enhanced service.

Based on 2012 ridership figures, the Rapid 522 is the fourth-busiest bus route in the VTA system. On a typical weekday, it accounts for nearly 6,000 passenger trips and 30.4 boardings per revenue hour. The rapid service – which operates between the Palo Alto Transit Center and Eastridge Mall – is also one of the highest performing Saturday routes and averages 22.1 boardings per revenue hour. The Rapid 522 has shown remarkable growth over the last few years as riders become more familiar with its fast, reliable service. It registers an average weekday peak load factor of 0.55, with 0.53 and 0.56 peak load factors during the morning and afternoon commute peaks, respectively. Due to the usage of larger, articulated vehicles by many Rapid 522 trips and the concurrent Line 22 service, these load factors are lower than what might be expected of a rapid service on the El Camino Real and Santa Clara/Alum Rock Corridors. The Rapid 522 travels at an average speed of 15.3 miles per hour, which is markedly faster than the other
three routes, but the route’s on-time performance is only 79 percent.\textsuperscript{313,314} This low reliability is likely explained by the Rapid 522’s headway-based schedule, which allows buses to run ahead of schedule, thus reducing the on-time performance results. Based on the above indicators, the Rapid 522 has established a solid ridership base but has not reached its full potential productivity and could benefit from additional service.

9.6 Comparative Analysis of Existing Service Frequencies & Spans

Although the three planned BRT corridors do not provide true BRT service, a brief comparison of headways and spans between existing local and BRT precursor routes may shed light on how the corridors will operate upon BRT implementation. As noted above, existing local service on Lines 22 and 23 is provided with 12 minute headways, but will likely be reduced to operate every 15 minutes with BRT. The BRT precursor routes – Line 323 and Rapid 522 – are slated to improve from 15 minute to 10 minute headways when they are converted into true BRT. Based on the fact that several of these routes serve multiple corridors, existing service will be evaluated by route pairs instead of by corridor.

Evaluation of Existing Line 22 & Rapid 522 Service

The current headways and spans of Line 22 and the Rapid 522 are designed to favor the local service. Based on the Line 22 and Rapid 522 average boardings per weekday revenue hour of 37.6 and 30.4, respectively, this seems to be a reasonable bias. Looking more closely at ridership by time of day, the Rapid 522 draws roughly half as many riders as Line 22 during the morning peak, midday, and afternoon peak periods.\textsuperscript{315} Since the existing rapid’s 15 minute headways are only 80 percent less frequent than the local route with 12 minute headways, it seems that even shorter headways for local weekday service could be implemented with success. This emphasis on local service is also warranted on Saturdays, when Lines 22 and the Rapid 522 average 42.7 and 39.0 boardings per revenue hour, respectively.\textsuperscript{316} Average weekday peak load factor data, however, measures the two routes at 0.39 and 0.55.\textsuperscript{317,318} This discrepancy is likely due to the vehicle sizes that are used on the two routes – Line 22 uses 55-seat articulated vehicles, while most Rapid 522 trips are run with standard-size, 37-seat buses. This trend continues throughout the duration of the day. The average passenger trip lengths on Line 22 and the Rapid 522 are 4.9 and 7.3 miles, and the average stop spacing distances are 0.23 and 0.83 miles, respectively. These values indicate that the desired trip differentiation between the local service and the BRT precursor route that will contribute to the healthy balance between Line 22 and the planned BRT 522 has begun to develop.

The current spans of Line 22 and the Rapid 522 are mostly adequate based on the existing ridership data outlined above. Line 22’s 24-hour span is justified by its strong evening and late night service. From the end of the afternoon peak to the beginning of the morning rush hour, Line 22 averages 36.5 boardings per revenue hour and an average peak load factor of 0.43.\textsuperscript{319} On weekends, the service hours for Line 22 also appear to be reasonable, with 42.7 and 48.9 average boardings per revenue hour on Saturdays and Sundays, respectively. The evening and late night service only demonstrate small drop offs from the daily averages with 39.0 and 47.3 boardings per revenue hour on Saturdays and Sunday, respectively.\textsuperscript{320} Conversely, Rapid 522 – which only operates Monday through Saturday – also maintains solid ridership throughout the week with 36.2 and 29.5 average boardings per revenue hour on weekdays and Saturdays, respectively. As currently configured, the Rapid 522 only operates from 5:00 AM to 8:30 PM on weekdays and 8:00 AM to 7:00 PM on Saturdays. A more detailed review of ridership and load factor data shows increased loads on the early morning weekday trips – particularly in the westbound direction – and the
first and last Saturday trips. Therefore, the extension of service hours and the introduction of Sunday service, as planned for January 2014 as part of the continued build-up to BRT, appear to be warranted.

**Evaluation of Existing Lines 23 & 323**

As with Line 22 and the Rapid 522, the current headways and spans of Lines 23 and 323 are designed to favor the local bus route, which has a much more established ridership base than the relatively new Line 323. In terms of weekday ridership, Lines 23 and 323 draw 36.8 and 18.0 average boardings per revenue hour, respectively. Similarly, while only operating 20 percent more frequently than Line 323, Line 23 local service draws over three times as many riders as Line 323 during the morning peak, midday, and afternoon peak periods. The average weekday peak load factors for the two lines of 0.55 and 0.45, respectively also reflect this discrepancy, which seems to be more pronounced during the morning and afternoon peak periods. Although these figures suggest that Line 323 is getting more than its fair share of the service, the comparison are likely misleading due to the fact that Line 323 has only been in operation for roughly one year and has far fewer BRT-style elements than the Rapid 522. VTA is also using Line 323 to cultivate a healthy ridership base for the future Rapid 523, so it would be unwise to reduce the current headways. On a positive note, the average stop spacing and passenger trip lengths further indicate that some trip differentiation is already beginning to develop. The average stop spacing for Lines 23 and 323 are 0.20 and 0.68, respectively, while the average passenger trip lengths are 4.2 miles and 6.2 miles.

The findings of the comparative frequency analyses outlined above also translate to the service spans on Line 23 and 323. Line 23, which runs approximately 19 hours per day, seven days a week, has a healthy, consistent ridership base that seems to mostly justify its extensive hours of operation. The route’s first weekday trips in each direction in the early morning register peak load factors of 0.32 and 0.34, which are below the overall weekday average but high enough to maintain. The last Line 23 trips, which run around midnight, draw average peak loads of 0.18 and 0.24 and should be monitored to determine if the late night hours need to be reduced. The first and last weekday trips on Line 323 also exhibit low peak load factors, but should not be reduced since that might curb ridership development efforts. On weekends, Line 23 peak load factor data in the early morning and late evening is generally between 0.30 and 0.50 so the current span appears to be warranted.

**9.7 Analysis of Planned BRT & Local Service Frequencies**

As noted previously, the VTA preferred operating plan for concurrent local and BRT service on weekdays calls for 10 minute BRT headways and 15 minute headways on the local routes. On weekends, Lines 22 and BRT 522 will both run every 15 minutes, while Line 23 and BRT 523 will each run with 15 minute headways on Saturdays and 20 and 15 minute headways, respectively, on Sundays. Based on the lessons learned from the previous literature review and case studies, this section will evaluate the service design details of the preferred operating plan.

**Evaluation of Planned BRT Headways**

VTA’s plan to run the BRT 522 and BRT 523 services on 10 minute headways on weekdays and 15 minute headways on weekends appears to be supported by the findings outlined in the preceding sections of this report. As noted in the literature review, Levinson et al concluded that BRT service should typically be run every 8-10 minutes during peak periods and every 12-15 minutes during off-peak hours. Alternatively, the FTA’s *Characteristics of Bus Rapid Transit Decision-Making* infers that BRT routes that operate
primarily in mixed traffic lanes should operate with 9-15 minute headways based on survey of 45 BRT corridors throughout the world.332 Therefore, the planned 10 and 15 minute headways for the two BRT routes – which will both run predominately in mixed traffic lanes – are consistent with the service frequency recommendations from the literature review. If additional segments of dedicate laneways are added, the headways may need to be adjusted accordingly.

The 10 minute BRT headways also appear to be appropriate based on the findings from the case study section of this report. The BRT weekday service frequencies for the five case studies ranged from 4-8 minute weekday headways on Los Angeles’ Wilshire Boulevard Corridor to 30 minute headways for Las Vegas’ MAX service on Las Vegas Boulevard North. Weekend BRT frequencies also vary greatly among the case studies, from 10 minutes headways in Los Angeles to 30 minute headways in Kansas City and Las Vegas to no weekend BRT service in Oakland. The two planned BRT routes fall within these ranges for both weekdays and weekends.

The Santa Clara/Alum Rock Corridor has greater population density (10,770 persons per square mile) and daily traffic volumes (32,500 average daily trips) than all of the case study corridors other than Wilshire Boulevard.333,334 Moreover, the three existing non-BRT routes on the Santa Clara/Alum Rock Corridor combine to average nearly 30,000 boardings per weekday, which is roughly equal to the BRT and local ridership on San Pablo Avenue, Las Vegas Boulevard North, Troost Avenue, and 3500 South combined.335 The higher densities and traffic volumes and the enormous difference in weekday ridership demand between the four comparable case studies indicates that the combined five minute headways of the two BRT services that will operate on the Santa Clara/Alum Rock Corridor are likely warranted. Based on the preferred operations plan, the two BRT routes would combine to provide 7.5 minute weekend headways along the Santa Clara/Alum Rock Corridor. Although this represents a higher level of Saturday and Sunday service than Wilshire Boulevard, it is operationally necessary in order to ensure the 15 minute weekend BRT headways on the Stevens Creek and El Camino Real Corridors that are described below.

The Stevens Creek Boulevard and El Camino Real Corridors have lower population densities of 7,589 and 6,548 persons per square mile, respectively, but still rank in the middle of the five external case studies.336 The average daily traffic volumes of the two corridors – 38,000 and 50,000 trips, respectively – are substantially higher than all but Wilshire Boulevard.337 With the exception of Los Angeles, the four remaining case studies are similar to the Stevens Creek Boulevard and El Camino Real in that they all connect primarily low-density residential areas with downtown business districts via major surface arterials; however, the Stevens Creek and El Camino Real Corridors include more major trip generators along their middle segments which increase the consistency of ridership demand throughout the route and require increased levels of service. This point is illuminated with the current average weekday ridership figures in the two planned BRT corridors – roughly 10,000 and 20,500 average daily boardings in the Stevens Creek and El Camino Real Corridors, respectively – which exceed the ridership figures of the four comparable BRT case study corridors.338 The routes operating in these two corridors also boast strong weekend ridership figures. Bus service along El Camino Real accounts for nearly 15,000 and 12,000 average boardings on Saturday and Sunday, respectively, while Line 23 on Stevens Creek Boulevard, draws over 6,000 and 5,000 on the two weekend days.339 These weekend ridership figures are exceeded only by the Wilshire Boulevard Corridor in Los Angeles and Las Vegas Boulevard North, which has disproportionately high weekend ridership activity due to the unique travel demands of Las Vegas. It therefore seems appropriate that the 10 minute weekday headways and 15 minute weekend headways for BRT 522 and 523 will rank among the most frequent of the five case study corridors.
Evaluation of Planned Local Headways

Local weekday service on Lines 22 and 23 is slated to be reduced from running every 12 minutes to operate once every 15 minutes. This represents a 25 percent reduction of weekday service on the two most productive routes in the VTA bus system and the effects of this significant change may require additional consideration. Current weekend headways on the two local routes will be mostly continued, but with a decrease of Line 23 Sunday service from 15 minute headways to 20 minute headways.

Although the decrease of local weekday service frequency on both routes will effectively be offset by the provision of 10 minute headways on the new BRT routes, it still represents a service reduction for the parts of the corridor that are not immediately adjacent to the new BRT stops. With average stop spacing distances on BRT 522 and 523 of 0.91 miles and 0.72 miles, there will be a large number of local stops that will see less frequent service. Perhaps even more telling is that fact that only 52 percent of Line 22 weekday boardings occur at stops that will be served by the BRT 522. Although this percentage does not include passengers that use a non-BRT local stop but could still easily walk to a nearby BRT stop, 52 percent is surprisingly low when compared to the case studies in Kansas City and Salt Lake City, which were estimated at closer to 80 percent. Line 23 is covered slightly better but still has only 63 percent of boardings taking place at future BRT 523 stations. These numbers indicate that the planned reductions of the headways on Lines 22 and 23 will have a detrimental effect on a significant proportion of the existing passengers on those routes.

As summarized in the literature review, Levinson et al recommend that corridors with concurrent BRT and local service should operate with combined headways of 2-4 minutes during peak hours and 5-6 minutes during middays. Based on the preferred operating plan, these combined frequency design guidelines would be met with the 3-4 minute weekday headways along most of the Santa Clara/Alum Rock Corridor, but would not be realized on Stevens Creek Boulevard or El Camino Real, which would both feature six minutes combined headways throughout the day. If the existing 12 minute weekday headways on Lines 22 and 23 were maintained after the introduction of BRT service, the BRT and local routes on these two corridors would operate with combined 5.5 minute headways which would be slightly more consistent with Levinson findings. Both the BRT and local headways would need to be improved by several minutes to achieve the 2-4 minute combined peak headways, but this is unlikely due to its prohibitive cost.

Local weekday headways among the five case study corridors range from 10 minutes in Los Angeles’ Wilshire Boulevard Corridor to 30 minutes in Las Vegas, Salt Lake City, and Kansas City. Weekend headways for local service are slightly longer, ranging from a bus every 15 to 20 minutes in Los Angeles and Oakland to a bus every 30-60 minutes in Las Vegas, Kansas City and Salt Lake City. As noted in the previous section, the three planned VTA BRT corridors are each characterized by population densities, average traffic volumes, and overall transit ridership levels that are consistent with or greater than most of the five case studies. Although it is slightly misleading to compare the ridership of a local route that is not yet supplemented with full BRT service with one that is, the average weekday boardings of Lines 22 and 23 – 14,500 and 9,000, respectively – are exponentially greater than four of the five case study local routes. By comparison, Lines 72 and 72-M on San Pablo Avenue in Oakland draw only 4,190 average weekday boardings and also operate with approximate 15 minute headways on both weekdays and weekends. Based on these case study comparisons, it seems plausible that the existing 12 minute weekday headways on Lines 22 and 23 could be successfully maintained alongside future BRT service instead of the 15 minute local headways that are currently planned. The planned weekend headways of one bus every 15 to 20 minutes are similar to those offered by Line 20 in the Wilshire Boulevard Corridor and therefore are likely adequate.
Comparative Analysis of Planned Service Frequencies

As shown in the preceding comparative frequency analyses, the distribution or ratio of frequency between BRT and local routes can be an important factor in determining the productivity and balance of transit service in the corridor. Based on the preferred operating plan, the 10 minute BRT headways and the 15 minute local headways would represent a 1.50 weekday service frequency ratio for the Stevens Creek and El Camino Real Corridors. On Saturdays, both of these corridors would feature 15 minute headways for both BRT and local service for headways ratios of 1.0. On Sundays, with reduced Line 23 frequency, the headway ratio of the Stevens Creek Corridor would increase to 1.33. Passengers traveling on the Santa Clara/Alum Rock Corridor – served by Line 22 and both BRT routes – would see three rapid buses for every one Line 22 local bus on weekdays. On Saturdays and Sundays, all three routes would operate at 15 minute intervals for a BRT-to-local headway ratio of 2.0.

Although comprehensive ridership estimations are not available, the 2030 average daily ridership projections from the BRT Strategic Plan provide for a basic comparison between ridership splits and headway distributions. As estimated by VTA staff, Lines 22 and the BRT 522 will draw 20,557 and 32,540 boardings, respectively, on an average weekday. This represents a BRT-to-local ridership ratio of 1.58 and supports the planned 1.50 weekday headway ratio on those routes. Lines 23 and the BRT 523, however, are projected to attract 6,474 and 24,007 average weekday boardings, respectively, in 2030. This equates to a ridership ratio of 3.71 BRT passengers for every one local passenger and does not correspond well with the planned 1.50 BRT-to-local headway ratio. This large discrepancy implies that the planned headways should be modified so that the BRT 523 runs even more frequently and Line 23 operates at even longer intervals. Based on consistency of BRT service and other operational considerations, a larger difference between BRT 523 and local Line 23 headways would further offset the balance of the Stevens Creek Boulevard Corridor and is not advised.

The five case studies demonstrated a wide range of headway ratios. On weekdays, the BRT was most heavily favored on Troost Avenue in Kansas City with three MAX buses for every one Line 25 trip. The Wilshire Boulevard Corridor in Los Angeles also ranked highly with a BRT-to-local headway ratio of 2.5. On the opposite end of the spectrum, the MAX and Line 113 are run on identical 15 minute headways for a ratio of 1.0 and the BRT-to-local headway ratios on Oakland’s San Pablo Corridor are only 1.25 and 1.33 during the morning and afternoon peak periods, respectively. All three planned BRT corridors in Santa Clara County fall within this range, though the Santa Clara/Alum Rock Corridor is understandably on the high end with its two BRT routes. Weekend headway ratios for the five case study corridors were generally lower than the corresponding weekday headway ratios, which may be indicative of the differences between weekday and weekend travel patterns. Among the corridors offering both BRT and local service on weekends, the highest weekend ratios typically featured roughly two BRT buses for every local trip, as demonstrated on Wilshire Boulevard, Salt Lake City’s 3500 South Corridor on Saturdays, and Troost Avenue in Kansas City on Sundays. Conversely, weekend BRT-to-local headway ratios of 1.0 are utilized in Kansas City on Saturday, and Las Vegas on both Saturday and Sunday. Based on these findings, the planned BRT headway ratios in Santa Clara County are each within this range.

Several additional comparisons can be made between the headway ratios of the case studies and those in the three planned BRT corridors in Santa Clara County based on stop spacing and average trip lengths. As noted in the previous case study analyses, a healthy corridor with concurrent BRT and local bus service will typically exhibit a visible trip differentiation whereby the longer trips will gravitate towards the BRT route, while the shorter trips will utilize the local service. Based on average passenger trip lengths, the case studies with the strongest trip differentiation were Kansas City and Los Angeles, where the average BRT
passenger traveled a distance at least twice as long as the average local passenger. These two corridors also feature the largest differences in average stop spacing – 4.4 and 4.6 local stops per BRT stop, respectively – and the largest weekday BRT-to-local headway ratios – 3.0 and 2.5, respectively – of the five case studies. A review of the planned stops for Lines 22, 23, 522 and 523 shows that the BRT-to-local stop spacing ratios are only slightly less than the Wilshire Boulevard and Troost Avenue Corridors. The 3.0 headway ratio of the Santa Clara/Alum Rock Corridor is also comparable to these two case study corridors, however, the 1.5 headway ratios on Stevens Creek Boulevard and El Camino Real are substantially lower. By this logic, in order to achieve the distinct trip differentiation that typically characterizes healthy shared transit corridors, the BRT routes would require shorter headways than the planned 10 minute intervals.

9.8 Analysis of Planned BRT & Local Service Spans

VTA staff has also identified the planned spans of service for all four routes. Line 22 will continue its 24-hour service seven days per week. Line 23 will be in service from 5:00 AM to 1:00 AM on weekdays, and 6:00 AM to 1:00 AM on weekends for spans of 19-20 hours per day. The new BRT routes will be run from 5:00 AM to 11:00 PM on weekdays, from 6:00 AM to 10:00 PM on Saturdays, and 7:00 AM to 9:00 PM on Sundays, equating to spans of 14 to 18 hours per day. Based on the lessons learned from the literature review and case study comparisons, these planned spans of service will be reviewed in the following section.

The literature review included several different guidelines for spans of BRT and local service. Based on the findings of Levinson et al, BRT routes that operate primarily in mixed traffic like those planned in Santa Clara County should operate 18-24 hours a day, seven days a week, and “may be augmented by conventional local bus routes.” Conversely, the *Bus Rapid Transit Practitioner’s Guide* states that BRT may only require a 12-hour span when concurrent local bus routes are available during evenings and weekends. Finally, the FTA’s *Characteristics of Bus Rapid Transit Decision-Making* surveyed 45 different corridors with BRT service. The vast majority of the BRT routes included in the report operate throughout the daytime, seven days per week. Based on these recommendations, VTA’s planned BRT spans appear to be adequate, although the Levinson guidelines imply that the BRT hours of operation could be extended, if warranted.

The five case study corridors comprise varying degrees of spans for BRT and local service. Among the BRT routes, weekday spans ranged from 22 hours in Los Angeles to just over 14 hours in Oakland and Las Vegas. BRT weekend service spans were also generally observed to be between 14 and 22 hours per day, although Oakland offers no weekend BRT service and Salt Lake City’s 35-M BRT service does not operate on Sundays. The planned spans for the BRT 522 and BRT 523 in Santa Clara County are in the middle of both of these ranges and will operate seven days per week. Among the five local case study routes, two routes – Line 20 in Los Angeles and Line 113 in Las Vegas – operate 24 hours a day, seven days a week. The shortest spans for local service were found in Kansas City’s Line 40 and Line 35 in Salt Lake City, which operate 14.5 and 17 hours, respectively, on weekdays. Both of these routes are in service for 14.5 hours on Saturdays and the two routes run for 13 and 11 hours, respectively, on Sunday. As might be expected based on their high ridership productivity, the planned spans for the two local VTA routes are on the higher end of this spectrum with 24-hour Line 22 service and Line 23 operating for 19-20 hours per day, seven days per week. In light of the higher population densities, greater mix of land uses, and close proximity to major trip generators noted in previous sections, the longer service spans identified by the BRT Strategic Plan appear to be reasonable.
The relationship between hours of operation for BRT and local service are also important in shaping the health and productivity of the corridor. According to the preferred operating plan, VTA staff envisions an arrangement in which BRT operates seven days a week with extensive hours, but only as warranted by ridership demand. The local routes will operate longer spans and provide service during late evenings and overnight periods when ridership demand is not sufficient to warrant both services. Since the local routes provide service to all stops, this is a logical arrangement to ensure that all individuals may have access to transit during these periods. Of the five BRT case studies, Los Angeles, Oakland, and Las Vegas feature similar span configurations with the longer local service hours. Conversely, Kansas City and Salt Lake City designed their BRT routes with longer spans to provide the baseline service when the local routes are not in operation. Based on interviews with KCATA and UTA staff, this arrangement was utilized because the BRT stops in the Troost Avenue and 3500 South Corridors were placed in locations that would provide access to the overwhelming majorities of transit users in each corridor. Since the geographical distribution of ridership along the planned BRT corridors in Santa Clara County does not lend itself to this type of route design, the decision to utilize local routes for baseline service and BRT routes during normal daytime and evening hours appears to have been the correct one.

One last comparative observation involves the differences between spans on weekdays and weekends. With the exceptions of Kansas City and Salt Lake City which specifically designed their BRT routes to maximize ridership coverage, the other three case studies feature little or no drop off in service spans between weekdays and weekends. The hours of operation on both the BRT and local routes in Los Angeles and Las Vegas remain virtually unchanged between weekdays, Saturdays, and Sundays. Although Oakland does not offer weekend Line 72-R BRT service, the Line 72 local service operates from 5:00 AM to 1:30 AM seven days a week. By comparison, the hours of operation for VTA’s local routes do not change significant from weekdays to weekends, but the BRT spans slip from 18 hours on weekdays to 16 hours on Saturdays and 14 hours on Sundays. This may be due in part to the fact that the BRT precursors – Line 323 and the Rapid 522 – either do not operate on weekends or only operate with limited Saturday service. As the BRT 522 and BRT 523 begin to gain traction and develop weekend ridership, these shorter Saturday and Sunday spans could be explored.

9.9 Santa Clara County Findings & Recommendations

The preceding analyses have yielded a wide range of findings for the planned BRT corridors in Santa Clara County. These conclusions and recommendations are summarized below:

Findings & Recommendations for Existing Service Frequencies & Spans

1. **The local bus routes in the three planned BRT corridors are currently operating at high levels of productivity and efficiency.** Lines 22 and 23 are the two highest performing routes in the VTA bus system in terms of absolute ridership and boardings per revenue hour. The two routes also account for roughly 22 percent and 33 percent of the total bus system ridership on weekdays and weekends, respectively.

2. **The two BRT precursor routes – Line 323 and the Rapid 522 – have demonstrated recent ridership growth and are laying the groundwork for the planned BRT service.** The Rapid 522 has emerged as the fourth-most productive route in the system, while Line 323 is drawing roughly 1,000 daily boardings in its inaugural year of service. The productivity of both routes is expected to increase over the next two years as service headways and spans improve, passengers become
more familiar and comfortable with the services, and they begin to develop a more consistent ridership base from which BRT will draw its users.

3. Based on the existing ridership splits between BRT precursor routes and local service in the three corridors, the current service design configuration with headways that favor local service is reasonable. In fact, if the planned implementation of BRT were not occurring, it could be argued that the local headways on Lines 22 and 23 should be shortened to promote a more productive balance between local and the rapid or limited stop service.

4. Although the current service design favors local service, the trip differentiation between longer rapid or limited stop trips and shorter local trips has already begun to develop. Average passenger trip lengths on Line 323 and the Rapid 522 are noticeably longer than those of the corresponding local routes. This is an important indicator of corridor viability for future BRT service.

5. The existing spans on Lines 22 and Lines 23 are adequate and the plans to introduce extended evening and weekend service for Lines 323 and the Rapid 522 are warranted. The consistently strong weekday and Saturday ridership performance of the Rapid 522 clearly suggest that the route could thrive with extended service hours. Though its ridership productivity is not as high, Line 323 will also benefit from additional evening and weekend service as it continues to solidify its ridership base.

Findings & Recommendations for Planned BRT & Local Service Frequencies

6. The planned 10 minute weekday headways and 15 minute weekend headways for the two BRT routes are generally consistent with the literature review guidelines and case study findings. The service frequencies for both the BRT 522 and 523 are within the ranges outlined by Levinson et al as well as those identified in the FTA’s Characteristics of Bus Rapid Transit Decision-Making. A comparison with BRT headways observed in the five case study corridors also finds that the 10 minute weekday headways and 15 minute weekend headways are consistent with similar, successful BRT services across the country.

7. The planned 15 minute local headways represent a 25 percent reduction from existing weekday service levels on the two busiest routes in the VTA system, and consequently may not reflect the most productive service design. Although the decrease in local headways will be largely offset by the new BRT service, the local stops that are not served by the BRT 522 or 523 will be adversely affected. Based on the longer distances between BRT stops and the fact that only 52 and 63 percent of the current weekday boardings on Lines 22 and 23, respectively, occur at planned BRT stations, this may be cause for concern.

8. Based on the literature review findings and observed local headways among the five case studies, the existing 12 minute local headways on both Lines 22 and 23 could potentially be maintained after the two BRT routes are introduced. This finding is based on the combined headway guidelines espoused by Levinson et al, as well as a comparative review of the densities, land uses, traffic volumes, and transit ridership of the planned BRT corridors and the five case studies. The weekend headways on Lines 22 and 23 – 15 minutes and 20 minutes, respectively – are comparable to the Wilshire Boulevard Corridor in Los Angeles and seem to be adequate.
9. Additional comparative frequency analyses between the planned BRT and local route pairs, finds that the 1.50 weekday BRT-to-local headway ratios are appropriate for BRT 522 and Line 22 based on long-term ridership projections and case study comparisons. This ratio matches the estimated 2030 ridership splits in the El Camino Real Corridor and is towards the top end of the range of case study headway ratios. The findings are less conclusive for Line 23 and BRT 523, although the case study comparisons suggest that the 1.50 BRT-to-local headway ratio is appropriate. The weekend headways ratios are also consistent with the case study findings.

10. In order to promote trip differentiation and create a more productive balance, the frequencies of BRT 522 and 523 could potentially be increased to provide one bus every eight minutes. Based on the average stop spacing ratios, average passenger trip lengths, and headway ratios on Wilshire Boulevard in Los Angeles and Troost Avenue in Kansas City, this improvement could have a marked effect on corridor productivity.

11. Based on the preceding findings, the balance and productivity of the three planned BRT corridors could potentially be improved with 7-10 minute BRT headways and 12 minute local headways on weekdays in all three corridors. In the BRT Strategic Plan, the scenario with the shortest BRT and local headways (Option 7A, BRT 10-15) was selected as the preferred operating plan due to its cost efficiency and high ridership potential. However, the analysis stopped with this scenario, and operating plans with shorter BRT and local headways were not evaluated. VTA should revisit the methodologies used in the BRT Strategic Plan to assess the potential benefits of a “BRT 10-12” scenario.

Findings & Recommendations for Planned BRT & Local Service Spans

12. The provision of local baseline service with BRT routes operating during the daytime and evening hours is consistent with similar case studies in Los Angeles, Oakland, and Las Vegas. The local routes in these corridors operate 24 hours per day, seven days a week – or close to it – while the BRT routes are run during peak commute periods, middays and evenings. This arrangement affords baseline transit service to the maximum possible number of persons during late evening and overnight periods and seems to be the appropriate model for Santa Clara County.

13. A review of the ranges of BRT and local service spans in the five case study corridors generally supports the planned BRT and local spans in Santa Clara County. The spans of BRT 522 and 523 are roughly in the middle of the range of case study BRT routes, while the planned Line 22 and 23 spans of 24 hours and 19-20 hours, respectively, are longer than all but the local routes in Los Angeles and Las Vegas. In light of the population densities, land use characteristics, traffic volumes and transit ridership in each of the corridors, the longer local spans appear to be justified.

14. The service spans on the two BRT routes could be expanded by 1-2 hours on both weekdays and weekends as the new services begin to gain traction. The planned BRT spans fall short of the guidelines identified by Levinson et al, but may be appropriate for the introductory phase of BRT service. However, the finding that the BRT spans could be increased is further demonstrated by comparisons to the Wilshire Boulevard and Las Vegas Boulevard North Corridors. Both of these corridors feature BRT spans of services that remain consistent seven days per week. Since the planned span of BRT 522 and 523 decreases from 18 hours on weekdays to 16 hours on Saturdays to 14 hours on Sundays, it follows that a slight increase of weekend service hours could improve overall ridership productivity.
The above findings and recommendations are designed to provide additional information, insight, and general guidance for the service planning, design, and implementation of concurrent BRT and local bus service in Santa Clara County. However, these findings may remain applicable in the years following BRT implementation as the actual interactions between the local and BRT routes in the Santa Clara/Alum Rock, Stevens Creek, and El Camino Real Corridors continues to evolve. In this case, the performance metrics for concurrent BRT and local service that are outlined in the following section may also prove useful.
10.0 PERFORMANCE METRICS FOR CONCURRENT BRT & LOCAL BUS SERVICE

In addition to contributing to the recommendations outlined above, the case studies also serve to identify several key performance metrics that may be used by transit properties to monitor and assess the adequacy of service headways and spans for concurrent BRT and local bus service. Instead of the complex statistical models and algorithms from the literature review that are of little use to most transit planners, these factors are much more comprehensible for daily service planning decisions. Examples of some of the more useful indicators include headway ratios, average peak load factors, boardings per revenue hour, average passenger trip lengths, transfer rates between the two lines, ridership distribution by stop type, operating costs, and passenger surveys.

10.1 Headway Ratios

The ratio between the headways – or buses per hour – of concurrent BRT and local bus service is a basic calculation for quantifying the relationship between the two routes. A corridor with 15 minute BRT headways and 30 minute local headways would have a headway ratio of 2.0. This value does not represent a performance metric, but instead can be used to normalize other performance metrics and draw comparisons between different BRT corridors.

10.2 Boardings Per Revenue Hour

Raw ridership statistics were compared with headway ratios to analyze frequencies but can be misleading because they do not account for differences in service hours. A bus route that draws 5,000 daily riders with 20 hours of service is not nearly as productive as a route with 5,000 daily riders over 12 hours of revenue service. Boardings per revenue hour are therefore a better measure of basic ridership productivity. Productivity levels will vary between corridors, but the successful case studies included in this report tended to draw at least 30 boardings per revenue hour. Routes that are not performing well will typically average 15 boardings per revenue hour or less, but this number may vary by agency.354

Boardings per revenue hour are also helpful in evaluating the balance between BRT and local bus service as defined by the service design characteristics of concurrent routes. Two routes with comparable numbers of boarding per revenue hour have similar ridership productivity and are likely well-balanced. Therefore, concurrent BRT and local bus routes that draw more than 40 boardings per hour and are comparable to one another are usually indicative of a healthy, well-balanced transit corridor, particularly when the trip types attributed to the two routes are clearly differentiated.

10.3 Average Peak Load Factors

The most important performance metrics for concurrent BRT and local service are the average peak load factors for the two routes. The average peak load factor accounts for vehicle sizes and capacities, while most other ridership indicators – such as boardings per revenue hour – do not. Vehicle capacity is one of the most important indicators of successful service and when adjustments are necessary. Accordingly, many transit agencies develop average peak load standards based on ridership demand and vehicle design to determine when such changes are necessary. As a point of reference, Bogota’s popular TransMilenio BRT service uses average load standards of 0.80 during peak hours and 0.70 during off-peak periods.355 The heavily-travelled Metro Rapid BRT routes in Los Angeles subscribe to a maximum average peak load standard of 1.30 based on high ridership and the vehicles, which are designed to accommodate a large number of standees.356 Finally, VTA uses an informal maximum load factor of 1.20 for standard and
articulated buses, but generally tries to keep community and express bus peak loads below 1.00 since those routes and vehicle types are not conducive to standees.\textsuperscript{357} Although minimum average peak load standards are more difficult to quantify, the case studies of this report suggest that routes with average peak loads that are below 0.30 may need to be re-evaluated.

Average peak load factors can also be helpful for quantifying the relationship between concurrent BRT and local bus service. A productive, well-balanced BRT corridor will usually feature BRT and local bus routes with similar average peak load factors that are at or near the Bogota standards outlined above. If the two routes have similar peak load factors, it generally implies that the various transit demands within the corridor are being effectively met by the two different services. This is similar to boardings per revenue hour, but factors in vehicle capacity. Although not referenced in this report, an additional performance metric could include peak capacity thresholds for an entire route or corridor. These measures would represent the number of passenger trips within an hour divided by the total route or corridor capacity, as calculated by the vehicle capacities multiplied by the number of buses per hour. This indicator would provide a more comprehensive understanding of the transit demand on the specific routes and the corridor as whole, which could inform frequency and span modifications.

10.4 Average Passenger Trip Lengths

Another key indicator for monitoring the health and balance of concurrent BRT and local bus service are average passenger trip lengths. A productive balance between BRT and local service is usually signified by a substantial difference in average trip lengths between the two routes. A big gap in average passenger trip lengths – presumably with BRT as the longer of the two – represents a corridor with healthy differentiation between trip types where BRT serves longer throughput trips and passengers making shorter trips use the local service. Two of the main factors that help create this trip differentiation are service frequencies and spans.

Based on the four case study corridors that calculated average passenger trip lengths by route, the average BRT trip length is roughly 4.9 miles and the average local passenger traveled 3.5 miles. The largest differences were found in Kansas City – 3.6 miles for the Troost MAX as compared to 1.6 for Line 25 – and Los Angeles with 6.3 miles for Line 720 and 3.2 miles for Line 20. Not surprisingly, these corridors also had the largest differences in average stop spacing at 4.6 and 4.4 local stops for every MAX or Line 720 stop. The clear trip differentiation in these corridors is another indicator that suggests that the current headways and spans are working as intended. Therefore, efficient, well-designed transit corridors will typically feature average BRT passenger trip lengths and average stop spacing distances that are significantly longer than those of the corresponding local route.

10.5 Ridership Distribution by Stop Type

As demonstrated by several of the case study corridors, it is important to identify the proportion of local daily boardings that occur at shared BRT stops as compared to those that take place at local-only stops. Kansas City and Salt Lake City carefully designed their BRT routes with stops that would serve roughly 80 percent of the total corridor ridership. This high percentage makes it possible to place greater emphasis on BRT headways and spans over local service with less of a negative impact on accessibility. In Santa Clara County, the percentages of local boardings on Lines 22 and 23 that occur at planned BRT stations are much lower at 52 percent and 63 percent, respectively. Lower percentages such as these can magnify the negative effects of placing additional emphasis on BRT service, particularly if the average BRT stop spacing is 0.75 miles or greater.
10.6 Interline Transfer Activity

The adequacy of the headways of BRT and local bus service may also be assessed based on the number of passengers that transfer between the two routes with consideration for the average stop spacing. In most cases, low transfer activity indicates that the headways of both services are being run with enough frequency – and sufficient reliability – that passengers are comfortable waiting for their specific bus and completing a one-seat ride to their destination. This is particularly true when the BRT and local stops are spaced more closely together. If BRT stations are further apart, passengers may be required to make additional interline transfers to reach their destinations and this number may be skewed.

Unfortunately, most transit agencies do not have the capacity to collect specific transfer data because they are unable to monitor the origins and destinations of individual passengers. Only one agency – Los Angeles Metro – was able to calculate the transfer activity between their rapid and local buses based on data from their TAP smart card users. As noted in the Wilshire Boulevard case study, the transfer activity from Line 20 to 720 and vice versa is 3.1 percent and 2.0 percent, respectively. Based on the overall balance and high productivity of BRT and local service in the Wilshire Boulevard Corridor, these percentages may provide a reference point for other urban corridors with similar service configurations.

10.7 Operating Cost Per Revenue Hour

More often than not, budgetary considerations will be the overriding factor in service design decisions, regardless of the other indicators outlined above. It is therefore important to monitor the operating costs by vehicle type so that the BRT and local headways and spans can be designed to deploy the vehicles and labor as efficiently as possible.

Of the five transit agencies surveyed, none were able to provide route-specific operating cost information. Instead, all five cited system-wide operating cost figures that failed to distinguish between the different vehicles used on BRT and local routes. Since different vehicle types necessitate varied operating costs, these costs should be monitored regularly and readily available to all those that are involved in the service design decision-making process.

10.8 Passenger Surveys

Finally, passenger surveys provide direct, qualitative feedback on the adequacy of existing service headways and spans. Survey questions relating to customer satisfaction with existing service levels can shed light on average wait times, seating availability, trip differentiation, and many other service indicators. This data can be used to tailor headways and spans of BRT and local bus service to more effectively meet corridor needs.

Of the five transit agencies, only Metro in Los Angeles had recently collected route-specific customer survey data. The questions asked passengers if their bus had arrived on time, how long they had had to wait, if they were able to find a seat, if the current schedule was meeting their needs, and how satisfied they were in general with the service. The results were overwhelmingly positive and seemed to affirm the sufficiency of existing headways and spans. If other agencies were able to incorporate similar questions into their route-specific customer surveys, they could collect valuable data to inform their headway and span decisions for BRT and local service.
11.0 OVERALL FINDINGS & CONCLUSIONS

As the concept of BRT continues to increase in popularity, it is imperative that BRT routes be designed with careful consideration for how it will operate alongside other transit services in meeting local and regional travel needs. Therefore, some of the most important decisions that will be made during the BRT planning process involve the determination of the frequencies and spans that will be implemented on concurrent BRT and local bus service. In order to inform this process in Santa Clara County, this research paper has included a review of relevant literature, an evaluation of five carefully-selected BRT corridors, and a series of operational and comparative analyses on the existing and proposed service design characteristics in the county’s three planned BRT corridors. The most significant findings and conclusions of the preceding research and analyses are summarized below:

Case Study Findings & Recommendations

1. **The Wilshire Boulevard Corridor in Los Angeles represents one of the most successful examples of concurrent BRT and local bus service.** The corridor’s high frequencies – 2-4 minute peak BRT headways and 5-8 minute peak local service – are supported by its intense urban development patterns and soaring transit ridership. The Line 720 evening headways could be slightly improved, but otherwise its service design characteristics and those of the local Line 20 are appropriate.

2. **San Pablo Avenue in Oakland is another healthy, productive transit corridor that is effectively served by corresponding BRT and local bus routes.** The 12 and 15 minute headways of the 72-R and its local counterparts, Lines 72 and 72-M, are mostly adequate based on their current ridership and operating performance. The decision to only provide BRT service on weekdays appears to be warranted, however, minor adjustments to the weekday spans of Line 72-R in the early morning and late evenings may help improve the corridor’s overall efficiency.

3. **The densities and land use characteristics of the Las Vegas Boulevard North Corridor represent an ideal environment for BRT, but the corridor’s overall productivity has been inconsistent in the last two years due to budget-related service reductions.** While the MAX had previously operated on 12-15 minute headways, the service frequency was decreased to 30 minute headways in 2010 to match those of Line 113 local service. Despite these recent trends, the past performance of the MAX and Line 113 has demonstrated the corridor’s potential, which could be restored with future frequency and span improvements.

4. **Kansas City’s newest BRT route, the Troost MAX, has cemented Troost Avenue as one of the most productive transit corridors in the region.** Although the ridership performance of both the MAX and Line 25 have been promising, the MAX’s 10-minute weekday headways could be increased slightly to promote a more productive balance between the two services. The utilization of BRT as the baseline service also appears to be working relatively well due to the fact that the majority of transit riders are able to directly access the shared BRT stops.

5. **The 3500 South Corridor in Salt Lake City has performed moderately well since the inception of Line 35-M BRT service in 2008, but the anticipated increases ridership – particularly among non-discretionary riders – have not materialized.** Based on existing ridership splits, the weekday headways on Line 35-M could be improved by 1-2 minutes to achieve more balance and higher productivity. The spans for the two routes seem to be mostly appropriate, although minor contractions of Saturday MAX hours and expansions of Line 35 Sunday hours may be beneficial.
6. **The local bus routes in the three planned BRT corridors are currently operating at high levels of productivity and efficiency.** Lines 22 and 23 are the two highest performing routes in the VTA bus system in terms of absolute ridership and boardings per revenue hour. The two routes also account for roughly 22 percent and 33 percent of the total bus system ridership on weekdays and weekends, respectively.

7. **The two BRT precursor routes – Line 323 and the Rapid 522 – have demonstrated recent ridership growth and are laying the groundwork for the planned BRT service.** The Rapid 522 has emerged as the fourth-most productive route in the system, while Line 323 is demonstrating ridership growth in its inaugural year of service. The productivity of both routes is expected to increase over the next two years as service headways and spans improve, passengers become more familiar and comfortable with the services, and they begin to develop a more consistent ridership base from which BRT will draw its users.

8. **The existing spans on Lines 22 and Lines 23 are adequate and the plans to introduce extended evening and weekend service for Lines 323 and the Rapid 522 are warranted.** The consistently strong weekday and Saturday ridership performance of the Rapid 522 suggest that the route could thrive with extended service hours. Though its ridership productivity is not as high, Line 323 will also benefit from additional evening and weekend service as it continues to solidify its ridership base in preparation for BRT implementation.

9. **The planned 10 minute weekday headways and 15 minute weekend headways for the two BRT routes are generally consistent with the literature review guidelines and case study findings.** The service frequencies for both the BRT 522 and 523 are within the ranges outlined by Levinson et al as well as those identified in the FTA’s *Characteristics of Bus Rapid Transit Decision-Making*. A comparison with BRT headways observed in the five case study corridors also finds that the 10 minute weekday headways and 15 minute weekend headways are consistent with similar, successful BRT services across the country. In terms of BRT-to-local headway ratios, the planned BRT and local service frequencies also compare favorably to the five case studies.

10. **The planned 15 minute local headways represent a 25 percent reduction from existing weekday service levels on the two busiest routes in the VTA system, and consequently may not reflect the best scenario for local service.** Although the decrease in local headways will be largely offset by the new BRT service, the local stops that are not served by the BRT 522 or 523 will be adversely affected. Based on the longer distances between BRT stops, and the fact that only 52 and 63 percent of the current weekday boardings on Lines 22 and 23, respectively, occur at planned BRT stations, this may be cause for concern.

11. **Based on the preceding findings, the balance and productivity of the three planned BRT corridors could potentially be improved with 7-10 minute BRT headways and 12 minute local headways on weekdays in all three corridors.** In the *BRT Strategic Plan*, the scenario with the shortest BRT and local headways (Option 7A, BRT 10-15) was selected as the preferred operating plan due to its cost efficiency and high ridership potential. However, the analysis stopped with this scenario, and operating plans with shorter BRT and local headways were not evaluated. VTA should revisit the methodologies used in the *BRT Strategic Plan* to assess the potential benefits of a “BRT 10-12” scenario.
12. The provision of local baseline service with BRT routes operating during the daytime and evening hours is consistent with similar case studies in Los Angeles, Oakland, and Las Vegas. The local routes in these corridors operate 24 hours per day, seven days a week – or close to it – while the BRT routes are run during peak commute periods, middays and evenings. This arrangement affords baseline transit service to the maximum possible number of persons during late evening and overnight periods and seems to be the appropriate model for Santa Clara County. A review of the ranges of BRT and local service spans in the five case study corridors also lends credibility to the BRT and local spans that are planned in Santa Clara County, although future increases to the spans of BRT 522 and 523 may be necessary.

General Findings & Recommendations

13. Based on the analyses described above, the following indicators may be useful to agencies who need to monitor and evaluate concurrent BRT and local service: headway ratios, average peak load factors, boardings per revenue hour, average passenger trip lengths, transfer rates between the two lines, ridership distribution by stop type, operating costs, and passenger surveys. Among these indicators, the average peak load factors and boardings per revenue hour are arguably the most important and informative. Performance metrics such as these are readily accessible to transit planners and can help them ensure that a productive balance between BRT and local service is achieved and maintained.

14. Several of the more obvious factors that also play a significant role in service design decisions include cost, funding requirements, equity, and public input. Not surprisingly, budgetary constraints were cited in all of the case studies as one of the main reasons for specific headway and span decisions. Similarly, as shown in Kansas City, funding requirements such as those associated with the FTA’s “Very Small Starts” Program can also shape the dimensions of service that is provided. To a slightly lesser extent, equity considerations and public input were cited in Oakland and Salt Lake City, respectively as factors that had influenced service design.

15. The importance of comprehensive data that can be used to inform service planning decisions cannot be overstated. Transit planners are able to perform their duties much more effectively when they have access to more detailed operational statistics such as peak load factors, average passenger trip lengths, on-time performance, and cost efficiency indicators. Ideally, these types of data would be broken down by corridor, route, direction, day type and time of day. Unfortunately, several major transit agencies that were surveyed for this project but ultimately not included as case studies did not collect these types of data or did not have them readily available.

16. Unlike decisions relating to capital investments, infrastructure planning, and physical operational characteristics, service frequencies and spans are inherently flexible and can be adjusted as necessary to meet evolving transit demands. Thus, while it might not be realistic to immediately implement these findings and recommendations, they should be kept in mind and may prove beneficial in the future as conditions change and these remarkable transit corridors continue to develop.
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